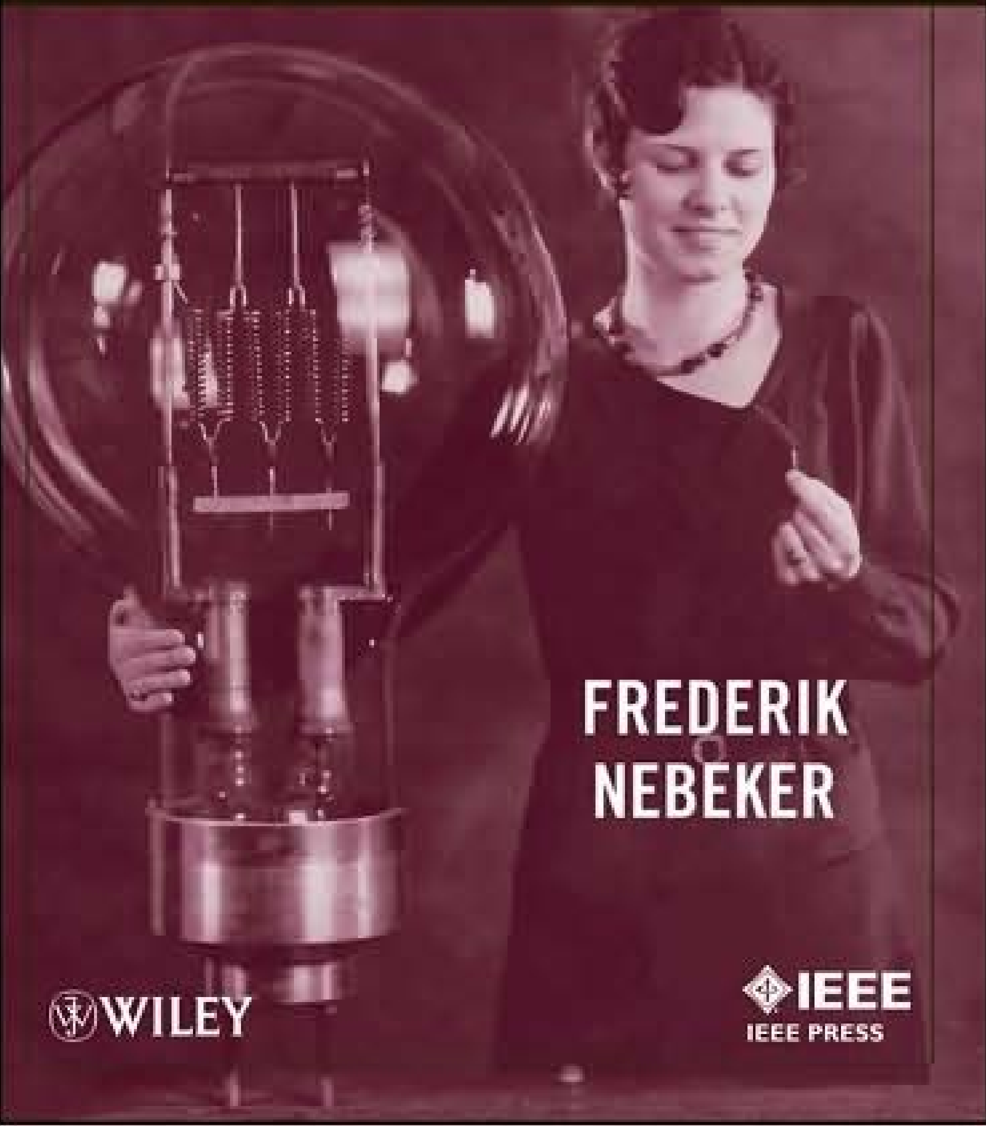
DAWN OF THE ELECTRONIC AGE

ELECTRICAL TECHNOLOGIES IN THE SHAPING OF THE MODERN WORLD, 1914 TO 1945



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Electrical Technologies in the Shaping of the Modern World, 1914 to 1945

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Introduction

Even at the end of the twentieth century, there are those who consider the Panama Canal the engineering wonder of the century, more impressive than space travel or supercomputers.[1] When it was completed in 1914, it was called "the greatest engineering work of all time", and its technological features were quite astonishing.[2] The physical tasks of digging deep channels, moving mountains of earth, and constructing dams and locks required ingenuity and mammoth effort, and the success in conquering yellow fever and malaria became famous, but most impressive to many observers were the electrical technologies providing motive power, communication, and control for this "all-electric canal".

The canal is about 50 miles long, much of it at 85 feet above sea level across the artificial Gatun Lake. There are three sets of locks, twelve lock chambers in all. Each chamber is 1000 feet long, 110 feet wide, and 81 feet high (see Figure 0.1). In 1914 these lock chambers were the largest machines ever made; they were larger than the largest ship and of greater extent than the tallest building, and each contained thousands of moving parts. At each end of the lock were two sets of gates as a precaution against ramming, and each gate was 7 feet thick and weighed 500 tons. Most of the locks had intermediate gates so that, when the size of the ships permitted, the lock could be operated as a pair of locks in order to conserve water. Every gate had struts, gears, and motors for moving it. There were valves—some of which weighed 10 tons—for controlling the flow of water through the 70 openings in the floor of each lock. Outside the lock at each end there was a fender chain (to protect the gates) that was raised and lowered appropriately, and at the upstream end there was an emergency dam that could be swung across the lock entrance.[3]

The gates, valves, fender chain, and emergency dam were all moved by electric motors. So were the mule locomotives that ran atop the walls of the locks. Ships were not allowed to move under their own power in the locks, so all motive force came from these mule locomotives, either by towing or by winding cable onto a large windlass (powered by its own electric motors) in the center of the locomotive. Indeed, motive power throughout the canal came from electric motors—some 1500

[1] Frederick Allen, p. 8.

[2] McCullough, p. 590.

[3] "How the locks …", and McCullough, pp. 590–595.

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Figure 0.1. The first trial lockage of the Gatun Locks (photo courtesy of the Library of Congress, LC-USZ62-128562).

in all—and one of their great advantages was that they could easily be controlled centrally.[4]

Typical was the control house for the Miraflores Locks. It contained a 60 foot electromechanical control board built by General Electric in 1910. The control board, which was essentially a model of the set of locks, indicated the position of fender chains and lock gates, the water heights, and the status of water valves, and it permitted control of these variables. The operator, however, was constrained by the control mechanism, which required that some operations be performed in a particular order (for example, opening the gate before lowering the fender chain) or that certain conditions be met before an action is carried out (so that, for example, a gate may not be opened unless water levels are equal on the two sides). The locks occurred as parallel pairs (one for travel in each direction) and shared water passages in the wall between them; the control system prevented operation of one lock from interfering with that of the parallel lock.[5]

Operation of a lock was more complicated than one might imagine. For example, once gates were closed, they needed to be clamped together by a special mechanism. There was also the requirement that at the upper end of the lock the water in the space between the principal gate and the guard gate be kept at an intermediate level. Sometimes water was saved by "cross-filling", that is, using water from the parallel lock. Thus the lock was not only an enormous machine, but also one of intricate operation. Nevertheless, as the journal *Scientific American* reported, the control board was "so ingeniously conceived and constructed that a single man, who need never see the ships which are passing through the canal, opens and closes lock gates weighing many tons and governs the course of thousands and thousands of gallons of water."[6] Perhaps even more impressive is the fact that this electromechanical control board at the Miraflores Locks was so well designed and built that it remains in use today.[7]

[4] McCullough, p. 599. In earlier canals, hydraulic or pneumatic systems provided the power to operate the valves and gates of a lock [Schildhauer].

[5] Frederick Allen, and "How the locks. …"

[6] "How the locks …", p. 110. This writer has understated the volume of water involved: raising a large ship through the Gatun locks required 26 million gallons of water, "the equivalent of a day's water supply for a major city" [McCullough, p. 596].

[7] Frederick Allen.

Figure 0.2. The Gatun dam and hydroelectric station (photo courtesy of the Library of Congress, pan 6a23215).

Electrical communications (especially telegraph and telephone), lights for navigation (in range towers and beacons), and lights for illuminating the locks (using 400-watt tungsten bulbs) were also important.[8] In building the canal, electrical technologies had been important in the form of floodlighting (so that excavation could continue at night), cranes, cableways, rock crushers, cement mixers, and dredging pumps.[9] And the new technology of radio was used to communicate with ships within a few hundred miles of the canal.[10]

The canal, whose muscular and nervous systems were electrical, produced all of its own energy hydroelectrically from the water in Gatun Lake (see Figure 0.2). The Gatun dam was, at the time, the largest ever built. Since the water behind the dam also did the work of raising and lowering ships in the locks and since Panama receives no rainfall in a 3-month-long dry season, it was often necessary to conserve water as much as possible. The waterwheels and generators, therefore, had to be as efficient as possible. The main equipment consisted of three units, each a massive turbine connected to a 2000-kilowatt generator (built by the General Electric Company), which achieved an efficiency of 95%. The power plant itself was an intricate machine that one person could operate from a central control-board. Electric motors moved the gates of the intake pipelines, ran small generators to provide exciting current for the main generators, adjusted the speed of the turbines, and pumped oil. Many of the operations were made to occur automatically. Because of the extent of the Canal Zone (about 50 miles by 10 miles), a high-voltage (44,000 volt) transmission system with four substations was constructed. The system included a backup 6000-kilowatt plant with steam-driven generators.[11]

The canal was a demonstration of the virtues of electric power: power could be generated in one place, transported with little loss throughout the Canal Zone, and turned into mechanical power or light exactly where required and in the quantity required. Moreover, electricity gave ease of control; some of the lock motors, for example, were half a mile from the control board. General Electric performed most

[8] Beyer, and "Navigating lights …".

[9] McCullough, p. 599.

[10] Radio stations at Colon and Balboa communicated with vessels within 300 and 200 miles respectively; already by late 1914 larger transmitting stations, capable of communicating with vessels within 500 miles, were being built to replace the first ones at Colon and Balboa [*The Electrician*, 30 October 1914, p. 102].

[11] "Gatun hydroelectric development …", and Schildhauer. The hydroelectric station provided power also to the villages along the canal.

of the electrical work, with Edward Schildhauer as the lead engineer. According to one historian, "This was not merely a very large government contract … but one that would attract worldwide attention. It was a chance like none other to display the virtues of electric power, to bring to bear the creative resources of the electrical engineer."[12] The engineering—notably the locks, which worked perfectly from the first—was a resounding success. Even more importantly, the project as a whole was so effectively carried out (ahead of time, under budget, and fully up to specifications) that it set an extremely favorable precedent for government–industry collaboration.

The canal changed economic geography overnight, making Japan and Australia closer to New York than to London, putting the Pacific coast of South America in direct touch with the Atlantic coast of North America, and cutting the water distance between San Francisco and Liverpool by 5600 miles. At the end of the twentieth century the Panama Canal retains its economic significance. More surprisingly, it remains, physically and technically, essentially the canal that was completed in 1914.[13] As the culmination of work that began with a French company under Ferdinand de Lesseps in 1881 and as an embodiment of the latest technology, the canal should have received worldwide acclaim on its official opening in August 1914. Other events, however, stole the limelight. On the same day—3 August 1914—that a ship made the first ocean–to–ocean transit, Germany declared war on France and invaded Belgium, making clear that the conflict that had begun a few days earlier in eastern Europe would involve almost all of the continent.

This book concerns the years 1914 through 1945. In 1914 Germany was the coming power in Europe: its economy, already leading the world in several sectors, was growing rapidly, and its population had doubled between 1870 and 1914, reaching 65 million, while the populations of Britain and France remained near 40 million. Two non-European nations had taken prominent positions on the world stage: the United States, with extensive area and a population of some 100 million, had a booming economy; and Japan, through rapid industrialization and victories in the Sino-Japanese War (1894–1895) and the Russo-Japanese War (1904–1905), had become the dominant power in east Asia. At the end of 1945 the scene was quite different; Germany and Japan were in ruins from a war that had left the U.S. relatively unscathed, and a new power, the Soviet Union, had joined the U.S. as the so-called superpowers of the postwar world.

The period from 1914 through 1945 was one of continual crisis. It began and ended with global wars, which, together, lasted more than 10 years. The 21 years in between were darkened by baneful effects of the first of these war (physical devastation, dislocation of large populations, and political instability); by numerous armed conflicts between and within states (the Russo-Polish war, fighting between Japan and China, Italy's invasion of Ethiopia, the Spanish civil war, and many others); by economic crises (the huge war debts and reparations, the hyperinflation in many

[12] McCullough, p. 601.

[13] Frederick Allen.

countries in the early 1920s, and the Great Depression worldwide in the 1930s); and, in the late 1930s, by the threat of another global war. Indeed, the entire period from 1914 to 1945 may be regarded as a single world war with a long armistice in the middle. The historian Eric Hobsbawm has written:

> *The decades from the outbreak of the First World War to the aftermath of the Second, was an Age of Catastrophe. … For forty years [the world] stumbled from one calamity to another. … While the economy tottered, the institutions of liberal democracy virtually disappeared between 1917 and 1942 from all but a fringe of Europe and parts of North America and Australasia. …*[14]

And Hobsbawm called these years "an era of havoc comparable to the Thirty Years' War of the seventeenth century in German history."[15]

Most historians see this period less negatively. It is true that democracy seemed in retreat in the 1930s, but the preceding decade was one of unprecedented advance. Democracies were established in Germany, the Baltic states, and the four successor states to the Habsburg Empire. Democracy seemed to be working in Japan and, sporadically, in China. In many countries women gained the right to vote, and it was a time of social legislation, as in restricting child labor or providing old-age pensions. There seemed to be goodwill among nations, manifested especially in 1925 at the Locarno Conference, when Great Britain, Germany, France, Italy, and Belgium mutually guaranteed the peace and Germany recognized the German–Belgian and Franco–German borders established by the Versailles Treaty. The 1920s was a decade of economic prosperity in many parts of the world, and even in Europe the late 1920s were good ones economically.

Whatever the political, social, and economic ups and downs, from the technological vantage point the period 1914 to 1945 was an age of spectacular progress. The First World War gave an enormous impetus to a wide range of technologies; these and others evolved rapidly in the interwar period; and the Second World War provided even more of a boost than did the First. It is true that the wars retarded technological advance in some areas and that the Depression slowed it in many, but progress there was nevertheless, and it was progress of a magnitude the world had never before experienced. In this 31 year period, the generation, distribution, and application of electric power saw great advances. Telegraph and telephone communications extended their reach. Radio, for point-to-point communications and broadcasting, propelled the development of electronics, a new realm of techniques that found a great many new application areas before 1945. Computer technology was arising in numerous contexts.

Despite the world wars, new dictatorships, and economic depression, when this period ended many people felt optimistic and expected an age of social progress, with increased material prosperity, better education, wider appreciation of arts and literature, and scientific advance. The optimism owed much to the technological

[14] Hobsbawm, pp. 6–7.

[15] Hobsbawm, p. 52.

advance of this period, since all these goals would—it was thought—be more achievable because of the new technologies.

This book is a story of electrical technologies and the modern world: how societies elicited from individuals and companies much improved and sometimes entirely new technologies, and how the technologies in turn affected the political, economic, and social worlds. Because a great many of the technological and social developments appeared first in the U.S., much of the narrative concerns that country. An effort, however, has been made to review events throughout the world, and several chapters focus on countries other than the U.S.

This book will be concerned with how the technologies themselves worked—otherwise the course of technological development would be quite mysterious—but explanations will be nonmathematical and understandable to the general reader.

One of the most remarkable aspects of the story here told is that relatively few physical phenomena underlie almost all of the technologies involved. Perhaps the most basic of these phenomena is an electric current. The atoms that compose the physical world consist of a small positively-charged nucleus surrounded by electrons, which are negatively charged. In the materials called conductors, which are typified by metals, the electrons are relatively free to move from one atom to another, so that if one end of a wire is placed at a source of electrons and the other end is able to discharge electrons, there will be a flow of electrons through the wire. In 1799 Alessandro Volta discovered how to produce such a current chemically, that is, he devised the first battery. Others later found that a current could do useful things, such as electroplating (placing a continuous thin coating of a metal such as silver or chromium on another metal) and carrying a signal (activating an indicator or, as in telegraphy, bearing a longer message).

Another basic phenomenon, discovered by Hans Christian Ørsted in 1820, is that an electric current always generates a magnetic field. (See Figure 0.3.) This discovery led not only to electromagnets, but also to electric motors. The latter are possible because it is easy to cause motion with a magnetic force; in one early

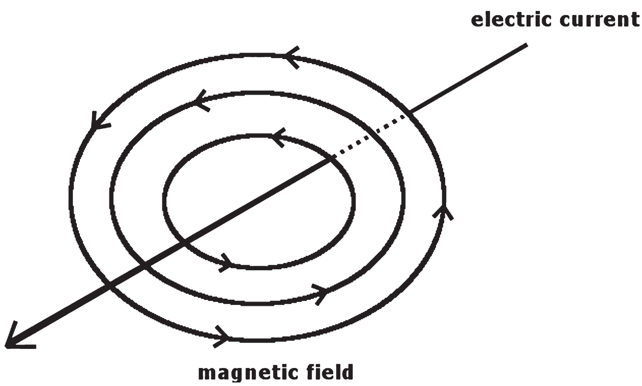

Figure 0.3. Ørsted showed that a current in a wire generates a magnetic field, whose lines of force (imaginary lines indicating the direction a tiny north magnetic pole would move) circle the wire.

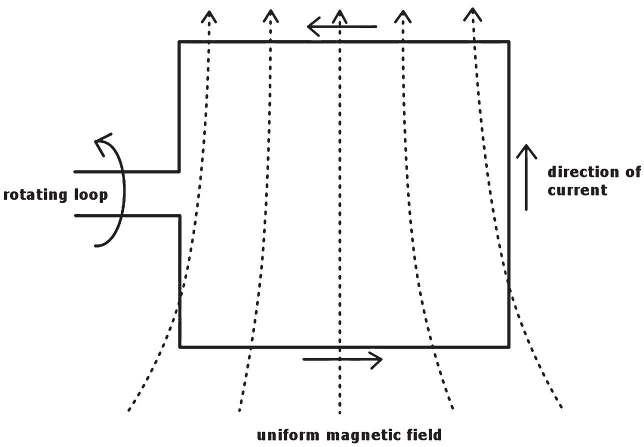

Figure 0.4. Moving a wire through a magnetic field generates a current in the wire. If a loop of wire is rotated in a magnetic field as shown, the currents generated in the two sides of the loop reinforce each other.

electric motor the current caused a bar magnet to rotate. This created, for the first time, the conversion of electrical energy into mechanical energy.

In 1831 Michael Faraday discovered an inverse phenomenon (electricity from magnetism rather than magnetism from electricity); one could generate an electric current by moving a conductor in a magnetic field. (See Figure 0.4.) Here mechanical motion produces an electric current, and a device that does this is called an electric generator or dynamo. Many people contributed to the gradual development of efficient dynamos, and they began to be used to power electric-arc lighting in the 1870s and incandescent lighting and electric motors in the 1880s.

Finally, one other basic phenomenon of great importance to nineteenth century electrical technology was electroacoustic transduction: the conversion of sound into an electric signal and the reconversion of the signal into sound. In 1876 Alexander Graham Bell demonstrated his telephone, which converted human speech to a continuously varying electric current at the mouthpiece and turned current back into speech at the earphone.

This book's story opens in 1914, the year not only of the completion of the Panama Canal and the outbreak of war, but also of Henry Ford's $5 day (double the prevailing wage for factory work), Irving Berlin's musical *Watch Your Step* (the first of many), and Charlie Chaplin's movie *Tillie's Punctured Romance* (which broke new ground in length, filling six reels). The economies of the industrialized nations had been growing, mass production made many goods available for the first time to ordinary people, and innovations such as automobiles, airplanes, electrical appliances, wireless telegraphy, and motion pictures excited people.

Electrical technologies had long since become economically important. In the U.S. in 1914, the annual sales of electrical apparatus, such as generators, transformers, and motors, had reached the $1-billion level. Supplying electric power was a

$500-million business, while the operation of electric railways and subways was even larger, $780 million annually. Telephone systems grossed $380 million annually, telegraph systems $100 million. The manufacture of electrical lighting fixtures was an $80-million business, and electroplating was a $10-million industry.[16]

Electric technologies began to leave their mark on the largest scale: man-made lakes behind hydroelectric dams and long-distance transmission lines. Electric trolleys were the principal means of urban and, in some places, suburban transit, and electric cars still claimed a sizable fraction of the automobile market. One could send telegrams, either by undersea cable or by wireless, across the Atlantic. Telephone service became more and more extensive, first spanning the North American continent in January 1915.

Besides these technologies, which people encountered every day, there was much talk of the newest electrical marvels. There was wireless voice-transmission, and a tour-de-force of 1915 was a voice transmission between Arlington, Virginia and the Eiffel Tower. A teletypewriter and a portable fax machine were developed. In Paris in 1914 was demonstrated the Sperry autostabiliser, a complex system involving four gyroscopes and many electrical components that automatically maintained straight and level flight.[17] The popular attitude was reflected in Charles W. Eliot's inscription for the Union Depot in Washington DC completed in 1907: "Electricity: carrier of light and power; devourer of time and space; bearer of human speech over land and sea; greatest servant of man—yet itself unknown."[18]

The world had entered an age of electricity, leaving behind the age of coal that the Industrial Revolution had created. In the nineteenth century, steam engines powered factories, ships, and trains, and artificial lighting usually came from flames. Now jobs were increasingly done by electric motors, and electric lighting was clean, safe, effective, and readily available. In addition, instantaneous communications by telegraph and telephone—and, recently, radio—had transformed commerce and directly affected everyday life.

In all of these technologies, an electric current was made to do useful things. Power came ultimately from fossil fuels or swiftly moving water, was transmitted over considerable distances in the form of electricity, and then turned into mechanical work, heat, or light. The characteristic devices were dynamos (to turn other forms of energy into electric energy), transformers (to change the electrical tension or voltage to levels appropriate to transmission or use), electric motors, heating elements, and light bulbs. The current was controlled by a mechanical device (just as a steam engine was controlled by a valve on the pipe carrying steam to the piston). The simplest, an on-off switch, sufficed for many applications. A rheostat or potentiometer allowed graduated control of the current, and the transmitter of Bell's telephone gave continuously varying control. Telegraph engineers had developed electrically-triggered switches; an electric current in one circuit could open or close

[16] Bright, p. 13.

[17] Bennett 1979, p. 134.

[18] Boorstin, p. 539.

REALM	BASIC PHENOMENON	CHARACTERISTIC DEVICES	MEANS OF CONTROL
traditional electrical engineering	electricity moving entirely in conductors	dynamos, transformers, motors, heating elements, and lighting elements	mechanical and electromechanical
electronics	at one or more points, electron flow through vacuum, gas, or semiconductor	electron tubes and transistors (amplifiers, oscillators, cathode-ray tubes, phototubes, and electronic switches)	electronic (with virtually no mechanical motion)

Figure 0.5. In the from period 1914 to 1945 electrical engineering expanded to include the newly discovered realm of electronics.

a switch for a second circuit. These were called relays because they allowed a telegraph signal to be regenerated at a distant location. (See Figure 0.5.)

Sophisticated as many of these control devices were, all of them were in part mechanical, which is to say that they involved physical motion on a macroscopic scale. In the first decades of the twentieth century, there emerged a different means of controlling electric currents. This means is called electronics and is an entirely electrical way of controlling electric currents. As Chapter 1 will show, the fundamental idea is to cause a current to flow through a vacuum or low-pressure gas and there exert control over the current. Indeed, electronics may be defined as the study and use of devices involving the flow of electric current through a vacuum or gas. (This definition worked in the years considered in this book, but with the invention of the transistor in 1947 it needed to be modified: the study and use of devices involving the flow of electric current through vacuum, gas, or semiconductor.)

The secret of electronics is to free electrons in order to control them more precisely and rapidly. The freedom and the control occur within a glass envelope, called an electron tube, where a stream of electrons moves through a vacuum. The control is exerted in a great variety of ways, many of which will be covered in more detail in the chapters of this book, but following are several basic types. The strength of the electron stream can be varied according to a signal; then the tube is an amplifier. By connecting the output of a tube to its input, the stream can be made to consist of a regular train of pulses; then the tube is an oscillator. By using a signal to control the amplitude of an pulsing stream, the signal can be imprinted on a continuous wave; then the tube is a modulator. By directing the stream of electrons toward the end of the tube, which has been coated on the inside with phosphors, and by deflecting the stream up or down or side to side according to a signal, the signal can be made visible on the end of the tube; this is the cathode ray tube.

A crucial point is that the means of fine control of electron flows involves no macroscopic mechanical motions. The absence of mechanical inertia in control loops means that they operate almost instantaneously and that they may be compounded—control loop on control loop—almost without limit. This opened up, as we will see, entirely new possibilities for communications, machine control, instrumentation, and computing.

The social transformations of the twentieth century are unprecedented in all of history. These transformations all involved technological change. Electrical engineering—encompassing all electrical, electronic, and computer techniques—played a part, often the leading role, in most of the century's technological changes. The period with which this book deals was pivotal. Though electrical engineering was well established at its outset, electronics was bringing in a new technological age. All of the traditional electrical technologies—electric power for lighting, traction, and machinery in the factory, office, and home, and electric communications—were greatly enhanced by electronics, and there emerged the new technologies of radio, television, radar, and electronic instrumentation. Moreover, this period sowed the seeds—by the development of electronics—of much greater technological and social change in subsequent decades. Though it was a troubled period, most people believed in social betterment and saw electrical technologies as means to that end.

The next chapter turns to the events that stole the limelight from the opening of the Panama Canal. Known to a generation as the Great War, World War I had a profound influence on the development of electrical technologies. Conversely, electrical technologies constantly affected the course of that war, often in surprising ways.

Chapter 1

The Great War and Wireless Communications

1.1 LAND-BOUND COMMUNICATIONS

1.1.1 The Battle of Tannenberg and the Electron Tube

The guns of August 1914 thundered along a western front from Belgium through northeastern France to the Jura mountains and along an eastern front from East Prussia through Russian Poland and Austro-Hungarian Galicia. (See Figure 1.1.) When war broke out at the beginning of that month, German leaders followed a strategy formulated by Alfred von Schlieffen nine years earlier in directing most of the available manpower and materiel against their enemies in the West, while fighting a holding action against the Russians. Fearful of a two-front war, they hoped to force France to sue for peace before the massive Russian armies could be brought effectively to bear on the much smaller German armies in East Prussia and Silesia.

In the West, the Germans moved steadily through Belgium, entering Liège on 7 August and Brussels on 20 August, and at the same time sharply repulsed the French offensive in Alsace-Lorraine. But news from the Eastern Front was, from the German point of view, quite disturbing. Russia's huge First and Second Armies, numbering some 200,000 men each, had mobilized and reached the front much faster than expected. On 17 August the Russians took the offensive, and on 20 August the Germans suffered a defeat at Gumbinnen. Soon a third of East Prussia was in Russian hands. There was widespread fear and some panic behind German lines, and refugees streamed westward toward Berlin.

This was the situation on 20 August when the chief of the German general staff, Helmuth von Moltke, placed a telephone call from his headquarters near the Western Front, in Koblenz, to General Max von Prittwitz, commander of the German Eighth Army in East Prussia. Prittwitz could talk only of the many difficulties of his

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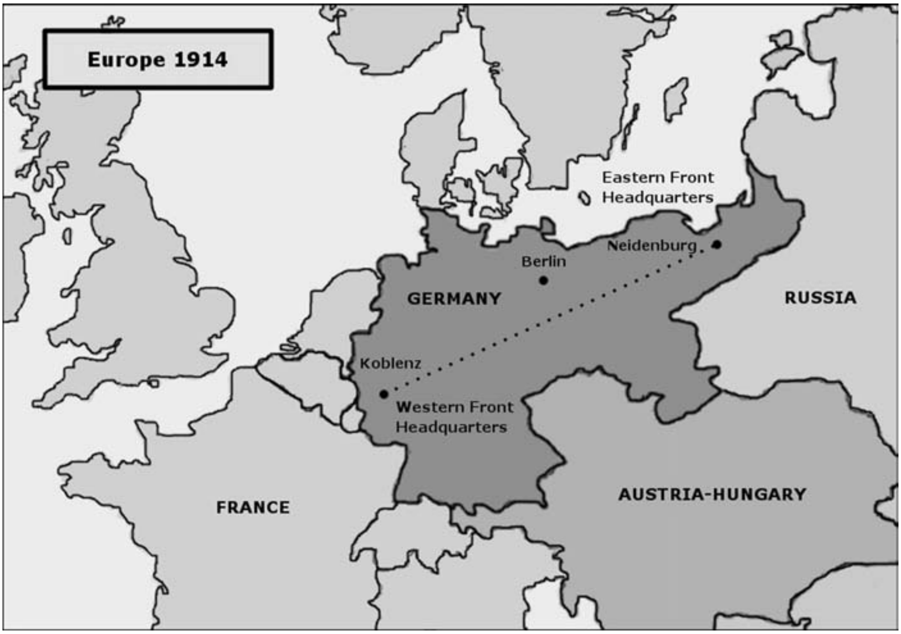


Figure 1.1. Map of Europe showing the disposition of military forces in August 1914 and the locations of Moltke's and Prittwitz's headquarters.

position, and his defeatism so appalled Moltke that on the following day he relieved Prittwitz of command. To take Prittwitz's place, Moltke called out of retirement the little-known, 66-year-old General Paul von Hindenburg and named Erich Ludendorff as Hindenburg's chief of staff. Thus—from one long-distance telephone conversation—began Hindenburg's rise to military and political prominence.[1] Battlefield success later led to his appointment as chief of the general staff and to the Hindenburg Cult of the later war years, when he served as the revered father figure behind whom Ludendorff operated as virtual dictator of Germany. And in 1925 came his presidency of the Weimar Republic that continued into the early 1930s, when he provided a respectable front behind which Adolf Hitler came to power.

Hindenburg and Ludendorff quickly assumed command of the Eighth Army. They moved almost all of their forces so as to entrap the Russian Second Army, trusting to the reliability of intercepted radio messages that the Russian First Army, positioned further north, would not advance.[2] There resulted, beginning on 26 August, the Battle of Tannenberg, which changed the course of the war. The Russian Second Army was devastated, the Germans taking more than 100,000 prisoners. Not only was Tannenberg one of the most complete victories in military history, it was

[1] Marshall, p. 60, and Falls.

[2] At this time the Germans regularly intercepted Russian radio messages. Barbara Tuchman writes [1962, p. 307]: "[Lieutenant Colonel Max] Hoffmann acknowledged the intercepts as the real victor of Tannenberg. 'We had an ally,' he said, 'the enemy. We knew all the enemy's plans.'"

also a decisive victory that put an end to the Russian threat to Prussian territory and allowed Germany to continue to give most of its attention to the Western Front.[3]

The telephone call that led to the change of command in the East Prussian army—and thence to the battle of Tannenberg and the rise of Hindenburg—was possible only because of a remarkable and very recent technological advance.

Since the introduction of the telephone in the late 1870s, engineers in many countries had sought ways to extend its range, particularly through the development of an effective telephone relay or repeater, a device able to restore the strength of an attenuated signal. Many inventors, beginning with Thomas Edison in 1877, proposed forms of microphonic amplification, with the mechanical oscillations of a telephone receiver actuating a microphone in a second circuit (whose stronger current made possible amplification).[4] Even with the best of these devices, however, the amplification process so degraded the signal that they were scarcely practical. What finally allowed a successful telephone repeater was what is now known as the triode-electron tube. This device appeared at about the same time on the Continent and in the U.S.

A key event in the Continental line of development was a 1906 patent on a "cathode-ray relay" by Robert von Lieben of Vienna.[5] A discovery made in 1903 by a German researcher, Arthur Wehnelt, had impressed von Lieben. Wehnelt was studying cathode rays (what we now think of as a flow of electrons), which could be produced in an evacuated tube when a high voltage was applied across two metal contacts inside the tube. Wehnelt discovered that if the negative contact (the cathode) was coated with calcium or barium oxide and heated to incandescence, a much lower voltage sufficed to produce cathode rays.[6]

The cathode rays bridged the gap between cathode and anode, completing a circuit. Lieben realized that one might obtain amplification if a way could be devised for a weak input current to control the stronger current from cathode to anode. His first successful device, patented in 1906, regulated the current by the effect on the cathode rays of a magnetic field produced by the input current. Working with Eugen Reisz and Siegmund Strauss, Lieben then made a much improved amplifier by replacing magnetic control with electrostatic control: a wire grid, connected to the input current, was placed between cathode and anode. In this arrangement, a negative charge on the grid diminished the cathode-ray current (because it repelled the

[3] Falls, and Cruttwell, pp. 44–47.

[4] Hunt, pp. 61–65. Two successful means of extending the range of telephony were the use of heavier lines and the placement, along the telephone lines, of inductance (either continuously or, more usually, at intervals with so-called loading coils).

[5] Principal sources for the information on Lieben's work are Siemens, pp. 11–14, and Tyne, pp. 73–83.

[6] Wehnelt pointed out that if the heated electrode was made electrically positive and the other electrode negative, no current flowed, hence the device could be used to convert alternating current to direct current. Indeed, it was as a rectifier that Wehnelt patented the device on 15 January 1904.

If within the tube there is a very high vacuum, then almost all the current consists of a flow of electrons from cathode to anode. Whenever gas molecules are present in the tube, some of the current consists of motion of ionized molecules to the electrodes. In most early tubes, including Lieben's and Lee de Forest's (discussed below), ionized gas accounted for a large part of the current.

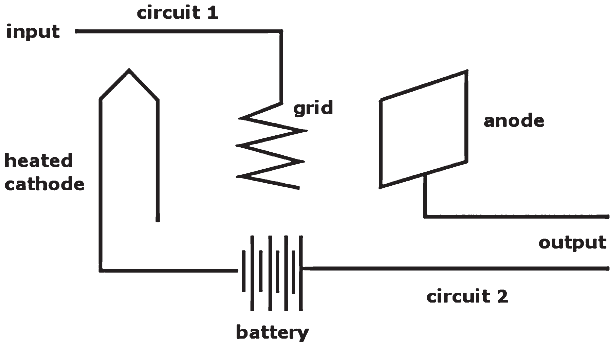


Figure 1.2. The weak input signal from circuit 1 controls the stronger current in circuit 2 because the flow of electrons from the cathode to the anode is highly dependent on the charge on the grid. Thus the signal in circuit 2 is an amplification of the signal in circuit 1.

electrons leaving the cathode) and a positive charge enhanced it. This device, patented in 1910, is now known as the triode, or three-element electron tube. A schematic triode is shown in Figure 1.2.

Four German companies were so interested in this tube that they jointly contracted with Lieben, Reisz, and Strauss for its further development.[7] In 1912 there resulted an improved tube, known as the LRS relay, that was manufactured both by Siemens & Halske and by the Allgemeine Elektrizitäts Gesellschaft (AEG) and its subsidiary Telefunken. The LRS Relay was used in a number of telephone circuits shortly before the war and, in August 1914, in the circuit connecting the central army headquarters in Koblenz with the East Prussian headquarters, more than a thousand kilometers away. By the end of the war the Germans were using about a hundred telephone repeaters of the LRS type.

The U.S. line of development began with the invention in 1906 by Lee de Forest of a "three-electrode audion".[8] De Forest was influenced by the Englishman John Ambrose Fleming's 1904 discovery of a two-electrode vacuum tube, which was used as a rectifier of alternating current and as a detector of high-frequency electromagnetic waves. De Forest's key contribution was to add a control grid as a third electrode. Initially the audion was used only as a detector of wireless signals, but in 1912 several people recognized that the audion might be made to work as an amplifier. One of the first to succeed was Fritz Lowenstein, who applied in April 1912 for a patent on an improved form of the audion as an amplifier. Irving Langmuir at General Electric undertook a quantitative study of the audion's behavior, and by the end of 1913 General Electric Company was manufacturing an amplifying tube under the name Pliotron. It was also in 1912 that de Forest himself succeeded in getting audio-frequency amplification from the audion, and he gained the interest of the

[7] Tyne, pp. 234–240. The four companies were AEG, Siemens & Halske, Telefunken, and Felten & Guilleaume.

[8] Principal sources for the information on de Forest's audion are Aitken 1985, pp. 194–249, and Tyne, pp. 52–72, 84–92, 133–142.

American Telephone and Telegraph Company (AT&T) in the device. AT&T needed to make substantial improvements before the tube could be used as a telephone repeater, but this process was completed by 18 October 1913, when a triode repeater went into service on the line between New York and Washington, D.C. Such repeaters subsequently attracted great notice when they were used in the transcontinental telephone line between New York and San Francisco that opened on 15 January 1915.

The triode vacuum-tube is one of a small number of technical devices, such as the printing press and the internal-combustion engine, that have radically changed human culture. It defined a new realm of technology, that of electronics, which before the invention of the transistor, could be conveniently defined as the technology of devices incorporating electron tubes. Though invented in 1906, the triode was little developed before 1912, as its function—detecting wireless signals—could be performed satisfactorily by several other devices (such as the electrolytic detector or the crystal detector). But in 1912 there began a remarkable development of the technical potentials of the device. Before the end of the Great War it had found numerous applications and was being mass produced in huge quantities. This technical development and the proliferation of applications continued at a rapid pace in the decades after the war, to the degree that the world that emerged after the next Great War was, as a result of electronics, strikingly different in many respects from the world of 1914.

1.1.2 The Telegraph

Communication is of supreme importance in war, and war and the threat of war have often stimulated inspired efforts to improve communications. The chain of signal fires to warn of the approach of the Spanish Armada in 1588 and the semaphore system initiated by Claude Chappe in Revolutionary France are two examples.

Wartime communication serves two vital functions, permitting one to solicit and receive information and to direct military forces on land and sea. Improved communications allows more and better information to be used in decision making, and improved communications permits concerted action to be larger, more rapid, and more flexible. For example, the dispersion of an army along a front several hundred kilometers wide became practical only through the use of the telegraph.[9] The immense size of armies in World War I, with chains of command having a dozen or so links, and the need to coordinate infantry, artillery, tanks, and aircraft made extreme demands on communications capabilities. Even on a single battlefield, communications were vital. (Wellington once remarked that the art of war was knowing what was happening on the other side of the hill.)[10] Artillery, especially, depended upon rapid communication as its increased range frequently meant that gunners never saw the targets at which they were shooting.

9 Van Creveld, pp. 169–170.

10 Cusins.

The mainstays of diplomatic and military communications in the First World War were the telegraph and the telephone. Despite the increasing availability of triode telephone repeaters, the usual means of communications over more than a few hundred kilometers remained the telegraph. In particular, business between governments was conducted largely by telegraph.

Since wars often result from misunderstandings, one might suppose that telegraphy contributed to the long peace enjoyed by most European countries from 1815 to 1914. This was, indeed, the view expressed by a telegraphy expert in 1898, who wrote that the telegraph "has often been the means of averting diplomatic ruptures and consequent wars during the last few decades."[11] Yet because telegraphic communications increased the speed of decision making, it may on occasion have contributed to the outbreak of war. This was the opinion of the French historian Charles Mazade, who wrote in 1875 that the Franco-Prussian war might have been avoided if diplomats had taken time for deliberation rather than reacting swiftly to telegraphed messages.[12] Telegraphy has been implicated too in the outbreak of the Great War: the historian Stephen Kern writes that diplomacy failed at that time because diplomats had not learned to cope with the volume and speed of electrical communications. A feverish tempo of questions and demands, constant use of the telephone, piles of telegrams, and ultimatums with time limits unthinkable in an earlier age contributed to Austro-Hungary's declaration of war—delivered by telegram—on 28 July and the fateful decisions of the next few days.[13]

Military operations became heavily dependent on the telegraph. An indication of the volume of traffic is the estimate that the wired network built by the U.S. Army in Europe was conveying more than a million telegraph messages a month (more than 30,000 messages a day) by the end of the war.[14] In response to the huge wartime need for communications, the German telegraph network increased its capacity through the use of a new high-speed telegraph, which was put into use as fast as the Siemens company could manufacture the devices.[15] Naval operations, too, made much use of the telegraph. By 1890 almost all major ports worldwide had telegraphic service, prompting a U.S. Navy officer while on the China station to comment, "Now we have become mere messenger boys at the end of the cable."[16]

The British government had long recognized the military significance of telegraphy. In the first decade of the century, it formulated policies for censoring telegraph service in the event of war, and by 1912 it had achieved its goal of invulnerability to such interruption on the part of other countries by having for "every important colony or naval base … one cable … which touches only on British territory or on the territory of some friendly neutral."[17] When war broke out, Britain moved rapidly to isolate its main adversary; the first British act of war was the severing of five German under-

[11] Charles Bright quoted in Headrick, p. 75.

[12] Headrick, p. 74.

[13] Kern, pp. 275–277.

[14] *Report of the Chief Signal Officer*, p. 186.

[15] Siemens, p. 8.

[16] Howeth, pp. 10–11.

sea cables, leaving Germany only one transoceanic link, the Liberia-Brazil cable—it too was cut by 1915—and the first British military engagement was a raid on the German cable station at Lome, Togo.[18] The severing of these cables meant, for one thing, that German cruisers away from the Continent were almost incommunicado, as they were reluctant to risk giving away their position by using wireless.[19]

The Germans, too, sought to disrupt enemy communications. They made attacks on three British cable stations overseas, and they severed land lines connecting Britain to India and the Baltic cables connecting Britain and France to Russia.[20] The disruption—and threatened disruption—of telegraph links gave a great impetus to the development of wireless communication. Telegraphy suffered from two other shortcomings: a telegraph link required trained operators on both ends, and the encoding and decoding of a message took some time. Hence, on the battlefield it was principally the telephone that gave commanders up-to-the-minute information and control-by-wire.

1.1.3 The Telephone and the Battle of Neuve Chapelle

Telephone lines connected each unit to its subordinate and superordinate units, so that, for the first time in a major war, commanders at different levels (such as company, brigade, division, and corps) could be in direct contact. This allowed the exchange of information and tactical ideas and the immediate conveyance of orders (Figure 1.3).

The military telephone system appears in Arnold Zweig's novel about the war on the Eastern Front, *The Case of Sergeant Grischa*. Zweig described it as "that great net, that tissue of slender telephone wires which, like a spider's web, brought that vast land within the hearing of its masters".[21] He wrote of the signalers, the telephone stations, the labor companies, and the repair parties needed to construct, operate, and maintain the system:

> *… there stretched over the land a network of black lines in all directions: wires, flexible and coated with rubber, soaked in protective solution, and covered with twisted thread. Like thin black nerves, they coiled over the earth in shallow ditches, just beneath the surface, or traversed the air on tall poles. They accompanied the telegraph wires along all the railway lines; they crossed the forests on straight paths decreed for them. The telephone wires of the army hung high above the earth in the forest tree-tops; their course was marked on the map and the line was carefully secured whenever necessary. In the summer no one paid any attention to them, but in the winter they paid dearly for this neglect. The forests, where the wind-spirit waved his snowy hands, took little heed of these black rubber-coated wires.*[22]

17 Headrick, pp. 98–99. The quotation is from a British government report of 26 March 1902.

18 Beesly, p. 2.

19 Cruttwell, p. 74.

20 Headrick, pp. 141–142.

21 Zweig, p. 71.

Figure 1.3. Field telephone in World War I (photo courtesy of the Library of Congress, World War I Posters, LC-USZC4-12670).

At the front, the telephone lines connecting artillery observers to those directing the guns were extremely important. (The telephone could even be used in observation balloons, as the telephone line could be attached to the tethering cable.)[23] The telephone was used, too, to warn of the firing of a long-range gun—a shell could be as much as five minutes in flight—in those cases where a telephone line joined an observing post near the enemy gun with the intended target.[24] And telephone lines were unrolled to keep advancing units in touch with base camps. The battlefield importance of telephony is suggested by the efforts of the U.S. Signal Corps to provide communications for the American Expeditionary Force in the final year of the war: the Signal Corps strung approximately a quarter million kilometers of telephone wire and set up 273 telephone exchanges, and by the time of the armistice, Signal Corps telephone traffic had reached some 150,000 local calls and 4000 long-distance calls every day. Advanced techniques, such as multiplexing, were exploited; 4 copper wires could be made to simultaneously carry 3 telephone circuits and 12 telegraph streams (6 in each direction).[25]

[22] Zweig, p. 298.

[23] Clark.

[24] Cruttwell, p. 531.

[25] Kennelly, pp. 225–228, and *Report of the Chief Signal Officer*, p. 174. For U.S. use some 100,000 field telephones were manufactured; the telephone was a modification of one Western Electric had made before the war for the forestry service [*Report of the Chief Signal Officer*, pp. 10, 232].

Though the telephone was clearly the favored means of communication in the field, it was also, as experience repeatedly showed, a deficient means. One problem was that telephone lines were frequently tapped by the enemy.[26] Much more serious was a problem revealed clearly in the battle of Neuve Chapelle.

In August and early September 1914, the Germans moved rapidly through Belgium and deep into France, threatening to take Paris. An Allied counterattack, the "Miracle of the Marne", pushed the leading German forces back to the Aisne River, and there followed a series of flanking movements that extended the battle line northwestward to the sea. The line thus established, stabilized by entrenched troops with machine guns behind barbed-wire barriers, would hardly move in the next three and a half years of intense combat. Commanders then, of course, did not know this and continued to believe the war could end quickly with one breakthrough. In fact, despite dozens of major attempts in four subsequent years of fighting on the Western Front, the opposing line was cleanly broken only three times.[27] The first of these penetrations was the battle of Neuve Chapelle.

In February 1915 Russia suffered another colossal defeat when the Germans destroyed its Tenth Army, taking 110,000 prisoners, at the second battle of the Masurian Lakes. Germany decided to reverse the von Schlieffen strategy and was now sending as many troops as it dared to the Eastern Front, trying to knock Russia out of the war and standing on the defensive in the West. France and Britain, therefore, felt obliged to relieve the pressure on their ally by launching a major offensive. Sir John French, commanding the British forces, decided to break the enemy line at Neuve Chapelle, not far from the German held railway junction at Lille, with an assault launched early in the day on 10 March.

It began with a 35-minute "hurricane bombardment" that was one of the first demonstrations of the unprecedentedly intense use of artillery that became characteristic of the war. This opening barrage carried more shells than had been fired in the whole of the Boer War, fought from 1899 to 1902.[28] The Germans likewise made heavy use of artillery. One unforeseen result was an almost complete disruption of telephone communications, even though signalmen worked constantly to mend line breaks and repeatedly laid new line. So although British units broke through the German line, the lack of communication—laterally at the front, between advancing units and commanders trying to coordinate actions, and between guns and observers—precluded exploitation of the initial successes. According to one historian, "it was glaringly obvious that the breakdown in communications, the inevitable lack of speedy reaction to the situation at the front, the shattering of the telephone lines between observers and the guns, had been almost wholly responsible for the frustrations and delays."[29] The Germans succeeded in reforming their trench line just a thousand yards or so farther back, and the battle

[26] Hartcup, p. 78.

[27] Marshall, p. 87.

[28] Gilbert, p. 132.

[29] Macdonald, p. 140.

ended, in the words of another historian, “Neither a defeat nor a victory, but a two-sided blood sacrifice. …”[30]

The battle of Neuve Chapelle, intended to be a decisive blow, instead showed how difficult it would be to break the stalemate. The vulnerability of telephone lines to artillery fire continued throughout the war. Even along stationary lines, enormous numbers of shells were fired, and an assault could be preceded by a barrage of a million rounds. On one occasion on the Western Front, an artillery barrage caused 350 breaks in a 1-kilometer line.[31] A contemporary assessment was that, in the forward zones of warfare, “the intense effect of modern artillery fire has practically ruled out the use of wired communications.”[32] Late in the war, the practice of preceding an assault by a massive bombardment fell into disfavor, as it removed the element of surprise, yet Ludendorff and other commanders still advocated the use of a short artillery barrage before an attack, specifically to disrupt enemy communications. Some immunity from shellfire could be obtained by burying the line 6 feet underground, and the British began doing so in 1915.[33] Still, telephony was hardly suited to offensive operations. Indeed, the historian Peter Dewey has written: “Perhaps the greatest weakness of the attack lay in the lack of communication once it had begun. Commanders in the trenches were almost powerless to communicate with their advancing troops.”[34]

1.1.4 Ground Telegraphy

To overcome such problems—which of course also beset traditional telegraphy—there was frequent reliance on the ancient means of battlefield communication, couriers (dispatch riders and, much more usually, runners), and, occasionally, on carrier pigeons, messenger dogs, and signal flags. (Adolf Hitler was one of the thousands of soldiers who served as dispatch runners.) An electrical technology, signal lamps, came to be quite important, as lamps suitable for daytime as well as nighttime use were developed, including ones using ultraviolet light in order to be invisible to the enemy.[35] Another electrical technology that avoided reliance on electrical lines was TPS (télégraphie par le sol), also called “ground telegraphy” and “earth current signaling”.[36] The experiences at the battle of Neuve Chapelle and other early actions gave great impetus, in mid 1915, to the development of this technique.

Engineers had long known that electric impulses could be detected after traveling several hundred meters through the ground. The enterprising engineer Gustave-

[30] Marshall, p. 87.

[31] Kennelly, p. 230.

[32] Cusins, p. 768.

[33] Woods, pp. 126, 195.

[34] Dewey.

[35] Kevles, p. 137.

[36] Sources for the information on TPS are Amoudry, pp. 179–181; Blake, pp. 332–334; Hartcup, pp. 76–78; and Kennelly, pp. 243–244.

Auguste Ferrié, who headed the French Radiotélégraphie Militaire, had two important insights: the newly available electron tube could significantly extend the range of this technique, and it might then be of enormous value in the fighting on the Western Front. He made improvements in the signal generator and in the receiver—notably by the use of a triode amplifier—and achieved a usual range of several kilometers. The transmitter was essentially a buzzer (an electromechanical device that interrupts the circuit at a very high rate) powered by a battery. Ferrié found that there was less interference when high tones were used. The receiver was an amplifier, employing a triode electron tube. Earth connections were usually made by driving steel pins into the ground; often a short length of insulated wire was laid along the ground and anchored at each end by a spike.

These devices began to be used in large numbers in 1916, and by the end of the war the French had produced almost 10,000 of them for use by the Allies. The Germans also deployed a system of ground telegraphy; it was mainly the work of a young mathematician, Richard Courant, who became famous after the war for his work on quantum mechanics.[37] So did the Americans.[38]

Users of ground telegraphy discovered that their receivers frequently could pick up telegraph and telephone signals from lines buried nearby. They were thus used to tap enemy lines and also to receive one's own telegraph or telephone signals when a line had been severed. These receivers came to play a large role in eavesdropping, a subject considered more fully below.

Its portability and its freedom from electrical lines made ground telegraphy an important means of communication during the Great War. It was a technique, however, that scarcely outlived the war. Even before war's end it began to be displaced by another wireless communication technique, one with a much wider applicability and a much greater potential.

1.2 COMMUNICATION THROUGH THE ETHER

1.2.1 Origins of Wireless Telegraphy

The leaders in developing the new communications medium were the navies of several nations. They had long used other wireless means, such as lanterns and gunfire, to signal from ship-to-ship or ship-to-shore. The availability of telescopes led in the mid seventeenth century to signal-flag systems, which underwent considerable refinement over the next two-and-a-half centuries.[39] A major advance came with electric-light signaling, which the U.S. Navy adopted in 1878 for conveying Morse

[37] The famous physicist Arnold Sommerfeld also contributed to the German development of ground telegraphy [Hartcup, p. 77]. In the United States Lee de Forest patented a system of signalling by earth currents [Blake, p. 334].

[38] A 2-way earth telegraphy set, the SCR-76, was designed by Western Electric engineers [*Report of the Chief Signal Officer*, p. 290].

[39] Howeth, pp. 4–10.

code.[40] All of these signaling methods were slow and had a range of only 10 or 20 kilometers, even under the best of weather conditions. Hence when wireless communication by electromagnetic waves became possible, many naval officers showed interest.

The origin of radio may be traced back to James Clerk Maxwell's prediction, made in the early 1860s, of the existence of electromagnetic waves (thus called because they consist of interacting electric and magnetic fields) or to Heinrich Hertz's demonstration of their existence a quarter century later. In 1892 William Crookes attracted international notice in arguing that these waves provided an excellent means of communication, yet the exploitation of this possibility, either for commercial or military purposes, took several years.[41] The person most responsible for turning the laboratory demonstration into a useful device was the young and largely self-taught Guglielmo Marconi.

In the late 1890s Marconi developed a wireless system that drew heavily on the achievements of contemporaries, notably the Hertzian transmitter of his teacher Augusto Righi and the coherer detector of Édouard Branly (which registered the presence of an electromagnetic wave by the changed conductivity of a tube of metal filings). (See Figure 1.4.) The historian Hugh Aitken writes of Marconi: "The original acts of creative insight were seldom his. Where he excelled was in the indispensable process of critical revision."[42] Marconi succeeded not only as what would today be called a systems engineer, but also as an entrepreneur.

After extensive experimentation with antenna designs (which showed him that he could achieve much greater distances with a grounded vertical antenna), Marconi in 1896 put together a system capable of signaling several kilometers and soon obtained an English patent. The following year a company was formed to exploit the patent, and in 1900 a second company, specifically for marine communications, was established. What came to distinguish the Marconi companies was their provision of a complete service, not only the equipment but also the personnel to operate and maintain it.

Effective use of radio was hindered by a problem associated with early transmitters. Most pre-war transmitters were the so-called spark oscillators, which generated radio-frequency waves in extremely short pulses that were rapidly damped. Both the short pulse-length and the damping caused a substantial broadening of the signal spectrum (that is to say, the signal contained a wide range of frequencies). (See Figure 1.5.) Interference between two simultaneous transmissions was then almost inevitable, since they could not be sharply tuned to different frequencies. It was widely recognized that a reliable generator of waves of a single frequency could

[40] Howeth, p. 10.

[41] The belief that Oliver Lodge's Hertzian-wave demonstration in 1894 (at the annual meeting of the British Association for the Advancement of Science) included the transmission and reception of Morse code, as Hugh Aitken concluded [Aitken 1976, p. 123], has been convincingly refuted in Sungook Hong's 1994 article in *Technology & Culture*.

[42] Aitken 1976, p. 187. The main source for this paragraph is Aitken 1976, pp. 179–297.

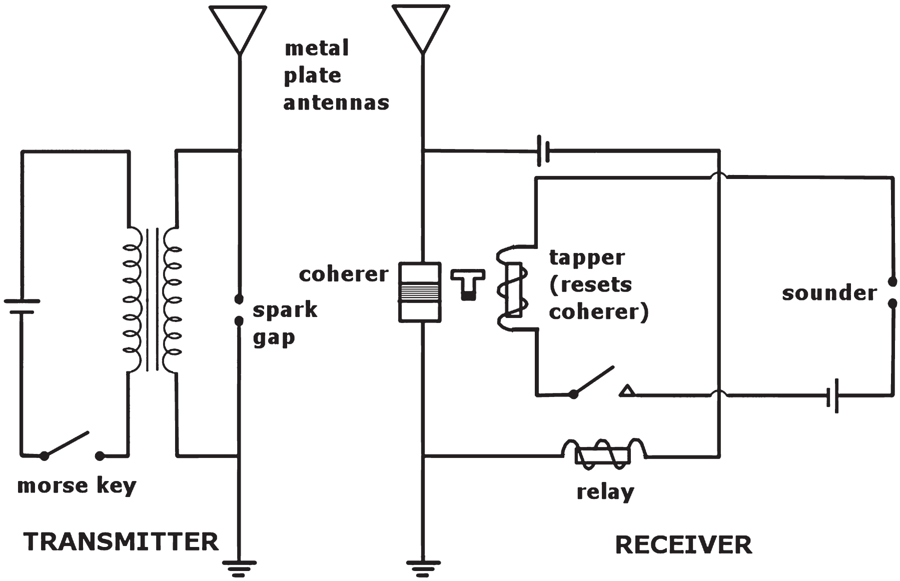


Figure 1.4. The system of wireless communication that Marconi developed by the turn of the century.

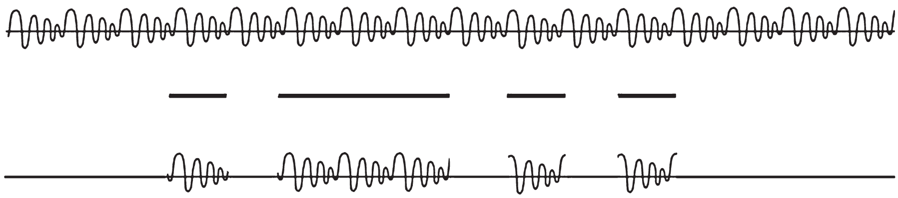


Figure 1.5. These curves indicate how Morse code is carried by the output of a spark transmitter: at the top is output typical of a spark transmitter, in the middle is the code for the letter L (dot-dash-dot-dot), and at the bottom is the transmitted signal.

solve this problem. (As we will see, another crucial advantage of a continuous-wave generator was that it made possible transmission of voice signals.) Efforts to produce a continuous-wave transmitter predated the war, and two means of generating continuous waves were already successfully developed: the Poulsen arc transmitter and high-frequency alternators.

At the beginning of the nineteenth century, Humphry Davy had observed that, under certain conditions, if he made a small break in an electric circuit the current continued to flow in a steady arc-discharge across the gap, and he exploited the phenomenon to produce an extremely bright light (later commercialized as arc lighting). Almost a century later, the Danish engineer Valdemar Poulsen, building on the recent work of the English scientist William Duddell, showed how to obtain regular oscillations in the radio-frequency range from a steady arc-discharge, and in 1903 he demonstrated transmission over 150 miles.[43] In 1913 the U.S. Navy began building Poulsen-arc transmitters,[44] and most of the major units of the British navy were equipped with Poulsen transmitters by the end of 1916.[45] Though the arc transmitter easily outperformed spark transmitters, its range was less than hoped for, as it proved difficult to increase the power much beyond 30 kilowatts.[46]

Greater power was obtained with radio-frequency alternators. Generators of alternating current for electric power provided, of course, great power—a capacity of several thousand kilowatts was common in the first decade of the century[47]—but at a frequency, typically 50 or 60 Hertz (cycles per second), far below what was needed for radio. The person most responsible for the successful redesign of alternators to produce radio frequencies was Ernst F.W. Alexanderson of General Electric, and in 1909 that company began produced the first 100-kilohertz, 10-kilowatt alternator.[48] In February 1917, General Electric delivered a 50-kilowatt alternator to the Marconi wireless station in New Brunswick, New Jersey; the station was taken over by the navy after the United States entered the war in April 1917, and beginning in February 1918 it was regularly used for official radio traffic to Europe.[49] This transmitter was used when direct radio communication with Germany (through the station at Nauen, near Berlin) was established in October 1918.[50] A still more powerful radio-frequency alternator was built by the French company Société française radioélectrique (SFR); its 125 kilowatts of power were ample for communication across the Atlantic.[51]

By war's end, it was clear that the future of radio transmission lay with continuous-wave generators. Some engineers thought the Poulsen arc would become the dominant type, others the high-frequency alternator. In fact, as we will see, the future lay with a third means of generating continuous waves.

1.2.2 Wireless at Sea

In the first decade of the century, the Marconi companies and other promoters established a place for wireless in maritime and naval operations. In 1900 the Cunard and White Star lines began installing wireless apparatus on their liners, and in 1901 Lloyds of London, the marine insurance firm (which had more than 1000 agents in ports around the world), signed a contract with the Marconi Company. In the U.S. the Radio Ship Act of 1910 required all ocean-going vessels carrying 50 passengers

[43] Howeth, p. 133.
[44] Aitken 1985, pp. 93–95.
[45] Hartcup, p. 128.
[46] Aitken 1985, pp. 96–97.
[47] Hunter and Bryant, p. 346.
[48] Brittain 1992, p. 67.
[49] Brittain, pp. 117–131.
[50] Brittain, p. 130.
[51] Amoudry, p. 177.

or more to be fitted with radio equipment. Besides for ship-to-shore and ship-to-ship communications, radio was important in another way; accurate navigation at sea required accurate timekeeping, and just after the turn of the century the Greenwich Observatory began broadcasting time signals.

Navies, too, found wireless a boon to operations. The British navy began equipping its ships with Marconi wireless sets in 1900, and in 1903 the newly created Telefunken began receiving orders from the German navy.[52] As early as 1905 wireless played a major role in combat, allowing the Japanese navy to surprise the Russian navy at the time of the battle of Tsushima.[53] The U.S. Navy, however, was unusually slow to adopt the new technology; it was not until 1913 that tactical signaling by wireless became regular practice.[54]

At the highest level, radio changed the way navies fought. According to the British historian C.R.M.F. Cruttwell, "… the Admiralty from its great wireless masts in Whitehall necessarily directed and controlled strategy far more powerfully than in earlier wars."[55] Wireless finally ended the need for dispatch vessels, which carried messages to and from ships at sea. It also made possible the new British strategy of distant blockade. The traditional British practice of cutting off enemy trade by close blockade of harbors was too dangerous because of torpedo boats and U-boats, but good communications and reconnaissance allowed the safer alternative to be almost as effective.[56]

Wireless was also important at the tactical level. In fleet operations, however, the British, concerned that wireless transmitting would reveal their locations and aware of the danger that their codes might be broken, maintained wireless silence when using other forms of signaling made this possible.[57] German warships made greater use of wireless, not knowing how skilled the British were at locating transmitters and falsely believing as we will see below, that their codes were secure.

Wireless communication was especially important for submarines, as their deployment could often benefit from recently received information about threats from the enemy and about possible targets. In April 1915 Admiral John (Jacky) Fisher reported to Winston Churchill, First Lord of the Admiralty, that German U-boats were transmitting and receiving signals, day or night, at distances up to 300 miles and termed it "vitally necessary" that the British submarines be capable of the same.[58] (British submarines on patrol could not report sightings in a timely way

[52] Headrick, pp. 118, 123.

[53] Griset, p. 104, and Okamura, p. 54.

[54] Susan Douglas 1985.

[55] Cruttwell, p. 62.

[56] Schmitt, p. 40.

[57] Beesly, p. 32. Communicating by signal flag was neither rapid nor reliable. For example, at the Battle of Dogger Bank early in the war orders conveyed by signal flag were misinterpreted; otherwise the British would have achieved a much greater victory [Beesly, p. 62].

[58] Hartcup, p. 128.

because, in the first year and a half of the war, their wireless sets had a range of only 30 miles or so.)[59]

To achieve longer-range communications, two avenues were pursued. The first was the development of more sensitive receivers. Electron tubes helped here in three ways: as detectors (the purpose for which both Fleming's diode and de Forest's triode were invented); as amplifiers (the purpose of electron tubes in telephone repeaters); and as local oscillators for what is known as "heterodyning".

The process of heterodyning—whereby the incoming signal is combined with a continuous wave generated in the receiver—had been proposed before the war as a way to gain sensitivity.[60] (The so-called beat frequency—equal to the difference between the input frequency and the local-oscillator frequency—carries unchanged the audio signal.) There were, however, no good sources of local oscillation at appropriate frequencies, as neither the alternator nor the Poulsen arc could be readily scaled down to the right size.[61] The electron tube proved to be ideal as a small, low-power oscillator, and, indeed, it was for heterodyning that the electron tube first became standard in naval apparatus.[62]

The second avenue toward long-range radio was the development of more powerful and effective transmitters. During the war the most powerful and effective type was the Poulsen-arc transmitter. Built in various sizes—the largest for the highest-power land stations, the smallest for transmitters for submarines—the arc transmitter functioned well, both for telegraphy (its usual use) and telephony. For the latter application there gradually emerged a rival in the electron-tube oscillator. Alexander Meissner, Telefunken's chief engineer, produced an effective transmitting tube early in 1915,[63] and engineers in Britain and the United States achieved similar results at about the same time. As we will see below, tube transmitters were developed for the mobile use of radio telephony, and for a short time this seemed the only area where it was preferable to the Poulsen arc.

1.2.3 Wireless on Land and in the Air

With the availability of powerful transmitters, radio became a vital means of long distance communication for several governments. Its oceanic cables severed, Germany could communicate with its colonies and ships away from the Continent only by radio; the transmitter at Nauen could reach America, South-West Africa, and China.[64] France relied on radio to communicate with its allies in Eastern Europe

[59] Hezlet, p. 97.

[60] Heterodyning was first introduced, by Reginald Fessenden in about 1901, as a way of making audible the Morse-code signals sent by a continuous-wave transmitter [Aitken 1985, pp. 58–59].

[61] Gossling. Small Poulsen-arc oscillators were, in fact, developed for use in heterodyning, but were soon displaced by vacuum-tube oscillators.

[62] Gossling.

[63] Hartcup, p. 127.

[64] Beesly, p. 30.

(Russia, Rumania, Greece, Montenegro, and Serbia) and with certain of its colonies.[65] After U.S. entry into the war, a radio link between Lyon and Sayville, New York permitted the exchange of 40,000 words per week between the two allies.[66] The most important of the French transmitting stations was at the Eiffel Tower, which Alexandre-Gustave Eiffel had made available in 1903 to the French military for radio communication.[67] It was, indeed, from the Eiffel Tower that the message stopping the war was transmitted at 5:00 am on 11 November 1918.[68]

Armies in the field made considerable use of wireless. Because early sets were not very portable, wireless was used principally between headquarters, though small radios for use in the trenches were developed before the end of the war.[69] In the first year of the war, Moltke made wireless a favored means of communicating with general headquarters, but his lack of radio capacity, a problem greatly exacerbated by intentional interference from the Eiffel Tower station, caused severe communication deficiencies.[70] Electron-tube transmitters, which became available for field use toward the end of the war, alleviated two difficulties associated with earlier transmitters: the much narrower signal spectrum made it easier to tune out other transmissions; and the smaller size improved portability.[71] These transmitters were particularly welcome for communicating between gunners and forward observation posts.[72]

These, as well as the naval uses of wireless mentioned above, were applications of wireless telegraphy, which conveyed Morse code or some other discrete code. As early as 1900 Reginald Fessenden, a Canadian-born electrical engineer, had recognized that radio waves could transmit voice and music, provided one found a source of continuous waves at radio frequency. The audio signal could be imposed on the continuous wave at the transmitter and extracted from the incoming signal at the receiver. (See Figure 1.6.) Fessenden's idea was that one could design an alternator able to produce radio-frequency oscillations (in the neighborhood of 100,000 Hz, rather than the 60 Hz produced by many electric-power generators). General Electric pursued this idea and, as mentioned above, built a series of radio-frequency alternators. In 1906 at Brant Rock, Massachusetts, Fessenden used one of them for experimental broadcasts of speech and music that were received by wireless operators on nearby ships.[73]

[65] Griset, p. 105, and Amoudry, p. 185.

[66] Griset, pp. 105–106.

[67] Libois, pp. 52–53. The Eiffel Tower, completed in 1889, was the tallest structure in the world for four decades.

[68] Amoudry, p. 201. The message transmitted read "Marshall Foch to the Allied commanders: Hostilities will cease at 11:00 a.m."

[69] Kennelly, p. 234.

[70] Cruttwell, p. 25, and Amoudry, p. 155.

[71] Eoyang, p. 29. Early in the war the problem of mutual interference was so severe that the British army allowed only one radio set per division along the front.

[72] Cusins.

[73] McNicol, pp. 74–77.

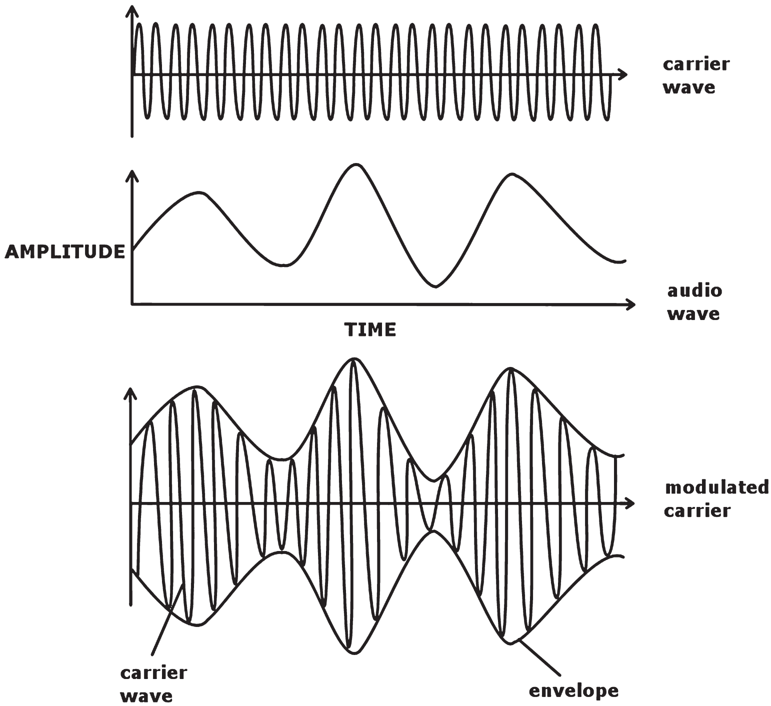


Figure 1.6. These curves indicate how a voice signal is carried by a continuous wave, which is then called the carrier wave: at the top is a single-frequency wave, in the middle is an audio wave produced in speaking, and at the bottom is the carrier wave modulated by the audio signal.

The two other sources of continuous waves—the Poulsen arc and the electron tube—were also applied to radio telephony. In 1914 Bell engineers began to investigate electron-tube circuits as oscillators, and in April 1915 they transmitted speech from Montauk, Long Island to Wilmington, Delaware. These engineers then constructed a transmitter containing some 300 oscillating tubes (in order to reach a power of two to three kilowatts) and in October 1915 successfully transmitted speech across the Atlantic (to the Eiffel Tower station of the French military).[74] During the war and in the first few postwar years, the Poulsen arc, along with the radio alternators, were favored over the electron tube because they generated much more power. Both, however, were much larger, so not suited to portable radio telephones.

Radio was also important to the military use of aircraft. Aviation underwent rapid development during the war, both in numbers—by Armistice Day some 200,000 aircraft had seen service—and in capabilities. Speed increased from 100 to 200 km/hr, motor power from 100 to 300 horsepower, flying height from 1200 to 9000 meters, and flight duration from 5 to 9 hours.[75] The most important military function was reconnaissance.[76] Here rapid communication was essential, especially

[74] Fagen, pp. 364–368.

[75] Braun, p. 202.

when the purpose was the directing of artillery fire. In 1912 the U.S. Navy successfully tested a radio transmitter and receiver mounted in an aircraft, but the considerable weight of the apparatus and the difficulty of communicating in telegraphic code made wireless unpopular with aviators.[77] In Germany airplane transmitters underwent testing as early as 1912. By the end of 1916 they were standard equipment, and German planes began to be equipped with receivers as well.[78]

One of the most important improvements was making radio apparatus smaller and lighter. Using an on-board generator (run by the airplane motor or a wind-driven vane) rather than batteries reduced the weight further. Since keying in Morse code was difficult in that era's airplane and also required considerable training, alternative means were sought. The Germans experimented with automatic code senders (so the aviator needed only to key in letters) and with wireless transmission of drawings from aircraft to the ground.[79] Cylinder phonographs were used to record observations in the air, though with this device the information could not be shared until the flight ended.[80] The most important advance was the transmission of voice rather than code, something that the electron tube, as oscillator and amplifier, made possible.

One of the engineers who developed radiotelephony for aircraft, A. Hoyt Taylor, recalled some of the problems:

> *The first time I went up in a plane and listened to signals from the ground, I felt pretty hopeless. The places assigned for the radio operator were in no way shielded from the tremendous noise of the engines. Engine mufflers were not too efficient. In addition to this, the ignition interference from the spark plugs in the engine was terrific. In order to shut out the engine noise we experimented with all kinds of radio helmets, the telephone receivers being buried in the ear caps of the helmet, surrounded with a sponge rubber device, which was supposed to close up the ear against extraneous sound.*[81]

Work went into ameliorating the interference problem and making a transmitter that would respond well to the human voice, but not to engine or wind noise. Engineers devised a soundproof helmet bearing both microphone and earphone, an antenna system that would radiate effectively but not interfere with tactical maneuvering, and a power supply suitable for the electron-tube circuits. It was necessary to make the set as simple to operate as possible, and the tubes had to be small and rugged, yet capable of mass production.[82]

The French successfully tested air-to-ground wireless telephony at the battle of Verdun in 1916 and air-to-air telephony at Villacoublay the following year.[83] The

[76] Hartcup, p. 152, and Howeth, p. 189.

[77] Howeth, pp. 189–191.

[78] Schwarte, p. 193, 266–268. Some planes were equipped with telephones between pilot and observer, because engine noise made communication between them difficult [Hopkins p. 50].

[79] Schwarte, p. 267, and von Weiher, p. 47.

[80] Hopkins, pp. 47, 50.

[81] A. Hoyt Taylor, pp. 66–67.

[82] Clark.

[83] Amoudry, p. 172.

latter use of wireless allowed a group of airplanes to coordinate their actions in the course of a mission; thus the voice-commanded squadron became a new fighting unit.[84] The Royal Air Force began using interplane communication in 1917. In early 1918 aviation radiotelephones (SCR-67 and SCR-68) began to be produced in large numbers in the U.S.[85] By the end of the war, wireless communication was generally recognized as having great value for military aircraft.[86] While pilots in 1915 usually regarded a radio set as an unwelcome nuisance, many in 1919 refused to fly without one.[87]

Aviation presented the greatest need for radio telephony, but sea and ground applications followed quickly. During the war Western Electric produced a small radio telephone (the CW-936) that was used on sub-chasers and destroyers, and this set popularized voice communications in the U.S. Navy.[88] Toward the end of the war, radiotelephones began to be used in tanks; without them, unplanned mass maneuvers of tanks were not possible.[89]

A contemporary wrote: "… radiotelephone-equipped airplanes closed the control loop and subjected airplane pilots to the same principles of command and control incumbent upon the rest of the Army."[90] Radio served similarly with ships at sea and tanks on land. On a larger scale, radio combined with other means of instantaneous communication to change forever the nature of military activity. In 1920 Arthur Kennelly wrote:

> *Just as a spider on watch at the center of her net, becomes a combined spider and net organization, extended into space as a circular plane surface with physiological and nervous mechanism at the center; so a human being armed with a sufficiently powerful radio apparatus becomes in the same sense, a combined man and ether organization, pervading the whole world, and capable of initiating intelligent response over all the globe.*[91]

1.3 EAVESDROPPING

1.3.1 Military Intelligence

Homer's *Iliad*, one of the oldest accounts of war, portrays the use of runners for communications and the practice of infiltrating enemy lines to eavesdrop.[92] The use

[84] Kennelly, p. 238.

[85] Clark.

[86] Prince, and Hartcup, p. 155.

[87] Prince.

[88] A. Hoyt Taylor, p. 64.

[89] Clark. This difficulty was clearly foreseen by the British Colonel Ernest Swinton, one of the early proponents of the tank [Dupuy, pp. 221–223]. At the battle of Cambrai in November 1917, a few tanks carried radios [Macksey, p. 94].

[90] Clark.

[91] Kennelly, p. 234.

[92] See, for example, pages 283, 286, and 336 in Robert Fagles' translation of the *Iliad*.

of radio in war facilitated communications enormously, but it facilitated eavesdropping even more. Wireless, indeed, opened two new windows on the activities of the enemy: messages sent by wireless could be intercepted and interpreted; and infantry units, artillery units, ships, and zeppelins using transmitters could be located with direction-finding antennas even when the messages could not be read. The historian Daniel Headrick has written: “As secret interception and code-breaking were added to the arsenal of the warring powers, a new weapon was forged: communications intelligence. This … was as important to the outcome of the First World War as the strategies and tactics that were formerly emphasized.”[93]

All of the belligerents worked to eavesdrop on enemy communications. The British navy, for example, maintained a large network of radio listening stations, and along the Western front the Allies maintained a sequence of such stations at intervals of about 15 kilometers.[94] Frequently, even wired communications could be overheard. On occasion it was possible to tap directly into an enemy line.[95] More often, one could pick up a telegraph message or telephone conversation with a receiver of the type used for ground telegraphy, since the signal-bearing wire induced currents in the ground. This became an important use of the ground-telegraphy receivers, and often collecting loops were laid out in the ground as close to enemy communications as possible.[96] The listening services of the opposing armies were so effective that both the British and the Germans were prompted to develop devices (the Fullerphone and the Unabhorchbare Telegraph, respectively) for sending telegraph signals that could not easily be tapped.[97]

The other new window that radio gave to military intelligence was direction-finding. Radio waves generally travel in straight lines from the transmitter, though, like other waves, they are subject to reflection, refraction, and diffraction. The direction from which they arrive at a remote location can be roughly determined by using an antenna consisting of wire wrapped on the perimeter of a square wooden frame; there is no signal when the antenna is perpendicular to the line of propagation, and maximum signal when the line of propagation lies in the plane of the antenna. (See Figure 1.7.) By taking the bearings of a transmitter at two or more locations, one can then determine its approximate location.

The British had used crystal radio-wave receivers for direction finding, but the availability of electron tubes beginning in about 1914 made the technique much more powerful, since tube receivers were immensely more sensitive. Direction

[93] Headrick, pp. 138–139. Perhaps the earliest instance of intercepted radio communications in wartime was the reading by Japanese radiomen of Russian fleet signals during the 1904–1905 war [Dear, p. 626].

[94] Kennelly.

[95] U.S. forces used a device called the telautograph that indicated any variations in line conditions, but if a line was tapped skillfully, even with the telautograph it was difficult to detect the wiretap [*Report of the Chief Signal Officer*, p. 243].

[96] Cusins. A countermeasure was the use of twisted-pair conductor; with ground-telegraphy receivers could read messages from single-wire lines up to a distance of four miles [*Report of the Chief Signal Officer*, p. 115].

[97] Hartcup, pp. 77–78.

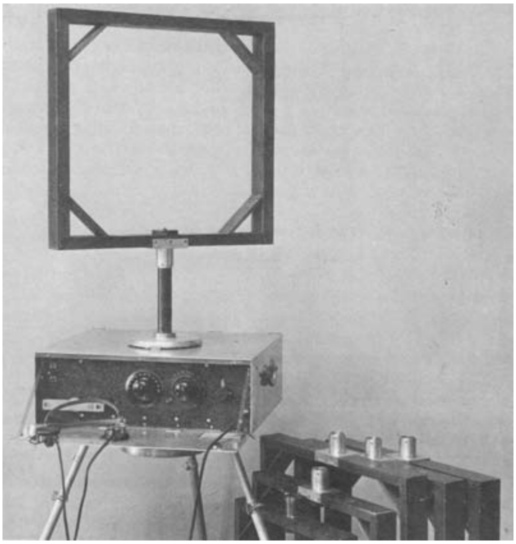


Figure 1.7. Direction-finding antenna (photo courtesy of NIST Boulder Labs).

finding, therefore, grew to be a large branch of military intelligence, one employed almost every place the enemy used wireless transmitters.[98]

The Germans used the technique as early as the first month of the war, following the location of the Russian staff, which was using a transmitter, throughout the battle of Tannenberg.[99] The French used direction finding to follow the forays of German zeppelins, in particular in warding off such attacks on Paris.[100] It was the British, though, who most effectively employed the technique. Whenever a German surface ship, U-boat, or zeppelin in the North Sea made a radio transmission, it was likely that several British listening stations determined its direction. The information was telegraphed to the Admiralty, where the location of the transmitter was calculated.[101] By May 1915 the British were in this way tracking U-boats across the North Sea with an accuracy of about 20 miles.[102] For the Atlantic Ocean, fewer listening stations and greater distances meant that the accuracy was only about 50 miles. Direction finding was thus an effective tool in the fight against the U-boat, and it became especially important after the institution of the convoy system, since evasive routing was then possible (and because the latest information could be supplied to the convoy by wireless).[103]

[98] Cusins. The first use to which British-army engineers put the triode was in a direction-finding receiver.

[99] Cusins. According to Cusins, Hindenberg gave some credit for the victory to this employment of the direction-finding technique.

[100] Amoudry, pp. 187–190, and Beesly, p. 141.

[101] Hartcup, p. 123.

[102] Beesly, p. 254.

[103] Beesly, p. 261, and Howeth, p. 210.

The information gathered by direction-finding stations could be used in another way: "traffic analysis". Even without decrypting enemy messages, one could often deduce much about their activities and intentions by analyzing when wireless transmissions were made, from what locations, and in what numbers. The significance of deviations from established patterns could sometimes be guessed. On many occasions traffic analysis combined with direction finding and cryptanalytic results to give an accurate picture of enemy operations.[104] Of course, if one drew conclusions from radio traffic, one could also be deceived by it. In the summer of 1918 the British increased wireless activity at a position on the Western Front where they wished to make the Germans believe an offensive was imminent, and the deception was reportedly successful.[105]

Aviators used direction finding for navigation in two different ways. In the first, the aviator transmitted a coded message identifying himself. Direction-finding stations replied, also in code, giving the bearing of the first transmission. With responses from two or more stations, the aviator could find his position on a map. (The British learned the identifying code of many German zeppelins and were thus helped in tracking zeppelins across the North Sea.) The second way had the advantage that the aviator need not break radio silence, but required direction-finding capability on the plane: the aviator took bearings on two or more transmitters in known locations.[106] Many ships acquired direction-finding sets, which they used to determine their bearings relative to what might be called "radio lighthouses", stations set up along coasts to broadcast identification signals for navigation purposes.[107] In the 1920s it became usual for ships to have direction-finding sets, and in 1935 it became mandatory for all large ships on the British ship register.[108]

During the war Telefunken devised a way for a navigator without direction-finding equipment to determine his bearing relative to a known location. Lighthouses had long provided such a service for mariners; a light flashed when the rotating beam aimed directly north, so that the bearing could be deduced from times from the flash to the passage of the beam and from the passage of the beam to the next flash. Telefunken built a transmitter with 32 directional antennas oriented as the points of a compass. After a start signal, which was radiated from all 32 antennas, the antennas radiated in sequence, one at a time, each for 1 second, moving around the circle from North. The navigator deduced his bearing simply by counting seconds from the start signal to the transmission that was loudest.[109]

Heavy artillery use, as we have seen, was often intended to disrupt wired communications. The belligerents sought also to disrupt radio communications by

[104] Morgan.

[105] Terraine 1965, pp. 165–166.

[106] Cusins, and Kennelly.

[107] Kayton.

[108] J.E.D. Williams, p. 184.

[109] J.E.D. Williams, p. 187. After the war improved versions of "wireless lighthouses" were built and operated.

jamming; that is, by sending out strong interfering signals so that enemy messages would be unintelligible. The technique began early in the war, and its use grew as the use of wireless transmissions grew. In the 1918 offensives German jamming stations put out what was described as a "wireless barrage".[110]

The enormous efforts made during the war to maintain one's own wireless communications, to interfere with the enemy's by jamming, to intercept and decode the enemy's messages, to prevent the enemy from doing the same, and to use direction-finding to locate the enemy constituted what was called "the wireless war" or "the war of wave lengths".[111] This highly technological warfare, where any move might elicit a countermove, resulted in many innovations. Besides the ones already mentioned, there was high-speed automatic transmission of code (regularly used by the Germans and countered by the French using phonographic recording of the transmission) and frequent changes of transmission frequency (used by the Germans and countered by the British with automatic searching devices).[112] Of the many intelligence and counter-intelligence activities, the one that attracted the greatest efforts and yielded the greatest returns was cryptanalysis.

1.3.2 Cryptology and the Zimmermann Telegram

In the course of battle, especially early in the war, messages were sometimes sent "in the clear," that is, without encryption (other than into the dots and dashes of Morse code). Such messages were then almost equally accessible to the enemy. As mentioned earlier, the German victory at Tannenberg owed something to intercepted Russian transmissions, which had been sent "in the clear." It soon became practice, however, to encode all messages before transmission, and this had the result, not surprisingly, that both sides devoted considerable resources to decoding enemy messages.

Though cryptography (encoding and decoding messages) and cryptanalysis (solving unknown codes) are ancient practices, they first became major government activities with the widespread use of wireless during World War I.[113] The French had for decades cultivated cryptology (the study of cryptography and cryptanalysis) in the Bureau du Chiffre, and during the war they repeatedly broke German codes.[114] For example, intercepted information vitally contributed to Allied victory at the Battle of the Marne, which in September 1914 finally stopped the German on-rush a few dozen miles from Paris.[115] Other French successes due to intercepted and decoded messages were the capture of the spy Margheretta Zelle,

[110] Cusins, p. 769. To overcome the effects of such jamming, the General Electric engineer Ernst Alexanderson devised an antenna system called the "barrage receiver" [Gorowitz, p. II.58].

[111] The former phrase is Beesly's, the latter Hartcup's.

[112] Amoudry, pp. 188–189, and Beesly, p. 126.

[113] Morgan.

[114] Amoudry, pp. 155–156.

[115] Amoudry, p. 154.

better known since as Mata-Hari,[116] and a successful counterattack on 18 July 1918,[117] that drove the Germans—who had again approached within a few dozen miles of Paris—north of the Marne and marked the final turning of the tide in the war in France.

The British case provides a more typical picture of the status of cryptanalysis in 1914. Early in the war, Admiralty and other wireless stations picked up strange unintelligible messages that were passed on to the Director of Naval Intelligence, Rear-Admiral Henry Francis Oliver. The messages accumulated on Oliver's desk until he chanced one day to talk with Alfred Ewing, Director of Naval Education. Ewing, it happened, cultivated cryptology as a hobby and asked to be allowed to study the messages. Ewing quickly determined that these were German encryptions and was asked by Oliver to set up a department to see if such transmissions could be decrypted.[118]

The department, which became famous as Room 40, grew in size—by 1917 it employed 800 wireless operators and between 70 and 80 cryptographers and clerks—and delivered valuable information throughout the war.[119] The British were extremely fortunate to obtain, in the first months of the war, copies of codebooks for the three principal codes used by the German navy.[120] Intercepted messages led to the destruction of the German raider *Dresden* on 14 March 1915 and the German collier *Rubens* later that year.[121] An early British naval victory, the battle of Dogger Bank, came about because the German operation order was intercepted and decrypted by the British.[122] Intercepted messages and direction finding afforded Room 40 knowledge of the number of U-boats at sea and the number in port, as well as approximate positions for many of them.[123] According to one historian, radio intelligence was "the most important single factor in the defeat of the U-boats in 1914–18".[124] In other ways, too, the work of Room 40 was vital to the Royal Navy's control of the sea routes throughout the war, and without this control, victory by the Allied armies would not have been possible.

In early 1917, Room 40 scored a triumph on the diplomatic front that changed history: it intercepted and decoded—and then shared with the U.S. government—what came to be called the Zimmermann telegram. (See Figure 1.8.) In this communiqué, German foreign minister Alfred Zimmermann proposed that, in the event of U.S. entry into the war, Mexico become an ally of Germany, saying that in exchange for this action Germany would promise a return of the "lost territories" of

[116] Amoudry, p. 191.

[117] Amoudry, p. 197.

[118] Hezlet, pp. 89–90.

[119] Tuchman 1958, p. 16.

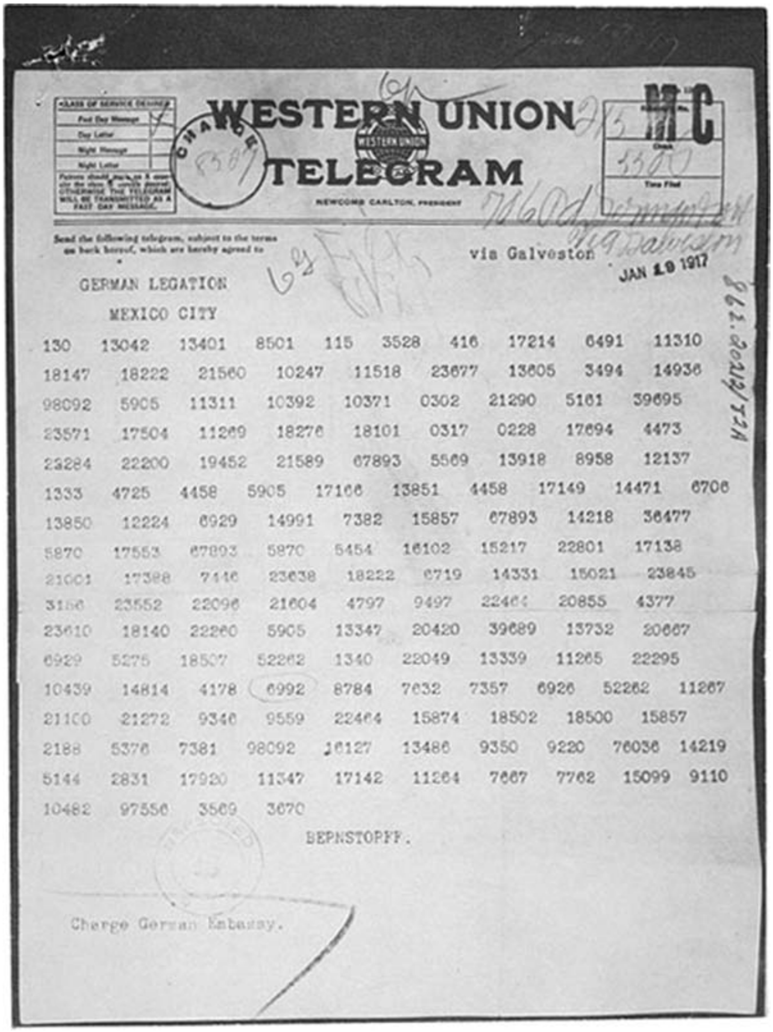
[120] Beesly, pp. 3–7.

[121] Beesly, pp. 78–79.

[122] Hezlet, p. 94.

[123] Beesly, p. 91.

[124] Hezlet, p. 143.



WESTERN UNION
TELEGRAM
NEWCOMB CARLTON, PRESIDENT

Send the following telegram, subject to the terms on back hereof, which are hereby agreed to

via Galveston
JAN 19 1917

GERMAN LEGATION
MEXICO CITY

130 13042 13401 8501 115 3528 416 17214 6491 11310
18147 18222 21560 10247 11518 23677 13605 3494 14936
98092 5905 11311 10392 10371 0302 21290 5161 39695
23571 17504 11269 18276 18101 0317 0228 17694 4473
23284 22200 19452 21589 67893 5569 13918 8958 12137
1333 4725 4458 5905 17166 13851 4458 17149 14471 6706
13850 12224 6929 14991 7382 15857 67893 14218 36477
5870 17553 67893 5870 5454 16102 15217 22801 17138
21001 17388 7446 23638 18222 6719 14331 15021 23845
3156 23552 22096 21604 4797 9497 22464 20855 4377
23610 18140 22260 5905 13347 20420 39689 13732 20667
6929 5275 18507 52262 1340 22049 13339 11265 22295
10439 14814 4178 6992 8784 7632 7357 6926 52262 11267
21100 21272 9346 9559 22464 15874 18502 18500 15857
2188 5376 7381 98092 16127 13486 9350 9220 76036 14219
5144 2831 17920 11347 17142 11264 7667 7762 15099 9110
10482 97556 3569 3670

BERNSTORFF.

Charge German Embassy.

Figure 1.8. A copy of the Zimmermann telegram (photo courtesy of the National Archives).

Texas, New Mexico, and Arizona.[125] Ray Stannard Baker, Wilson confidant, said of the Zimmermann telegram, "no single more devastating blow was delivered against Wilson's resistance to entering the war."[126] Secretary of State Robert Lansing, who hoped to move public opinion toward support for U.S. entry into the war, said that the telegram "in one day accomplished a change of sentiment and public opinion

[125] This was, it should be remembered, a time of animosity between the United States and Mexico. On 28 January 1917 U.S. forces under General John J. Pershing were recalled from Mexico, which they had entered seven months earlier in a fruitless attempt to capture the revolutionary and bandit Pancho Villa.

[126] Quoted in Tuchman 1958, p. 199.

that otherwise would have required months to accomplish."[127] Barbara Tuchman wrote:

> *Had the telegram never been intercepted or never been published, inevitably the Germans would have done something else that would have brought us in eventually. But the time was already late and, had we delayed much longer, the Allies might have been forced to negotiate. To that extent the Zimmermann telegram altered the course of history.*[128]

Other belligerent also intercepted and decoded enemy messages. Even after the Russians stopped sending wireless messages "in the clear" (which they did for the first year of the war), the Germans succeeded in reading them because they obtained the Russian cipher.[129] Also, they broke the American cipher used for messages prior to the major assault on the St. Mihiel salient on 12 September 1918, so the Americans found the position largely evacuated.[130] Yet in the same engagement, a German counterattack on 14 September was repulsed, in part because of foreknowledge gained by the U.S. Radio Intelligence Subsection through decrypting a German message.[131]

Later chapters show that governments continued to support cryptologic activities in the years after the war and, at a much higher level, during World War II.[132] An important consequence for the history of electrical technologies is that these activities played a large role in the development of the modern computer.

1.4 THE ART AND SCIENCE OF RADIO

1.4.1 The Manufacture of Electron Tubes

When war broke out, electron tubes were used as detectors in radio receivers and as repeaters in a few long-distance telephone circuits. When the war ended, tubes performed four essential functions for radio: generating the carrier wave in transmitters, modulating the carrier wave with the audio signal, detecting the signal in receivers, and amplifying signals in both transmitters and receivers. In addition, tubes were used as oscillators in heterodyne receivers, as amplifiers in ground telegraphy and some instruments, and in several other ways (mentioned in Chapter 2).

More striking than the proliferation of uses was the burst in tube production. The total number of audions sold before 1913 was less than 2000; in 1913 sales

[127] Quoted in Tuchman 1958, p. 199.

[128] Tuchman 1958, p. 200. U.S. entry into the war was helped by the fact that Russia's Czarist government was overthrown in March 1917 and replaced by a provisional, ostensibly democratic government; thus the Allies could more plausibly claim to be fighting to save democracy.

[129] Cruttwell, p. 45.

[130] Headrick, p. 157.

[131] Morgan.

[132] The U.S. and French navies had cryptographic departments during the war and retained them after the war; in the 1920s the German and Japanese navies set up cryptographic departments [Hezlet, p. 164].

reached 1700 and in the following year almost 6000.[133] By then, of course, the tube had undergone considerable development and other manufacturers had entered the field. French engineers designed an improved version of the audion (with a cylindrical, coaxial arrangement of the electrodes), known as the TM tube (the initials coming from "Télégraphie militaire"). Mass production began in October 1915, and by war's end more than a million had been made, most of them by Grammont and Compagnie Générale des Lampes, two incandescent-lamp manufacturers.[134] Because the TM tube was both effective and robust, the British mass produced several versions of it.[135] By late 1918 many types of radio receiving tubes were being manufactured by several German companies, and a single Telefunken tube (the RE16) was being turned out at the rate of 1000 a day.[136]

Western Electric developed a number of tubes for the U.S. Signal Corps and the U.S. Navy. For example, the 203A (designated the VT-1 by the Signal Corps and the CW-933 by the Navy) was a general purpose tube, used as detector, amplifier, and oscillator.[137] General Electric was another major U.S. supplier of tubes. GE and Western Electric had agreed to divide the task, GE manufacturing transmitting tubes, Western Electric receiving tubes.[138] By the end of the war, GE had supplied the military with some 200,000 tubes, and Western Electric had supplied half a million.[139]

For the manufacture of electron tubes it helped enormously that light bulbs had been mass produced for many years. Both devices consisted of metal filaments, with external connections, in an evacuated or gas-filled glass enclosure. But electron tubes were more delicate physically, and their behavior depended sensitively upon the shape and spacing of electrodes, the precise level of vacuum, and the presence of adhering or occluded gases on surfaces within the bulb.[140] Engineers worked out techniques for mass production at the same time other engineers were improving tube design.

In the U.S., AT&T, GE, and Westinghouse made the largest contributions. Westinghouse pioneered high power tubes for radio transmitters.[141] In the 1920s both GE and Westinghouse marketed tubes through RCA, which set up its own manufacturing facilities in 1930.[142] The number of tubes made continued to increase; in the United States the production of receiving tubes alone reached 69 million for the year 1930.[143] In Germany one of the most important tube manufacturers was Siemens &

[133] Tyne pp. 108–111, 131.

[134] Amoudry, p. 167, and Tyne, p. 193.

[135] Tyne, pp. 200–232.

[136] Tyne, p. 251.

[137] Tyne, p. 99

[138] Hawkins, p. 62.

[139] Tyne, p. 146.

[140] Fleming 1924, p. 178.

[141] Stokes, p. 21.

[142] Stokes, p. 15, and Tyne, p. 308.

[143] Henney, p. 20.

Halske, where Walter Schottky pioneered the development of multigrid tubes.[144] Whereas Siemens & Halske concentrated on tubes for wire telephony, the other major German tube manufacturer, Telefunken, concentrated on tubes for radio.[145]

England in the 1920s had some half dozen major tube manufacturers. Two of the most innovative were Metropolitan-Vickers Electrical Company and Marconi Osram Valve.[146] The latter was formed in 1919 when the Marconi Company and GEC (General Electric Company Ltd., not affiliated with the General Electric company in the U.S.) set up a joint company for the design and manufacture of electron tubes. In the Netherlands, N.V. Philips Gloeilampenfabrieken, a manufacturer of incandescent bulbs, began producing electron tubes in 1917 and soon became an international leader in the field.[147] France in the 1920s had four major manufacturers of electron tubes; particularly innovative was Société La Radiotechnique, which introduced the "azide" or "nitride" process of filament manufacture in 1926 and AC tubes in the following year.[148] In 1931 La Radiotechnique was purchased by Philips. In Japan the Tokyo Electric Company (which after merger with Shibaura Engineering in 1939 became Toshiba) began manufacturing three-element electron tubes in 1917, and already in early 1920 five Japanese companies were in the business.[149]

Widespread use of electron tubes received a great boost from the government imposed standardization, all tubes had to be made to the same government specifications.[150] A British engineer commented that during the war the standard triode became: "as much an article of consistent manufacture as a metal-filament lamp."[151] Among all users of tubes, telephone engineers were probably most concerned that tubes be uniform in their characteristics, stable in operation, and long lived. (A long-distance telephone connection might involve more than a hundred tubes, and failure of a single tube could break the circuit.) Bell System engineers—some of them in the engineering department of Western Electric, which manufactured tubes—brought about many improvements. In 1925 the life expectancy of a tube was 50 times that of the early tubes of 1914.[152]

There was, of course, more to the radio art than tube production; transmitters, receivers, power supplies, and antennas also needed to be manufactured. Many companies, typically those already involved in electrical technology, began supplying the rapidly growing needs of the military. The largest French company, the Société française radioélectrique (SFR), like most of the others, adopted the techniques of mass production; by itself during the four years of the war, SFR produced

144 Tyne, pp. 252–255.

145 Tyne, p. 431.

146 Tyne, pp. 373–374, and Thrower, pp. 2–4.

147 Tyne, pp. 270–271.

148 Tyne, pp. 398–405.

149 Okamura, p. 25.

150 Barnouw, p. 49.

151 Cusins, p. 769.

152 Fagen, pp. 840–841.

and installed for the Allied armies 63 permanent wireless stations, 300 ship stations, 18,000 airplane stations, and 12,500 mobile stations.[153] Batteries, which provided the power for radios, were manufactured in huge numbers, more than a million in the U.S. alone.[154]

1.4.2 The Science of Electron Tubes

The triode vacuum-tube, which revolutionized 20th-century technology, had a slow start. For six years after its invention in 1906, it was used only as a detector of radio waves, where it was just slightly more effective than the diode tube or a galena crystal.[155] Other applications for the triode—in wired telephony and in wireless communications—began to be found in 1912, but these came only after improvements in the tube design.

Most important was the move from the "soft" tube, containing gas at low pressure, to the "hard" tube, with the enclosed space at high vacuum. De Forest had believed the gas necessary for the tube's operation. He and others were misled by the fact that when used strictly as a detector of radio waves, the "soft" tube was indeed more sensitive than the "hard" tube.[156] For the tube to function effectively as an amplifier or oscillator, however, a high vacuum was necessary. This was recognized in about 1912 by several engineers working independently: Harold Arnold at AT&T's manufacturing subsidiary, Western Electric; Irving Langmuir at General Electric; and Alexander Meissner at Telefunken.

Other improvements came rapidly. Harold Arnold devised filaments (of alkaline-earth oxides on a platinum-alloy core) that were much better electron emitters.[157] Better electrode-configurations—such as the cylindrical, coaxial arrangement of the electrodes in the TM tube, mentioned above—were found. Tubes came to be designed for particular applications: for radio reception, for radio transmission, for telephone repeaters, for various types of amplifiers, and so on. A few examples are a double-grid tube designed by Walter Schottky of Siemens and Halske for terminal amplification in telephone circuits, a tube (the EVN129) designed by Telefunken as a heterodyne oscillator, and a tube (the Type E) designed by Western Electric for transmitters in airplanes.[158] For use in aircraft, ships, and other places where mechanical shocks and vibrations were common, "ruggedized" tubes were designed.[159]

Some tubes had one or more electrodes in addition to the cathode, control grid, and anode of the audion. In 1913 Langmuir, who had discovered "space charge" (a

[153] Griset, p. 40, and Libois, p. 53.

[154] *Report of the Chief Signal Officer*, p. 10.

[155] Stokes, p. 8.

[156] Stokes, p. 8.

[157] Smits, p. 134, and Thrower, pp. 28–29.

[158] Tyne, pp. 100, 245, 248.

[159] Fagen, p. 845.

build-up of electrons in the space around the cathode), found he could reduce the space charge, and thus increase gain, by inserting a grid between the cathode and control grid.[160] In 1916 Schottky inserted a grid between control grid and anode in order to increase gain, thus making what came to be called the screened grid tube.[161]

As these examples suggest, much of the advance came from increased understanding of how the tube functioned. Walter Schottky of Siemens & Halske, G. Stead at the Cavendish Laboratory of the University of Cambridge, Henry J. Round of the British Marconi Company, and Harold D. Brown of Western Electric were leading contributors, but perhaps most influential was Irving Langmuir of General Electric. A Columbia University graduate who obtained a Ph.D. under H.W. Nernst at Göttingen, Langmuir began publication of his studies of vacuum tubes in 1913. His most famous paper, presented to the Institute of Radio Engineers in April 1915, was entitled "The pure electron discharge and its applications in radio telegraphy and telephony"; it made famous the so-called "3/2 power law".

Walter Schottky published a landmark paper in 1918. It analyzed two basic sources of noise in an amplifying tube: thermal noise (arising from random heat-motion of atoms) and the shot effect (arising from the randomness of emission of electrons from the cathode). In the 1920s Bell System engineers John B. Johnson and Harry Nyquist extended Schottky's theoretical and experimental work, and such studies enabled engineers everywhere to reduce electronic noise in a great variety of circuits.[162] The Bell System engineer H.J. van der Bijl pioneered in the analysis of tube performance using measurable parameters and in the techniques for designing circuits whose behavior could be predicted from these parameters. His 1920 text *The Thermionic Vacuum Tube and Its Applications* was a widely-used guide to such methods.[163]

Better understanding of the electron emission process and better materials for filaments and filament coatings led an increase in the efficiency of cathode emission by a factor of four in the 1920s.[164] The continued proliferation of tube types yielded tubes well suited to a great variety of tasks. In power output, for example, the tubes of the 1920s ranged from one-hundredth watt (in the miniature or "peanut" tubes used especially in portable devices) to 100 kilowatts (in the large water-cooled transmitting tubes).[165]

Wartime urgencies, which brought great human and material resources to the development of wireless communications, resulted in startling technological advances. Other factors contributed. The hindrances of patent claims were swept

[160] McNicol, p. 168, and Thrower, p. 10.

[161] Thrower, p. 10.

[162] Fagen, pp. 910–912.

[163] Fagen, p. 262. In 1920 van der Bijl returned to South Africa, his native country, and played an important part in the technical development of that country.

[164] Fagen, pp. 974–975.

[165] Fagen, p. 841.

aside by government edict.[166] In the U.S., Assistant Secretary of the Navy Franklin Roosevelt told contractors to use any patented invention required, guaranteeing them against claims for government work.[167] The patent moratorium and the fact that almost all radio equipment was manufactured for the military caused companies to concentrate on research and development rather than on litigation or marketing.[168] Technology transfer was facilitated by collaboration by different companies on government orders and by sharing of techniques between allies.

One finds in the writings of engineers who were involved in radio at this time many expressions of how rapid the wartime development was. Arthur Kennelly wrote: "It has been estimated that … the war advanced [radio communication] more in four years than perhaps might have been accomplished in twenty or thirty years of peace. …"[169] Less exaggeratedly, George Squier commented on the development of vacuum tubes in the period of the U.S. involvement in the war as follows: "The engineering advancement accomplished in less than two years represents at least a decade under the normal conditions of peace. …"[170] The British engineer B.S. Gossling wrote:

> *The thermionic valve passed during the period of the war through all the various stages of the transition from an instrument the value of which was already recognized, but whose operation was erratic and theory obscure, to a product as reliable and as thoroughly standardized in manufacture as the incandescent lamp, and in addition capable, as regards all the main principles of its action, of explanation in terms of well-established principles of physical science. …*[171]

It is important to recall the status of wireless communications before 1914. In 1912 a U.S. court condemned Lee de Forest for "abuse of trust on the basis of valueless patents, in particular a three-electrode lamp called an 'audion' which has been proved to be without any interest whatsoever!"[172] At that time electron tubes had found only one use, as a detector of wireless signals, and even in this application other devices, notably crystal detectors, were much more widely used. Wireless technology itself had only limited applications. The historian Howard Aitken has written, "What was the new technology good *for*? Until World War I the answer could without serious error be summed up in two words: ships and lighthouses."[173]

[166] The most famous example of legal logjam was the ruling in 1916 by the U.S. District Court in New York City that the audion infringed on Fleming's valve patent, but that the third electrode was protected, so that both patents were required to manufacture triodes [Barnouw, p. 47].

[167] Barnous, pp. 47–48.

[168] Susan Douglas 1985, p. 169.

[169] Kennelly, p. 245.

[170] Squier, p. 304.

[171] Gossling, p. 670.

[172] Quoted in Antébi, p. 125.

[173] Aitken 1976, p. 306.

Military needs so stimulated radio's development that the years 1914 to 1920 stand out as a distinct phase in its history.[174] This period followed the experimental period from 1886 to 1900 (set off by Hertz's investigations) and the maritime period from 1900 to 1914 (dominated by the Marconi companies, which provided ship-to-shore and ship-to-ship communications), and it prepared the way for the broadcasting period beginning in 1920 (the subject of Chapter 4). Indeed, the technology of broadcasting came directly from wartime work. In the United States most of the early household receivers were copies of ones designed for the military, and early transmitters used the techniques developed for military and other governmental use during the war.[175]

1.4.3 Radio Engineers

Radio engineering involved much more than tubes. The most powerful transmitters were Poulsen arcs and alternators. Intense laboratory study by engineers at the Federal Telegraph Company, led by Leonard F. Fuller, resulted in much more powerful arc transmitters; a 100-kW arc was built in 1916 and several 500-kW arcs just two years later.[176] By 1920 some 200 stations were using arcs for transmission.[177] As mentioned earlier, the AC generator, or alternator, was another way to generate continuous oscillations, and alternators were used in some of the most important transmitting stations during and after the war.

There were advances in all facets of radio. Antennas were improved. The U.S. Navy, for example, developed a number of static-reducing antenna systems.[178] Power supplies for radio transmitters and receivers were improved. According to the Chief Signal Officer of the U.S. Army, "Scarcely a single piece of technical apparatus that was regarded as adequate at the beginning of the war is to be found in the Signal Corps equipment at the time of the signing of the armistice."[179] Perhaps most remarkable for the military period of radio development was innovation in transmitting and receiving circuits.

The so-called regenerative circuit was discovered just before the war. In 1912, while working to obtain greater amplification with his audion, Lee de Forest found that when the output of a tube was connected to its input (in order to obtain greater amplification), the tube sometimes produced a howl in his earphones, and he then worked to eliminate the phenomenon. At about the same time, Edwin Howard Armstrong made the same discovery and recognized how important it was that an electron tube could generate oscillations. Indeed, tubes were soon in use in transmitters to generate continuous waves and in receivers as the local oscillator in

174 Howeth, p. 207.

175 Howeth, p. 211.

176 Brittain 1991.

177 Finn 1967.

178 Howeth, p. 209.

179 *Report of the Chief Signal Officer*, p. 9.

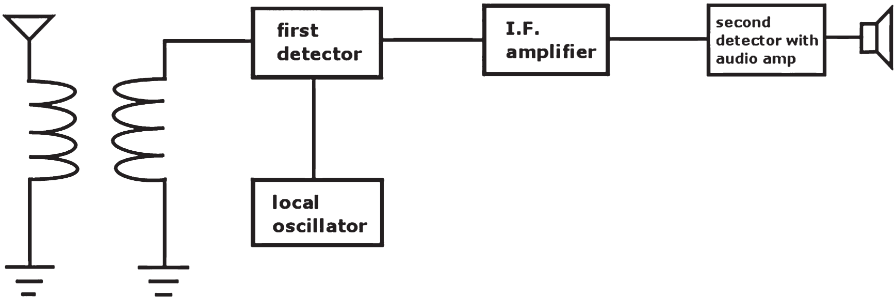


Figure 1.9. The superheterodyne circuit.

heterodyne circuits. Though the arcs and alternators were more powerful, they were much larger and much more expensive than tubes. Moreover, they could not reach frequencies that tubes could, 200 kHz being an upper bound for almost all arcs and alternators. Thus when high-power transmitting tubes were developed in the 1920s, they displaced these devices.

Another great advance was the heterodyne receiver, described above. A refinement of the heterodyne principle was the superheterodyne, invented by Edwin Howard Armstrong while serving in the U.S. Signal Corps in France. Armstrong's idea was to build first a highly efficient fixed-frequency amplifier (at the so-called intermediate frequency), then to tune a local oscillator so that the difference between the incoming frequency and the locally generated frequency equaled the intermediate frequency (which was then produced by heterodyne action). (See Figure 1.9.) In the 1920s it became, and remains today, standard in radio receivers.

Another achievement of this period was the establishment of professional societies for radio engineers. In the first decade of the century, the electric power industry, already large, was still rapidly growing, and power engineers dominated the American Institute of Electrical Engineers (AIEE). Many of those concerned with other types of electrical technology, such as electrochemistry or wireless telegraphy, felt that the AIEE was not serving their interests adequately, and some of them formed new societies. In 1909, in an effort to prevent further splintering of the profession, the AIEE directors decided to promote the establishment of technical committees within AIEE, such as the Electricity in Mines Committee and the Electrically Propelled Vehicles Committee. This organizational innovation succeeded in its purpose, as the technical committees, numbering 13 by 1915 and 51 by 1962, undertook more and more activities for their members.[180]

The wireless engineers, however, had already set up their own professional home. In 1912 the Society of Wireless Telegraph Engineers (started in Boston in 1907) and the Wireless Institute (started in New York in 1908) merged to form the Institute of Radio Engineers (IRE).[181] The following year *Proceedings of the Institute of Radio Engineers* began publication. With papers by such engineers as Michael

[180] McMahon, pp. 124–127, and Ryder and Fink, pp. 61–62.

[181] McMahon, pp. 127–132, and Ryder and Fink, pp. 65–67.

Pupin, Lee de Forest, and Arthur Kennelly in its first year, it quickly became a premier journal of the rapidly developing field. From its beginnings, the profession of radio engineering had an international character. The founders of IRE decided against including "American" in its name, arguing that IRE interests were international in scope, as was radio itself.[182]

Radio engineering, even more than traditional areas of electrical engineering, had close connections with science. Maxwell, Hertz, Lodge, and Fleming were all physicists, and many of the inventors of wireless techniques, such as Lee de Forest and Walter Schottky, had been educated as physicists. The better understanding of electron behavior, as in photoemission or space-charge buildup, was physics of direct relevance to tube design, and engineers made important contributions to this type of physics. Moreover, radio raised new questions for physicists. For example, Marconi's long distance transmissions, which surprised physicists (who knew that radio waves, like light waves, propagate in a straight line), led to the discovery of a reflecting layer in the atmosphere, soon given the name "ionosphere". And radio engineering provided new tools for physical investigation, as in the studies of the ionosphere in the mid-1920s by Gregory Breit and Merle Tuve.[183] Later chapters pick up the story of radio's growth as a business and a technology and describe its continuing close relationship with science.

[182] Ryder and Fink, p. 66.

[183] G. Breit and M.A. Tuve (1925), and G. Breit and M.A. Tuve (1926).

Chapter 2

Electrical Technologies in Total War

2.1 REMOTE AND AUTOMATIC CONTROL

2.1.1 The Battle of Jutland and Electrical Technology at Sea

By the time of the Great War, electrical technology was important on virtually all ocean-going vessels. Consider, for example, the installations of the British liner, the *SS Aquitania*.[1] It contained some 200 electric motors, which operated ventilation and heating fans, passenger and service elevators, winches for lines and lifeboats, and culinary and other equipment. Lighting was electric—a momentous change that made ships much brighter and safer—and so were gyroscopes and sounding machines. There were 18 loudspeaking telephones to facilitate the navigation of the ship and 27 intercommunication telephones. There were electric signaling lamps, an electric helm indicator, electric fire alarms, remote control—from the bridge—of bulkhead doors, electrically controlled whistles, and remote reading of water level in the boilers. There was a master clock controlling electric clocks throughout the ship, and some 1500 bell-pushes with indicator lights, mainly for signaling from the state rooms.

Warships made many other uses of electrical technology as well. Electric power turned guns and turrets and raised ammunition from the magazines up to the guns.[2] Searchlights—both incandescent and carbon-arc—became vital for nighttime navigation, for long-range daytime signaling, and for illuminating enemy ships in night engagements.[3] Indeed, so rapid was the wartime development in this area that an

[1] Lowson.

[2] Von Hase, pp. 85, 88.

[3] Kelly. Searchlights were used, perhaps the first time in naval combat, in the clash of Japanese and Russian fleets at Tsushima in 1905 [Macksey, p. 54]. Because searchlights provided a target for enemy

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engineer writing in 1919 asserted that "searchlights purchased in one year became almost entirely obsolete the next year."[4] The cooling, feeding, and rotation of electrodes within the searchlights were done though automatic controls.[5] There were other control systems: for gunnery, for navigation, and for stability (some of them described below). Increasingly, steering gear came to be electrically powered and controlled, and by the end of the war electric steering was standard in the British navy.[6]

Electric propulsion was becoming important. All submarines, when submerged, were powered by electric motors running off batteries; when surfaced, the vessels used diesel engines for propulsion and for recharging of the batteries. For large ships the most efficient prime movers—steam turbines and diesel motors—ran best at speeds far above propeller speeds. Rather than connecting the engine to the propeller by shafts and elaborate gearing, one could directly couple a generator to the engine and an electric motor to the propeller, with only electric wires in between. (The diesel–electric locomotive, introduced shortly after the war, worked on the same principle.) The U.S. Navy launched its first electrically propelled ship (the *USS Jupiter*) in 1912, and in 1915 chose a turboelectric drive for a new battleship (the *USS California*, which entered service under the name *USS New Mexico*).[7]

Electrical technology was also vital for communication within the ship. Warships often had two extensive telephone systems: one for control of guns and one for all other uses.[8] Besides indicator lights, as for showing which bulkhead doors were open, there were "telegraphic indicators" that automatically conveyed quantitative information from one part of a ship to another, as from engine room to the bridge or from range-finding stations to the fire-control room.[9]

Just as electrical technology helped a field army function as a single entity by providing rapid communication—which facilitated information gathering, central control, and feedback from all parts—so electrical technology made a ship a more integrated system. There was greater central control, mainly because of greater awareness of the state of the vessel through automatic and human-mediated signaling. And, of course, the electric lighting and electric motors used throughout a ship greatly enhanced local control. A British electrical engineer drew the following picture in 1918: "Electricity plays a vital part in the lighting, heating, ventilation, internal and external means of communication, operation, and control of every

gunners, star shells and parachute lights (which could illuminate enemy ships while leaving friendly ships in darkness) were often preferred in night fighting; toward the end of the war, naval searchlights were also used against enemy aircraft [Kelly].

[4] Kelly, quotation on p. 1606.

[5] Hughes, 1971, p. 218.

[6] Nielson.

[7] Gorowitz, pp. II.47, II.52; Nielson; and McBride. In next few years turboelectric or diesel-electric drives were chosed for other warships and some cargo ships, but improvements in reduction gearing soon made direct-drive propulsion preferable in large ships.

[8] Fagen, p. 175.

[9] Von Hase, pp. 78–80, 106.

possible means of defence and offence of a modern battleship, cruiser, and even torpedo-boat destroyer. The switchboard is the heart of a battleship, the electric cables radiating or controlled therefrom are its nervous system. …"[10] The British admiral Jacky Fisher contrasted modern battle with that of a century earlier at Trafalgar: once Admiral Nelson had given his orders, he had nothing to do but walk "up and down the quarterdeck of the *Victory*, having a yarn with his Captain! He had got his ships alongside those of the enemy and had nothing more to do, and then it became a sailors' battle. But now it's the Admiral's battle. All is worked from the conning tower. You press a button and off go the torpedoes. Another electrical signal fires the guns, a third works the engines, and so on."[11]

Electrical technology revolutionized fleet operations as well. As we have already seen, wireless apparatus was soon regarded as essential, and the larger the fleet, the more difficult to maintain control and receive information by other means of signaling. With the availability of radio, naval battles have increasingly been directed by fleet commanders, rather than ship commanders.[12] These points were underlined in the greatest naval battle of the war.

At 2:15 on the afternoon of 31 May 1916 in the North Sea, West of Jutland, the easternmost ship of Vice Admiral David Beatty's battle cruiser fleet spotted smoke on the eastern horizon. It sailed to investigate what turned out to be a Danish merchant ship. At the same time, two destroyers from Rear Admiral Franz von Hipper's battle cruiser fleet were approaching the merchant ship from the other side. The British and German warships sighted each other, shots were exchanged, and messages were radioed to both fleets. The Danish ship thus acted as a magnet in drawing together two of the most formidable navies ever to sail, for the two battle cruiser fleets were but advance guards for the main fleets of the two great naval antagonists. The British Grand Fleet, under the command of Admiral John Jellicoe, consisted of 24 dreadnoughts—as battleships similar to the *HMS Dreadnought* were called—four fast battleships, nine battle cruisers, and more than a hundred other ships. The German High Seas Fleet, under the command of Admiral Reinhard Scheer, consisted of 16 dreadnoughts, 6 pre-dreadnought battleships, 5 battle cruisers, and 72 other ships.

From the turn of the century, Great Britain and Germany had engaged in a naval arms race—the first technological arms race—that was given enormous impetus by the launching in 1906 of the *Dreadnought*.[13] Powered by turbine (rather than reciprocating) engines, heavily armored, and equipped with large-caliber, long-range guns directed by new means of fire control, *Dreadnought* made obsolete all earlier warships.[14] Britain, Germany, and, to a lesser extent, other countries, rebuilt their fleets at a frenzied pace.

[10] Nielson, p. 57.

[11] Quoted in Massie, p. 441.

[12] Brody 1941, p. 248.

[13] Van Creveld, p. 207.

[14] Cruttwell, p. 56.

By the end of 1915, a year that saw little movement on the Western Front, people on both sides thought increasingly that the war might be won by sea power, hoping for some dramatic payoff from the enormous expense of the naval buildup. On the aforementioned day in the late spring of 1916, each battle cruiser fleet was seeking to lure the enemy into range of its main fleet, neither knowing that the enemy's main fleet was also present. Thus began the battle of Jutland, the only encounter of the war between the Grand Fleet and the High Seas Fleet. It was also the only full-scale encounter between fleets of dreadnoughts that ever took place. Indeed, the battle of Jutland was a watershed in the history of naval warfare, being the last major action in which the opposing ships fought within sight of each other, also the last fought mainly by means of guns.[15] Electrical technology played many important roles in the encounter.

Radio signaling was crucial. It was used to bring the two main fleets into contact as well as for tactical signaling in the course of the battle. It was even responsible for the calling out of the Grand Fleet, since the British had advance knowledge, through intercepted and decoded German messages, of some German fleet action. The British were surprised, however, to find the High Seas Fleet at sea; they had been misled into believing that it was still in port because they did not know of the German practice of assigning the flag ship's call sign to a shore station when the fleet sailed (in order that the admiral not be bothered by administrative matters when at sea).[16]

In the course of the battle, the British did most of the tactical signaling by means of flags. This proved to be error-prone. Twice in the 80 minute clash of Beatty's and Hipper's battle cruiser fleets that initiated the battle, the British missed important signals that might well have altered the outcome.[17] As it was, the British suffered more, losing two battle cruisers. The clash was broken off when one of Beatty's ships sighted the main German fleet approaching from the south. Beatty turned north and radioed Jellicoe that he was approaching with the entire High Seas Fleet in pursuit. The two fleets closed, and a 20 minute encounter was broken off when Admiral Scheer found himself in an unfavorable tactical position. He extricated his fleet by ordering *Gefechtskehrtwendung* ("battle about-turn"), the difficult maneuver of a simultaneous reversal of course by every ship, which ran a high risk of collision and which the naval historian Colin White called "a miracle of seamanship".[18] Less than an hour later the fleets closed again, and again Scheer soon broke off the engagement by ordering *Gefechtskehrtwendung*. The German fleet was outnumbered and outgunned in these encounters and suffered considerable damage. The Germans had an advantage, however, in that they made much greater use of radio for tactical signaling; this signaling was a low-power transmission that did not reach the British shore stations where it could be decoded.[19] The British, by contrast, relied mainly

[15] Information on the battle of Jutland comes mainly from Beesly; Cruttwell, pp. 318–338; Macintyre; and Ruge.

[16] Macintyre, p. 548.

[17] Macintyre, p. 549, and Livesey, pp. 86–88.

[18] Colin White, quotation on p. 121.

[19] Beesly, p. 160.

on flag and lamp signaling, and partly as a result had consistently poor communications throughout the battle.[20]

Nightfall found the Grand Fleet between the High Seas Fleet and its bases in Germany. Jellicoe decided against night action, partly because the Germans had much more powerful searchlights, and he expected to resume the battle the following day.[21] In the night, however, Scheer managed to slip past the British, helped by the failure of some British ships to communicate sightings of the German ships and by the failure of information gained by Room 40 to reach Jellicoe promptly.[22] The battle was thus at an end, the British having lost twice as much tonnage as the Germans (three battle cruisers, three armored cruisers, and eight destroyers versus one battle cruiser, one pre-dreadnought battleship, and five destroyers). The German claim of victory had immediate propaganda value, and, more importantly, the battle put an end to British thoughts of opening the Baltic to Allied shipping, something Russia had long argued for and urgently needed.[23]

Whether the Germans should be considered victorious is, however, doubtful. For the remainder of the war, the High Seas Fleet avoided another such encounter, spending most of the time in port. This inaction contributed to the mutiny of the sailors beginning 28 October 1918, which in turn contributed to the willingness of the German government to accept peace terms. Perhaps the most important effect of the battle of Jutland was that the German navy turned to submarine warfare. Within a month of the battle, Admiral Scheer reported to the Kaiser: "A victorious end to the war at not too distant a date can only be looked for by the crushing of English economic life through U-boat action against English commerce."[24]

The damage that each fleet was able to inflict on the other depended directly on how accurately the guns were aimed. This was a task carried out by a man–machine system of utmost complexity.

2.1.2 Fire Control and Analog Calculation

In 1900 naval guns could not fire a shell more than 4000 yards, and in the Spanish-American War (1898) and the Russo-Japanese war (1904–1905), warships exchanged fire when a few thousand yards apart.[25] But ranges increased so much that two encounters early in the Great War (the battle of the Falklands and the battle of Dogger Bank) took place at a distance of about 16,000 yards (approximately nine miles).[26] As the range of naval guns increased, so did the need for improved means of directing the guns.

[20] Colin White, pp. 121–122.

[21] Cruttwell, pp. 333, 336, and von Hase, p. 218.

[22] Cruttwell, pp. 333–334; Macintyre; and Beesly, pp. 160, 162.

[23] Ruge, p. 555.

[24] Quoted in Cruttwell, p. 336.

[25] Hughes 1971, p. 231.

[26] Sumida 1989, pp. 297–298.

At the turn of the century, when electrical firing made it possible for a group of guns to be fired simultaneously with the push of a button, there appeared the concept of "fire control" or "director firing," which was the centralized and coordinated control of the large guns of a warship.[27] Two important objectives were thereby fulfilled: to avoid duplication of effort in determining the aim of the guns and to improve aim correction by firing the guns together (in salvos).

The general procedure was that one determined the course and speed of the target ship by taking range and bearing measurements. One then combined this information with knowledge of the course and speed of the firing ship—ideally taking into account roll, pitch, and yaw—in calculating the bearing and elevation of each gun. The measurements taken of the target ship had to be conveyed to the fire-control station, and the firing orders had to be sent from there to each gun. The system involved, then, three functions—measuring, communicating, and calculating—and by the time of the Great War electrical technology was playing an important part in carrying out all three. This was an early example of a type of control system that would become common in military and civilian technologies by mid-century: distributed sensors, data transmitters, centralized information processing, control-signal transmitters, and distributed sensors.[28]

The ways electrical technology could assist in the measurements required for fire control may be illustrated with the system designed by Elmer Sperry in the U.S. in the years from 1912 to 1916.[29] Since accurate measurement of the bearing of the target required an accurate reference line, Sperry devised a system of repeater compasses, whereby the reading of the extremely accurate gyroscopic compass he had invented was duplicated at the sighting telescopes and in the plotting room. Two other measurements were automatically performed and conveyed to the plotting room: the true compass course of the ship and the speed of the ship (determined by revolution counters on the ship's propeller shafts).

The second function, communication, was enormously improved by electrical means. For example, on the German battle-cruiser *Derfflinger* there was a "telegraphic indicator" that conveyed the readings of the range finders to the control room, and in the control room there was a "director" that automatically conveyed firing directions to all the guns of the ship.[30] In most ships telephones connected observers, gunners, and controllers.

The third function, calculating the aim of the guns (that is, the bearing and elevation of each), was extremely complicated. It was not enough to calculate the exact relative position of the target ship, because the target and firing ships were moving relative to each other and because the measurements, the calculations, and the flight of the shell all took time. (A shell took a minute or so to travel 20,000 yards.) The task, then, was to use current data on the relative motion of the target, together with time-of-flight data, to set the aim so that shell and target would reach the same

[27] Massie, p. 417, and Sumida 1989, p. 48.

[28] Mindell 1995.

[29] Hughes 1971, pp. 230–233.

[30] Von Hase, pp. 79–80.

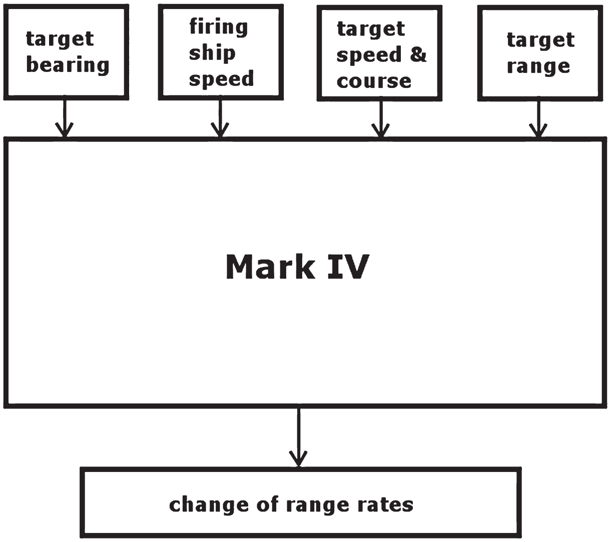


Figure 2.1. Schematic drawing of the operation of the Mark IV.

position at the same time. One scheme was to measure not only current distance and bearing, but also the rates at which those quantities were changing, and then assume that these rates of change would be constant over the next minute or two.

In the first decade of the century, a number of mechanical calculating aids were developed, especially in England, as aids to this calculation. In 1902 John Dumaresq invented a trigonometric slide rule that calculated the changes in range and bearing from the courses and speeds of the two ships, and shortly thereafter the armaments firm of Vickers developed a clockwork device that indicated range continuously after being set with initial range and the change-of-range rate.[31]

By the time of the Great War, much more sophisticated electromechanical calculators had been built that could accommodate changing rates-of-change. It was also appreciated that automatic calculation, since it was faster, could be vital in coping with such tactics as zigzagging.[32] Perhaps most advanced was the Mark IV calculating table, made by the Argo Company for the British Admiralty. Its operation is depicted in Figure 2.1.

A key component of this electromechanical calculator was the ball-and-disk integrator, depicted in Figure 2.2 below. Integration, the calculation of the cumulative effect of many small changes, is a recurring task in many areas of science and certain types of technology. For continuous changes with known mathematical description, the techniques of the integral calculus are applicable. Even so, the problem can be difficult and is often not possible except by approximation or by physical-analog techniques. The ball-and-disk integrator is an example of the latter.

[31] Sumida 1989, p. 74.

[32] Hartcup, p. 121.

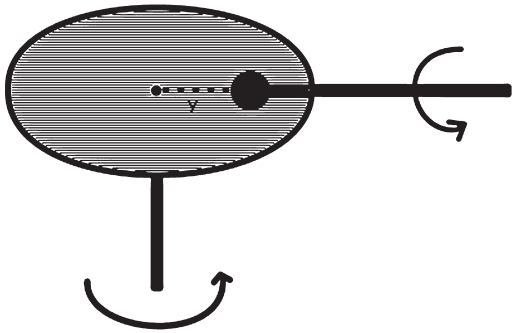


Figure 2.2. The ball-and-disk integrator.

An electric motor turns the disk at a constant rate. The ball at the end of a shaft can move in or out, but is held firmly against the disk by a spring. The amount the shaft turns is then the integral of the function ("y" in Figure 2.2) that determines the distance between the ball and the center of the disk. (If the values of y are plotted as the height above the time axis in a rectilinear coordinate system, then its integral is the area under the curve.)

Jon Sumida, a historian of fire-control technology, concludes that the British hits made during the battle of Jutland were largely attributable to superior fire control (since the British ships that scored hits were, by and large, the ones with the most advanced fire control).[33] The relative success of the German ships in the battle is explained by a variety of other factors, including that the Germans had better range finders, that conditions of visibility favored the Germans, and that British armor-piercing shells did not function properly.[34]

2.1.3 Gyroscopic Control

In this century, land, sea, and air vehicles have been great exploiters of electrical technology. Using electricity for motive power had advantages that often outweighed the principal difficulty of either transferring electricity to the moving vehicle or storing or generating it in the vehicle; in some situations, such as underwater or in subway or mine tunnels, electric power was the only practical means. Electric power in smaller quantities was suitable for many other tasks in the vehicle, such as lighting, ventilation, and hoisting. Navigation and communication often depended on electrical technology. And as vehicles became larger and faster, electrical means of control became increasingly important; gyrostabilizers provide a significant example.

Though the device we call a gyroscope was not known by that name until the mid nineteenth century, the peculiar properties of a spinning top or a spinning hoop

[33] Sumida 1989, pp. 299–305.

[34] Iain Russell (1989) disputes the view presented in standard accounts of the Battle of Jutland that the German rangefinders (manufactured by Carl Zeiss) outperformed the British rangefinders (manufactured by Barr & Stroud).

Figure 2.3. The gyroscope.

were long known. Two properties are particularly striking: if a flywheel is mounted so that it is free to tilt in any direction and set spinning rapidly, then its axis of rotation will continue to point in the same direction regardless of any transverse or rotary motion imparted to the mounting; and if a spinning flywheel is subjected to a force oblique to the spin axis, the flywheel will respond by moving not in the direction of the force, but orthogonal to it ("precession" is the name given to the resulting change in direction of the spin axis). (See Figure 2.3.) It proved to be difficult to use the first property alone in a practical device,[35] and gyrocompasses and gyrostabilizers exploited the second. (The basic idea was Foucault's: precession caused by gravity and the earth's rotation might keep a gyrocompass pointing north.)

For a gyroscope to be a practical device, there had to be a way to drive the rotor continuously (to counteract the unavoidable friction generated by its motion). This could be provided by the electric motor, as G.M. Hopkins demonstrated in 1878.[36] The gyroscope is an example of a basically mechanical device that became practical only with the help of electrical technology. Other such devices are the submarine (requiring electric motors and storage batteries), the assembly line (in many cases requiring movable power tools), motion pictures (requiring an electric motor and an intense source of light), and a large-scale digital computer (requiring electronic switches).

The person who did the most to exploit gyroscopic properties was Elmer Sperry, who Thomas Hughes calls "the father of modern electromechanical, feedback guid-

[35] J.E.D. Williams writes [p. 158], "It was not until 1950 that an aircraft gyro-direction indicator with a random wander of only 1 ° per hour was available. This standard of accuracy was invaluable in aircraft flying for a few hours in very high magnetic latitudes; but it would have been of little value as a ship's compass. …"

[36] J.E.D. Williams, p. 157.

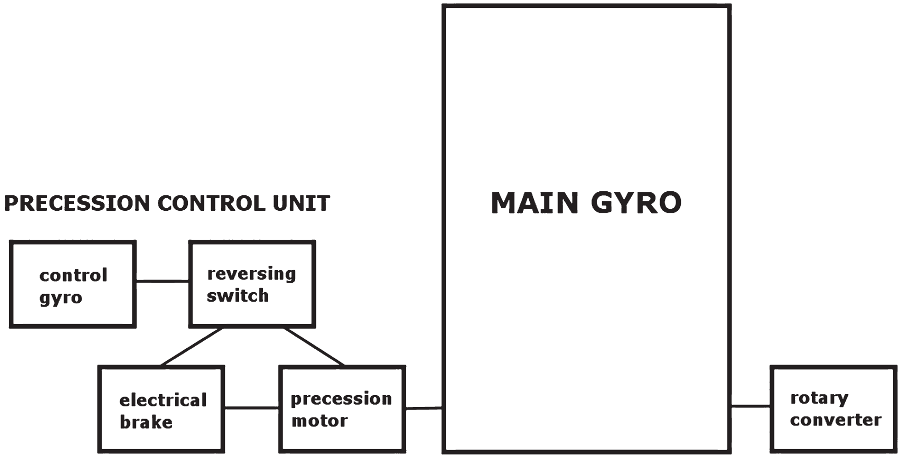


Figure 2.4. Schematic drawing of the operation of the Sperry ship stabilizer.

ance-and-control systems".[37] Sperry, who grew up on a farm in upstate New York, had earned a high reputation as an inventor and engineer before beginning, in 1907 at the age of forty-six, the work with gyroscopic instruments that was to make him known throughout the world.[38] In the years immediately preceding 1907, the German Ernst Otto Schlick and the Englishman Louis Brennan showed how to stabilize a vehicle (a ship and a monorail car, respectively) with a large gyroscope; a destabilizing force caused the precession of an onboard gyroscope rather than the overturning of the vehicle. Sperry went beyond this work by designing an "active gyro," whose precessional motion was artificially initiated by an electric motor. The precession motor was controlled by a system that was sensitive to extremely small motions (of the sort to be eliminated) and that incorporated feedback in order that motions not be overcompensated. (See Figure 2.4.) Sperry later designed much more sophisticated stabilization systems, but in the meantime perfected a device that gained a much larger market.

The magnetic compass worked satisfactorily on wooden ships, but quite unreliably on steel ships and not at all in submarines. In Germany, Hermann Anschütz-Kaempfe recognized that a gyrocompass, which determines North not by any magnetic sensor but by its response to the rotation of the earth (the spin axis is automatically positioned parallel to the earth's axis), would solve the problem. The Anschütz compass, whose rotor was driven by electric motor, passed a sea trial in 1908, and soon the German and British navies were installing the device on their vessels. In 1910 Sperry, already at work on the gyrostabilizer, began work on improving the Anschütz compass. As with the gyrostabilizer, Sperry designed an

[37] The principal source for what follows on gyrostabilizers and gyrocompasses is Hughes 1971.

[38] As Hughes explains and as was appreciated at the time, the gyroscope will not exert a stabilizing effect unless it is free to precess, that is, turn in a direction orthogonal to the motion to be damped.

electrical feedback system, incorporating sensors and servomotors, that improved the performance of the compass. He also designed a mechanical analog computer, to be attached to the gyrocompass, that automatically corrected certain errors. The gyrocompass had the advantage that, as an electrical device, its readout could relatively easily be replicated at many points in a ship. This became increasingly important: at the turn of the century a battleship might have compasses at seven or eight locations, while by mid-century a battleship—bristling with guns, torpedo launchers, radar, sonar, and other equipment where directional information was needed—might have repeater compasses at more than a hundred locations.[39]

Sperry continued to develop his compass in cooperation with the U.S. Navy. Before the war he sold compasses to the navies of the U.S., Great Britain, Russia, and Italy, and with the coming of war, his business boomed, as the Allied navies turned to Sperry to provide the compasses they needed on all vessels. After the war the gyrocompass became the primary means of determining direction on all large ships.[40]

Before the war Sperry had begun applying the gyroscope to the problem of airplane stabilization. In 1914 he completed a system that used signals from gyros to activate servomotors that moved the airplane's control surfaces.[41] Though Sperry gained the interest of the U.S. military and the interest of several Allied governments in the device—he sold 40 of them to the French in 1916—combat aircraft were not so equipped during the war, mainly because the stabilizer added substantial weight and because use of automatic control reduced maneuverability.[42]

Electrical technology, though, did prove valuable to airplanes in many other ways, as electricity was used for heating, defrosting, position lights, control of aerial photography, light signaling to the ground, and wireless telegraphy. So important were these functions that in 1916, the French agency overseeing aircraft construction established a section for electrical equipment.[43] Because batteries were heavy, the power in many applications came from a generator whose rotor was turned by the air moving past the airplane. Automatic control solved a problem with this onboard generator. Since the speed of an airplane varied considerably, so did the output of the generator (which turned by the motion of the air). Soon such generators incorporated a vacuum tube automatic compensator that helped maintain constant voltage over a wide range in speed.[44]

Automatic control was carried to a high level in the aerial torpedo built by Sperry in the last two years of the war.[45] Here the gyrostabilizer was but one

[39] Hitchins, pp. 97–98, 111.

[40] Kayton.

[41] Hughes 1971, pp. 190–192.

[42] Hughes 1971, pp. 261–264.

[43] Bongrain.

[44] Kennelly, p. 237.

[45] Hughes 1971, pp. 262–274, and Hughes 1989, pp. 126–135. After witnessing a Sperry aerial-torpedo test in 1917, Charles Kettering led another project to develop an aerial torpedo (see Leslie 1983, pp. 80–87).

component of a complicated system that would maintain the aircraft in level flight, hold it on a preset course, and cause it to dive at its target after flying a preset distance. On 6 March 1918 the aerial torpedo made a successful test flight, taking off automatically, achieving level flight, and shutting off at the preset distance of one thousand yards. But further tests were less encouraging, and the aerial-torpedo project did not reach fruition before the end of the war. This line of development eventually resulted in the automatic pilots installed in many airplanes.

2.1.4 Sound Ranging and Other Systems of Control

The history of technology is the story of efforts to enhance and extend human control over things and processes. The technical devices that are the subject of much historical writing—such as a spinning jenny or a steam turbine—function as tools or as power sources in processes that are still directly controlled by people. But machines may also convey human control over great distances and even take over some of the control themselves.

Because electrical signals can be conveyed over a light-weight wire, or even through the air, many electrical systems of remote control were developed during the Great War. We have already seen that some ship operations, such as steering or opening and closing of bulkhead doors, could be controlled from the bridge. The detonation of explosives from a distance—a well-established practice and probably the oldest military use of electricity—occurred in many contexts.[46] Explosives placed in tunnels dug under enemy lines were thus detonated. Late in the war the Germans used remote control to set off anti-tank mines. Some Allied minefields off the British Isles and the French and Belgian coasts had both underwater microphones (hydrophones) and mines connected to the shore by cable, so that mines could be triggered remotely when a hydrophone revealed the presence of an enemy submarine.[47]

Such systems might involve other types of remote control, as in the remotely-steered explosive boats the Germans deployed to hinder the operation of British ships off the Flanders coast.[48] At first these were controlled by signals sent through a cable that trailed behind the boat. Later they were controlled by wireless. Some hydrophones, including ones towed behind a ship, could be rotated by a remotely controlled motor in order to determine the direction of a sound.[49] Remote controls were also developed for the directing of searchlights, since they were often so bright that anyone close to the searchlight would be blinded by the glare.[50]

[46] Caron and Cardot, p. 899.

[47] Hartcup, p. 134. Hartcup writes: "Two U-boats were definitely sunk, two possibly sunk and two damaged. Of course the same results might have been achieved if hydrophones had not been used."

[48] Siemens, p. 16, and Miessner, p. 28. These boats sank at least one British warship [Hammond and Purington, p. 1260]. In 1898 Nikola Tesla had demonstrated wireless control of model ships [Aitken 1985 p. 179].

[49] Hayes 1920.

[50] Hughes 1971, p. 220.

Automatic control is a subject conceptually richer than remote control. Today it almost always involves electrical and electronic techniques, but when electrical technologies burst onto the scene in the late nineteenth century, there was already a long tradition of automatic control by means of mechanical devices.[51] A few examples are the float regulator for a water clock built by Ktesibios of Alexandria in the third century BC, the furnaces of Cornelius Drebbel in seventeenth century Holland that had automatic temperature control, the "fantail" invented by Edmund Lee in 1745 that kept a windmill headed into the wind, and James Watt's centrifugal governor for a steam engine of the late eighteenth century. But as electrical devices proliferated in the nineteenth and early twentieth centuries, so did the needs and opportunities for automatic control. Systems for automatic control of the distance between the electrodes of an arc lamp were patented as early as 1847, and beginning in the 1870s systems were designed to control the voltage or current from electric generators.[52]

Control devices were the essence of a development of World War I that has been emphasized by the military historian Martin van Creveld.[53] Earlier, the technical devices used in war were, in most cases, tools used by an individual, and it was people who were coordinated in military action. In the Great War, technical devices were increasingly part of an integrated system of men and machines, with the machines themselves coordinated. This, indeed, is the defining characteristic of what van Creveld calls the "Age of Systems". He writes: "… the technological revolution that opened with the telegraph and the railway very largely turned war itself into a question of managing complex systems."[54] We have already seen examples in communications systems (involving automatic recording and automatic repeaters), in naval fire-control, and in Sperry's gyrostabilizers.

A man–machine system of great military importance in World War I was the directing of field artillery. Especially on the western front, where the front lines hardly moved for three-and-a-half years, the war was largely a battle of artillery.[55] Even when movement was the objective, artillery was expected to make it possible: "Artillery conquers, infantry occupies," as General Henri Pétain expressed it. The British preliminary bombardment for the first battle of the Somme required 2,000,000 shells; for the third battle of Ypres, it required 4,300,000.[56]

The most difficult part of fire control was the location of targets. Often the principal target was the enemy artillery. Guns were typically placed out of enemy sight from one to five miles from the front line, and aerial reconnaissance was often

[51] Two monographic treatments of this subject are Bennett 1979 and Otto Mayr 1970.

[52] Both of these topics are treated in Bennett.

[53] Van Creveld, pp. 153–156.

[54] Van Creveld, p. 161.

[55] William McNeill writes [p. 319]: "In all previous wars, field artillery spent nearly all the time trying to get into firing position. Active bombardment of the foe usually lasted only a few hours. … The trench warfare of 1914–18 reversed matters, for the guns were perpetually in position to fire. … The supply of shells … therefore became the effective limit on operations as never before."

[56] Pearton, p. 156.

ineffective because typography, trees, camouflage, dummy emplacements, clouds, and fog obscured enemy guns. Hence both sides developed means to locate guns from the sounds of the firing.

The principle behind sound ranging is simple. If one measures the time interval between the arrival of a sound at two locations, then, knowing the speed of sound, one can plot on a map a curve—it will be a hyperbola—somewhere on which the source of the sound must lie. If this process is repeated for another pair of locations, then the location of the source is given by the intersection of the two hyperbolas. Carrying this scheme through successfully depended upon several capabilities of the electrical technology of the time: the almost instantaneous transmission of electrical impulses along a wire, the selectivity of special microphones in responding to certain frequencies only, amplification by means of the electron tube, and the ability to measure a short time interval.[57]

Experiments by the French in the fall of 1914 were encouraging enough to establish a sound-ranging service, but it was not until electron tubes were used for amplification that convincing results were obtained.[58] A typical sound-ranging system consisted of six listening posts, a central station, and two forward observation stations. As soon as a person at one of the forward observation stations heard enemy artillery, he activated, by remote control, the recording apparatus at the central station. After the sounds were recorded, people at the central station calculated the locations of enemy guns and conveyed that information to the counterbatteries. The disposition of a sound-ranging system is depicted in Figure 2.5.

A crucial contribution was that of Lucien Bull, a French physicist who had been working on electrocardiography. He adapted an instrument for sound ranging that he had used for physiological measurement, the string galvanometer, an extremely sensitive device in which the current passes through a fiber suspended in a magnetic field. (Even a feeble current would cause the fiber to move.) A microphone in each listening post was connected to a galvanometer fiber at the central station. There the motion of all the galvanometer fibers was simultaneously recorded by the casting their shadows on light-sensitive paper. Also recorded on the paper were chronometric marks, one hundred per second, produced by the motion of a toothed wheel governed by a tuning fork. The sound of a gun, when it arrived at a listening post, caused a twitch of the corresponding galvanometer wire, so one could readily determine the precise interval between the times of arrival of a sound at the different listening posts. Where use of a stopwatch failed because of the variable reaction times of a person, this scheme succeeded by the automatic recording of sound and time.

To be effective in battle, considerable refinements were necessary. One difficulty was that correction had to be made for the dependence of the speed of sound on temperature and for the direction and speed of the wind; this was partially overcome by arranging to receive meteorological information and by making rapid calculations

[57] The information on sound ranging comes mainly from the following sources: Trowbridge; Kevles; Hartcup, pp. 68–76; Hensman; and Amoudry, pp. 159–160. The first two also contain information about flash ranging, a similar system of locating enemy artillery.

[58] Amoudry, p. 159.

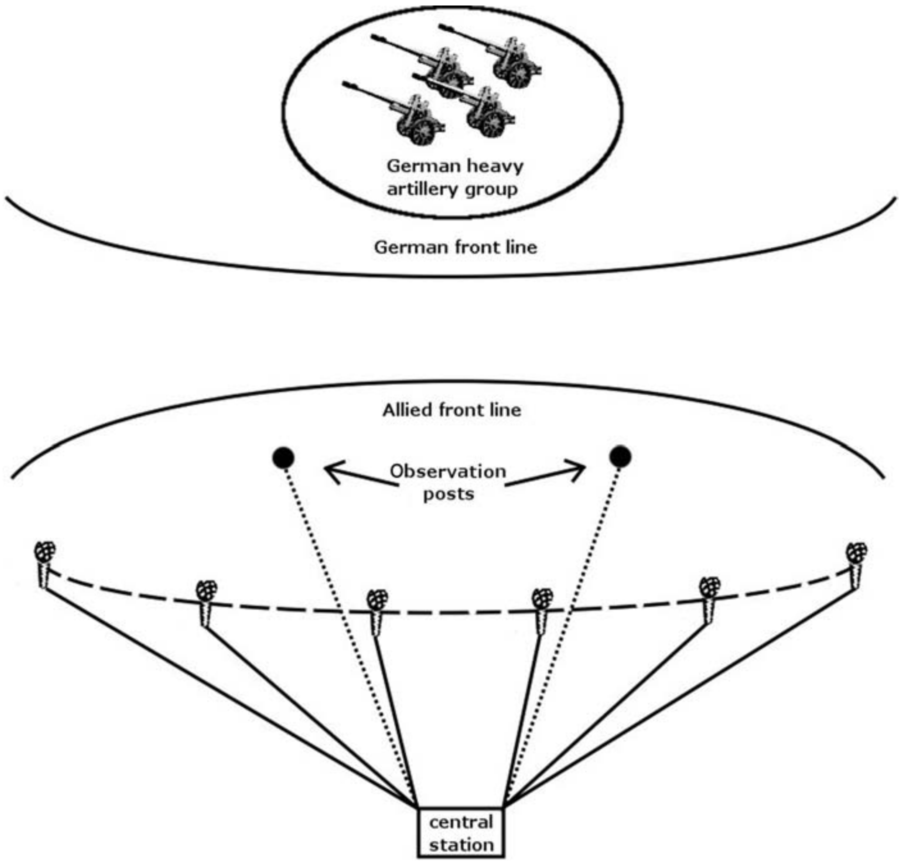


Figure 2.5. A typical sound-ranging system consisted of six listening posts, a central station, where the sounds are recorded and locations calculated, and two forward observation stations.

by graphical means. The greatest difficulty in sound ranging, however, was distinguishing the muzzle report from many other sounds: the bow wave of the shell as it passed over the listening post, the explosion of the shell, rifle fire, the barking of dogs, the sounds of vehicles, and so on. A solution was found by the English physicist W.S. Tucker, who designed a microphone that only responded to very low frequencies.[59] He knew that a wire that was being heated by carrying an electric current would show a change of resistance when air moving past the wire cooled it. He hypothesized that low-frequency sounds would cause this effect, but that high-frequency sounds, where the back-and-forth motions of the air are extremely rapid, would not, since the layer of warm air surrounding the wire would not be displaced. The resulting device, called the Tucker microphone, served its purpose in responding only to low-frequency sounds and was even more sensitive than the human ear to

59 The bow wave is heard as a sharp crack. Similarly, most of the other interfering sounds predominantly consist of higher frequencies.

these frequencies. It came into service in June 1916, and some 13,000 were manufactured in the next two-and-a-half years.[60]

The accuracy of sound ranging was sufficient enough that commanders did not doubt its value, though one should probably treat skeptically the claim of Augustus Trowbridge, head of the U.S. sound-ranging service in France, that the error in the average of a series of sound-ranging locations was “often less than ten meters and rarely more than twenty-five meters at a distance of from five to eight miles.”[61] And sound-ranging equipment could do more than locate enemy guns. The sound records were distinctive enough that one could estimate the caliber of the gun. Sound ranging also proved useful in correcting the fire of friendly batteries, since shell bursts could be detected and thus located.

Sound ranging succeeded because it was the subject of considerable research and development, especially in France and England. We next consider another major research effort to gain military advantage by the sensitive detection of sound: anti-submarine research.

2.2 MILITARY RESEARCH AND DEVELOPMENT

2.2.1 Research Against the Submarine Threat

In 1914 few people thought of the submarine as a commerce destroyer. Rather its expected role was to protect the coast and accompany the fleet into battle.[62] As submarines gained cruising range and long-range communications, other possibilities emerged. Still, in the first year or so of the war, the Germans used the submarine mainly as a submerged torpedo boat against enemy warships.[63] In this role, it had some success, notably the sinking, on 22 September 1914, of three British armored cruisers. Thereafter the British were very cautious about exposing warships to submarine attack, with the result that the movement of the fleet was severely restricted.[64] For example, at the battle of Jutland, Admiral Jellicoe’s failure to pursue the High Seas Fleet late in the first day was due in part to his fear of submarines.

From the beginning of the war, both sides did interfere with the commerce of the other. Germany mainly used surface ships, some of them disguised as merchantmen. Britain too relied on surface ships and succeeded in cutting off almost all of Germany’s maritime trade, except for shipping in the Baltic. It is noteworthy that the effectiveness of this blockade owed much to British control over long-distance communications, because the British used the information gathered from ports

[60] A Tucker microphone was also used in a device that could determine direction of artillery from a single location; see Hunt, p. 40, and the references cited there.

[61] Trowbridge, p. 85.

[62] J.M. Roberts, and van Creveld, p. 209.

[63] Hackmann 1984, p. 12.

[64] Hackmann 1984, p. 12.

around the world to prevent goods from reaching Germany through neutral countries.[65] The damage to the German economy was severe. Civilians especially suffered privations of various sorts, and the winter of 1916/17 was known as "Turnip Winter" (*Kohlrübenwinter*) because people ate fodder beets in place of potatoes.[66]

As a reply to the British blockade, Germany announced that beginning on 4 February 1915 any ships in the waters around the British Isles might be sunk without warning. After the 7 May sinking of the *Lusitania*, with the loss of 1198 lives (114 of them American), strong protests from the U.S. government led to Germany's abandonment of that policy in August. German submarines continued, however, to attack Allied shipping, and losses in 1916 were 1,237,634 tons, nearly 50% higher than in the previous year.[67] One of the lessons drawn by German admirals from the battle of Jutland in the spring of that year was that little could be gained from that sort of fighting, and shipyards switched from building surface ships to building submarines.[68]

In February 1917 Germany again adopted unrestricted submarine warfare, believing the weapon so potent that it could win the war with or without U.S. involvement. In the next four months, 3,750,000 tons of Allied shipping were lost, and one ship out of every four leaving British ports never returned.[69] Jellicoe said at the time, "It is impossible for us to go on with the war if losses like this continue."[70] France too suffered from the interruption of commerce, and 1917 came to be called *l'année des privations*.[71] Despite U.S. entry into the war on 6 April, it seemed to many that the submarine blockade would prove decisive.

Even earlier, a great many engineers and physicists in England, France, and the United States had been recruited to work with naval officers in developing countermeasures. In December 1916 the British anti-submarine research, which had been conducted by three different divisions of the Board of Inventions and Research, was united under the newly formed Anti-Submarine Division.[72] Before the end of the war such research was carried out at some two dozen centers.[73] In France antisubmarine research was carried out—under the auspices of the ministry of inventions—in laboratories in Paris and at three naval bases.[74] In the United States, work on submarine detection involved both the National Research Council and the Naval Consulting Board in the Special Board on Anti-Submarine Devices, formed in the

[65] Roskill.

[66] The Nobel-Prize winning physicist Wilhelm Wien, who worked on U-boat communications during the war, recalls that winter in his reminiscences [Wien, p. 37].

[67] Roskill.

[68] Taylor, p. 144.

[69] Hackmann 1984, p. 12, and Taylor, p. 177.

[70] Quoted in Taylor, p. 180.

[71] Marwick, p. 787.

[72] Hackmann 1984, p. 20–26.

[73] Hackmann 1984, p. 22.

[74] Hackmann 1984, p. 14.

spring of 1917.[75] And several measures were taken to facilitate cooperation between research groups in different countries.[76]

Though attempts were made to detect submarines by their own magnetic fields or by their inductive effect on generated magnetic fields, most research aimed at means of picking up the engine noise of U-boats by hydrophones (underwater microphones).[77] Many of the devices, some of them functioning just as a stethoscope does, were purely acoustic, that is, non-electrical. Several factors, however, led to the widespread development of electrical detectors: the sensitivity of (electric) microphones, the ability to convey an electrical signal a considerable distance (permitting the detector to be placed in locations inaccessible to a human listener), the existence of electrical filters cutting out certain frequencies, and the amplification allowed by electron tubes.

By the summer of 1915 the British naval officer C.P. Ryan had developed a sensitive hydrophone (where the microphone was of the type standard in telephones) that could be used on ships for the detection of submarines.[78] This device did not, however, reveal the direction of the sound, but soon several types of directional hydrophones had been built, including one designed by the physicist Ernest Rutherford.[79] The devices developed before 1917 required the hunting vessel to stop its engines in order for the hydrophones to be used effectively.[80] A partial solution to this was the towed hydrophone, which placed some distance between the hydrophone and the engine of the hunting vessel. A further improvement, made by the French in 1917 and also by the Americans, was the use of amplifying tubes for increased sensitivity.[81] U.S. researchers were probably the first to employ electrical filters to enhance the signal-to-noise ratio.[82]

During the war, three main types of microphone were employed (see Figure 2.6). In the magneto type, current is induced in a coil of wire that is attached to a diaphragm and that moves in a magnetic field. In the carbon-granule type, the resistance of a disc of carbon granules varies according to the pressure applied by a diaphragm, which is moved by the sound vibrations. In the condenser type, the electric charge held by a capacitor (then usually called a condenser) varies with the movement of the diaphragm, since that movement changes the spacing of the capacitor plates.

All three types were of ancient lineage, relatively speaking.[83] Alexander Graham Bell used the magneto type for the transmitter—as the microphone in a telephone

[75] McMahon, pp. 142–145.

[76] An Allied committee was formed in 1914 [Crowther, p. 154] and in 1917 a commission from Great Britain and France brought information on submarine detection to the United States [Hayes].

[77] Most of the information on anti-submarine research comes from Drysdale 1920; Hackmann, pp. 11–71; Hartcup, pp. 129–140; Hayes; and Kevles, pp. 117–126.

[78] Hartcup, p. 129 and Hackmann, p. 46.

[79] Hartcup, p. 130.

[80] Hartcup, p. 132.

[81] Hartcup, p. 132, and Kevles, p. 123.

[82] Hackmann, p. 58.

[83] Fagen, pp. 59–103, 179–182.

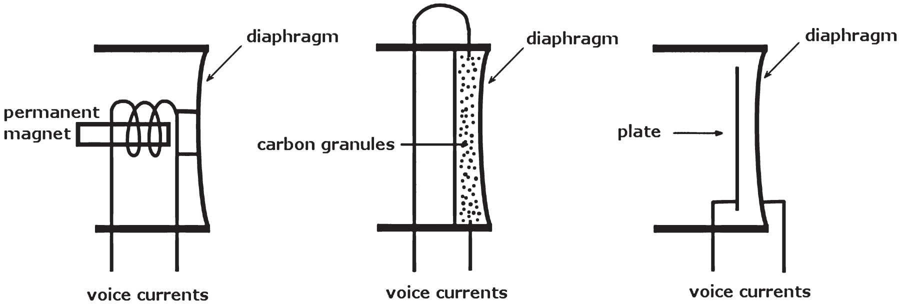


Figure 2.6. Schematic drawings of three types of microphone used during World War I for submarine detection.

was called—in his first commercial telephones. In 1877 Thomas Edison used compressed lampblack in a transmitter, and in 1886 he showed that carbon granules gave superior performance; the carbon-granule microphone soon became the standard in telephones. The origin of the condenser type may be traced to C.F. Varley's discovery in 1870 that a capacitor could emit sounds (through movement of the plates) when subjected to a varying current, but a practical condenser microphone did not emerge until the Great War.

The principal reason for this delay was that, by itself, the condenser microphone was much less sensitive than the carbon-granule type. When, however, it was enhanced with the newly-gained capacity to amplify sound, using the electron tube, it gave superior performance because it produced much less noise than the carbon-granule type (which therefore could not stand as much amplification).[84] For the same reason, electronic amplification gave new life to the magneto type as well.[85] These advances came too late, however, to find much use during the war in submarine detection, and acoustic and carbon-granule microphones were the ones principally used.[86]

By the end of the war, about 4000 Allied vessels were equipped with hydrophones, as were a few dozen minefields connected to listening stations on shore.[87] According to the British Admiralty, of 255 encounters between patrol vessels and U-boats, hydrophones played a part in 54 of them, while shore-controlled minefields

[84] Fagen, pp. 179–182. The most important developer of the condenser microphone was E.C. Wente of Bell Telephone.

[85] Drysdale 1920, p. 578.

[86] Hayes, p. 9. Before the availability of amplification, the magneto type was used in at least two applications where its limited sensitivity was an advantage: in minefields triggered by remote control (mentioned in the previous section) and in towed hydrophones. When carbon microphones were used in minefields, their long range made it impossible to tell when the submarine was very close to the mines [Hackmann, p. 47]. With towed hydrophones, noise of the water moving past the hydrophone masked the sounds sought; magneto type microphones were less affected by water noises than were carbon microphones [Hackmann, p. 55].

[87] Hackmann, pp. 64, 68.

were credited with two U-boats sunk, two possibly sunk, and two damaged.[88] (Half of the 307 German submarines employed in the war succumbed to enemy action.)[89] More significant, no doubt, than the damage thus inflicted was the restriction in U-boat activity that hydrophones caused.

A much more sophisticated and effective means of detecting submarines was sonar, or echo ranging as it was then called.[90] In the years just before the war, several people had the idea that ships could locate objects, such as icebergs, by detecting sound reflected off them. Because of the wartime need for a means of detecting submarines, a large developmental program for echo ranging began in France in March 1915, the main contributors being a Russian electrical engineer, Constantin Chilowsky, and a French physicist, Paul Langevin. What finally led to a successful system was the use of the piezoelectric effect, discovered by Jacques and Pierre Curie. Certain crystals, including quartz, change dimension when subjected to an electric potential and, conversely, produce an electric potential when subjected to pressure. Langevin designed both a quartz transmitter and a quartz receiver (the latter constituting a new type of microphone) that exploited this effect. According to the historian Willem Hackmann, achieving a practical system required two breakthroughs. First, Langevin obtained excellent quartz crystals and designed an appropriate receiver incorporating them. In Hackmann's words, "The second, and much more important, event was that at last a high-frequency amplifier had been developed that could cope with the extremely feeble piezoelectric charges produced by this transducer without masking these signals by self-noise generated within the amplifier."[91] The amplifier Langevin used was one designed by the Radiotélégraphie Militaire that contained eight electron tubes. In February 1918 Langevin achieved a transmission range of eight kilometers and, for the first time, obtained clear echoes from a submarine, and after several more months the range of detection of a submarine reached one and a half kilometers.

The French shared their results with their allies. Both Britain and the United States started their own development programs for echo-ranging, and both reached the stage of successful operational trials before the end of the war. However, all these developments, including the French work, came too late to play a role in the fighting. Had hydrophones and, more importantly, the convoy system not succeeded as well as they did in reducing losses due to submarines, echo ranging probably would have played a role in the war.

2.2.2 A War of the Engineers

Around the turn of the century, the German navy, perhaps influenced by the difficulty of overtaking Great Britain in numbers and size of warships, concentrated on techni-

[88] Hartcup, pp. 134–135.

[89] Winter, p. 158.

[90] Accounts of work during World War I on echo ranging are in Hackmann, pp. 73–95; Hartcup, pp. 136–140; and Hunt, pp. 44–53.

[91] Hackmann, p. 80.

cal advances. As the British responded in kind, there resulted history's first qualitative arms race. At the beginning of the war, the German warships were better armored than the British, German guns fired further, German explosive shells and torpedoes were more effective, and German mines were better.[92] Moreover, Germany outpaced Great Britain in developing newer means of warfare such as mines, torpedoes, and submarines.[93] The war itself, from its very outset, so clearly displayed the value of technological advance that Great Britain and its allies made great efforts to overtake the Germans technologically. Comment on this aspect of the war was frequent: in 1915 Admiral Jacky Fisher wrote, "The war is going to be won by inventions"; the same year H.G. Wells wrote that the war was essentially a "struggle of invention"; and in Germany the war was called "Krieg der Ingenieure".[94]

The advances that attracted most attention were non-electrical technologies. Among the weapons used for the first time on a large scale in this war were the rapid-fire rifle (capable of a sustained rate of fire of 15 rounds per minute), the machine gun (capable of eight rounds per second), and some large-caliber field artillery (such as the Austrian 30.5-centimeter Skoda).[95] Poison gas, the flamethrower, and the tank were developed during the war. Mechanized transport played a large role for the first time in war. Dirigibles, especially the German zeppelins, provided reconnaissance on land and sea, and airplanes evolved into specialized weapons for reconnaissance, bombing (both tactical and strategic), and attacking other airplanes. Naval warfare was changed by the greater speed of warships, by rapid-firing and long-range guns, by torpedoes and mines, and by submarines.

New electrical technologies, too, were important. We have already considered the roles played by several new means of communications (long-distance telephony, wireless telegraphy and telephony, ground telegraphy, and signaling lights) and by a variety of automatic and remote controls (naval fire-control systems, gyrocompasses and gyrostabilizers, and sound-ranging systems). In the section that follows, a number of new electrical technologies that were important in increasing the industrial capacity of a country—such as arc welding and electric metallurgical furnaces—will be described. And there are a great many others, too numerous for detailed treatment. Sensitive detection of sound played a part in systems to locate aircraft, in devices to detect the digging of trenches and tunnels, and in devices to eavesdrop on conversations of the enemy.[96] To impede infantry advance, electrified barriers were erected.[97]

[92] Zentner, p. 220. In 1914 Jellicoe admitted that the German ships were of higher technical quality.

[93] O'Connell, p. 248.

[94] Fisher and Wells are quoted in Hackmann, on pages 17 and 13 respectively; the German designation of the war is mentioned in Braun, p. 194. Both Fisher and Wells emphasized that the British were not keeping pace technologically with the Germans. Fisher wrote, "Eleven months of war have shown us simply as servile copyists of the Germans. When they have brought explosive shells into damnable prominence, then so have we … Noxious gases made us send professors to study German asphyxiation! German mines and submarines have walked ahead of us by leaps and bounds …" Wells commented, "On our side we have not so far produced any novelty at all except in the field of recruiting posters …"

[95] Dewey, p. 71, and Livesey, p. 20.

[96] Hartcup, p. 163; Amoudry, p. 159, and Hartcup, pp. 79–80; and Tyne, p. 240.

Searchlights proved to be important in land, sea, and air warfare; high-intensity searchlights, mobile searchlights, and remote-controlled searchlights were developed.[98] X-ray machines improved treatment of the wounded.[99]

The prominence of new technologies in the Great War greatly increased the interest in scientific research for improving military and industrial techniques. The interruption of international trade caused by the war further heightened this interest, as industrial research was needed to match or to substitute for the products earlier purchased from abroad.[100] (German overseas trade was largely blocked off, while Great Britain, France, and the U.S. found themselves without suppliers of many high technology products that had come from Germany before the war.) And some people hoped that new technologies would break the long stalemate on the western front.

Even before the war, it should be pointed out, there was a growing interest in research and development. In the United States, leaders of certain industries, recognizing the commercial value of research, provided for in-house R&D. DuPont, Goodyear, General Electric, AT&T, Eastman Kodak, Westinghouse, United States Steel Corporation, and others established research divisions before the war. The war certainly heightened this interest among leaders of industry. In his presidential address to the AIEE in 1916, J.J. Carty said that the European war had brought with it "a growing appreciation of the importance of industrial scientific research, not only as an aid to military defense but as an essential part of every industry in time of peace."[101]

Unlike most leaders of industry, a great many government and military leaders entered the war with little appreciation of the value to the nation of R&D. A British engineer wrote in 1917, "… the lesson which has been driven into our lawyer politicians and generals is that this is a war of engineering, where every powerful and delicate device which the resources of science can give is needed."[102] The astronomer George Ellery Hale, who did war-related research, wrote: "At the outbreak of the war the statesmen of the Allies were but little concerned with the interests of research. Necessity, as we have seen, soon opened their eyes, and the results so rapidly obtained convinced them that a radical change of policy was essential."[103] The author of a history of General Electric Research Laboratory wrote: "… in 1917, no one in Washington except Secretary [of War Josephus] Daniels seemed interested in mobilizing science in the national defense. … The laboratories which contributed to the war effort did so for the most part on their own initiative and at their own expense."[104] Lenin wrote: "The war taught us much … especially the fact that those

[97] Caron, p. 898.

[98] A table on page 897 of Caron shows the increase in size of searchlights during the war. Other sources of information of searchlights during World War I are Hughes 1971, p. 221, and Nye, p. 66.

[99] Caron, p. 898.

[100] Kevles, p. 103, and Hawkins, p. 59.

[101] Carty 1916.

[102] Drysdale 1917, quotation from p. 188.

[103] In Yerkes, p. ix.

[104] Hawkins, pp. 60–61.

who have the best technology, organization, and discipline, and the best machines emerge on top. … It is necessary to master the highest technology or be crushed."[105]

The new interest in technological advance and in R&D immediately led to the establishment of institutions to support and direct military R&D. This no doubt was one of the most important effects of the war, as many of the institutions became permanent parts of the governmental or military bureaucracy.

2.2.3 Institutionalizing Military R&D

The "military–industrial complex" can be defined as an informal coalition of groups, from the military, industry, university, and civilian government, with vested interest in high levels of defense spending.[106] The phrase itself became current through President Eisenhower's 1961 farewell address, while widespread public attention to the relationship between industry, the military, and the state dates back at least to the "merchants of death" theory of the 1930s.[107] (According to this theory, the international munitions industry had encouraged hostile feelings between nations and helped bring about World War I.) Many scholars regard the modern military–industrial complex as emerging in the wake of the Korean War (with the unprecedented level of peacetime defense spending); some see its roots in the naval buildup of the late nineteenth century; and others see the modern military–industrial complex as emerging in World War I.[108] This last named view is supported by an examination of one important aspect of the military–industrial complex, namely, state direction and support of military R&D.

As already shown, the war convinced most government and military leaders of the value of military R&D. There resulted a variety of new governmental institutions, which took different forms in different countries. (See Figure 2.7.)

In 1915 the British government established a Board of Invention and Research and an Advisory Council for Scientific and Industrial Research; the former dealt mainly with inventions of strictly military value, the latter mainly with improvements in manufacturing.[109] Both of these organizations grew, spawning many subsidiary units, and both became lasting institutions. During the war, other parts of the British Empire, including Australia, Canada, New Zealand, and South Africa, also established institutions, having large government appropriations, to direct military and industrial R&D.[110]

France had at least two institutions of this sort before the Great War: the *Commission d'examen des inventions intéressant les armées de terre et de mer*,

105 In McDougall, p. 24.

106 Brunton.

107 Trotter.

108 Brunton.

109 Hackmann, pp. 14–17.

110 Yerkes, p. x.

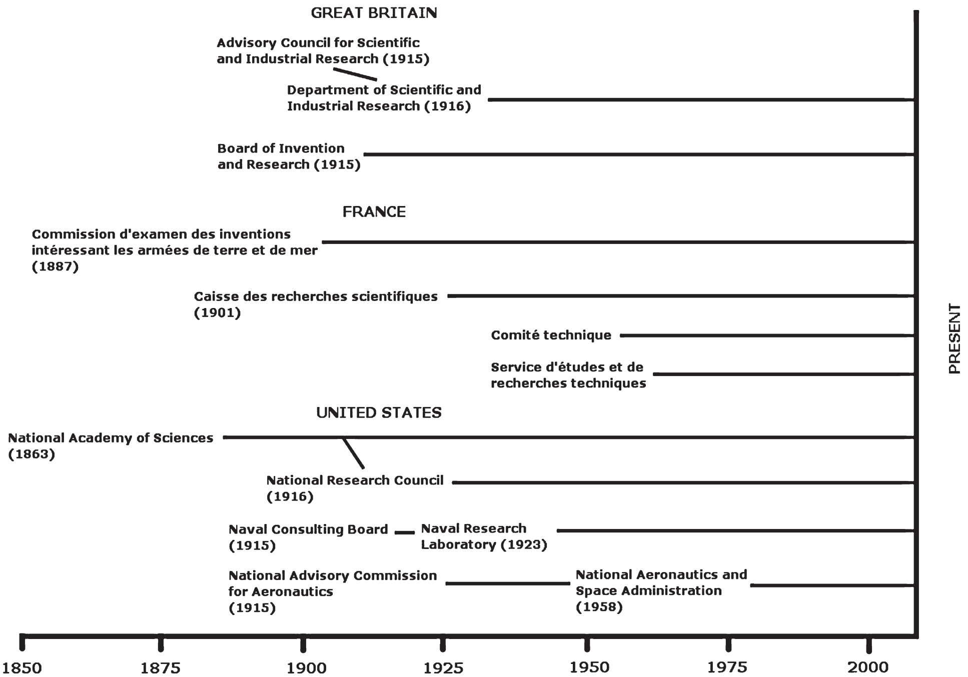


Figure 2.7. Some of the government institutions established in Great Britain, France, and the United States, to direct military and industrial R&D.

established in 1887, and the *Caisse des recherches scientifiques*, established in 1901. Both of these became very active during the war, and many new committees and offices were established.[111] Examples of other research institutions established during the war are the *Comité technique* of the Ministry of Commerce, Industry, Post and Telegraph and the *Service d'études et de recherches techniques* of the *École supérieure des postes et des télégraphes*.[112]

In the U.S. the Naval Consulting Board was formed in 1915 to consider the whole range of scientific and technological problems of interest to the military.[113] Shortly thereafter, the National Academy of Sciences, itself created during the Civil War to give advice to the government, established the National Research Council to bring research organizations—governmental, academic, and industrial—into cooperation for the national defense.[114] Also formed at this time was the National Advisory Commission for Aeronautics. All three of these new organizations long outlasted the

[111] Paul, pp. 320–338.

[112] Libois, p. 225. The *Service d'études et de recherches* techniques, established in 1916, became an autonomous service in 1934, and in 1941 it became the *Direction des recherches et du contrôle techniques*.

[113] Dupree, p. 306.

[114] Dupree, p. 309.

war: the Naval Consulting Board evolved into the Naval Research Laboratory, which still exists; the National Research Council still exists; and the National Advisory Commission for Aeronautics evolved into the National Aeronautics and Space Administration (NASA). Indeed, it is a recurring pattern in U.S. history that war produces new institutions that survive the war and influence the growth of science and technology in the peacetime that follows.[115]

In Great Britain, France, and the U.S., the war brought about a momentous change in the government role with respect to defense-related technologies: a shift from merely screening innovations proposed by civilians to government management of directed R&D. It is also noteworthy that engineers, as distinct from scientists, assumed more importance in this period. In 1916 the National Academy of Sciences created a section for men who had contributed "to the science or art of engineering".[116] Members of the National Research Council included several electrical engineers, and the major funding for the NRC came from the Engineering Foundation, headed by Gano Dunn and then Michael Pupin, both electrical engineers.[117] The Naval Consulting Board was composed almost entirely of engineers, and when the absence of members of the American Physical Society from its roster was pointed out, a spokesman for the Board said that the intention was to name "*practical* men who are accustomed to *doing* things, and not *talking* about it."[118]

Other countries, too, established institutions during the war for military and industrial R&D. In Italy a Department of Invention and Research was created, and in Russia scientific committees were formed to meet military and industrial needs.[119] Japan's Institute for the Study of Iron and Steel was established in 1916 especially to further military technology.[120] Germany, which had the strongest tradition of industrial research, was further helped by the establishment of *Kaiser Wilhelm Gesellschaft zür Förderung der Wissenschaften* in 1911, which supported research institutions such as the Kaiser Wilhelm Institute for Physical and Electrochemistry (1915), which became the center of research for chemical warfare.[121]

The Great War was the first in which there were "technical liaison officers", who worked to match technical possibilities with military needs.[122] Also new with this war was the scientific mission, whose purpose was to share technical advances with one's allies. Great Britain and France formalized scientific cooperation with an agreement on 6 October 1916, and scientific exchange between these two countries

[115] Roland 1985, pp. 257, 263.

[116] Kevles, p. 113.

[117] McMahon, p. 138.

[118] The words are those of M.R. Hutchinson, Edison's chief engineer, and are quoted in Hughes 1989, p. 120.

[119] Hartcup, pp. 33–34.

[120] Eckert and Schubert, p. 36.

[121] Hartcup, p. 4.

[122] Hartcup, p. 38.

and the U.S. began soon after the latter entered the war.[123] And during the war Great Britain and France provided technological aid to Russia and Italy.[124]

The war showed the military and industrial value of technological advance, and this lesson had lasting impact. Shortly after the war George Ellery Hale wrote: "… if scientific methods and the aid of scientific research were needed in overcoming the menace of the enemy they will be no less urgently needed during the turmoil of reconstruction and the future competition of peace."[125] The assumption by government, both civilian and military, of responsibility for fostering advance by establishing R&D institutions was, however, but a small part of the enormous increase in state power brought about by the Great War.

2.3 MOBILIZATION FOR TOTAL WAR

2.3.1 A War of Attrition

In August 1914 most people believed that the war would last no more than a few months and that civilians would not be greatly affected. What followed, however, was a protracted contest involving all the inhabitants of the belligerent nations. History's first "total war", the struggle elicited the mobilization of entire economies and evolved into a war of attrition rather than of battlefield exploit.

Great battles there were. Before the end of 1914 the Western Front saw the German advance through Belgium and northeastern France, the Battle of the Marne, and the Race to the Sea (a series of flanking movements to the northwest), and the eastern front saw the Battle of Tannenberg and the Battle of the Masurian Lakes. In this period the Allies lost a million and a half dead, wounded, or captured, and the Central Powers nearly that many.[126] Yet no nation had sued for peace nor seemed likely to do so soon, and the expectations that the fighting would be over by Christmas and that most people could pursue "business as usual" despite the war were clearly belied.

The difficulty of breaking enemy lines and of exploiting a breakthrough when it did occur—difficulties that seemed to increase in 1915 and 1916—led some military leaders to a new overall strategy: to inflict casualties on the enemy over a long period at a rate exceeding what could be replaced. Battles came to be justified, not because they won strategic ground, but because they inflicted greater losses than they incurred on the attacker. The major Allied offensive of 1916, the Battle of the Somme (which produced one and a quarter million British, French, and German casualties), was partly motivated by the idea that the Allies could win the war by a process of attrition on the battlefield, since the population of England and France

[123] Hackmann, pp. 39–43.

[124] Hartcup, pp. 33–34.

[125] In Yerkes, p. viii.

[126] Marshall, p. 95.

exceeded that of Germany.[127] The French chief of general staff Joseph Joffre used the phrase "Je les grignote" ("I am nibbling them") to describe his strategy.[128] In 1916 the Germans made Verdun their objective in a 10-month battle (which produced 900,000 casualties); they knew that the French would suffer enormous losses rather than relinquish that venerated fortress, and it was their objective, as chief of staff Erich von Falkenhayn expressed it, "to bleed the French white" rather than gain any particular piece of ground.[129]

The generals who saw the war as a war of attrition thought mainly of attrition of soldiery. The war indeed turned out to be one of attrition, but attrition of weapons, ammunition, vehicles, equipment, fuel, food, national financial credit, and national industrial output generally rather than of soldiers. It was a clash more of national productivity more than of armies. As the historian Alex Roland has written, "The machines on the home front producing bullets and canning beans contributed more to the outcome of the war than did any machines on the battlefield, save perhaps the machine gun."[130] The Germans used the word *Materialschlacht* (battle of materials) to describe the fighting on the western front.[131]

In England, although almost five million men served in the army, the civilian workforce was not severely depleted as 3.3 million new workers (1.7 million men and 1.6 million women) were recruited.[132] Not surprisingly, production of arms and munitions increased enormously; for example, 274 machine guns were manufactured in 1914, 120,864 in 1918. In addition, the army and navy required vast stores of food, clothing, equipment, and other supplies. These needs were met by the wholesale redirection of the economy by the government. In the summer of 1918, 61% of the male industrial labor force was engaged in war work, and government expenditure, which accounted for 7% of England's gross national product in 1913, accounted for 57, or 58% at its peak in the middle of the war.

Germany, too—once it became clear that the war would not be quickly decided—mobilized most of its economy for the war effort, but its mobilization differed in three respects from England's. In Germany it was the army rather than civilian authority that managed the economy, beginning with a War Raw Materials Department (*Kriegsrohstoffabteilung*) established in August 1914 within the Prussian War Ministry and achieving a high degree of control with the Hindenburg Program instituted in late 1916.[133] Secondly, Germany had to devote great resources to developing and producing substitute products, as the British naval blockade stopped

[127] Lloyd, p. 74. The British official historian of the battle wrote that it had "no strategic objective except attrition" [quoted in Terraine 1965, p. 157].

[128] Marshall, p. 126.

[129] Taylor, p. 121.

[130] Roland, 1985 p. 262.

[131] Hobsbawm, p. 45.

[132] The information in this paragraph comes from Dewey.

[133] Feldman 1966, pp. 7–8, and Homze, pp. 93–95.

almost all of its seaborne trade.[134] And Germany, unlike England, inflicted great deprivation upon the civilian population in order to meet military needs.[135]

In some ways France effected the most remarkable economic mobilization of any belligerent country. The German occupation of northeastern France, which lasted almost the entire war, had deprived France of much of its industry. The districts invaded or under fire—though in area only 11.5% of France—employed 21% of the manufacturing workforce in 1913, and many basic industries were concentrated there.[136] These districts accounted for 74% of French coal production in 1913, 81% of its pig iron production, 94% of its copper production, 44% of its chemical production, most of its wool and linen production, and most of its glass production. French authorities called upon existing firms to manufacture war materiel often quite different from their usual products. Production methods suitable to local conditions were improvised, machinery was converted to new uses, and new assembly lines were set up.[137] Though dependent on imports for many raw materials, France equaled or exceeded its allies in production of arms, munitions, and military equipment; in the words of William McNeill, "France, more than Britain and far more than America, became the arsenal of democracy in World War I."[138]

What happened was that in each of the warring countries, the government, beginning with new laws governing the manufacture of munitions, assumed greater and greater control of the economy, so that by 1916 dirigisme was the rule.[139] Civilian and military government agencies, labor unions, and businesses were all guided by laws and bureaucratic administration so that the whole functioned as a single national firm for waging war.[140] In 1916 an American observer wrote, "… [the war in Europe] has gotten down … to the question of whether every man, woman, and child of the nation has been engaged and is engaged in the production of some kind of materials for the armies at the front."[141]

The success achieved in mustering the national productive capacities for war depended heavily upon electrical technology. The demands of a war of attrition thus led to what William McNeill calls, "a distinctive hallmark of the twentieth century: the industrialization of war and the politicization of economics."[142]

[134] At first the substitutes (*Ersatzprodukte*) were always regarded as inferior to the original, but beginning with the production of synthetic ammonia just before the war, certain ersatz products were seen as equal or superior to the original [Braun p. 15].

[135] Dewey, p. 80.

[136] Fontaine, pp. 3–21.

[137] McNeill, p. 319.

[138] McNeill, p. 322. McNeill points out that most of the heavy equipment of the U.S. Expeditionary Force was supplied by French factories and arsenals.

[139] Pearton, pp. 158–160.

[140] McNeill, p. 317.

[141] The statement came from Howard E. Coffin, chairman of the Committee on Industrial Preparedness of the Naval Consulting Board [Coffin 1916].

[142] McNeill, p. 294.

2.3.2 Electrical Technology and Mobilization

The enormous demand for munitions and all manner of military supply, together with the need to produce goods formerly imported, required the building of a great many new factories, large and small. In most of these the mechanical power came from electricity, which was provided by central power stations. For example, in England, where 95% of munitions factories were electrically powered,[143] an engineer wrote that "their rapid construction and setting to work would not have been possible had it not been for central power and lighting being available. …"[144] The expanded hours of operation in factories required artificial lighting, and there were no good alternatives to electric lighting. Steam power was, in most cases, the only alternative to electric power, and if it had been necessary to install boilers and steam engines in every new factory, the mobilization would have been much slower.[145] The industrial use of electric power was, it should be pointed out, rapidly increasing in the decade before 1914, but the trend was accelerated by the war. According to two British engineers, "It may be said that the War definitely established the pre-eminence of electricity as *the* motive power for industry."[146]

The great demand for electric power had several consequences. First, new power plants were built. In England the additional generating-plant capacity installed or ordered during the war equaled the capacity existing when the war broke out.[147] A war-induced shortage of coal stimulated the development of hydroelectricity in some countries; this was the case in Italy, for example, where the price of coal increased 40-fold.[148] Second, great efforts were made to conserve power and improve efficiencies. One such measure, daylight-savings time, led to significant reductions in private consumption of electricity, since lighting was the main use—often the only use—of electricity in homes. Third, a movement that had begun before the war, the interconnection of electric-power networks, was greatly accelerated. This interconnection of networks permitted fuller use of existing generating capacity, but required standardization of frequencies and voltages. In many countries, government intervention helped bring about this standardization.[149] In 1917 a British engineer said, "… [the war] has been primarily a mighty solvent, dissolving many obstacles to progress that formerly existed. …"[150]

143 Hannah, p. 56.

144 Stothert, p. 47.

145 Caron, p. 900, and Gridley, p. 406.

146 Gridley, p. 409 (emphasis in the original).

147 Gridley, p. 408. In the United Kingdom aggregate sales of electric power increased from 2100 gigawatt hours in 1914 to about 4000 gigawatt hours in 1918 [Hughes 1983, p. 291].

148 Sellin, p. 98. In the United States the war led to the large hydroelectric plant on the Tennessee River at Muscle Shoals, Alabama [Hughes 1983, pp. 286–287]; in Germany the war led to the development of large power-plants fueled by lignite (brown coal) [Hughes 1983, p. 287].

149 Caron, p. 934 (France), Hannah, p. 57 (England), Pavese, p. 401 (Italy), and Hunter and Bryant, pp 365, 368 (United States).

150 Wordingham, p. 8. In June 1916 the British government created a Department of Electric Power Supply and offered incentives to power companies to interconnect [Hughes 1983, p. 290].

The availability of electric power not only made it easier to set up new factories, but also gave new freedom to arrange a factory for an efficient production flow. (Before electric power, a factory had to be laid out with the machines in long rows so that they could be powered by belts attached to overhead shafts.) In this and other ways, electric power greatly facilitated adoption of assembly-line production. Although there are isolated uses of this technique in Europe as far back as the early 19th century, it was the example of Henry Ford's factory in Highland Park and the urgent needs for industrial products during the war that stimulated the widespread adoption of the technique in Europe.[151] In 1915 an English truck manufacturer and a French aircraft-engine manufacturer began using a moving assembly line; the following two years saw the technique adopted in new factories in Italy (the Fiat factory at Lingotto) and France (a truck-assembly factory at Vénissieux); and by the end of the war tanks, artillery, and aircraft engines were among products being mass-produced by assembly lines.[152]

The import of this innovation has been widely appreciated by historians. Hans-Joachim Braun and Walter Kaiser attribute the rapid proliferation of assembly-line production in the 1920s to its widespread adoption during the war.[153] Patrick Fridenson has written, "It was … the First World War which urged (and helped) the Europeans to follow the trend epitomized by Henry Ford …"[154] William McNeill has written, "The subsequent industrial and social history of the world turned very largely on the continuing application of the methods of mass production whose scope widened so remarkably during the emergency of World War I."[155] Less widely appreciated is how important electrical technology was to the widespread adoption of assembly-line production, a point that the historian David Nye has emphasized.[156] Electric cranes and lifts, electric illumination, and electrically powered ventilation enormously enhanced flexibility in factory design, and electrically powered tools could themselves be moved in the fabricating and assembling process.

Usually connected with the interest in Europe for assembly-line techniques (Fordism as it was called) was interest in the style of scientific management promoted by Frederick W. Taylor (Taylorism), which sought to increase industrial output by rationalization of the production process.[157] Electrical technology played a part in improving productivity: electrical control of machinery was increasingly adopted, and there was a great increase in automatic machinery for testing, which in some cases made it possible to use only partially skilled labor where skilled laborers had been required.[158]

[151] Fridenson.

[152] Fridenson. Fridenson also points out that in some ways the war hampered the adoption of assembly-line production.

[153] Braun, p. 178.

[154] Fridenson, p. 161.

[155] McNiell, p. 331.

[156] Nye, p. 221.

[157] Hughes 1989, pp. 249–294.

[158] Fontaine, pp. 93–96.

Most important in industrial production was electric motors, but other electrical technologies were extremely important. There was great reliance upon electrochemical and electrometallurgical processes.[159] The manufacture of, for example, calcium cyanamide (for explosives and as a fertilizer) or of aluminum required large quantities of electricity.[160] Especially noteworthy was the rapid wartime adoption—in England, France, and Germany—of electric furnaces for steel making.[161] Another electrical technology widely adopted during the war was arc-welding, which was only one of many electrical technologies important in shipyards (where electricity ran machine tools, pumps, air compressors, cranes, and lifts).[162]

Crucial to every country's mobilization was rapid communications; here the telegraph and, especially, the telephone were vital. The complicated tasks of acquiring and allocating scarce raw materials, of building and equipping new factories, of arranging for supply of materials to factories, of organizing the distribution of the products—all required long-distance communication. These tasks would have taken much longer before the age when offices were equipped with telephones, even if they did have messengers for shuttling to local telegraph offices.

2.3.3 The War for Minds

Communications played another role: enlisting support for the war among the population at large. Most important were newspapers, since mass literacy and large circulation gave them great influence. Particularly significant were the atrocity stories, fabricated on both sides, that in the first months of the war inflamed public opinion against the enemy and for the war.[163] Propaganda played a large role in winning support for the Allies in the U.S.; British control of the transatlantic cables gave them a great advantage in supplying U.S. newspapers with stories favorable to the Allies.[164]

Another important means of shaping public opinion was the cinema. In England the Committee on Public Information produced such films as *The Kaiser: The Beast of Berlin*, and Charlie Chaplin made several propaganda films, including one promoting British war loans.[165] Cinema was also influential in wartime France.[166] In the U.S., the Committee of Public Information, headed by George Creel, commissioned movies such as *Under Four Flags* and *Pershing's Crusaders*, and in 1917 D.W.

159 Caron [p. 935] writes that the war was a stimulus to the electrochemical and electrometallurgical industries in France.

160 Siemens, p. 18.

161 Robertson (England), Fontaine, pp. 269–319 (France), and Siemens, p. 10 (Germany).

162 Nielson.

163 Francis-Williams.

164 Francis-Williams. Germany did establish a wireless press service to send news stories to the United States, but its operation was hampered by the difficulties of transmission, as Francis-Williams points out.

165 Winter, p. 244.

166 Griset, pp. 106–108.

Griffith filmed *Hearts of the World* in France, showing realistic battle scenes and the mistreatment of civilians by Germans, which reportedly boosted recruitment in the U.S.[167]

Recorded music was used for propaganda purposes, as was radio, though this was before radio broadcasting existed. The German, French, and British governments all issued bulletins that were broadcast by wireless; so did the U.S. after it entered the war.[168] Such messages were intended for the press in other countries, though they also reached radio amateurs (even after, as occurred in several countries, amateur use of a receiver was forbidden). After the Bolsheviks took power in Russia, Leon Trotsky used a powerful transmitter at Petrograd to publish to the world the secret treaties to which Russia had been party;[169] this no doubt increased antiwar sentiment in the Allied countries.

The difference made by propaganda in World War I is difficult to assess.[170] It was vital in eliciting support for the war (mobilizing the home front and maintaining the morale of soldiers), and so raised the intensity of war. Moreover, propaganda made it more difficult to settle the war by compromise as it typically depicted the conflict as a challenge to national values, such as Russian barbarism against German culture, or German absolutism against British democracy.[171] Whatever the effects, it is clear that propaganda assumed, during the Great War, an important place among the means of waging war, and electrical technologies—telegraph, radio, and cinema—provided effective means for propaganda.

2.3.4 The Legacies of World War I

The political and economic impact of the war was enormous. Four empires—the Hohenzollern, the Hapsburg, the Romanov, and the Ottoman—met their end, new republics were established in place of monarchies, and the map of Europe assumed essentially its present form.[172] The war marked the end of the colonial period of European history and the beginning of great political significance for the Third World. Everywhere the war increased state powers, and in many countries the government assumed and retained large powers to direct the economy. Destruction of buildings and equipment and disruption of trade, great as they were, were remedied fairly rapidly; most countries surpassed their prewar production by 1925. What was lost forever, according to the historian A.J.P. Taylor, was the old order of financial stability, as depreciated currencies, reparations, and war debts plagued economies for years to come.[173]

[167] Marshall, p. 247, and Winter, p. 239.

[168] Douglas 1987, pp. 275, 280.

[169] Taylor, p. 202.

[170] Contrasting assessments may be found in Winter [p. 182], Zeman [p. 808], and Zentner [p. 245].

[171] Hobsbawm, p. 29.

[172] None of the defeated countries escaped political revolution in the war's aftermath.

[173] Taylor, pp. 279–280.

The social impact, too, was enormous. The death toll reached one million for the British empire, a million and a half for each of France and Germany, and probably more for Russia than all the rest put together.[174] During and after the war there were major displacements of peoples, and adding to the chaos of the last year of the war was an influenza epidemic that, before 1919 was over, claimed 20 million lives.

The status of women changed. In every belligerent nation women were recruited to jobs men had held before the war. In England during the war an additional 1.6 million women entered the workforce, 800,000 of them to jobs in industry.[175] Many others became typists in business and government offices, as "the male office-clerk vanished for ever".[176] In Paris women ran the Métro. Auxiliary military services for women were established in many countries, and in Russia women's combat battalions were formed.[177] Electrical manufacturers reflected this change: at Brush Electrical Engineering Company the percentage of women employed increased from 3.7 to 27.5; Dick, Kerr & Company employed 3000 women at war's end, 10 times the prewar number; in AEG factories in Berlin the number of women rose from 3000 before the war to 11,000 in 1917; and at Siemens Brothers almost half of the 5600 employees at the time of the Armistice were women.[178]

A war that caused so much destruction, suffering, and death could not help but have a great cultural impact. It was, indeed, a watershed for sensibilities, with the optimism, belief in progress, and idealistic nationalism of the postwar world lost in the widespread disillusionment that followed. Guillaume Apollinaire, France's greatest war poet, wrote that artillery gave birth to the modern literary spirit.[179] The literary critic Paul Fussell has written that "… the dynamics and iconography of the Great War have proved crucial political, rhetorical, and artistic determinants on subsequent life" and that "… there seems to be one dominating form of modern understanding; that it is essentially ironic; and that it originates largely in the application of mind and memory to the events of the Great War."[180] In some circles the postwar disillusionment included rejection of technological progress, though this was certainly a minority view.

If asked what difference electrical technologies made in the war, we might distinguish between technologies of the battlefield and technologies of the homefront. Particular technologies, such as those for locating enemy artillery, controlling naval gunnery, and detecting enemy submarines, certainly made a difference in fighting. Warships and, by war's end, airplanes were more effective instruments of war because of various electrical technologies. Rapid communications—by telegraph, telephone, ground telegraph, and wireless—were vital to military operations. Also

[174] Taylor, pp. 277–279.

[175] Dewey, p. 75, and Black, p. 626.

[176] Taylor, p. 87.

[177] Black, p. 626.

[178] Gridley, pp. 545–546, and Bessel, pp. 18–19.

[179] Llewellyn-Smith, p. 642.

[180] Fussell, p. ix and p. 35.

important were the disruption of enemy communications (severing wires or jamming wireless transmissions), the interception and decoding of them, and the use of them for direction finding. Rapid communications was vital also on the homefront in directing the production and distribution of goods. And the mobilization of productive capacity for the war depended heavily upon electric power.

If asked what difference the war made for electrical technologies, we might be forgiven a longer answer. The war, called the "war of invention" and "Krieg der Ingenieure", brought technology to the attention of everyone. It convinced many people that wars would henceforth be dominated by weapons and weapon systems; in Edison's words, "Modern warfare is more a matter of machines than of men."[181] This led to enormous efforts in military R&D, and many of the national R&D institutions outlived the war. Industry leaders, taking note of the effectiveness of this directed research, increased their commitment to research; R&D expenses by U.S. firms doubled in the period from the end of the war to the beginning of the 1930s, while R&D by German firms tripled.[182]

It was not only military technology that advanced in these years. For example, the immense popular interest in the war gave a great stimulus to improvement in techniques of news gathering and dissemination. The telegraph was the principal means of conveying information from the battlefields to the cities, where newspapers were the principal means of disseminating that information to the people. Even with the frequent appearance of extra editions of newspapers, faster means of disseminating information were sought. In Copenhagen, three new means were employed, all of them electric technologies: a "telephone newspaper", public posting of telegrams from the war, and display of the latest news in lights, on an electric moving message board, at the city-hall square.[183] The cultural historian Stephen Kern has even argued that the wartime communication technologies changed the way people thought about space and time:

> "… [the fighting was] witnessed by the millions at home, who learned about these multifarious events almost at the same time as they were happening. … Europe became a communications network that processed more information than ever before about more people involved in more events in widely distant places at the same time. World War I was the simultaneous drama of *the* age of simultaneity."[184]

In a few areas of electrical technology the war acted to slow advances. Improvement in civilian telephony slowed, particularly the installation of automatic switching.[185] The war certainly restrained the sale of a great many electrical products for the home, such as electric toasters, washing machines, razors, and vacuum cleaners, that were introduced before the war. The war also slowed the development of television, an active area of work in the decade preceding the war.[186]

181 Quoted in McMahon, p. 139.

182 Braun, p. 208.

183 Christiansen, p. 197.

184 Kern, p. 295.

185 Libois, pp. 64, 69 (France), and Fagen, p. 584 (United States).

186 Abramson, pp. 23–41.

The wartime disruption of commerce was, however, beneficial to some electrical manufacturers, as it reduced competition from foreign manufacturers. For example, the British blockade greatly reduced German exports of electrical equipment, with the result that the Swedish and Swiss electrical industries expanded vigorously,[187] and Philips of Eindhoven, the Netherlands, was forced into greater self-reliance, taking up the manufacture of products it had earlier imported.[188]

The war gave, of course, an enormous impetus to the development of technologies of military importance. There were many besides the ones described above, such as the cathode-ray oscilloscope. At the suggestion of J.J. Thomson, it was developed to study underwater explosions of the sort produced by mines, and the device proved so valuable that, for other investigations, a self-contained and portable oscilloscope was designed.[189] As with this example, the development for military ends frequently found other applications.

Perhaps the largest single effect of this type was the impetus given to the development and application of the electron tube. At the beginning of the war the electron tube was a little-known and scarcely exploited device, manufactured by hand in small numbers. During the war it came to be employed in a wide variety of ways and mass production began, and by Armistice Day, millions had been manufactured. After the war, the electron tube continued its increase in numbers, varieties, and effectiveness, all the while finding new applications. The war was the dawn of the electronic age.

In March 1917 strikes and riots in Petrograd (St. Petersburg) led to the abdication of Czar Nicholas and the establishment of a parliamentary government. There was no talk of Russia's leaving the war.[190] Indeed, most people expected that removal of the discredited and ineffective Romanov officials would strengthen the country militarily. However, one prominent figure, Vladimir Ilyich Lenin, leader of the Bolsheviks, the more radical of two main factions of the Russian Communist party, advocated Russian withdrawal from the war. But Lenin was in exile in Switzerland, and he was not allowed to pass through France and England.

In April German military authorities, hoping to incite revolution in Russia but not in Germany, permitted a "sealed train" to carry Lenin and other Bolsheviks across the Reich, and on 16 April he arrived in Petrograd.[191] Lenin's hope was to gain power and give Russia a new political and social order. A central element of his plan was the rapid development of electric power, as made famous in his slogan, "Communism is Soviet power plus the electrification of the whole country."

Lenin, influenced no doubt by Karl Marx's view that technological changes bring social ones, became interested in electrical technology as a transforming force while in exile in Siberia in the 1890s.[192] A fellow exile was the engineer G.M.

[187] Siemens, p. 26.

[188] Atherton, p. 320.

[189] Drysdale, pp. 580–581.

[190] Taylor, p. 173.

[191] Germany also spent millions of marks supporting Bolshevik activities in Russia [Zeman].

[192] Hughes 1989, pp. 259–261.

Krzhizhanovsky, who argued that "The rise of a machine culture on an electrical basis can be achieved in the most perfect and unfolded form only in conditions of socialist economy."[193] By the time of the war Lenin believed that "the 'electrification' of all factories and railways [would] accelerate the transformation of dirty repulsive workshops into clean, bright laboratories worthy of human beings" and that electrification "will provide a link between town and country, will make it possible to raise the level of culture in the countryside and to overcome … backwardness, ignorance, poverty, disease, and barbarism."[194] Lenin was probably impressed with the electrical technology he saw in the West, particularly in Switzerland, whose electrification on the basis on hydroelectric power was already far advanced in 1914.

In November 1917 Lenin and the Bolsheviks overthrew the parliamentary government headed by Alexander Kerensky, and by the end of 1920 electrification was the declared means by which the new government aimed to achieve its political and economic goals.[195] The outcome of Bolshevik efforts to electrify a huge, largely agricultural nation is the main subject of the following chapter.

[193] Quoted in Hughes 1989, p. 260.

[194] Quoted in Coopersmith, pp. 153–154.

[195] Coopersmith, p. 1.

Chapter 3

Electrification in the Interwar Period

3.1 LENIN'S PROGRAM OF DEVELOPMENT THROUGH ELECTRIC POWER

3.1.1 "Communism is Soviet Power Plus the Electrification of the Whole Country"

When the Bolsheviks seized power in Petrograd in November 1917, Vladimir Lenin announced his program: immediate peace, land to the peasants, and industrial development through socialism. The war had impoverished the country, causing economic and political breakdown and killing millions of soldiers and civilians. At Brest Litovsk the Bolsheviks signed a treaty with Germany that ended the war but surrendered a third of Russia's territory.[1]

There followed a civil war between the Communists and the Whites, led by Czarist generals. Leon Trotsky ably organized the Red Army, which by the end of 1919 had defeated the White forces. When a Polish army attacked Russia the same year, the Red Army turned it back and invaded Poland, but was defeated outside Warsaw. The Treaty of Riga, which followed, ceded large areas of ethnic-Russian territory to Poland.

The revolutions, civil war, Russo-Polish war, and attendant circumstances (such as a trade embargo by several Western nations) so disrupted the economy that people spoke of the de-industrialization of Russia. In 1920 the output of manufactured goods was only 13% of the prewar level. Many urban workers drifted back to their native villages, so that in 1920 Petrograd had lost 70% of its population, Moscow 45%.[2]

[1] Taylor, p. 1027.

[2] Johnson, p. 88.

Dawn of the Electronic Age: Electrical Technologies in the Shaping of the Modern World, 1914 to 1945, by Frederik Nebeker

Lenin, like most socialists, believed that a socialist revolution would first succeed in an advanced industrial country, and the Russian revolution in March 1917 greatly surprised him. After taking power in November he believed that continued Bolshevik rule required the spread of the revolution across Europe. When this did not happen, he decided that Communism could survive in Russia only through rapid industrialization.[3]

The autocratic, expropriatory measures of his first years of rule Lenin called "war communism", arguing that the threat to the new regime from reactionaries and foreigners justified them. Agricultural produce was forcibly taken from the peasants, and factories and other businesses were nationalized. The production of electric power, like most types of agricultural and industrial production, continued to fall in these years, yet there arose, in certain circles, an optimism for societal transformation through electrification.[4]

Many Russians in the decade preceding 1917 proposed plans for rapid electrification, believing it to be a great force for economic and social development. The electrical engineering community, which gained political influence from the great demand for electric power during the war, advocated rapid electrification based on regional stations. In addition, the war increased support, in Russia as elsewhere, for large-scale, state-directed engineering projects.[5]

Many people, then, favored the idea of a government program to electrify the country rapidly. As early as December 1917, a month after taking power, the Bolshevik government proclaimed the need for a network of state-owned regional stations.[6] What turned that goal into reality was its advocacy by Lenin.

As we have seen, Lenin became interested in electrification in the 1890s and, like the engineer G.M. Krzhizhanovsky with whom he shared exile in Siberia, believed that a socialist economy would best allow electrification to effect its beneficent transformation of factories and homes. After the October revolution, his emphasis on electrification increased. One historian writes that the phrase "after the electrification of Russia" assumed in Lenin's speeches the same role that "after the revolution" had earlier, and H.G. Wells, who met with Lenin in September 1920, wrote, "For Lenin, who like a good orthodox Marxist denounces all 'Utopians', has succumbed at last to a Utopia, the Utopia of the electricians."[7]

Krzhizhanovsky, the chief architect of the electrification plan that was soon adopted, remembered:

> *Our country was still in the midst of the calamity of war; we were still continuing to roll into the abyss of deepest economic disorder. And then, according to directives of the Party, there was created the first prospective economic plan. We proceeded to collect a handful of people, scientific and technical workers, and under the immediate guidance of Vladimir Ilyitch [Lenin], we tried to pick our way among the chaos*

[3] Taylor, pp. 1026–1030.

[4] Coopersmith, p. 121.

[5] Coopersmith 1991, pp. 220, 224.

[6] Coopersmith 1991, pp. 220–221.

[7] The historian is Adam Ulam, quoted in Coopersmith, p. 154. Wells is quoted in Coopersmith, p. 154.

surrounding us, tried to harness to the conquest of science and technique those active elements among the workers and peasants whose creativepower we perceived and recognised in the midst of ruin and war. In this plan we daringly sketched an impression of our future, a design of that building which we can and must convert into reality. Very soon we were assailed with banter: people said that it was not a plan of electrification but of 'electric-fiction'; they said it was poetry, an imaginative creation, far from reality.[8]

Lenin believed that Communism could survive in Russia only if the country industrialized rapidly, and he believed electrification was the means to rapid industrialization. His slogan became famous: "Communism is Soviet power plus the electrification of the whole country." He wrote, "We shall consider the victory of socialism over capitalism … guaranteed only when the proletarian state power … reorganizes the whole industrial system on the basis of large-scale collective production and the newest technique, with electrification throughout."[9]

Because of Lenin's nearly absolute control over the Communist Party, his advocacy of electrification was decisive. The historian Jonathan Coopersmith writes: "Lenin proved invaluable in prodding the state bureaucracies into action. His collected works contain numerous letters to obtain supplies, gather information, and make disagreeing officials agree. His assistance proved especially helpful in obtaining foreign equipment for regional stations, an assist necessitated by the newly established state monopoly on foreign trade."[10] Thanks to Lenin's support, by 1920 construction had begun on four regional stations in the Moscow and Petrograd areas. His most important action was generating support, both by party leaders and by the population as a whole, for GOELRO, an extremely ambitious plan of country-wide electrification.[11]

3.1.2 The State Adopts an Electrification Plan

In 1920 the Communist party made electrification the state technology. In February the Supreme Council for the National Economy created the State Commission for the Electrification of Russia (GOELRO), to reconstruct and modernize the country through electrification. About a month later the Ninth Party Congress called for an electrification program as part of the state economic plan; and in December of that year the Communist Part approved a 10-year plan, worked out by GOELRO.[12]

GOELRO decided to concentrate on Russia's industrialized regions, where large industrial users and large cities could provide the load commensurate with high-capacity power stations; less industrialized regions would have to wait.[13] GOELRO

[8] Quoted in Dobb, p. 315.

[9] Quoted in Lawton, p. 372.

[10] Coopersmith, p. 154.

[11] Coopersmith, pp. 147, 155.

[12] Coopersmith, pp. 151, 158.

[13] Coopersmith, pp. 159–160.

chose to electrify the country in a centralized way by building large regional stations. Two alternative paths of development, though each had many proponents, were not chosen: a conservative path of expanding existing utilities, and a radical path of rapidly electrifying the countryside in a decentralized manner.[14] GOELRO assumed that the West would provide, as it had under the Czars, both technology and financing for electrification.[15] Because of a serious fuel shortage, GOELRO sought to avoid conventional thermal stations: where water power was not available, low-grade fuels, such as peat or industrial wastes, would be used for thermal stations.[16]

The first GOELRO plan called for 100 power stations. In January 1921 that overly ambitious goal was reduced to 27 stations. The unavailability of many supplies and types of equipment and a shortage of skilled labor made progress extremely difficult, and two years later only three projects were receiving any attention. These were the Svir and Volkhov hydroelectric stations, both in the Petrograd area, and the thermoelectric station at Nizhni-Novgorod.[17]

Some sectors of the economy were barely functioning, and the regime was in danger of losing political control. A strike by Petrograd workers in February 1921 and mutiny at the Kronstadt fortress in March convinced Lenin that the country would no longer accept the stringencies of "war communism". He therefore announced a New Economic Policy, which was in part a return to a free enterprise economy.[18] Lenin replaced requisition of agricultural products from the peasants by a tax in kind and permitted the peasants to trade surplus products. This greatly reduced peasant discontent and stimulated agricultural production.[19]

Work on the new regional stations proceeded, but proceeded slowly. The Svir and Volkhov stations were the first large hydroelectric plants in Russia, and they used recent technology, including 115-kilovolt (kV) transmission lines.[20] The Svir hydroelectric station took 13 years to complete, even though several U.S. and Swedish construction companies contributed and the turbines and generators were imported.[21] At the Volkhov station, Swedish engineers implemented Swedish construction methods. Though completed in 1927, its operation was irregular and unreliable. Four of the eight generators came from Sweden, and four were built in Petrograd. Problems arose in operating them together.[22] Progress was also slow at Nizhni-Novgorod, where British and German firms contributed.[23]

GOELRO set an example that the Communist leaders adopted generally. A historian of the Soviet economy wrote, "Planning machinery, as a specialised and

[14] Coopersmith, pp. 152–153.

[15] Coopersmith 1991, pp. 222–223.

[16] Coopersmith, p. 161.

[17] Sutton, p. 201.

[18] Bradley, p. 1011.

[19] Schapiro, pp. 215–216.

[20] Coopersmith, p. 149.

[21] Sutton, pp. 201–202.

[22] Sutton, p. 202.

[23] Sutton, pp. 201, 204.

permanent arm of the State, had its beginnings in the foundation of the famous GOELRO, or State Commission for Electrification, mainly on the initiative of Lenin, in March, 1920. …"[24] And in February 1921 GOELRO was merged into a larger body, the state planning commission known as Gosplan.[25]

3.1.3 Engineers Gain in Status

What Lenin promised the Russian people was technological modernization. For the peasants, the single most important aspect of the new life was electric lighting. Lenin took advantage of this to win support for his programs. According to a 1924 obituary: "Only 'Illich' [Lenin] understood the might and role of electricity in the national economy and transformed it from a narrow, technical idea to the ideal of peasants and workers, connecting it organizationally to Soviet power."[26]

The regime glorified electrical power. Coopersmith has written, "The image of the peasant seeing his first light bulb has been immortalized on Soviet lacquer boxes, posters, stamps, photographs—on anything that would convey the message."[27] And the regime distributed posters that advertised the benefits of electrical power.

Other Soviet leaders shared Lenin's view of the importance of technology for state-building. Trotsky, though not valuing electrification as highly as Lenin did, still regarded it as an important long-term goal, and in 1925 he wrote that "scientific technology is one of our most important weapons of our state self-assertion in the world struggle."[28] The historian Paul Johnson has written, "Thus [because of Lenin's enthusiasm for electrification] began a curious cult which has persisted in the Soviet Union to this day, and which has made the heavy electrical engineer the most valued figure in Soviet society (next to the arms designer)."[29] Electrification came to be associated with Communism in the popular imagination. In George Orwell's *Animal Farm*, a depiction of the evils of Communist society, the animals electrify the farm.

Lenin, along with many other educated people at the time, had great hopes for the transforming power of new technology. He greatly admired Karl Ballod's *Der Zukunftsstaat*, published in 1919.[30] During World War I in Russia, as in many other countries, a centralized and technocratic approach to social problems gained favor, and this trend continued in the first years of Communist rule. A particularly influential expression of the technocratic vision was Vasilii Grinevetskii's 1919 *Postwar Perspectives on Russian Industry*, which advocated electrification of industry through regional stations.[31] (It might be pointed out that the Bolshevist embrace of an

[24] Dobb, pp. 314–315.

[25] Dobb, pp. 315–316.

[26] Quoted in Coopersmith, p. 155.

[27] Coopersmith, p. 155.

[28] Quoted in Coopersmith, pp. 196–197.

[29] Johnson, p. 94.

[30] Johnson, p. 94.

[31] Coopersmith, pp. 139–141.

ideology of technological transformation made Bolshevism attractive, or less unattractive, to many Russian engineers.)[32]

Technocracy, as the movement was called, was popular elsewhere as well. In the U.S. a number of artists of the 1930s portrayed technology in a positive way.[33] And in the U.S., technocracy was an intense but short-lived movement that began in 1932 with the formation of the Committee on Technocracy based at Columbia University. Its members argued that new technology could create abundance, but only if social organization were adjusted appropriately.[34] The technocractic movement attracted much interest, but it failed to provide a detailed alternative to existing social structures and a plan to achieve the necessary changes.[35]

3.2 GENERATORS, POWER LINES, AND MOTORS

3.2.1 Generating Electric Power

Large power stations and long-distance transmission of electricity formed the basis of the Soviet program. Electric power technology was then a half-century old, having grown out of a long series of scientific investigations of electric currents that began early in the nineteenth century.

Alessandro Volta's 1799 invention of the electric battery set off a great deal of experimentation by giving investigators a convenient source of constant current. In 1820 Hans Christian Oersted found that an electric current creates a magnetic field. Eleven years later Michael Faraday found a reverse effect; moving a conductor in an magnetic field generates an electric current. (See Figure 3.1.) There was then a second way to produce electrical energy—by converting mechanical energy, rather than chemical energy as in a battery—but it was not until the 1850s that Werner Siemens in Germany, F.H. Holmes in England, and others developed practical generators.

At first, generators, or dynamos as they were also called, were used to power electroplating or arc-lighting systems for single users, with the generator on the premises. A new technological era began in 1882 when Thomas Edison, shortly after his invention of a practical incandescent light, set up public systems in London and New York, showing that a central station could supply electricity to many users by means of distribution lines. Such a system comprised three principal components, which we will consider in turn: generation, distribution, and utilization.

Though chemical, thermal, or solar energy can be converted directly into electricity, the large-scale generation of electric power has proceeded by producing mechanical power, which a dynamo then converts into electric power. The prime

[32] Balzer.

[33] Copp and Zanella, p. 73.

[34] Akin, pp. 64–65.

[35] Akin, p. 80.

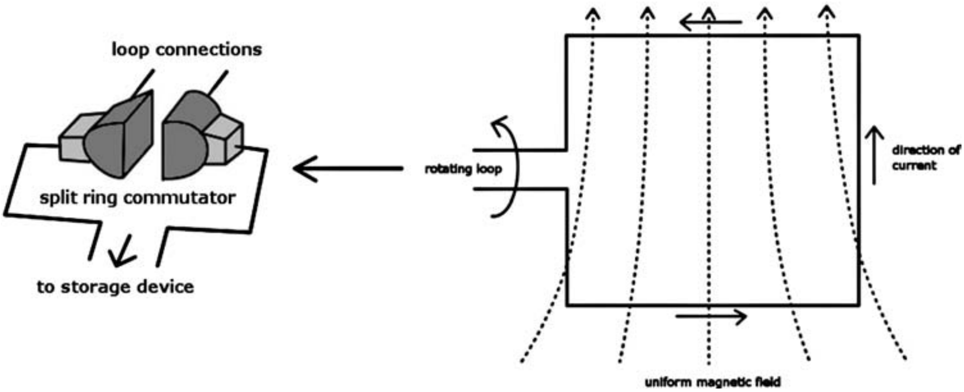


Figure 3.1. As the loop of wire turns in the magnetic field, an electric current is induced to flow in the wire, first in one direction, then the other. Here the loop is provided with a commutator (the split-ring device at the left) so that the current flows in one direction only (though it fluctuates greatly in intensity).

movers have been the traditional (reciprocating) steam engine, water wheels and water turbines, and steam turbines. The most efficient have been the large turbines, either water or steam driven.

Beginning in the late 1820s water turbines (usually with curved vanes on a central shaft along which the water flowed) gradually replaced older types of water-wheels, and later in the century when people began converting water power to electricity, they used turbines. Steam turbines, developed by Charles Parsons in England in the 1880s and 1890s, were more efficient than reciprocating steam engines.[36] The turbine had another important advantage: its speed (Parsons' first turbine ran at 18,000 rpm) greatly exceeds that of a reciprocating engine (perhaps 1000 rpm) and matches well the speed of a dynamo of corresponding power, so that the turbine and the dynamo can be directly coupled.[37] Milestones in large-scale energy production are the 2500-horsepower system Sebastian Ferranti built in 1889 to supply London, the three 5000-horsepower hydro turbogenerators installed in 1895 at Niagara Falls, and the 1500-kilowatt steam turbogenerator put into operation in 1901 by the Hartford Electric Light Company in Connecticut.[38] So effective were turbines that their widespread use in power plants after 1900 gave rise to excess capacity and the search for more load.[39]

The generators developed by Siemens, Holmes, and others in the 1850s underwent continual improvement. Magnetos, which are generators whose magnetic fields comes from permanent magnets, gave way to generators using electromagnets. Greater efficiency came from improvements in arrangement of the field coils (pro-

[36] Hannah, pp. 13–14.

[37] Houston, p. 43.

[38] Dunsheath, pp. 163–164, and Hughes 1976, p. 647.

[39] Hughes, pp. 363–364.

ducing the magnetic field) and in design of the armature (bearing wires in which current is generated). Using the ring armature invented by Antonio Pacinotti, the Belgian engineer Z.T. Gramme in 1870 designed a machine producing a fairly constant direct current (DC) that for the first time made large-scale commercial DC generation possible. A further advance was the drum armature introduced in 1872 by Friedrich von Hefner-Alteneck, chief designer at Siemens & Halske; it became the standard for the next quarter-century.[40] In the first decade of the new century a different design became standard; instead of a fixed magnetic field and a rotating armature, it used a rotating magnetic field, the current being generated in the stator.[41]

Most striking was the continual increase in generator size and power. When Edison opened his New York station in 1882, his 90-kilowatt (kW) Jumbo generator was the most powerful in the world.[42] The move to turbogenerators brought higher power; in 1900 the C.A. Parsons company supplied two 1500-kW generators to Elberfeld, Germany. By 1895 the average size of generators being installed in British power stations was 500 kW; in 1905 it reached 2.5 megawatts (MW) and in 1913, 5 MW.[43]

Technical advances gave a clear competitive advantage to large-scale power generation. Had it been otherwise, universal electric power might have been supplied by means of generators in each home, office, and factory, just as heating is usually provided locally. Indeed, the efficiency of the very large generators was one force moving the electric supply industry to larger and larger power networks, a subject of the last part of this section. Large networks also required efficient means of power transmission, this chapter's next subject.

3.2.2 Transmitting Electric Power

Though difficult to store, electrical energy is easy to transport. In 1729 Stephen Gray discovered that an electric charge was readily spread from one object to another if the two objects were connected by certain substances, which we now call conductors. In 1827 G.S. Ohm published what is now famous as Ohm's law: $V = I\,R$. It says that the current I in a conductor is proportional to applied voltage V, with the constant of proportionality R, called the resistance, being determined by the particular composition and form of the conductor.

Power, defined to be the rate of doing work, is often measured in horsepower or kilowatts. The power P transmitted by an electric line is simply the product of current and voltage: $P = I\,V$. So to transmit a particular level of power, there are many possibilities; any reciprocal change in current and voltage, such as doubling the current and halving the voltage, leaves the power the same. Such a change does,

[40] Atherton, pp. 119–123.

[41] Dunsheath, p. 200.

[42] Atherton, p. 134, and Hughes, p. 73.

[43] Hannah, p. 12.

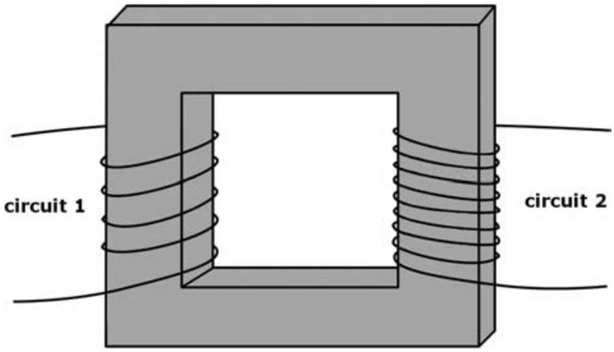


Figure 3.2. Schematic drawing of a transformer.

however, affect the power loss. In typical situations, power loss is approximately equal to I^2 R, where I is the current and R the resistance. This means that doubling the current would multiply the power loss by a factor of four. Hence, to reduce power loss it is advantageous to use very low current, and therefore very high voltage.

High voltage, however, is dangerous. It might, nevertheless, safely be used for transmission if there were an efficient means of converting it to a low voltage before it entered factories, offices, and homes. Almost all electric power systems of the 1870s and 1880s used direct current, and it proved very difficult to build efficient and reliable DC transformers. For example, one could step voltage down by coupling a high-voltage motor to a low-voltage generator. With alternating current, on the other hand, voltages could be stepped up or down by means of a simple device with no moving parts (see Figure 3.2).

The electric power transmitted in the 1880s was, almost everywhere, direct current, and DC systems continued to be built into the twentieth century. But the more efficient transmission of alternating current (AC) and the development of efficient AC motors and power meters gradually led to the virtually universal adoption of alternating current. (For a time there were some mixed systems—the power transmitted as AC, but used as DC.)

One of the first demonstrations of the system that became standard occurred at the 1891 International Electrical Exhibition in Frankfurt am Main. The German firm of AEG (Allgemeine Elektrizitäts-Gesellschaft) and the Swiss firm of Maschinenfabrik Oerlikon collaborated in demonstrating a three-phase AC system for long-distance power transmission. According to Thomas Hughes, the exhibition "contributed greatly to the establishment of this system as standard instead of the two-phase system that was being tried by Westinghouse in the United States and by other manufacturers abroad."[44] Westinghouse and GE collaborated to build a system of AC power generation and transmission that tapped the energy of the Niagara River

[44] Hughes, pp. 129–135. In a typical two-phase system, electric power is provided by two oscillations of electric current, 180 degrees out of phase. In a typical three-phase system the three oscillations are 120 degrees apart.

and sent part of it to the city of Buffalo, 20 miles away. The system, which began operation in 1895, used both two- and three-phase current.[45]

Transformers were improved, as by subdividing the iron core to reduce power losses due to eddy currents. William Stanley, working for George Westinghouse in the early 1880s, contributed greatly to better transformer design. There were improvements also in power lines, switches, and system operations (some of which are considered below). As a result, it became practical to use higher and higher voltages for transmission. By 1910, 110,000-volt transmission lines were practical; by 1923, 220,000-volt lines.[46]

By the turn of the century, the large electrical manufacturers accepted the three-phase AC system for providing electrical power, which had been developed mainly by AEG in Germany and Westinghouse in the U.S.[47] Of course, such systems spread only because there were devices that made electric energy useful to people.

3.2.3 Using Electric Power

Electricity gave rise to the telegraph, telephone, and electroplating industries before there were many central power stations. Power stations proliferated in the 1880s and subsequent decades for electric lighting and, to a lesser degree, for electric motors.

Though the English chemist Humphrey Davy, one of the first to experiment with Volta's battery, found how to produce a brilliant and continuous electric arc in 1808, this type of illumination did not become practical until efficient electric generators became widely available in the 1870s. Arc lighting then began to be used for lighthouses, street lighting, and interior lighting in large public buildings, such as railroad terminals. One of the most successful types was the Jablochkoff candle, invented by the Russian Paul Jablochkoff in 1876 (see Figure 3.3). Yet the market for arc lighting proved quite limited. In telling this history, W.A. Atherton has written, "The brilliance of the arc lamp made it unsuitable for widespread domestic use. Hardly anyone wanted a lighthouse in their living room." Efforts to "subdivide the electric light" met success only with a different technology: incandescent lighting.[48]

Thomas Edison in Menlo Park, New Jersey, and Joseph Swan in Newcastle, England, independently developed practical incandescent bulbs in the late 1870s. Both Edison and Swan set up companies to manufacture electric lamps, and, as we have already seen, Edison was soon in the business of building public power stations. For some decades, however, electric lighting remained a luxury in most places, since it was more expensive than other forms of lighting, including gas lighting.

An electric generator, if supplied with current, can operate as a motor, a fact brought to public attention at the 1873 electrical exhibition in Vienna when Z.T.

[45] Hughes, pp. 135–139.

[46] Hughes, p. 294.

[47] Hughes, pp. 118–120.

[48] Atherton, pp. 123–127. The quotation is from page 127.

Figure 3.3. A Paris street lighted by the Jablochkoff candle in about 1880 (photo courtesy of IEEE).

Gramme used one of his dynamos to drive a second one in reverse. Because motors could run on the same current supplied for lighting, their use spread.[49] The first motors ran on DC, but by 1890 the work of Galileo Ferraris in Italy, Nikola Tesla in the U.S., and Michael von Dolivo-Dobrowolksi in Germany had led to a practical AC motor (see Figure 3.4).[50]

The business historian Leslie Hannah has pointed out that at the turn of the century England was still a man-powered and horse-drawn society: "The steam engine had replaced these animate power sources in a limited range of uses in factories and on railways …" and "… the population of horses did not in fact reach its peak until the early years of the twentieth century."[51] Chapter 1 covered the use of electric motors in industry; the flexibility of electric drive allowed much more efficient manufacturing processes, including the assembly line. Mechanical power was the most important industrial use of electricity, but thermal devices (such as bread ovens, brass foundries, and enameling furnaces) for heating and electrochemical devices (especially for plating and electrolysis) were also important. Chapter 4 considers in more detail the multifarious industrial applications of electric power. Suffice it to say that by 1920, about two-thirds of the electric power sold in Britain went to industry.[52]

[49] Atherton, p. 153.

[50] Atherton, p. 158.

[51] Hannah, pp. 14–15.

[52] Hannah, p. 60.

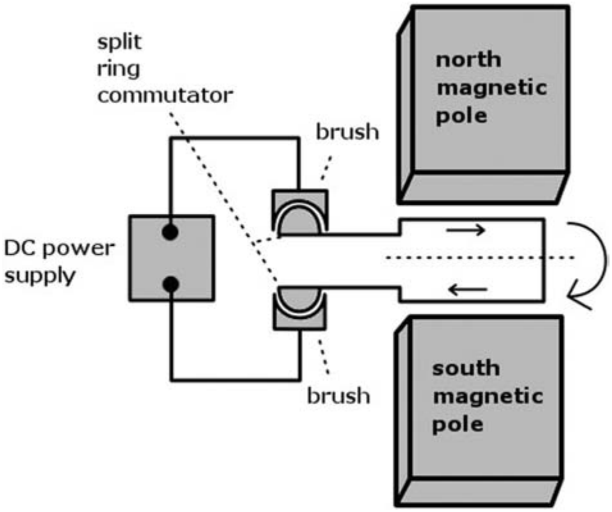


Figure 3.4. Schematic drawing of the operation of the electric motor.

The first widespread application of electric motors, however, was in transportation rather than manufacturing. In 1879 at the Berlin Exhibition, the Siemens company ran a small electric railway and two years later began operating an electric streetcar service in the Licterfelde district of Berlin. Perhaps the first commercially successful electric trolley system was the one built in 1888 for Richmond, Virginia, by Frank Sprague. Soon cities throughout the U.S. and in Europe were building trolley systems. There resulted rapid growth of cities and of suburbs. These developments, too, are considered in more detail in Chapter 4.

3.2.4 Interconnecting Power Networks

The success with interconnection of power networks during World War I, described in Chapter 1, stimulated further interconnection after the war.[53] In many countries people argued that an abundant and inexpensive supply of electric power, which was necessary for national economic strength, required a unified system under government control. Outstanding proponents of control were Governor Gifford Pinchot in Pennsylvania, Treasury Minister Wilhelm Mayer in Germany, and the engineer Charles Merz in England.[54]

Large power networks allow lower costs, because they are better at taking advantage of differences in the time-distribution of load. High daytime use of electricity in an industrial area, for example, might be matched with high evening use in a residential area. Large systems can more readily compensate for the failure of

[53] Hughes, p. 296.

[54] Hughes, pp. 285–323.

a component. A large system can have a complementary set of energy sources, for example, a hard-coal urban plant, a lignite plant at an open pit mine, a high-head hydroelectric site, and a run-of-river (low-head) hydroelectric site. Besides greater reliability, this confers lower costs, because one can adjust production schedules to take advantage of changes in the relative costs of the different energy sources. Finally, a large system is better able to deal with uncertainties about future resources and demands.[55]

After the war, interconnection proceeded in the U.S., but the movement was not directed by any governmental plan for an entire state or region.[56] Governor Pinchot championed an integrated system for Pennsylvania, believing that inexpensive electricity and rural electrification could bring about a social revolution.[57] Though his plan was not approved by the state legislature, interconnection nevertheless proceeded, though fitfully and uncoordinatedly. Such piecemeal integration was typical of the developments throughout the United States.

A notable step in interstate integration of power systems was the Pennsylvania–New Jersey (PNJ) Interconnection. It joined the systems of three private utilities: Philadelphia Electric, Public Service Electric & Gas of New Jersey, and Pennsylvania Power and Light.[58] (See Figure 3.5.) When formed in September 1927 it was the world's largest centrally controlled power system, with a capacity of one-and-a-half million kilowatts. By means of the PNJ Interconnection, the three utilities achieved economic benefits of a large system while remaining separate companies. This business arrangement prospered. In 1981 the Pennsylvania–New Jersey–Maryland Interconnection, as it was then called, had a capacity of 45 million kilowatts and connected private utilities.

In Europe, too, interconnection continued. On 31 December 1919 the young Weimar Republic enacted legislation to place electric power under government control, but the new law was never implemented since objections by the various utilities (some governmental, some private, some of mixed ownership) were not overcome.[59] Several utilities, however, cooperated through the Bayernwerk, a regional transmission grid using 110-kV lines, which began operation in 1924.[60]

Great Britain followed the same course. Parliament passed the Electricity Supply Act of 1919, which called for the establishment of joint electricity authorities (JEAs) to consolidate electricity generation and provide regional transmission, but because implementation was left to voluntary action and persuasion, results were quite limited.[61]

In the 1920s loss of national prestige and power was a dominant issue in Britain, and many placed blame on the fragmented electric energy system and a slowness

[55] Casazza, pp. 5–6, and Hughes, p. 367.

[56] Hughes, p. 313.

[57] Hughes, p. 297.

[58] Hughes, pp. 325–334.

[59] Hughes, pp. 314–315.

[60] Hughes, pp. 334–350.

[61] Hughes, pp. 319–323.

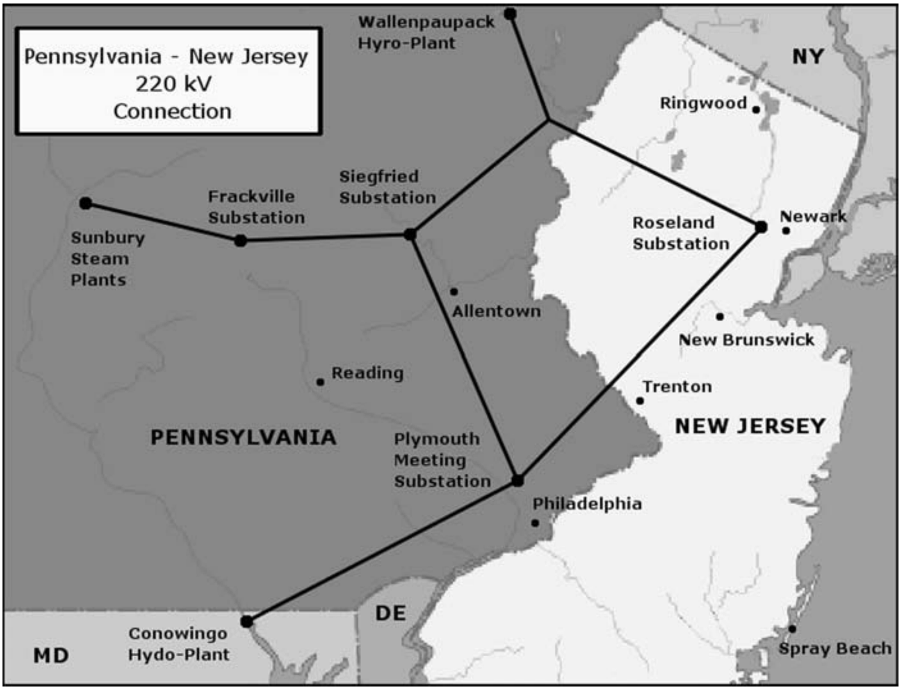


Figure 3.5. The 220,000-volt trunk lines of the Pennsylvania-New Jersey Interconnection.

(relative to Germany and the U.S.) in electrifying industry and transportation.[62] The 1926 Electricity Supply Act aimed at organizing the generation and distribution of electric power. The national grid began operating in 1933, and by 1936 it was in full operation in all regions except the northeast coast of England. Interconnection was a major factor in the reduction in the cost of electricity in Britain from 1.1 pence in 1923, to .34 pence in 1939.

The development of electric power in Britain was slowed by the great variety of voltages and frequencies; in 1924 there were 17 different frequencies in use in Britain.[63] The high cost of converting frequencies required standardization of frequency when two networks were connected.[64] Thus standardization came with interconnection.

In the early stages of a technology, it would probably be unwise to impose standardization as it would limit exploration of the technical possibilities. Standardization itself, however, often yields great gains in economies of operation and production—standardized manufacture of all types of power equipment—and in directing technical developments to a particular channel. But these gains come

[62] Hughes, pp. 350–362.

[63] Hannah, pp. 39, 88.

[64] Hannah, p. 32.

after standardization, and achieving it was expensive. Power generating and transmission equipment as well as motors and other user equipment had to be replaced or converted. So both interconnection and standardization proceeded slowly.

3.3 POWER ENGINEERING

3.3.1 The Science of Power Engineering

Matthew Boulton, partner of James Watt in manufacturing steam engines, once said, "I sell here, Sir, what all the world desires to have. Power." From the 1880s on, electrical engineers have offered the same commodity, and the business of operating electric power systems has grown steadily. In the U.S. it reached annual sales of $84 million in 1902 and $1.8 billion in 1927.[65] This made electric power a major branch of engineering and stimulated continual technical advances.

Most people imagine that engineering advance results from the application of antecedent science. Thomas Hughes, historian of electric power, argues that in the period from 1890 to 1930, power engineering advanced through its own research and development, with little contribution from physics. He argues further that the principal relationship between science and engineering is not that the latter derives from the former but that the two share a methodology:

> *The authorities they cited and the periodicals they used and for which they wrote represented organized knowledge; the engineers consciously or unconsciously used and attempted to formulate general statements or laws; mathematics was an analytical tool and a language for them; hypotheses were formulated by them; and experiments were designed for the laboratory or in nature to test these hypotheses.*[66]

Such theories constitute engineering science, as distinguished from natural science (analytic language and hypotheses relating to the natural world). Another historian, Ronald Kline, made a detailed study of the development of alternating-current motors that shows clearly the growth of engineering science; in the last two decades of the nineteenth century, scientists and engineers, well versed in mathematical physics, elaborated theories accounting for the behavior of electric motors, and then used these theories to design better motors.[67] With the design of dynamos and transformers, too, an engineering science was painstakingly developed.[68]

In the new century, power systems became larger and larger and more and more complicated. In the 1920s regional systems flourished, as point-to-point transmission gave way to network with several generating stations and major switching stations.[69] Control became much more complex. Earlier, there was typically a marble-paneled

[65] Brights, p. 13.

[66] Hughes 1976, p. 659.

[67] Kline 1987.

[68] Atherton, pp. 149–159.

[69] Hughes, pp. 363–364.

switchboard located in the power house, and the switches were operated manually. In the 1920s, a control center was typically separate from the power house and the switchyard. Remote sensors kept the control center informed about the state of unattended units throughout the system, and at the switchyard, remote-controlled electromagnets and motors operated oil-filled switches. So complicated was control that large models of the systems were maintained to simulate their behavior. Such control centers were emulated in other industries.[70]

Pioneering in the use of instruments and controllers was the electric power industry, which before 1930 installed systems to maintain constant frequency and voltage and to control the operation of boilers. Early voltage regulators had moving parts that compromised reliability, so electronic regulators (incorporating the thyratron tube, a rectifying tube containing a low pressure gas instead of a vacuum) were developed in the 1930s. An additional benefit of electronic control was, in the words of G.E. engineer A.W. Hull, "the absence of mechanical inertia which made the method remarkably free from hunting or overshooting of voltage with sudden changes of load."[71] The accurate control of frequency made electric clocks practical. Subsequently, the use of electric clocks required power companies to maintain an exact frequency.

The power industry set an example not only with such control centers, but also with industrial R&D. Hughes points out that "Edison and his associates formed an urban utility at about the same time they launched their research-and-development program for developing an electric lighting system."[72] The Siemens companies were also pioneers in industrial R&D.

With high voltages came new phenomena, such as power loss between lines from the corona effect.[73] There were also problems posed by other types of short circuit, by lightning (which created the need for surge-proof components, adequate insulation, circuit breakers, and lightning arresters), and by rectification (streetcars, for example, continued to use DC motors). As a result there arose high-voltage laboratories, both in industrial and academic settings.[74] Beginning in 1913, the Schenectady plant of General Electric, F.W. Peek, Jr., conducted scientific studies of lightning and its effect on power lines for 20 years.[75] At Cornell University, Harris J. Ryan published some three dozen articles on high voltage and transmission problems in the period between 1904 and 1925. A 1905 paper by Ryan, for example, presented an equation relating the critical corona voltage to conductor size and separation.[76]

A science of insulation arose, though this was an area in which much work had already been done by telegraph engineers.[77] In Britain in the years after World War

[70] Hughes, pp. 372–374.

[71] Bennett, pp. 2–4.

[72] Hughes, p. 384.

[73] Hughes 1976, pp. 647–648.

[74] Hughes, pp. 377–380.

[75] Hughes, pp. 382–384.

[76] Hughes, pp. 651–652.

[77] Hannah, p. 14.

I, transmission voltages increased from 20 to 30 kV. The design of underground cables that had performed satisfactorily at 20 kV proved problematic at the higher voltage. After considerable research on dielectrics and on cable design in laboratories in Europe and the United States, solutions were found. A notable advance was Luigi Emanueli's cable design, introduced in 1920, that was soon in use around the world for high voltages.[78]

The power engineering R&D stimulated the development of many research instruments. For example, to investigate corona (the glow at the surface of an electrical conductor that indicates an early stage in the electrical breakdown of the surrounding gas) F.W. Peek designed a 200 kV impulse generator, and later used it to study lightning, increasing the power of the impulse generator to the order of a million kilowatts so as to be able to approximate natural lightning.[79] Harris J. Ryan pioneered in the use of the oscilloscope to study AC phenomena.[80] Perhaps most impressive was the development of analog calculating devices, to which subject we now turn.

3.3.2 Network Analyzers

The first chapter covered electromechanical computers for fire control on warships and for piloting unmanned aircraft. In the 1920s power engineers designed even more sophisticated analog computers to assist in the understanding and control of large-scale power systems.

Just after World War I, engineers at General Electric began building laboratory simulations of power systems, in which the actual generators, transmission lines, and loads were modeled by much smaller components. At MIT in 1924, Hugh Spencer and Harold Hazen, working under Vannevar Bush, constructed a power-system model that adequately represented the behavior of the full-scale system. MIT and General Electric collaborated in building a much more sophisticated device for modeling power systems, which in 1929 received the name "network analyzer".[81]

The network analyzer, though built as an educational tool, was made available to commercial users for a fee.[82] Also in 1929 Westinghouse built a similar device, the AC Calculating Board, which it manufactured and sold to electric utilities in many countries. Network analyzers soon became a standard tool of power systems engineering, and they remained in use into the 1960s when they were replaced by digital computers.[83] (Phyllis A. Fox, in her 1949 MIT master's thesis, may have been

[78] Dunsheath, pp. 259–261.

[79] Hughes 1976, pp. 655–656.

[80] Hughes 1976, p. 653.

[81] Wildes, pp. 99–103.

[82] Wildes, pp. 103–104.

[83] Aspray, p. 36.

the first to demonstrate that power-system stability problems could be solved using a digital computer.)[84]

Network analyzers simulated the operation of power systems. Through experimentation with the laboratory analog, engineers could better understand and thus better control a full-scale power system. A more cerebral approach was to write equations describing the power system and then study the equations. Engineers were indeed able to write a set of equations constituting a mathematical description of the system, but deducing the logical consequences of the equations was extremely difficult.

In 1924 Vannevar Bush, in the midst of a several-month-long struggle with equations describing a particular power system, wondered whether a machine might be built to carry out parts of the calculation. The following year Bush, assisted by Herbert Stewart and Frank Gage, completed a "product integraph" that calculated integrals using a watt-hour meter (a commercially produced device to measure electric energy consumption). The machine, which could solve first-order differential equations and, through successive approximation, second-order equations, was applied to a number of other engineering problems.[85] Because similar equations arise in many areas of engineering, the more cerebral approach to solving stability problems of power systems proved widely useful.

Bush and his research assistant Harold Hazen designed improved calculating machines. In 1931 they completed the "differential analyzer", able to solve a sixth-order differential equation with an accuracy of one part in a thousand. Instead of watt-hour-meter integrators, it used "disk-and-wheel" integrators. The differential analyzer won wide acceptance, and similar machines were built elsewhere in the U.S. and in the United Kingdom, Norway, and the Soviet Union.[86]

What made this much more complicated machine practical was the use of a torque amplifier. Invented originally for power steering in motor vehicles, this is a mechanism in which an electric motor provides the torque that augments the torque exerted by the input shaft. Thus the small output of a disk-and-wheel integrator can drive shafts, gears, and other integrators. This electromechanical calculator, like the fire-control calculators, used electricity only for motors and simple switches; the elements for integrating, for amplifying torque, and for storing and transferring quantities were essentially mechanical.

The differential analyzer, as a successful and fairly general-purpose device, stimulated the development of other computers, both analog (some of them entirely electronic) and digital. In 1935 Bush began developing an improved differential analyzer that represented variables as electrical signals rather than as shaft rotations. Here it was not a human operator but electrical relays and servomotors controlled by the information on a punched-paper tape that set up the machine for a particular problem.[87] Other development of other computers influenced by the differential analyzer are described in Chapters 4, 7, and 8.

[84] Wildes, p. 104.

[85] Wildes, p. 87.

[86] Wildes, pp. 87–92.

[87] Bromley, p. 185, and Wildes, p. 92.

This section looked at engineering research; the next section turns to the business of power engineering. It was primarily economics, not science, that directed that research.

3.3.3 The Business of Power Engineering

The electric power industry was a principal shaper of national economies in the twentieth century, as it reduced costs for existing industries and established markets for new industries. The many advantages of electrified production methods; discussed in Chapter 1, led to their rapid adoption in the first decades of the century; hardly used in industry at the turn of the century, electric motors provided 78% of all mechanical drive by 1930.[88] The power industry contributed by continually reducing the cost of electric energy and by helping to develop means of using electric energy.

Electric power systems are large human-and-machine systems whose operation requires technical, business, and political considerations. At the technical level, systems engineering is required to achieve the proper functioning and coordination of the many components. The remote sensors, test instruments, and analog computers already discussed assisted in this systems engineering. A principal aim was to achieve reliable operation, which, by one definition, a system had attained if the reserve generating capacity was at least as large as the largest likely failure of a generator or a transmission line.[89] (Since joining two systems makes it easier to meet this condition, it provided an additional reason for interconnection.)

Of the business considerations, one was to increase the consumption of electricity, and utilities promoted industrial, commercial, and residential uses. Another principal business consideration was the concern to reduce fluctuations in load. Because capital costs were a large part of the cost of providing electric power, obtaining a more constant load factor (defined as the ratio of electricity produced to the amount that would have been produced if peak demand had been maintained throughout the period) greatly increased efficiency. To this end, each utility sought diversity of load. (Here, too, interconnecting two systems confers an advantage.)

There were also political considerations as utilities came to be regulated, and in many cases owned, by governments. In Britain, for example, electric power was partly private and partly governmental, until full nationalization in 1948.[90]

The highly technical operations of electric power companies gave rise to a thriving business of industrial consulting. Thomas Hughes has written:

> *Consulting engineers also played a highly important, though still largely unacknowledged, role in furthering the growth of regional systems. The technical, organizational, and financial problems inherent in regional systems demanded the entrepreneurial spirit, comprehensive experience, and talent possessed by the consulting engineering firms and their principals. When political problems entered the*

[88] Devine, p. 21.

[89] Hughes, p. 370.

[90] Hannah, p. 27.

> *mix as an important component, the consulting engineer's broad view and capacity for a multifaceted response became even more important. The consulting engineer assumed the mantle of the entrepreneur ready to preside over technical change in a complex environment.*[91]

In Great Britain, at the turn of the century, many municipalities took the lead in building power systems, and they often relied on consulting engineers.[92] In England, Merz & McClellan was the leading power consulting firm. In Germany, it was Oskar von Miller. In the United States, the firm of Stone & Webster provided engineering expertise to 28 power, light, gas, and traction utilities throughout the country; it pioneered in the use of statistics as a management tool.[93]

The benefits of interconnection, along with other advantages of size, led to the formation of many utility holding companies. In the U.S., the five most important were American Gas & Electric (formed in 1906), American Power & Light (1909), National Power & Light (1921), American & Foreign Power (1923), and Electric Power & Light (1925).[94] In Great Britain the two most notable were the Greater London and Counties Trust, which controlled 54 utilities by the end of 1929, and the Power Securities Corporation.[95] In Germany, it was the Rheinish-Westfälisches Elektrizitätswerk.

The organizational mechanism of the holding company made it easier to raise capital and to achieve regionalization and standardization.[96] The holding company could provide the most effective management tools, just then being developed.

3.4 TECHNOLOGY TRANSFER TO THE SOVIET UNION

3.4.1 Transfer of Technology from One Country to Another

Improved technology allows greater efficiency in producing goods and providing services, and may consequently raise a nation's standard of living. Historians have given more attention to the development and introduction of new technologies than to their transfer to other companies or countries. This and the following section focus on the latter process.

Technology transfer occurs in various ways: purchase of equipment or patent rights, flow of information through technical journals and trade shows, movement of people for study or employment abroad, and activities of foreign firms. The central

[91] Hughes, pp. 365–366.

[92] Hannah, p. 22.

[93] Hughes, pp. 386–390.

[94] Hughes, p. 398.

[95] Hughes, p. 402.

[96] Hughes, pp. 393–395.

mechanism in the case of Soviet economic development in the period from 1917 to 1930 was the concession whereby a foreign company organizes, finances, equips, and operates a business in return for the surplus, which is usually taxed by the host country. In the 1920s in the Soviet Union there were many variants on this arrangement, such as the mixed company—with both Soviet and foreign participation—or operation of the business by a Soviet organization. In these cases a foreign company paid for the opportunity of making money in the Soviet Union. In the "reverse technical concession", the Soviet government paid a foreign company for the right to exploit its technological resources (such as patents or designs).[97] All of these are vehicles for technology transfer.

Because the characteristics of a technological system usually depend to some degree upon local conditions—geographic, economic, social, or political—the transfer of technology is usually a complicated process, involving a great deal of organizational and technical innovation. For example, though Edison exported his central-station technology to Germany with the formation of the Deutsche Edison Gesellschaft für angewandte Elektricität in 1883, the German company, which changed its name in 1887 to the Allgemeine Elektricitäts-Gesellschaft (AEG), soon developed its own style of central station technology.[98] The adaptation of technology to local conditions will be more fully described below in the cases of the Soviet Union and Brazil.

Another way in which the phrase "technology transfer" may mislead is in suggesting that the flow of information is in one direction only, which is seldom the case, even when one region is much less technically advanced than another. Russian engineers working in Europe and the United States contributed greatly to the development of electrotechnology; prominent examples are Pavel Jablochkov (who developed the world's first commercially successful arc light while working in Paris), Mikhail Dolivo-Dobrovolskii (who in 1891 in Germany directed AEG's successful demonstration of long-distance transmission of AC power), and Achilles de Khotinskii (a pioneering manufacturer of light bulbs in Russia and the West in the 1880s).[99]

Finally, "technology transfer" may mislead in suggesting that it is only technology that is transferred. Almost always there is transfer also of business practices, popular expectations, and social practices. Very often, the people active in transferring technology also worked to transfer other aspects of foreign cultures. For example, in Brazil in the late nineteenth century, many prominent citizens, who admired many European ideas and institutions, saw themselves as "modernizers".[100] The historian J.M. Roberts has commented: "Few modernizing statesmen in the non-European world have been able to confine their borrowings from the West to technical knowledge."[101]

97 Sutton, pp. 6–8.

98 Hughes, pp. 67–78.

99 Coopersmith 1991, p. 218.

100 McDowall, p. 23.

101 Roberts, p. 745.

3.4.2 The Soviet Context

Rapid industrialization began in Russia in the 1890s, about 40 years later than in the U.S. The Tsar ruled autocratically through a highly centralized government, and his Minister of Finance, Sergei Witte, vigorously promoted industrialization. So successful were his policies that by 1914 Russia ranked behind only four countries—United States, Germany, Great Britain, and France—in industrial production.[102]

In the half-century up to 1914, tens of thousands of Russians went abroad for technical and scientific training. Within Russia too foreign technology was studied: a 1913 survey of graduates of the St. Petersburg Polytechnical Institute found that they read 13 electrical journals, three of them Russian, three British or American, and seven German.[103]

Russian industrialization in the half century up to World War I involved massive transfers of technologies from Western countries, mainly Germany. The army and navy were the main actors in the introduction and diffusion of electrotechnology into Russia, exemplifying, according to the historian Jonathan Coopersmith, the frequent pattern in Russian history of "the military sector keeping up with Western activity and the civilian sector lagging behind. …" German firms, especially Siemens & Halske and AEG, dominated the electrical industry, although other foreign firms, such as Brown-Boveri (Swiss), Westinghouse (U.S.), and Metropolitan Vickers (British), and Russian firms took part. (An exception was the domination of the large electric-trolley business in Russia, as in other countries, by Belgian firms.) By 1914 Russian firms were supplying half the country's electrical equipment, but the war painfully revealed the country's continued dependence on foreign electrical technology.[104]

Foreign firms provided financing, equipment and techniques, as well as training of engineers, managers, and workers. An electric power system, however, is a site-specific technology. Topography, demand for electric power, availability of fuel, the qualifications of workers, financial resources, and governmental constraints—all of these shape a power system wherever it is constructed.[105] Hence innovative engineering and management is necessary to bring about technology transfer.

The Russian electrical equipment manufacturing industry, which employed some 60,000 people in 1917, came through the Revolution with little damage to its equipment. Partly because of its prewar standing and partly because of Lenin's advocacy, in the 1920s the electrical industry was the most advanced sector of the Soviet economy.[106] The next section considers how that sector grew in that decade and the next.

[102] Grenville, pp. 53–54.

[103] Coopersmith 1991, pp. 217–218.

[104] Coopersmith 1991, pp. 214–217.

[105] Hughes, p. 47.

[106] Sutton, pp. 185, 196.

3.4.3 The GOELRO Projects

In the 1920s Soviet industrial plants reached agreements with many foreign companies to participate in the development of Soviet industry. Among the companies involved were General Electric (US), RCA (US), Western Electric (US), AEG (German), Siemens (German), Metropolitan-Vickers (British), A.S.E.A. (Swedish), Ericsson (Swedish), and Companie Générale de TSF (French). The agreements usually called for technical assistance, patents, drawings, and exchange of personnel, but sometimes the Western company obtained a concession to develop a business opportunity in the Soviet Union using its own expertise and capital.[107]

Several examples will illustrate some mechanisms of technology transfer. The Soviet production of electric lights was increased from four million bulbs in 1922–1923 to 33 million bulbs in 1929–1930 with the aid of expertise from Osram (German), Phillips (Dutch), and General Electric (US).[108] A contrasting example is provided by the Ericsson company, which itself operated a telephone manufacturing plant in Russia (as a foreign concession), with output rising from 13,300 telephones in 1923–1924 to 117,000 in 1929–1930.[109] In 1923 the Companie Générale de TSF reached agreement with a Soviet trust to supply technical assistance. The trust sent its engineers to France for training, and French engineers came to the trust plants to give technical assistance. Equipment and patents were obtained from the French company. In the first two years of the agreement, 38,000 technical drawings and 3000 technical specifications were transferred.[110]

With contracts signed in 1928 and 1930 there began a long period of technical assistance from the General Electric Company. Soviet engineers received training in the U.S., and groups of GE engineers worked in many Soviet factories. The Soviets set up an office at GE headquarters in Schenectady, New York, and GE set up an office in Moscow. This was one of the most significant channels of technical information to the Soviet Union, and in 1943 (at a rare time of favorable public opinion of the Soviet Union) a General Electric publication called it "a continuous uninterrupted record of close technical collaboration and harmonious commercial association."[111] In 1927 RCA signed an agreement to provide the Soviets with radio equipment and technical assistance; another such agreement was signed in 1935, and it was extended until mid-1941.[112]

Another such channel flowed from Metropolitan-Vickers, a British subsidiary of Westinghouse. The company had long operated in Russia, building several power stations and electrifying the Moscow tramway system in the first decade of the century. After the war, Metropolitan-Vickers returned and by 1924 was at work on several large projects. Notable for this business connection was the speed with which

107 Sutton, pp. 186–188.

108 Sutton, p. 192.

109 Sutton, pp. 193–194.

110 Sutton, p. 195.

111 Sutton, p. 198.

112 Sutton 1971, pp. 161–163.

technical advances made in Britain were put to work in the U.S.S.R. Indeed, some new Metropolitan-Vickers equipment was installed in the Soviet Union earlier than in Britain. For example, the company installed transformers for Soviet 110 kV and 115 kV transmission systems in 1923, five years before the British grid began using such voltages. And in 1926 the generator with the fastest operating speed in the world was one that Metropolitan-Vickers had installed in a Soviet power station.[113] In all of its contracts in the period from 1921 to 1939, Metropolitan-Vickers helped install one million kilowatts of generating capacity, making it the single most important firm in the electrification of Russia.[114]

During the 1920s in the Soviet Union there was a political struggle over who would direct electrification—the central government or local governments.[115] In the early 1920s, according to Coopersmith, "With four central planning organs and a state-approved plan, electrification suffered not from a deficit of thought but a lack of meaningful action. … These planning bodies did not contribute to the realization of electrification, only to its bureaucratization. …"[116]

All but one of the first seven regional stations imported major systems; Kizelov, the exception, did not because it used machinery from a Czarist station.[117] The famous Dniepr project, with a dam larger than any other then existing, used foreign methods and equipment almost entirely, mostly from the United States and Germany. H. Cooper (builder of the Muscle Shoals hydroelectric dam in the U.S.) supervised the project, and General Electric supplied generators, transformers, and switchgear.[118] The electrification program suffered greatly from a lack of managerial skills. A 1928 report of the Workers' and Peasants' Inspection Department said, "In no instance were plans or calculations ready when the construction of an electric station was begun. … Construction work proceeded slowly. Not a single region-station was built in less than four years. Complete lack of organisation and disregard of economic prudence were observable; indeed, everything was in chaos."[119]

In 1925 Soviet leaders made the development of indigenous engineering capability a high priority, and embarked on a course of economic self-sufficiency. The goal of regional electrification remained the same, but it was to be achieved without the importing of equipment.[120] A major channel of information from the West was Russian electrotechnical journals, which resumed publication in 1922 after a four year hiatus.[121]

The Soviet electrification program achieved results. (See Figure 3.6.) In 1927–1928 Soviet Russia produced five billion kilowatt hours of electricity, an increase

[113] Sutton, p. 199.

[114] Sutton 1971, p. 201.

[115] Coopersmith, pp. 192–193.

[116] Coopersmith, p. 198.

[117] Coopersmith, p. 225.

[118] Sutton, pp. 202–203.

[119] Quoted in Lawton, pp. 432–433.

[120] Coopersmith 1991, pp. 215, 227.

[121] Coopersmith, pp. 199–200.

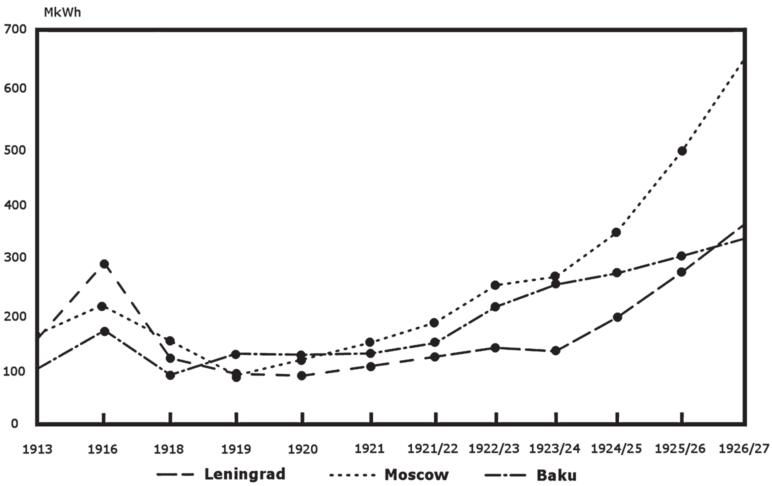


Figure 3.6. Measures of Soviet electrification.

of 259% over that produced in 1913, but only one-eighteenth that produced in the United States and about the same as that produced in Belgium.[122] Though electrotechnical imports doubled in value from 1921 to 1926, domestic production increased so much that the share of the market taken by imports dropped from 57% to 20%.[123] Domestic production of heavy electrical equipment increased markedly, from 1925 to 1930 the production of transformers increased tenfold, of electric motors fivefold, and of turbogenerators tenfold.[124]

3.4.4 Soviet Electrification in the 1930s

The worldwide economic depression that began in 1929 had relatively little impact on the Soviet Union because international trade was not a large part of its economy. The First Five Year Plan attained its primary objective, the rapid development of heavy industry. Over the four-and-one-half years of the First Five Year Plan, the total capacity of electric power stations increased to two-and-a-half times its initial value, though this was less than what had been planned.[125] The Second Five Year Plan placed emphasis on non-ferrous metallurgy, especially the production of copper, zinc, tin, nickel, and aluminum. One motivation was that the electrical industry needed increasing quantities of such metals. The Second Plan also included an ambitious program of railroad electrification, but most of the program had to be postponed. Overall the Second Plan went more smoothly than the First, though the

[122] Lawton, p. 427.

[123] Coopersmith 1991, p. 225.

[124] Sutton, p. 190.

[125] Dobb, pp. 255–256.

consumer goods industries again fared poorly and the troubling international situations prompted accelerated development of the defense industry.[126]

The shortage of skilled labor in the Soviet Union did not hamper the program to expand the electrical power industry as much as other industries. An explanation is given by Allan Monkhouse, chief engineer of Metropolitan-Vickers operations in the U.S.S.R.: "… during the constructional period the main responsibility for skilled workmanship fell upon the erectors sent to the U.S.S.R. by foreign contractors; and of course, once the stations are complete there is not a great deal of work about a power station which necessitates employing highly skilled workmen."[127]

One form of technology transfer, the foreign concession, all but ended in the Soviet Union in the 1930s. The country also moved away from the mixed company, preferring individual work contracts with foreign companies. This gave the Soviets full title to all operations within the country and a greater control over technology transfer.[128] Of 350 foreign concessions permitted by the Soviets, only a few lasted beyond 1933. An interesting exception (which may have been permitted to operate so long because state services were much less efficient) was the Danish company Great Northern Telegraph, which operated its international telegraph concession until the late 1930s. Great Northern had many offices in the Soviet Union, each under a Danish manager.[129]

In the 1930s technology transfer from Germany became more important. In 1930 at the Elektrozavod plant in Moscow, which produced a significant fraction of the country's electrical equipment, there were 100 Germans as heads of department and in other important positions.[130]

It was the intention of Soviet leaders that technology transfer lead to domestic production. In 1928 the Soviets hired C.H. vom Bauer, New York consultant, to be technical director of a division of Elektrozavod to produce electric furnaces. Until then all electrical metallurgical furnaces in Russia were imported. Bauer remained until 1932, at which time his division was manufacturing 100 furnaces per year.[131] Turbine manufacturing provides another example. With great assistance from General Electric, the Soviets completed a turbine-manufacturing plant at Kharkov in 1935. This factory alone had twice the capacity of General Electric, which was until then the largest turbine manufacturer in the world. Before 1935 most turbines had been imported; after 1935 all turbines, with one exception, were Russian-made.[132]

GE also played a large role in the transfer of electric welding technology to the Soviet Union. Electric welding was important in many types of steel construction, particularly in building ships and submarines. With the assistance of GE expert E.J.

[126] Dobb, pp. 271–279.

[127] Quoted in Sutton 1971, p. 170.

[128] Sutton 1971, p. 16.

[129] Sutton 1971, pp. 166–167.

[130] Sutton 1971, p. 155.

[131] Sutton 1971, pp. 156.

[132] Sutton 1971, pp. 153–154.

O'Connell, the Elektrik Plant in Moscow in the 1930s became the country's principal supplier of welding machines.[133]

The Soviet electrical supply and manufacturing industry continued its rapid growth in the 1930s. The amount of electrical power per industrial worker more than doubled in the time of the Second Plan.[134] The production of electricity increased from 2 billion kilowatt hours in 1913, to 5 billion in 1928, to 39 billion in 1939, and to 48 billion in 1940.[135] The power produced per capita, however, remained far below the level in western economies; in 1937 the Soviet figure was 1/7 that of the U.S.[136] Nevertheless, the growth of the electric power industry played a large part in the overall economic growth of the country. The USSR increased its share of the world industrial output from 2% in 1921, to 10 percent in 1939.

3.5 WORLDWIDE DISSEMINATION OF TECHNOLOGY

3.5.1 Third World Industrialization

For most of the belligerents, World War I was an economic disaster: economic production dislocated for wartime needs, workers killed, railroads and manufacturing plant destroyed, and huge debts accumulated. On the heels of the war came one of the worst pandemics of modern times, the influenza outbreak of 1918 and 1919, which killed more people—27 million according to one source—than did the fighting of the war. Reversion to a peacetime economy caused widespread unemployment, and the system of international finance barely functioned.

At the same time, World War I gave many less developed countries a great economic boost. The belligerents needed to import more foodstuffs and other raw materials, improving the export market for these countries, and the disruption of commerce from European industrial powers stimulated the creation and expansion of indigenous industries. Japanese overseas trade, for example, increased from less than one billion yen in the period 1913 through 1917, to almost two billion yen for the following four-year period.

The first years after the war were turbulent. The Versailles Treaty of 1919 redrew the map of Europe. Communist parties were organized in many countries, a few suffered Communist uprisings, and many people expected revolution to break out worldwide (which was the aim of Lenin's Third International). In 1919 there occurred a civil war in Russia, a war between Russia and Poland, Mussolini's formation of the Fasci del Combattimento, Ireland's declaration of independence from Britain, Mustafa Kemal's declaration of the Turkish Nationalist Congress (in defiance of the

[133] Sutton 1971, p. 165.

[134] Dobb, p. 280.

[135] Dobb, p. 311.

[136] Dobb, p. 289.

Ottoman government in Constantinople), and the beginning of Mahatma Gandhi's passive resistance movement for India's independence.

In the early 1920s, however, the economies of many countries began an expansion that continued through most of the decade. In the United States the number of automobiles increased from eight million in 1920, to 23 million in 1930, and a construction boom transformed the skyline of cities. In Europe, as the ravages of war were repaired, economies grew steadily. The principal impetus for the economic boom came from the mass consumer market, where electrical products played a large part (which will be considered in detail in Chapter 5). Economic growth also came to many late, industrializing countries. Brazil, the world's fifth largest nation in area, provides an instructive example. The most rapid development occurred in southeastern Brazil, where there was an abundant supply of inexpensive electric energy.

3.5.2 Electrification of Brazil

Southeastern Brazil has been at the forefront of industrialization in the developing world. The catalyst for this economic growth was a Canadian company, the Brazilian Traction, Light and Power Company, which, beginning in the first decade of the century, provided the São Paulo and Rio de Janiero areas with abundant hydroelectric power. What Brazilian Traction brought to that new market was Canadian entrepreneurship, U.S. engineering skills, and European capital.[137]

At the end of the nineteenth century, Brazil, largely an exporter of primary products (notably sugar, cocoa, coffee, rubber, and gold) and an importer of finished goods, began to look to foreign expertise and capital to diversify its economy. A severe hindrance was the country's lack of energy resources, and Brazilian industry and railroads depended on costly imported coal. Though there were many sites suitable for hydroelectric generation, Brazil lacked the expertise and capital required to exploit this resource on a large scale.[138]

In 1897 a Brazilian businessman, Antônio de Souza, and an Italian-born engineer, Francisco Gualco, obtained from the São Paulo government an exclusive concession to build and operate an electric traction company. Gualco, who had earlier been a railway contractor for the Canadian Pacific, found backing in Canada, most importantly from William Mackenzie, who had successfully developed streetcar companies in Toronto and Montreal. After consulting with the engineer Frederick Stark Pearson, who had helped establish power and traction services in several U.S. cities, Mackenzie in April 1899 set up the São Paulo Railway, Light and Power Company Ltd., with head offices in Toronto.[139]

The new company soon acquired rights to build a power station at a site 36 kilometers outside São Paulo, to transmit power to the city, and to sell electric power as well as to provide a streetcar service. F.S. Pearson and his associate Robert C.

[137] McDowall, pp. 3–4.

[138] McDowall, pp. 17–19.

[139] McDowall, pp. 31–39.

Brown, who moved to São Paulo to be general manager of the new utility, designed the system. Construction proceeded rapidly, and on 7 May 1900 the streetcar service was officially inaugurated, using power from a thermoelectric plant.[140] In September 1901 the large-scale hydroelectric plant, which was Brazil's first, began operations with a capacity of 2000 kW, which increased in steps to 16,000 kW in 1912. During this time the company gradually increased its sales of electricity for lighting and industrial uses, as well as for urban transit.[141]

In 1903 Pearson turned his attention to Rio de Janeiro, the largest city and capital of the republic. It sorely needed an efficient transportation system and less expensive electric power than that generated from imported coal, and in 1904 William Mackenzie and his allies obtained a charter for the Rio de Janeiro Light and Power Company Ltd., with head offices in Toronto.[142] To dramatize the advantages of electricity, the company concentrated on illuminating the city's principal streets and shops, and in 1910 a U.S. engineer wrote that "the city of Rio is the best lighted city in the world, there being at least double the amount of illumination on its principal streets and avenues to that in the best lighted streets of the other large cities of the world."[143] The tramways permitted a rapid expansion of the city, hitherto severely constrained by the mountainous terrain bordering the narrow lowlands where the old city lay.[144]

The growth of the São Paulo and Rio de Janeiro companies depended on continuing capital expenditure, necessitating an appeal to investors outside the original group of Canadians. Skillful marketing, which took advantage of F.S. Pearson's reputation, soon created an international market for the bonds and shares of the two companies.[145] In 1912 William Mackenzie and associates formed a holding company, the Brazilian Traction, Light and Power Company Ltd., that amalgamated the São Paulo and Rio companies.[146]

In 1913 Brazilian Traction operated 810 tramcars on more than 600 kilometers of track in the two cities and supplied electricity to more than 40,000 lighting and industrial customers, and it had begun providing telephone service. The company continued to seek out and develop hydroelectric sites so as to stay ahead of power demand.[147]

In the 1920s the economy of southeastern Brazil became more dependent than ever on coffee export, but its industrial capacity gradually increased. Demand for electric power from individuals and businesses grew steadily, and several railways began electrifying their lines. Brazilian Traction responded by building one of the world's largest and most innovative power stations. For the fast-flowing Paraíba

140 McDowall, pp. 42–46.

141 Cabral, p. 21.

142 McDowall, pp. 133–137.

143 F.A. Huntress quoted in McDowall, p. 153.

144 McDowall, pp. 154–155.

145 McDowall, pp. 103–106, 137–139.

146 McDowall, pp. 185–190.

147 McDowall, pp. 202–206.

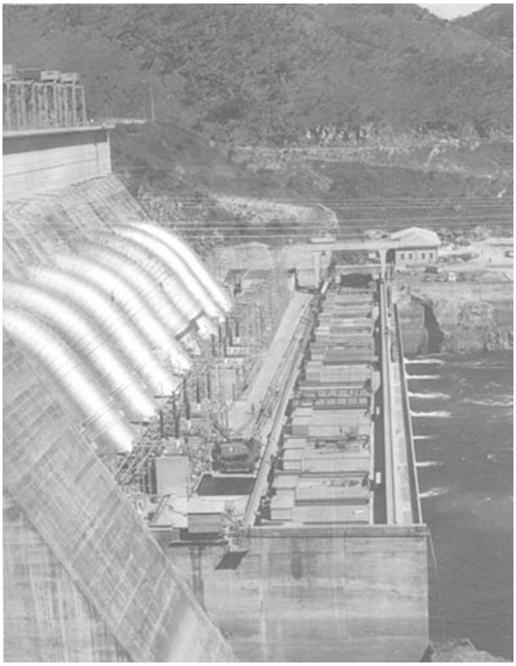


Figure 3.7. The Cubatão power plant and penstocks in 1927 (photo courtesy of IEEE).

River, the U.S. hydroelectric engineer, Asa Billings, designed in 1922 a "run-of-the-river" station, which did not require a reservoir, to augment the supply of energy to Rio de Janeiro.[148] An even greater achievement was Billings's 1925 design of the Cubatão power plant outside São Paulo, which involved reversing the course of rivers and sending water over the great coastal escarpment to the powerhouse below. (See Figure 3.7.) The plant opened in October 1926 with a capacity of 20,000 kW, soon increased to about 60,000 kW.[149]

The installation so impressed Rudyard Kipling when he visited São Paulo in 1927, that he wrote a chapter on it in his book *Brazilian Sketches*.[150] Kipling, personifying the dynamo as Abu Bijl', Father of Lightnings, wrote:

> *[When] Abu Bijl' develops power to his normal capacity, it is—that it may go further at cheaper rates—damned and devilled up from six thousand volts to eighty-eight thousand by means of "transformers". … He was playing with his work while I watched him, and his masters' telephones told him what more or less power was needed as the trams and trains came on and off in distant cities, and a pen on a drum wrote down what he was giving. … Very soon more brothers will be bolted down alongside him, and more after that if needed; for the Power House has been designed to expand like a patent book-case over the little astonished river.*[151]

[148] McDowall, pp. 242–250.

[149] Cabral, p. 32.

[150] McDowall, pp. 254–260.

[151] Kipling, pp. 28–29.

The use of electricity expanded greatly in the 1920s, which was the last decade gaslights and animal-traction trams could be seen in the nation's capital.[152] Brazilian Traction's sales of electricity climbed from 458 million kW hours in 1925, to 817 million kW hours in 1929. By this time the state of São Paulo led Brazil economically, accounting for 37.5% of the national industrial production. Abundant, inexpensive, and reliable electric power was crucial to this advance.[153]

By transferring technical and managerial expertise, Brazilian Traction helped reduce the economic gap between North and South America.[154] A large part of Brazil's electrotechnical infrastructure was put in place by this single Canadian company. In 1946 it produced 60% of Brazil's electric power, carried more than a billion streetcar passengers, and supplied 75% of the nation's telephones.[155] Other foreign companies—mainly U.S., British, and German—set up affiliates in Brazil, but there were also many successful electrotechnical companies established and operated by Brazilians. These included Companhia Mineira de Eletricidade (founded in 1888), which supplied electric power to the industrial city of Juiz de Fora, and Companhia Força e Luz Cataguases-Leopoldina (founded in 1905), which provided power to a number of towns in the state of Minas Gerais.[156]

In the early years, since Brazil's industrialization was just beginning, much of the materials and equipment for the new utility had to be imported. As time went on, the company increasingly found local sources, thus reducing costs and acquiring products designed for local conditions. For example, the native woods used in the Brazilian-built trolleys lasted much longer in the tropical climate than did the wood on trolleys imported from North America.[157] Later only the most complex electrical equipment needed to be imported.[158]

Though the company trained Brazilians to operate the power stations and trams, higher management remained for several decades in the hands of North Americans.[159] The growing nationalistic feeling of the 1920s, accompanied by rising hostility toward foreign enterprises, prompted Brazilian Traction to further "Brazilianize" the company. Brazilian engineers were given greater responsibilities, and in 1924 the Brazilian Edgar de Souza became general manager of the São Paulo company. The trend continued, so that by the late 1940s foreign managers were a small fraction of the staff in Brazil.[160]

Assessing the economic impact of a new technology is difficult, particularly in the case of electricity, which affected many areas of economic life. Economists often

[152] Cabral, p. 32.
[153] McDowall, pp. 261, 406.
[154] McDowall, p. 7.
[155] McDowall, p. 386.
[156] Cabral, pp. 24–30.
[157] McDowall, pp. 85–91.
[158] McDowall, p. 154.
[159] McDowall, pp. 75–76.
[160] McDowall, pp. 269–275.

describe the impact in terms of "linkages".[161] Backward linkage is the stimulation of home production of the inputs for the new technology, as the electric trolleys built for the São Paulo and Rio transit systems. Forward linkage is the stimulation of new industries using the outputs of the new technology, as the electrically-powered commodities factories (producing textiles, footwear, and foodstuffs) that emerged in the São Paulo area.[162] Final-demand linkage is the stimulation of domestic production resulting from the wages paid to those employed in the new technology; Brazilian Traction became the nation's largest private employer, with nearly 50,000 workers.[163] In addition, the Brazilian economy benefited from the already mentioned transfer of technical and managerial expertise from the Brazilian Traction to other companies.

Of course Brazilian Traction was established and operated principally to enrich its investors, almost all of them foreigners. It succeeded in doing this, though profits were usually modest; for example, in the relatively prosperous 1920s, shareholders received dividends ranging from 4% to 6%.[164] By operating in harmony with Brazilian social, commercial, and political mores, and by providing reliable service at reasonable rates, the company lasted until 1979, when it was purchased by the Brazilian government.[165]

3.5.3 An International Arena for Power Engineering

The history of steam power in England or of the automobile in Germany may be told as a continuous line of development within the country influenced from time to time by work done elsewhere. In no country, however, can the rise of electric power be viewed as a mainly indigenous development. Scientists from many countries—Volta in Italy, Oersted in Denmark, Ampère in France, Faraday in England, Henry in the U.S., Ohm in Germany, and numerous others—interacted continually in gaining an understanding of electrical and magnetic phenomena. The technical devices, too, arose in many countries with constant influence across national borders. And from the earliest days of the power industry, the engineers and companies frequently operated in more than one country.

For example, British engineers and British equipment contributed to the consolidation of electric power systems in the Chicago area by Commonwealth Edison in the first decades of the century, and in 1906 when the Newcastle-upon-Tyne Electric Supply Company increased the highest voltage it used for transmission to 20,000 volts, it collaborated with AEG to produce the appropriate cable because English cable manufacturers had been unwilling to experiment with such high

[161] Myllyntaus, pp. 7–8.

[162] Cabral, p. 31.

[163] McDowall, p. 386.

[164] McDowall, p. 281.

[165] McDowall, p. 384.

voltage.[166] Because of its requirements of technical expertise and capital investment, an electric-power industry could hardly be developed indigenously in countries poorer and less industrialized than those in Europe and North America.

This is not to say that national differences were unimportant. As the accounts of Soviet and Brazilian electrification show, the form that an electric power system took in a country was strongly influenced by the setting. One might contrast the electrification of Finland with that of Brazil; though both had predominantly agricultural economies, Finland, unlike Brazil, electrified with little direct foreign investment and with students' study abroad being a principal channel of technology transfer.[167]

Power engineering operated on an international plane. Many electrical equipment companies produced for the export market, and many were ready to establish affiliates in foreign countries. Individual engineers frequently worked for companies outside their homelands, and some of those who made a living as consultants had clients in many different countries.

Frederick Stark Pearson, whom we met above as engineer to the Brazilian Traction, Light and Power Company, epitomized what Duncan McDowall called "the technological missionary". McDowall wrote:

> *"In a career that was to span just three decades, Pearson made a significant contribution to the public-utility industries of his native United States, Canada, Mexico, Spain, the Caribbean, and Brazil. [He carried] the message and the means of electricity into urban America and then abroad to lands eager to emulate the prosperity of North America. If he was also the servant of business profits, he never lost sight of 'the vision of the more perfect future' for his fellow man."*[168]

Pearson, only 54-years-old and in the midst of numerous ventures in several countries, died on 7 May 1915 when a German U-boat sank the *S.S. Lusitania*.[169]

3.6 RURAL ELECTRIFICATION

3.6.1 The Soviet Countryside Electrified

For Lenin, a principal reason for national electrification was to eliminate the economic and social separation between town and country. He wrote that electrification "will provide a link between town and country, will make it possible to raise the level of culture in the countryside and to overcome … backwardness, ignorance, poverty, disease, and barbarism."[170]

The number of Russian peasants grew from 56 million in 1867, to 103 million in 1913 (when the number of factory workers and miners numbered 3.5 million),

[166] Hannah, pp. 32, 52.

[167] Myllyntaus, pp. 289–292.

[168] McDowall, p. 60.

[169] McDowall, p. 234.

[170] Quoted in Coopersmith pp. 153–154.

and it was the peasants who made the revolutions in 1917. In 1917 the Bolsheviks for the first time gained adherents in the countryside because of Lenin's policy to withdraw from the war, while Kerensky's efforts to extract crops from the peasants led to open revolt in many areas.[171] When Lenin came to power, however, he found it necessary, in the period of "war socialism" to adopt similar practices. By the summer of 1921, Lenin's policies—notably expropriation of crops and promotion of collectives and state farms—together with a drought caused such a decline in agricultural production that there was severe famine the following winter, killing perhaps three million people.[172]

For Lenin the two principal means for socializing agriculture were collectivization and electrification.[173] In his view, the two went hand-in-hand, as electrical equipment in one location could serve a large number of farmers. For example, if meals were prepared in an electrically-equipped communal kitchen instead of in a hundred separate kitchens, ninety cooks could be freed for other work.[174] With collectivization not attracting many peasants, Lenin hoped new technology would turn the trick: "The critical point is whether we shall be able to proletarianise the peasantry before they are able to organise themselves against us. Their numbers are overwhelming, and they could swamp us. This conversion of the peasants to socialism can only be carried out by electrification and tractorisation. …"[175] In 1921 he said, "If we get electrification in ten or twenty years neither the individualism of the small agriculturalist nor his local free trade is in any way dangerous. If we do not get electrification, the return to capitalism is in any case inevitable."[176]

The basic problem faced with rural electrification in Russia, as elsewhere, was that there are high capital costs to providing electric power, while farms are far apart and consume little electricity. Not surprisingly the Communist party decided to develop industrial power principally for industrial use (rather than for lighting or consumer use), focusing efforts on traditional industrial districts.[177]

One GOELRO objective, however, was to bring electric lighting and appliances to farms, first to those near existing power stations. Besides being in the electric plow, electric motors would assist in harvesting and processing crops and in pumping water for irrigation. An initial goal of agricultural electrification was to substitute electric power for animal power, and with Lenin's support the development of an electric plow was vigorously pursued. Most electrical engineers opposed this program, viewing it as quite impractical, and in the mid 1920s it was quietly terminated.[178]

It was not only electrical engineers who failed to support agricultural electrification. Agricultural experts argued that such measures as increasing the number of

[171] Johnson, pp. 59–61.

[172] Johnson, p. 93.

[173] Lawton, p. 380.

[174] Lawton, p. 462.

[175] Quoted in Lawton, p. 477.

[176] Quoted in Lawton, p. 474.

[177] Dobb, p. 391.

[178] Coopersmith, pp. 164–166.

horses and introducing gas-powered mechanization would bring greater return than would electrification. Without strong support from these groups and with many other demands for electric power, it is understandable that agricultural electrification made little progress in the 1920s.[179]

In June 1924 the Soviet government set up a joint-stock company, Electroselstroi, to expand the use of electricity in rural areas. The company sold generators, motors, and other equipment to farm collectives, and also constructed district generating stations. A principal shareholder was the Swedish company A.S.E.A. (Allmanna Svenska Elektriska A/B), which supplied the equipment for sale by Electroselstroi.[180] One element of the First Five Year Plan was the construction of small hydroelectric plants in Central Asia, mainly to supply power for irrigation.[181]

In his speeches and writings, Stalin, like Lenin before him, promoted electrification as a boon for rural life. Yet in his actions, again like Lenin, he gave predominant place to electrification for industry. Both extracted the capital required for electrification principally from agricultural "surpluses" (thus denominated, despite severe food shortages), and both were ruthless in their treatment of the peasants. Stalin's collectivization of farming in the late 1920s brought on a new civil war in which millions or peasants were killed or transported.[182]

3.6.2 The Tennessee Valley Electrified

In 1921 Henry Ford submitted a plan to take over the U.S. government's Muscle Shoals facility—dam, hydroelectric station, and nitrate plant—on the Tennessee River in Alabama. Knowing that power could be transmitted economically over a large area, he promised a new prosperity through regional development.[183] His plan was not adopted. As we have already seen, at about the same time Governor Gifford Pinchot of Pennsylvania championed an electrification plan called Giant Power. The idea was to provide the entire state, including rural areas, with inexpensive electric power generated at giant mine-mouth plants and distributed by a single network of transmission lines.[184] This plan, too, failed to win sufficient support to be adopted.

In the economic depression of the 1930s, with a President anxious to show the power of government to improve conditions, plans to electrify the Tennessee Valley as well as rural areas generally were at last implemented. One of the measures passed during the famous Hundred Days following Franklin Roosevelt's inauguration on 4 March 1933 was the Tennessee Valley Act, authorizing government construction, operation, and ownership of a dam, power station, and electric-power distribution system.[185] The more general goal was the objective of the Rural Electrification Administration, established in May 1935.

[179] Coopersmith, pp. 165–167.

[180] Sutton, pp. 197–198.

[181] Dobb, p. 392.

[182] Roberts, p. 727.

[183] Hughes, pp. 293–294.

[184] Hughes, pp. 297–298.

[185] Hughes, p. 295.

The Tennessee River drains a region that includes part of seven states—Tennessee, Kentucky, Virginia, North Carolina, Georgia, Alabama, and Mississippi. This was an area much less developed economically than most of the rest of the country. The Tennessee Valley Authority eventually built five dams and improved 20 others, became one of the nation's largest and most efficient suppliers of electricity, and engaged in many other efforts, such as flood control, reforestation, and soil conservation, to improve conditions in the Tennessee Valley.

The Rural Electrification Administration (REA) was authorized to build power lines and help finance power production in areas not served by private electric-power companies. The REA made the greatest contribution in the Midwest and the South. The preponderance of large-scale farming in the West and the great use of irrigation there made it profitable for power companies to provide service, so 63% of California farms already had electricity in 1935. In 1930 the North Central states averaged 13% electrification, the South Central states just 3%.[186]

Private companies, because of limited profitability, moved slowly in providing electricity to rural areas. In many areas farmers organized cooperative associations to provide power, but the financial and technical barriers on the road to an efficient power system were high. The success of cooperatives in Europe, as in Sweden where 50% of farms were electrified by 1936, stimulated the movement. Also noticed was the result of government subsidy for rural electrification, as in France which, with half the population in rural areas, had achieved an overall electrification of 71% by 1930.[187]

REA, after a slow start, stimulated rural electrification greatly by providing low-interest loans to cooperatives, public bodies, and municipalities. REA also provided loans to farmers for wiring their homes and purchasing electric equipment and appliances.[188] Another stimulant to rural electrification in the 1930s was government regulation of private utility companies.[189] The result was steady growth of electric power provision before World War II—by 1944, 45% of U.S. farms had electricity—and rapid growth in the postwar decade—by 1953 only the most remote farms did not have service.[190]

3.6.3 Rural Life Transformed

From the 1880s until World War I, developers of electric power gave their attention to industrialized urban areas.[191] It was difficult for utilities to recover investment in a distribution network for rural areas, because the density of potential customers was small and each would likely use only modest amounts of electricity.

[186] Brown, p. x.

[187] Brown, pp. 15–16.

[188] Brown, p. 58.

[189] Hughes, p. 369.

[190] Brown, pp. 112–113.

[191] Hughes, p. 15.

In rural areas, as earlier in the cities, the electric light was the main incentive to install electricity.[192] Incandescent lighting, according to the Tennessee Valley Authority, added two to four hours to the working day for farmers. Electricity transformed life on farms in many other ways as well.

Particularly important were the electric pumps, making possible running water in houses and irrigation of fields. Household appliances, too, improved life substantially. Most of the electricity used on farms went to household operations. The refrigerator reduced food spoilage and food poisoning; the radio brought valuable information (notably about crop prices and weather) and entertainment; the electric clothes washer saved 20 days a year in labor; the electric iron similarly reduced household drudgery.[193] Electricity gave a supplemental source of heat in many areas. In farm operations electricity was important for such tasks as milking, feed cutting, feeding livestock, wood sawing, and making repairs. Incubators, for example, came into general use; the percentage of hatchlings from incubators increased from 20% in 1918, to 85% in 1944.[194]

Some data on non-electrified farms make clear the impact of electricity. In 1919 rural families in the U.S. spent an average of 10 hours per week pumping and carrying water. Running water made possible the indoor flush toilet. (The outdoor toilet was a principal cause of ill health.) One study found that women on farms spent 20 days more per year washing clothes than women in the city using electric washing machines. Spoilage of food was an everyday occurrence before refrigerators.[195] D. Clayton Brown, a historian of rural electrification, concluded, “Because of its versatility, electric service was the single most important development responsible for ending the drudgery and toil of farm life and alleviating the generally depressed physical and spiritual condition of farmers.”[196]

Rural electrification was, as we have seen, promoted in the Soviet Union and the United States. In Britain it was especially rural housewives who pressed for electrification; in 1939, 2/3 of the homes in rural areas had electricity, but only 12% of farms were electrified.[197] And rural electrification was an important part of Oskar von Miller’s plan for electric power in Bavaria.[198]

The Soviet government under Stalin attained a degree of control over the political, economic, and intellectual life of the country that has seldom been equaled before or since. A vital element of that power was control of the mass media. Chapter 6, which focuses on Nazi Germany’s use of communications technologies, also describes Stalin’s use of radio broadcasting. The next chapter turns first, though, to the development of that medium in the 1920s in the U.S.

[192] Hannah, p. 192.

[193] Brown, pp. 116–118.

[194] Harvey Green, p. 42.

[195] Brown, pp. xiii–xiv.

[196] Brown, p. x.

[197] Hannah, pp. 190–192.

[198] Hughes, p. 346.

Chapter 4

The Jazz Age and Radio Broadcasting

4.1 RADIO IN THE TWENTIES

4.1.1 The Battle of the Century

On 11 May 1847 the Irish-American boxer Yankee Sullivan defeated the English boxer Robert Caunt at Harper's Ferry, Virginia. So great was popular interest that the *New York Herald* newspaper arranged for a relay of express riders to bring a description of the match from ringside. New Yorkers were thus able, just two days after the event, to learn the outcome. Less than two years later in Still Pond Heights, Maryland, Sullivan lost a heavily promoted fight to Tom Hyer. This time, though, there was telegraph service between Baltimore and northeastern cities, where multitudes waited at newspaper offices to learn the outcome.[1]

Though popular in U.S. cities and mining towns, boxing long remained a disreputable sport. Many people considered it barbaric, and most states had outlawed prizefighting. What professional boxing there was usually took place in smoke-filled halls, crowded with rowdy and often drunk spectators. In the years around 1920, however, the sport gained in status. It helped that during the war the U.S. Army had encouraged it as an activity for soldiers. It helped too that boxing had a shrewd promoter, determined to make it popular and respectable.[2]

Tex Rickard, who had tried making a living as cowboy, marshal, bartender, gambler, and saloonkeeper, finally found success in arranging boxing matches. He set up the celebrated fight between Jack Johnson and Jim Jeffries in 1910 and many other fights in the years that followed. Wanting to attract the middle and upper classes, Rickard arranged fights in clean, well-ventilated halls where ushers kept

[1] Gorn, pp. 82–83, 92–94, and Nugent.

[2] The information on boxing, Rickard, and Dempsey comes mainly from Randy Roberts, *passim*, and Perrett, pp. 213–218.

Dawn of the Electronic Age: Electrical Technologies in the Shaping of the Modern World, 1914 to 1945, by Frederik Nebeker

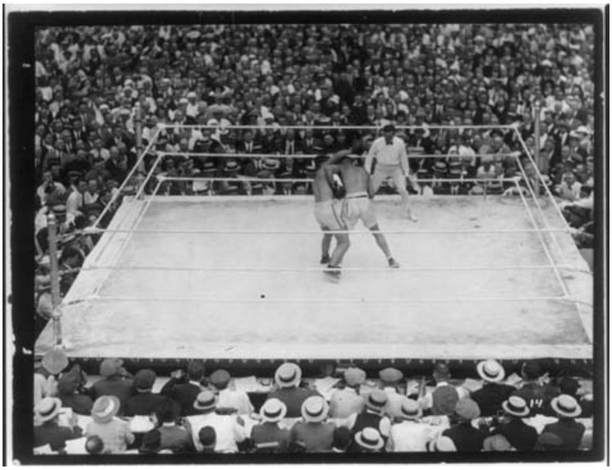


Figure 4.1. The Dempsey-Carpentier fight (photo courtesy of the Library of Congress, LC-USZ62-51215).

order. He also created a new type, the millionaire boxer, in the person of Jack Dempsey.

In 1919 Rickard arranged for the little-known Dempsey to fight the much larger Jess Willard, who had won the heavyweight title from Jack Johnson in 1915. Dempsey won the fight and instant fame. Dempsey stayed in the spotlight, performing boxing exhibitions with a traveling circus, starring in the movie *Daredevil Jack*, and twice defending his title in 1920, the second time at Madison Square Garden only months after the state of New York legalized prizefighting.

In 1921 Rickard set up what was called the Battle of the Century. Georges Carpentier, the French champion, was at the height of his career. He had taken just one round to knock out the best English heavyweight, and his strikingly good looks, congeniality, and wartime military service—he was twice decorated for heroism—added to his popularity. The Dempsey–Carpentier fight was to take place on July second in an arena Rickard had built in Jersey City, across the Hudson River from New York City. (See Figure 4.1) According to the sportswriter Grantland Rice, the whole country had taken sides for or against Dempsey.[3] A biographer of Dempsey has written, "By the end of June, the Dempsey-Carpentier fight was the biggest story in the world. Newspapers, both American and foreign, detailed each day's activity of both fighters."[4] The fight was both a financial and a popular success. Numerous diplomats, millionaires, and movie stars attended. It drew the largest crowd—more than 80,000 people—ever to witness a sporting event in the United States. What is more remarkable is that an additional 300,000 people were present in the sense that they heard, by radio, a blow-by-blow description of the fight as it was taking place.

[3] Rice, p. 119.

[4] Randy Roberts, p. 118.

This had not been the case two years earlier when Dempsey fought Willard for the title. Then people around the country gathered at newspaper offices—connected by telephone or telegraph wires to the Chicago site of the fight—to receive word of the outcome as soon as possible. In 1921 a young executive of the Radio Corporation of America (RCA), David Sarnoff, seized on the Dempsey–Carpentier fight to demonstrate how appealing radio broadcasting could be. Half a year earlier the first station licensed for radio broadcasting, the Westinghouse station KDKA in Pittsburgh, had begun operation, but it was not clear that the practice would become widespread, and RCA's top management showed no interest, preferring to concentrate on the point-to-point communication service the corporation was set up to provide.

One of the RCA people who were enthusiastic about Sarnoff's plan to promote broadcasting was J. Andrew White, editor of the magazine *Wireless Age*. He and Sarnoff worked together to arrange the fight broadcast.[5] They managed to borrow a powerful transmitter from the Navy, thanks to the support of the Assistant Secretary Franklin D. Roosevelt, and they set it up in a shed at the Hoboken train station, a few miles from ringside. The telephone company agreed to run a line between the two points. Hundreds of receivers, equipped with hearing-aid amplifiers and phonograph horns, were set up in movie theaters, stores, halls, and clubs. Sarnoff shrewdly promoted the broadcast as a charity event, as a portion of admission fees went to the American Committee for Devastated France.

The fight lasted only four rounds. Though Carpentier fans found reason to cheer in the second round, most people agreed with H.L. Mencken, who said "Dempsey was never in any more danger of being knocked out than I was, sitting there in the stands with a pretty gal just behind me and five or six just in front."[6] In the fourth round Dempsey knocked Carpentier down, then knocked him out. For Sarnoff and White, it was fortunate that the fight ended when it did, for the transmitter overheated and failed just afterwards.[7]

On the following day, the *New York Times*, usually restrained in its coverage of sports, gave most of its first 13 pages to describing the fight. The radio broadcast, too, received press attention; it was reported that some 300,000 people, most of them radio amateurs and some as far away as Florida, heard the fight.[8] The broadcast impressed not only the public at large; according to White, a few minutes after the fight he and Sarnoff received a cablegram from RCA's president, then vacationing in London, which said, "You have made history."[9]

4.1.2 The Radio Craze

The ratification on 29 January 1919 of the 18th amendment to the U.S. Constitution—prohibiting the manufacture, sale, and transportation of alcoholic beverages—was

[5] Lyons, pp. 99–101.

[6] In Randy Roberts, p. 126.

[7] Inglis, p. 63.

[8] George H. Douglas, p. 25, and Inglis, p. 63.

[9] In Sarnoff, p. 35.

an expression of Progressivist and Puritan ethics. Yet many features of the decade that followed may be seen as repudiations of those ethics: the pursuit of instant pleasures; an embracing of sex, alcohol, loud music, abbreviated clothing, and fast cars; a thrill in breaking the rules; and an acceptance of Freudianism (with, in the words of one historian, "a new word for all the world's ills—repression").[10] Women won increased freedom of action: it became common for unmarried women to live on their own and to behave unconventionally (to smoke or curse or wear bobbed hair and make-up) or dress unconventionally (scorning corsets and hobble-skirts and buying helmet hats, short skirts, and one-piece bathing costumes); more jobs were open to women; and women gained the right to vote nationwide with the passage of the nineteenth amendment in 1920. The economy grew rapidly, stimulated by a remarkable expansion of advertising and by a booming automobile industry (the number of cars increasing from 6.8 million in 1919, to 23.1 million in 1929). College enrollments doubled, and so did sales of cigarettes.

It was the time of popular heroes such as Charles Lindbergh, Rudolph Valentino, and Babe Ruth; of the evangelist Billy Sunday and President Calvin Coolidge ("The chief business of the American people is business"); of speakeasies, high-profile gangsters, and sensational murder trials; of tabloid newspapers, syndicated columnists (such as Dorothy Dix with advice for the lovelorn), and confession magazines; and of F. Scott Fitzgerald, Eugene O'Neill, Sinclair Lewis, and Edna St. Vincent Millay. It was the first decade of mass motoring, and there was a construction boom that gave many cities a new skyline.

The 1920s was also a time of fads. There were dance crazes (the Charleston, the Buzzard Lope, and the Shimmy) and marathon dancing. Ukuleles and saxophones suddenly became popular. In 1923 everyone, it seemed, was learning mah-jongg, and just a few years later most of them had taken up contract bridge. Crossword puzzles burst into popularity in 1924. There was Couéism—emphasizing autosuggestion, "Every day in every way I am getting better and better"—and ouija boards. Yo-yos and roller skates became, for a while, extremely popular. There were bathing-beauty contests, rocking-chair derbies, spelling bees, across-the-country runs, and flagpole sitting.

The faddishness of the times helped to transform radio, in the space of a year or so, from a little-known technology to an object of general interest. In February 1922 President Harding had a radio installed in his study. In March the *New York Times* reported, "In twelve months radio phoning has become the most popular amusement in America."[11] In April an article in *Review of Reviews* reported, "Never in the history of electricity has an invention so gripped the popular fancy."[12] In May *Radio Broadcast* reported: "The rate of increase in the number of people who spend at least a part of their evening in listening in is almost incomprehensible" and "To those who have recently tried to purchase receiving equipment, some idea of this increase has undoubtedly occurred, as they stood perhaps in the fourth or fifth row

[10] Perrett, pp. 148–149.

[11] In Susan J. Douglas 1987, p. 303.

[12] In Susan J. Douglas 1987, p. 303.

at the radio counter waiting their turn, only to be told when they finally reached the counter that they might place an order and it would be filled when possible."[13] In the next issue, a *Radio Broadcast* reporter described the scene on the West Coast: "The average man on the street had never more than vaguely heard of radio until two months ago … All of a sudden it hit us. The first most of us saw of it … was in first-page, first-column headlines from New York … proclaiming that the East had gone mad over radio. Within twelve hours, the interest swept the coast."[14]

In 1922 full sets, not just radio kits and parts, were on the market.[15] Sales of radio equipment totaled $60 million in 1922, and in 1925 they reached $430 million, which was more than twice as much money as was spent on all sporting equipment.[16] In newspapers, radio columns and radio supplements became common.[17] Magazines for radio amateurs, such as *Popular Radio, QST*, and *Wireless Age*, increased in number and circulation, and trade journals began to appear—*Radio Broadcast, Radio Dealer*, and *Radio World* all began publication in April or May 1922.[18]

What was the attraction of radio? For many people it was the marvel of receiving in one's home voices and music originating miles away, perhaps halfway across the country. Many an amateur made it his objective to pick up as many stations as possible, and a map marked with the stations received was found in many homes.[19] Picking up distant stations was likened to fishing: "There are times when it is as difficult to land a given station—making the same demands upon patience, ingenuity, and even skill—as to bring to boat that elusive creature, the sailfish."[20] The programs themselves were often of little interest, one amateur calling them "the tedium between call letters".[21] Yet if logging stations had remained the main attraction, radio, like other objects of faddish interest, would soon have been forgotten by most people. Instead, radio gained more and more listeners and occupied more and more of the time of radio owners. What held listeners, of course, was the programming.

4.1.3 Sports, Music, and Drama

Popular interest in sports, already great in 1920, increased markedly over the next 10 years. Large number of people took up sports as participants. Tennis and golf rather suddenly became common pastimes, and softball, bicycling, roller skating, and skiing were also popular. Added to this was a steady growth in spectator sports. According to one historian, "It was in the Twenties that sport became the all-

13 In Morris, pp. 441–442.

14 In Morris, p. 442.

15 Barnouw, p. 91.

16 Eoyang, p. 73, and J. Fred MacDonald, p. 12.

17 Barnouw, pp. 98–99.

18 Barnouw, p. 102.

19 Susan J. Douglas 1987, p. 307.

20 In Susan J. Douglas 1987, p. 307.

21 In Susan J. Douglas 1987, p. 307.

consuming interest that we know so well."[22] The ascent of radio and the ascent of sport—in the same decade—were mutually stimulating.

We have already seen that in 1921 Sarnoff chose the Dempsey–Carpentier fight to demonstrate the appeal of radio broadcasting. A year later in England, the British Broadcasting Company chose the Lewis–Carpentier fight for the same reason.[23] The association of radio with sports, however, began much earlier. The first commercial use of wireless was probably Marconi's reporting in 1898 on a regatta off Kingstown, Ireland, from a boat equipped with wireless, and Marconi first crossed the Atlantic when invited by a New York newspaper in 1899 to provide wireless reports of the America's Cup races off Long Island. Frank Conrad's experimental broadcasts that preceded the establishment of KDKA in 1920 regularly included the reading of baseball scores.[24]

Once regular broadcasting began, baseball scores and then entire games were broadcast. In August 1921 KDKA carried a Pittsburgh–Philadelphia game.[25] The first Westinghouse station in the New York area, WJZ Newark, hurried to begin broadcasting in time to capitalize on the interest in the 1921 World Series. Because there was no equipment to amplify the telephone reports for direct transmission, an announcer in the studio had to recreate the ballgame from the telephoned reports he was receiving, but the following year, the World Series was broadcast live by sportswriter Grantland Rice.[26] Interest in baseball, helped by radio, Babe Ruth, and the new livelier ball, increased throughout the 1920s.

Football made an even greater advance. Knute Rockne, coach at Notre Dame University, made the forward pass a large part of the game, and Red Grange made professional football popular. Again, radio helped. KDKA began broadcasting games in the autumn of 1921, and the following year several stations broadcast football regularly.[27] Radio allowed alumni no longer living near the college to follow the play of their teams and gave countless youngsters a reason to be interested in colleges.

It was, however, music that filled the bulk of the broadcast hours on almost every station. In the early 1920s most stations broadcast mainly European recital music, what today would be called light classical, usually alternating vocal and instrumental numbers.[28] In 1920 jazz, which had been played for years in New Orleans, began attracting popular attention in Chicago and soon spread to other cities, where it became the music of speakeasies.[29] It was not, however, until the mid-1920s that jazz was frequently heard on the radio, and then it was usually in

[22] Perrett, p. 222.

[23] Carpentier fared better this time, knocking Kid Lewis out in the first round. The front-page article in the *New York Times* (12 May 1922) mentioned that the fight was broadcast to radio amateurs.

[24] George H. Douglas, p. 113.

[25] George H. Douglas, p. 114.

[26] George H. Douglas, pp. 25, 117–118.

[27] George H. Douglas, p. 114, and J. Fred MacDonald, p. 9.

[28] Barnouw, pp. 126–127.

[29] Perrett, pp. 231–237.

the more respectable forms offered by Paul Whiteman, Vincent Lopez, Bix Beiderbecke, and others.[30] The new music and radio each increased interest in the other. This relationship is illustrated by what may have been the most celebrated musical event of the decade—the radio concert given by Paul Whiteman in 1924, for which Victor Herbert composed four serenades and George Gershwin composed *Rhapsody in Blue*.

Though music filled the broadcast hours, what gained legions of listeners for radio in the late 1920s and 1930s was drama. In August 1922 the WGY Players of the General Electric station in Schenectady presented the first radio drama, and beginning the following month the WGY Players were heard every Friday evening.[31] WGY's example was quickly followed by other stations. This new medium for drama was greatly enhanced by sound effects, a new art cultivated in dozens of studios. The clicking of typewriters, the sighing of wind, the creaking of doors, the gurgle of water flowing from a bottle, and a thousand other sound effects were effective stimulants to the imagination.

It was especially the development of serial drama (rather than self-contained presentations) that gave radio a boost. The story of the most successful serial drama in early radio begins with a Navy radio operator Freeman Gosden, who, like many others, sought to make a living from radio after the Great War. Gosden tried selling radio equipment, but his efforts were so unremunerative that he teamed up with Charles J. Correll in an effort to earn livings as vaudeville organizers and performers. Gosden returned to radio in January 1926 when he and Correll began presenting a song-and-joke routine in black dialect on radio station WGN in Chicago. The show, *Sam and Henry*, was so popular that when the performers moved to another Chicago station (WMAQ) in March 1928, WGN kept the name, and Gosden and Correll came up with a new name for their show, *Amos "n" Andy*.[32]

Gosden played Amos Jones, hardworking and church-going. Correll played Andrew H. Brown, who never worked but was already ready to take part in a scheme devised by the slick George Stevens, "Kingfish" of the "Mystic Knights of the Sea" lodge. According to a historian of radio programming, "… *Amos and Andy* at its peak may well have been the most popular show ever broadcast. People who lived through the early 1930's still remember the marquees on movie houses, announcing that the film would be stopped at 7 o'clock, so *Amos and Andy* could be piped in. That was the only way a theatre could hold an audience. In 1931 … the listening audience may have exceeded 40 million a night."[33]

The series stimulated radio sales, which increased from $651 million in 1928, to $843 million in 1929.[34] For many listeners, Amos Jones and Andrew H. Brown epitomized people without money or prospects of advancement, and listening to their troubles relieved the bitterness of hardships brought on by the

30 Barnouw, pp. 130–131.

31 Barnouw, pp. 135–137.

32 George H. Douglas, pp. 196–205, and Dunning, pp. 31–32.

33 Dunning, p. 33.

34 Barnouw, p. 229.

Depression.[35] Black listeners had mixed reactions, some supporting the program for presenting blacks as human and lovable, others seeing the program as demeaning.[36]

The great popularity of *Amos "n" Andy* attracted imitators. Also extremely successful was *The Rise of the Goldbergs*, introduced by NBC in 1929, which told of the struggles of a Jewish family in Manhattan's Lower East Side. Other serial dramas introduced in 1929 were *Polly Preston's Adventures* and *Soconyland Sketches*.[37] Soon there were adventure programs, such as *Death Valley Days*, and crime and mystery programs, such as *Fu Manchu, Sherlock Holmes*, and *The Shadow*. These evening serial dramas gave rise in the early 1930s to the afternoon programs, known as soap operas (because many of them were sponsored by soap manufacturers), such as *Ma Perkins* and *The Romance of Helen Trent* that long dominated afternoon broadcasting.

Variety shows were, by the end of the decade, another popular type of program. Broadcasts of vaudeville began in November 1922 with a show from S.L. "Roxy" Rothafel's theater in New York, and in the late 1920s, *Roxy and His Gang* was one of radio's most popular programs.[38] In December 1923 WEAF in New York City inaugurated *The Eveready Hour*, featuring comedy routines and musical numbers. In 1925 began *The Grand Ole Opry*, which featured the comedienne Minnie Pearl telling stories of life in Grinders Switch, Tennessee.[39] The most successful variety show of the period was the *Rudy Vallee Show*, begun in 1929.

4.1.4 Ballyhoo, Politics, and Religion

For eleven days in July 1925 the town of Dayton, Tennessee was at the center of the nation's attention. Thomas Scopes, a high-school biology teacher, had been arrested for teaching the theory of evolution, prohibited by Tennessee law. One of the defense attorneys was the famous lawyer Clarence Darrow. William Jennings Bryan, three times the Democratic candidate for President, and the Secretary of State under President Wilson, volunteered his services for the prosecution.[40]

The trial attracted more than a hundred newspaper reporters, Western Union set up a special office with 22 telegraph operators, and news agencies in London were besieged with requests for more copy. Chicago radio station WGN arranged to broadcast live the last part of the trial, paying $1000 a day in wire charges to AT&T for this distant feed to its transmitter. Broadcast was Darrow's examination of Bryan as an expert on the Bible, who affirmed that the world was created in 4004 BC, that

[35] Dunning, p. 33.

[36] Smulyan, p. 115.

[37] George H. Douglas, p. 191.

[38] Smulyan, p. 55, and Dunning, pp. 524–525.

[39] Rhoads, p. 115.

[40] Frederick Lewis Allen 1931, pp. 167–171.

Eve was made from Adam's rib, and that the Tower of Babel accounts for the diversity of languages.[41]

The Scopes trial was only one of a series of *causes célébres* in the 1920s. There was the Halls–Mill murder case in 1922, the Leopold-Loeb trial in 1924, the wreck of the dirigible *Shenandoah* in 1925, the unveiling of Ford's Model A in 1927, the sinking of the steamship *Vestris* in 1928, and the St. Valentine's Day Massacre in 1929. In 1925 Floyd Collins was trapped in a Kentucky cave (and interviewed by newspaper reporters before he died on the eighteenth day), in 1926 Gertrude Ederle swam the English Channel and Admiral Byrd flew over the North Pole, and in 1927 Lindbergh flew alone across the Atlantic. In these and many other instances, newspaper editors took advantage of the discovery that they could sell many more papers by catering to the tendency of the public to become excited about one thing at a time.[42]

Of course, as with the Scopes trial, radio played a part in the ballyhoo. The ticker-tape parade given for Charles Lindbergh was carried live on 50 radio stations; it was what broadcast historian Eric Barnouw calls "the first grand multiple-announcer broadcast", made sequentially by famous announcers spaced along the parade route.[43] A disastrous hurricane that hit Florida in 1926 was described over radio.

Another spectacle of the decade that was heightened by radio was the Democratic National Convention in 1924. In that year both national conventions were broadcast, and William Jennings Bryan declared radio to be "a gift of Providence".[44] Its outcome preordained because President Coolidge was seeking the nomination, the Republican convention was a staid affair—Mencken said it might as well have been conducted by postcard. One could hardly have imagined a greater contrast to it than the Democratic convention. The uncertain outcome, the spectacle of the event—speeches, bands, changes in delegates' votes, shouting matches, and fist fights—and the protracted suspense—it went on for 16 days before a dark horse candidate, John W. Davis, was selected on the 103rd ballot—made it a broadcasting triumph.[45]

In the ensuing campaign Coolidge was probably helped by radio. A Democratic commentator wrote, "[Mr. Coolidge] has a perfect radio voice. … Before an audience Davis glows, while the President always looks unhappy whether he is or not. Under these circumstances, the radio must be Mr. Coolidge's salvation."[46] On the eve of the election, 26 stations, linked by AT&T lines, carried a speech by Calvin Coolidge, which may have reached 20 million people, and in March 1925 his inaugural address was heard by a radio audience estimated at 23 million.[47]

From the 1924 Presidential campaign to the present, radio has played an important part in politics. In the 1928 campaign, radio may have hurt the Democratic can-

[41] Barnouw, p. 196, and Frederick Lewis Allen 1931, p. 170.

[42] Frederick Lewis Allen 1931, p. 158.

[43] Barnouw, p. 192.

[44] Morris, p. 452.

[45] George H. Douglas, pp. 104–105.

[46] In George H. Douglas, p. 106.

[47] Barnouw, pp. 152–153, and J. Fred MacDonald, p. 7.

didate Al Smith because of his New York accent. The Louisiana politician Huey Long (whose nickname "the Kingfish" came from the *Amos* "*n*" *Andy* character) made great use of radio to win elections and gain a national following.[48] In 1936 Franklin Roosevelt won reelection easily, despite the aggressive opposition of 3/4 of the nation's press, in part because of his contact with the voters by means of radio.[49]

Though church membership kept pace with population growth, the 1920s was an age of doubt. Many Protestant churches broke into two camps—modernists, or liberals, who tried to reconcile church doctrine with science, and fundamentalists (the word was coined in 1921), who believed in the literal truth of the Bible.[50] Radio on occasion—as with the broadcast of the Scopes trial—may have encouraged skepticism, but it more frequently served the forces of orthodoxy. At the end of 1921, KDKA began a regular Sunday-evening broadcast of a complete church service, and many other stations followed suit.[51] Some churches ran their own radio stations—as early as January 1923, 12 religious organizations had broadcasting licenses—and revivalists, such as Billy Sunday, took to the airwaves.[52] The leading revivalist of the decade, Aimee Semple McPherson, had her own radio station in Los Angeles that spread her preaching as far east as Colorado and New Mexico.[53] Radio also led to her undoing; her enormous influence suffered a crippling blow in 1926 when the public learned that she had eloped with the radio engineer hired to run the station.

4.1.5 Synergy of Radio and Culture

In the 1920s radio broadcasting and popular culture interacted so as to speed developments in both spheres. Radio benefited from the prosperity of the times, the widespread enthusiasm for science and technology, and the atmosphere of social change, and it provided a cultural medium that was extremely rapid and nationwide in its reach. Thus radio and cultural movements, such as interest in sports or new music, fed off each other. The rapidity of radio communication suited the fast-paced lifestyle, and the wide reach of broadcasting suited the desire to be "with it", in touch with the life of the biggest cities. As one historian puts it, that radio was taken up so quickly was partly due to the optimistic, innovating style of the time; "While this era might have been "the Jazz Age" or "the Roaring Twenties" to many urban, middle-class Americans, for the overwhelming majority of the citizenry it was the Radio Era."[54]

Everyone in the 1920s experienced new inducements to make purchases: a great expansion in advertising, general acceptance of installment buying, the rapid growth

[48] Dunning, p. 32.

[49] Morris, p. 457.

[50] Frederick Lewis Allen 1931, pp. 163–166.

[51] Susan J. Douglas 1987, p. 311.

[52] Barnouw, p. 4.

[53] Perrett, p. 203.

[54] J. Fred MacDonald, p. 12.

of chain stores, and the establishment of national brands for many products. Radio broadcasting, which was supported mainly by advertising, both benefited from and augmented these forces. The commercial success of new technologies—such as the automobile, the radio, and the electric refrigerator—and the expectation of continued growth contributed to the rise, for good and ill, of the stock market. Radio stocks were among the leaders, and RCA stock increased in value 600% from early 1928 to mid-1929.[55]

The decade was also one of enthusiasm for technology. There was great interest in aviation—it was the decade of barnstorming pilots—and scheduled passenger service began in 1926. The number of telephones increased from 14.3 million in 1922, to 20.3 million in 1930, and the domestic use of electricity increased 135% in the decade.[56] Motion pictures gained a huge following, and in the last years of the decade the "talkies" quickly replaced silent films. Electric refrigerators, electric toasters, electric mixers, and radios became popular consumer items.

Another aspect of the 1920s had a close relation to radio. Frederick Lewis Allen wrote: "One of the striking characteristics of the era of Coolidge Prosperity was the unparalleled rapidity and unanimity with which millions of men and women turned their attention, their talk, and their emotional interest upon a series of tremendous trifles—a heavyweight boxing match, a murder trial, a new automobile model, a transatlantic flight."[57] We saw above how radio itself became a fad, and thereafter it contributed—along with national magazines and large-circulation newspapers—to one fad after another. The fads were sometimes directly related to radio, as the broadcasting of mah-jongg lessons or the selling of goat-gland stimulants by Dr. Brinkley via his own station KFKB in Milford, Kansas.[58]

Radio took advantage of and fostered the general fascination with personalities. The famous became more famous, and many who had achieved a following in another arena became enormously popular through radio. For example, Will Rogers ("I tell you folks, all politics is applesauce"), gained an immense audience by means of radio in the 1920s and early 1930s. Radio personalities became famous. The sportscaster Graham McNamee received 50,000 letters after his broadcast of the 1925 World Series, and his voice became more familiar than that of anyone else in the country.[59]

The 1920s was an age of great interest in music, an interest suited to the new medium. Also, the "New Humor" of the vaudeville stage, much of it based on verbal misunderstandings and presented in stories in a compressed form with a punch line (the joke being then a recent invention), was well suited to radio.[60] Lectures, high culture in the form of drama and classical music, instruction in home economics and child rearing, and exercise programs catered to the interest in self-improvement of

[55] Barnouw, pp. 193, 233.

[56] J. Fred MacDonald, p. 23.

[57] Frederick Lewis Allen 1931, p. 155.

[58] Barnouw, pp. 168–172.

[59] George H. Douglas, p. 123, and Frederick Lewis Allen 1931, p. 138.

[60] Smulyan, pp. 119–120.

the 1920s. (Shortly after its debut in 1925, the WOR morning calisthenics program was the most popular of all WOR programs.)[61]

Attributes of radio—that it reached large numbers of people and reached them instantaneously, that it was a national medium, that it was supported by advertising—help to account for the synergy of radio and culture in the 1920s. So, too, do attributes of that decade—that it was a time of social change, that people were eager to be entertained, that most people were enthusiastic about new technology. The sportscaster Red Barber wrote,

> *People who weren't around in the twenties when radio exploded can't know what it meant, this milestone for mankind. Suddenly, with radio, there was instant human communication. No longer were our homes isolated and lonely and silent. The world came into our homes for the first time. Music came pouring in. Laughter came in. News came in. The world shrank, with radio.*[62]

In the 1920s radio became a vital part of national culture. The times were different—and they were experienced differently—because of radio. And people were aware of it at the time, as Cole Porter's 1934 song "Anything Goes" reminds us:

> *Just think of those shocks you got*
> *And those knocks you got*
> *And those blues you got*
> *From that news you got,*
> *And those pains you got*
> *(If any brains you got)*
> *From those little radios.*

4.2 THE ESTABLISHMENT OF BROADCASTING IN THE UNITED STATES

4.2.1 Radio Amateurs

For youngsters growing up in the second decade of the century, two of the most exciting things were the new technologies of aviation and radio.[63] The latter gave more scope for personal experimentation, as the apparatus was fairly simple and inexpensive. Electron tubes, it is true, were expensive, but one could build a usable receiver without tubes. Instructions for making a crystal radio appeared in newspapers and boy's magazines. (See Figure 4.2) Except for the crystal itself, the materials were readily available: copper wire, a cylindrical oatmeal box, tin foil, glass plates, and a telephone receiver. The cost was about $2 in materials for the radio, and perhaps another $4 for a pair of commercial earphones. Even a transmitter was easy to build using a spark coil from an automobile ignition system.[64]

[61] Barnouw, p. 168.

[62] In Nahin, p. xxiv.

[63] Kraus, p. 21, and Wheeler 1982, p. 28.

[64] George H. Douglas, p. 40, and Fagen 1975, p. 356.

Figure 4.2. A crystal radio (photo courtesy of the Library of Congress, LC-USZ62-78078).

In the years before the war there were wireless clubs in a great many schools and colleges.[65] In the U.S. the number of licensed amateurs increased from 322 in 1913, to 13,581 in 1917, and the number of unlicensed receivers in 1917 has been estimated at 150,000.[66] By the end of 1915 there were organizations such as the Radio Club of America (with its own station in New York City's Hotel Ansonia), the American Radio Relay League (set up by an indefatigable promoter of radio, Hugo Gernsback), the National Amateur Wireless Association (sponsored by the American Marconi company), and the Radio League of America (which conducted nationwide message relays to demonstrate the extent and efficiency of the amateur-radio communications network).[67]

The entry of the U.S. into the war gave amateur radio a temporary setback, as the government prohibited all amateur radio activities, receiving as well as transmitting. The military, however, suddenly needing large numbers of radiomen, started a campaign to entice radio amateurs to enlist and trained thousands of others. After the war a great many of these men, back in civilian life, pursued radio as a hobby, and these people, familiar with the great advances in transmitter and receiver design, in tubes, and in aerials that occurred during the war, did much to raise the level of the art.[68]

Interest grew rapidly. There was the thrill of reaching out to the world, of conversing with people hundreds or thousands of miles away, of exploring what Orson Welles later called "the vast ethereal plain".[69] In 1922 there were some 600,000 radio

[65] Barnouw, p. 28.

[66] Susan J. Douglas 1987, p. 293.

[67] Susan J. Douglas 1987, pp. 295–296.

[68] Susan J. Douglas 1987, pp. 298–299.

[69] In Rhoads, p. 434.

hobbyists.[70] As long-distance contacts became more frequent, many radio amateurs began to think of themselves as citizens of the world, with friends in many countries on several continents. Radio amateurs prepared the way for radio broadcasting, and they also occasionally contributed to technical advance (as we will see below with antennas and with the use of short waves for long-distance communications).

Just after the war the avocational use of radio—the pastime of amateurs talking to each other—seemed unimportant. It is true that a few people, such as Lee de Forest, inventor of the Audion, thought it might develop into something significant, but most expected it to remain the activity of a scattering of hobbyists.[71] In contrast, there was the already thriving business of providing point-to-point communication across water and great distances that the Marconi company and others were pursuing. It had existed for a decade before the war, it had proved extremely valuable during the war, and it seemed to have a great future before it.

4.2.2 The Formation of RCA

In 1919 the prestige of radio, which was then thought of as a means of point-to-point communication, was high among political leaders. President Woodrow Wilson had declared that international communications was one of three requisites of success in foreign relations (the other two being shipping and oil), and he therefore wanted U.S. industry to gain a strong position in that field.[72] At that time, however, Great Britain had a dominant position in the manufacture, laying, and financing of undersea cables, and the Marconi company threatened to extend this hegemony to long-distance radio.[73] Early in 1919, GE advised the U.S. government that it was negotiating a contract to supply American Marconi with at least 24 Alexanderson alternators (the radiowave-generators mentioned in Chapter 1). As this would consume all of GE's production for several years, the Marconi company would have exclusive use of the most powerful transmitter then available. Franklin Roosevelt, Assistant Secretary of the Navy, convened a meeting which led to the establishment of a U.S.-owned international-communications company. General Electric set up a subsidiary, the Radio Corporation of America (RCA), which would buy out American Marconi. The articles of incorporation stipulated that only U.S. citizens might be directors or officers of RCA and that no more than 20% of the stock might be owned by foreigners. A press release expressed the objective of the new firm: "To link the countries of the world in exchanging commercial messages."[74]

In addition to GE, Westinghouse and AT&T had manufactured radio equipment during the war, and both owned rights to important patents. So did the United Fruit company, which had established a wireless service for its cultivating, transporting,

[70] *Boy Scouts of America*, p. 316.

[71] Susan J. Douglas 1987, pp. 293–295.

[72] George H. Douglas, p. 13.

[73] Aitken 1985, p. 252.

[74] Susan J. Douglas 1987, pp. 285–288, and Barnouw, pp. 58–59.

and marketing activities. RCA, wanting rights to these patents, offered stock in return. Negotiations with all three companies were successfully concluded by the end of March 1921, at which point GE owned 30.1% of RCA, Westinghouse 20.6%, AT&T 10.3%, and United Fruit 4.1%, the rest being publicly held.[75]

RCA was not a manufacturing company, but a communications company that marketed services and, to a lesser degree, products, which were manufactured for it by GE and Westinghouse. Along with the pooling of patents, the companies agreed to divide the manufacturing market; AT&T would manufacture transmitters while GE and Westinghouse would share the receiver market, 60% for GE and 40% for Westinghouse.[76]

RCA and its three principal owner-companies constituted a radio trust that controlled almost all & the important radio patents. This radio trust did not, however, function as planned. First, the patents were not effective in restraining other radio manufacturers. In 1923 RCA sold radio equipment for $22.5 million, which was only 1/6 of total sales in the United States.[77] Second, the manufacturing agreement within the trust did not last. Third, the radio business did not develop as expected. The business of providing point-to-point communications did grow, but this business was soon dwarfed by a service not foreseen: radio broadcasting.

A leading character in the story of radio broadcasting is David Sarnoff.[78] Born in 1891 in a Russian *shtetl*, almost medieval in its primitiveness and poverty, he began a new life in 1900 in New York City, where there were such marvels as electric street lights, electric trolleys, and motion pictures. While working as a messenger boy for the Commercial Cable Company, Sarnoff acquired proficiency with Morse code, and in 1906, just 15-years-old, sought a job as telegrapher with the American Marconi company, then the only commercial wireless service in the city. He got a job with Marconi, but as office boy, not telegrapher.

Though Sarnoff had had to leave school—from age 10 he was the family's breadwinner—he educated himself: he read the letters he was asked to file, looking up unfamiliar words in a dictionary he carried with him; he studied technical books in the evenings; and he spent weekends at the Marconi company's experimental workshop. Before long he moved up to the job of wireless operator, taking increasingly important positions at ship-and-shore stations. On 14 April 1912 he was working as manager and operator of the wireless station of the Wanamaker department store in New York City when he received the message from the S.S. *Olympic*, "S.S. *Titanic* ran into iceberg. Sinking fast." He signaled receipt of the message and asked for details. He tried to reach the *Carpathia*, which the *Olympic* had told him was picking up survivors. He remained at his post for three days, relaying the names of survivors. (See Figure 4.3.)

Radio, and Guglielmo Marconi, received great credit for saving the lives of *Titanic*'s survivors. Marconi confided to his wife, "Everyone seems so grateful to

75 Inglis, pp. 54–55.

76 Inglis, p. 55.

77 George H. Douglas, p. 71.

78 Biographical information comes from Lyons and Barnouw.

Figure 4.3. David Sarnoff in later life (photo courtesy of IEEE).

wireless—I can't go about New York without being mobbed and cheered—worse than Italy."[79] The sinking of the *Titanic* led in July 1912 to a law strengthening the Wireless Ship Act of 1910, increasing the use of wireless at sea. It required also that all wireless stations in the United States be licensed by the Commerce Department.

Sarnoff, too, received credit, and he continued his rapid climb within the company, soon achieving the position of commercial manager. On 30 September 1915 he wrote a memo to Edward J. Nally, vice-president and general manager of the American Marconi company. It reads in part:

> *I have in mind a plan of development that would make radio a "household utility" in the same sense as the piano or phonograph. The idea is to bring music into the house by wireless. … The receiver can be designed in the form of a simple "Radio Music Box" and arranged for several different wave lengths, which should be changeable with the throwing of a single switch or pressing of a single button.*
>
> *The "Radio Music Box" can be supplied with amplifying tubes and a loudspeaking telephone, all of which can be neatly mounted in one box. The box can be placed on a table in the parlor or living room, the switch set accordingly and the music received. There should be no difficulty in receiving music perfectly when transmitted within a radius of 25 to 50 miles.*

[79] In Susan J. Douglas 1987, p. 231. According to Inglis [p. 47], the importance of Sarnoff's role in relaying information about the sinking is exaggerated in the accounts found in, for example, Lyon's biography of Sarnoff or Barnouw's history of broadcasting.

> *Within such a radius there reside hundreds of thousands of families; and … all can simultaneously receive from a single transmitter. …*
>
> *The manufacture of the "Radio Music Box" including antenna, in large quantities, would make possible their sale at a moderate figure of perhaps $75 per outfit. The main revenue would be derived from the sale of "Radio Music Boxes". …*
>
> *The company would have to undertake the arrangements, I am sure, for music recitals, lectures, etc. …*[80]

The memo was read and filed away. More than four years later, in early 1920, Sarnoff—now working for RCA—resubmitted the plan to Owen D. Young, Chairman of the Board. Again, the response was unenthusiastic, but $2000 was appropriated to develop the kind of radio receiver Sarnoff had in mind. But it was not until after the success of the Westinghouse station KDKA, described below, and the sensational broadcast, arranged by Sarnoff, of the Dempsey–Carpentier fight on 2 July 1921 that RCA management finally decided to promote radio broadcasting.[81]

4.2.3 The Beginning of Regular Broadcasting

Before U.S. entry into World War I, a number of amateurs transmitted voice and music. Charles Herrold in San Jose, California did so as early as 1909.[82] In 1915 Lee de Forest started nightly half-hour broadcasts of phonograph music, and in the fall of 1916 he broadcast the Harvard–Yale football game and reported returns from the Presidential election between Woodrow Wilson and Charles Evans Hughes.[83] Another early broadcaster of voice and music was Station 9XM at the University of Wisconsin at Madison.[84]

After the war, such activities resumed, and though a few earlier stations engaged, at least for a short time, in something like regular broadcasting, KDKA stands out as the first station specifically licensed to operate a general broadcasting service and as having been set up to appeal to a large part of the public, not just radio enthusiasts.[85] Moreover, KDKA succeeded as a business venture.

Westinghouse engineer Frank Conrad was a radio amateur before the war. During the war he supervised manufacture of portable transmitters and receivers for the Army, and when he resumed his amateur work after the war, he had the benefit of recently developed transmitting tubes. He began playing phonograph music at regular times, at first once a week, then more often. The interest these broadcasts aroused gave Harry P. Davis, a Westinghouse vice president, the idea of promoting such broadcasting as a stimulus to the sale of radio receivers.[86]

[80] Lyons, pp. 71–72.

[81] Aitken 1985, pp. 469–476.

[82] Mayes, pp. 200–207.

[83] Susan J. Douglas 1987, p. 294.

[84] George H. Douglas, pp. 145–146. Douglas writes, "According to campus tradition, 9XM leaned toward Hawaiian music in those early days since the station sounded twangy anyway."

[85] George H. Douglas, p. 1.

[86] Susan J. Douglas 1987, pp. 299–300.

On application by Westinghouse, the Department of Commerce authorized the company to provide regular broadcasting. The station, with call letters KDKA, was given a channel (360 meters, or 833 kilohertz) away from amateur use. In a shack on the roof of a Westinghouse building in East Pittsburgh, Conrad set up a 100-watt transmitter, and at 8 o'clock in the evening of 2 November began reporting the returns from the Presidential race between Warren Harding and James Cox. Though there was little doubt that Harding would win, the broadcast was nevertheless a great success.[87]

KDKA continued broadcasting daily, at first only one hour each evening. Within weeks Conrad installed a 500-watt transmitter, and the programming gradually expanded.[88] In 1921 Westinghouse set up three other stations: WJZ in Newark, New Jersey, WBZ in Springfield, Massachusetts, and KYW in Chicago.[89] At the end of 1921 there were only 10 general broadcasting stations in the U.S., but with 1922 came the radio craze, and in the first five months of that year, 254 new stations were licensed.[90] The new owners were radio dealers and manufacturers, newspapers, department stores, colleges and universities, religious groups, municipalities, and others.[91] By the end of 1925 more than 700 stations were on the air.[92]

4.2.4 Advertisement and Networks

In the early 1920s the question of how to pay for broadcasting was much discussed. Some means were already at work: radio manufacturers supported stations in order to sell receivers; colleges and universities operated stations as part of their educational mission; and municipalities paid for stations as a public service. Many other possibilities were considered: philanthropic bequests or numerous small donations from listeners; financing by state or federal government from general tax revenues or from a license fee on sets or from a tax on radio equipment, such as tubes; and the sale of advertising.[93]

The last method was first tried by WEAF, AT&T's New York station. AT&T's plan had been not to involve itself with broadcasting content, but simply to offer air time to all buyers just as it offered telephone service without concern for content. But after setting up the station in July 1922, AT&T found that it was not feasible to sell air time unless people were already listening, and it therefore began producing programs itself. Finally, a month after beginning broadcasting, WEAF sold 10 minutes of air time (for $50) to a real-estate company promoting a new apartment development in Jackson Heights, Queens. The following month, two other compa-

87 George H. Douglas, pp. 19–21.

88 Barnouw, p. 71.

89 George H. Douglas, p. 23.

90 George H. Douglas, pp. 26, 32.

91 George H. Douglas, pp. 32–33.

92 Inglis, p. 64.

93 George H. Douglas, pp. 82–84, and Inglis, pp. 65–66.

nies purchased air time, and the number of advertisers steadily increased thereafter.[94] Other stations, however, were slow to follow WEAF's example, and there was strong public opposition to radio advertising. Secretary of Commerce Hoover frequently expressed his fear that "advertising chatter" would pollute the airwaves, and Sarnoff called radio advertising "unseemly".[95] *Printer's Ink*, though hardly a disinterested observer, editorialized in early 1923, "An audience that has been wheedled into listening to a selfish message will naturally be offended. … We are opposed to it for the same reason that we object to sky writing."[96]

A number of factors help explain the eventual dominance of advertising as a means of financing broadcasting. Most of the alternatives required a large role for government in collecting additional taxes or license fees, and at the time most Americans wanted less, rather than more, government intervention. (The then President, Calvin Coolidge, believed that government's "greatest duty and opportunity is not to embark on any new ventures.") A second factor is that in the 1920s there was a great increase in and general acceptance of advertising.[97] Thirdly, advertising more easily won acceptance because in the first years it was quite subdued, without any direct selling, often consisting merely in several statements of the sponsor's name. Still, the issue was undecided in the mid-1920s (only a minority of stations were then selling broadcast time), when a new development gave a great impetus to radio advertising—the coming of networks.[98]

The radio industry wanted nationwide broadcasting, because they could then raise more money by advertising. Listeners, too, like the idea, because they knew from experience that distant stations often offered more exciting programs than those broadcast locally.[99] One possibility, the recording of programs to be rebroadcast by other stations, was little tried, because at the time there was no efficient means of recording programs and people much preferred "live" broadcasts.[100] Another possibility was to license a few very powerful transmitters ("super-power stations"), each capable of reaching most of the nation, but Sarnoff's proposal of this sort at a national radio conference in 1924 met widespread opposition.[101] This left the possibility of forming a "network" of regional and local stations linked so that a program produced in one place could be broadcast simultaneously from many stations and thus heard by listeners across the country. The network might rely on microwave

[94] Barnouw, pp. 108–112. (The station began with call letters WBAY, changing to WEAF on 16 August 1922.) There are earlier examples of what may be considered radio advertising: at both KQW in San Jose, California and 8XK, the experimental station that became KDKA in Pittsburgh, announcers agreed to name record stores on the air in exchange for records [Rhoads pp. 27, 37].

[95] George H. Douglas, p. 85, and Inglis, p. 66.

[96] In Banning, p. 119.

[97] Frederick Lewis Allen 1931, pp. 142–145.

[98] George H. Douglas, p. 89.

[99] Smulyan, pp. 11–36. In the early days of broadcasting, there was the practice of "silent nights" (often one night a week), when stations in one area stayed off the air to allow local listeners to receive distant stations that were usually masked by the local ones.

[100] J. Fred MacDonald, p. 24.

[101] Smulyan, p. 38.

links, and Westinghouse and GE investigated this possibility. Another company, however, was ideally positioned to develop the alternative technology of a wired network.[102]

AT&T already possessed a nationwide network of telephone lines, but radio stations could not simply use telephone lines to share programs. Telephone circuits were designed to carry a limited band of frequencies, 250 to 2500 hertz, since speech restricted to these frequencies is fully intelligible. For music, however, a broader band of frequencies is needed. Violins, for example, do not sound like violins when frequencies above 2500 hertz are removed, nor do percussion instruments sound at all right when frequencies below 250 are missing.[103]

There were other difficulties. A noise level that is hardly noticeable in a telephone conversation can be quite disturbing when listening to music. Distortion—unequal transmission of different frequencies—is less noticeable with speech than with music. Indeed, in telephone circuits, frequencies around 1000 hertz were emphasized in order to achieve greater efficiency in converting, in the receiver, electric energy to acoustic energy. With music, though, all frequencies should be transmitted equally. Finally, there was the problem that the dynamic range (from the softest to the loudest sounds) of telephone circuits was quite limited. Satisfactory transmission of the dynamic range of music (50 decibels or so) required that the weakest of these sounds be above the noise level of the circuit and that the strongest not overload amplifiers and speakers.[104]

AT&T engineers had made substantial progress in these areas in working on public address systems, which made greater demands on transmission circuits than did telephony. Through a number of equipment changes, including the adoption of improved amplifiers, the frequency band was extended to 50 hertz to 5000 hertz. The addition of equalizers to the transmission line reduced distortion. Low-noise circuitry and improved microphones and loudspeakers increased the dynamic range of the transmitted sound.[105]

On 4 January 1923, AT&T made a public test of the idea of linking two radio stations for simultaneous broadcast. They used specially prepared long-distance lines to link WEAF in New York with WNAC in Boston. The experiment was a great success, attracting an estimated 100,000 listeners, but it was not until the following summer that a station (WMAF in South Dartmouth, Massachusetts) began carrying the programming of another (in this case, WEAF) on a regular basis. The advantages of such an arrangement—abundant, low-cost programming for the receiving station, extra income for the producing station—were so apparent that the practice of multi-station broadcasting spread.[106]

[102] Smulyan, p. 39.

[103] George H. Douglas, p. 129, and Fagen 1975, pp. 296–297.

[104] Fagen 1975, pp. 296–297.

[105] Fagen 1975, pp. 296–298. Inductive loading (mentioned in Chapter 1) had to be removed from the lines used for radio programs since the loading restricted transmission to frequencies below 3000 hertz.

[106] George H. Douglas, pp. 129–131.

Permanent networks were presaged in nationwide hookups, such as the 22 stations, from the East coast to the West coast, that carried Coolidge's address on 23 October 1924.[107] Not eager to help its competitors in broadcasting, AT&T often denied them use of telephone lines. RCA tried to build a network using telegraph lines, but these gave poor sound quality. When, however, AT&T retired from broadcasting in 1926, it allowed RCA and others to rent telephone line for broadcasts. Already in 1930, AT&T was providing 35,000 miles of circuits for about 150 stations.[108]

In 1926, RCA, GE, and Westinghouse joined forces to set up the National Broadcasting Company (NBC). The official debut broadcast, on the evening of 15 November, featured the New York Symphony, dance bands, and popular comedians, including Will Rogers, and attracted an audience of 12 million.[109] In 1927, the 48 NBC stations did a business of nearly four million dollars.[110] Soon after its establishment, NBC became in effect two networks: "NBC Red" produced mainly at WEAF in New York, and "NBC Blue" produced mainly at WJZ in Newark.[111] It was not long before two other chains sought to emulate NBC's success: the Columbia Broadcasting System in 1927 and the Mutual Broadcasting System in 1934. Already in the mid 1930s, most of the commercial radio business was done by the networks.[112] NBC prospered under the direction of David Sarnoff. CBS accomplished the difficult task of competing with its rich and well-established rival under the vigorous leadership of William S. Paley.[113]

Network broadcasting was successful in part because improvements in transmission technology allowed improved sound quality for the programming sent over AT&T lines. AT&T invested $19.5 million for equipment (mainly wire lines but also special amplifiers and other devices) used solely for network service.[114] The high cost of using the AT&T lines, a major expense for the networks, was blamed in a 1934 study for having compelled the networks to seek a large amount of advertising revenue.[115] NBC played a major role in winning acceptance of radio advertising: Frank Arnold, appointed director of development in 1926, conducted a campaign to convince radio stations, potential advertisers, and listeners of the benefits of broadcast advertising.[116]

The amount of advertising and the advertising revenues of the networks increased markedly. A survey made at the end of 1932 found that 2365 hours of radio

[107] J. Fred MacDonald, p. 16.

[108] Fagen 1975, p. 299.

[109] Rhoads, p. 48, and Barnouw, pp. 190–191.

[110] Maclaurin, pp. 116–117.

[111] Barnouw, p. 191.

[112] Maclaurin, pp. 116–117.

[113] Paley's decision to provide the programming to local affiliates free of charge (unlike the NBC practice) helped CBS grow rapidly [Rhoads, p. 49].

[114] Eoyang, p. 163.

[115] Smulyan, p. 135.

[116] Smulyan, pp. 72–74.

broadcasting contained 12,546 advertising interruptions, and the total time of these interruptions exceeded the total time given to news, education, lectures, and religion.[117] In the first years of the networks, shows were produced, with few exceptions, either by the network or an affiliated station. Soon the advertising agencies themselves began to produce the radio programs, and in the early 1930s almost all sponsored network programs were produced by advertising agencies.[118] A second-order advertising appeared, as it became increasingly common to use advertisements to attract listeners to a particular show.[119]

The business structure that evolved—several networks, each achieving nationwide coverage through local affiliates—was successful and stable, and this business structure carried over to television broadcasting in the years following World War II.

4.2.5 Government Regulation

In the U.S., as shown saw in Chapter 1, the navy was the principal developer and user of wireless technology in the first two decades of the century. As radio amateurs became more numerous, their transmissions increasingly interfered with navy communications. The navy, therefore, pressed for government regulation of wireless, and in response Congress passed the Radio Act of 1912. Any nongovernmental radio station was required to have a license granted by the Secretary of Commerce and Labor, to restrict its transmissions to some single frequency (presumably freely chosen by the station) within the range of 187.5 to 500 kilohertz (kHz), and to observe certain other operating practices.[120]

When broadcasting stations began to be licensed in 1920, they were all assigned the same frequency, 833 kHz. Since this was outside the amateur bank, interference was at first not a problem since few cities had more than one radio station and transmitters were not powerful enough to reach distant cities. Seeing, however, a swelling tide of applications for broadcasting licenses, Secretary of Commerce Herbert Hoover foresaw that interference between stations would become an immense problem and called a national conference for 27 February 1922.[121] This conference assigned an additional frequency (750 kHz), and at the second national radio conference the following year the entire band from 550 kHz to 1350 kHz was allocated to broadcasting.[122] The conferences also established classes of stations: high power (up to 5000 watts), medium power (500 watts), and low power (100 watts).

The number of stations, however, continued to grow, and in 1925 the interference problem became so serious that the Commerce Department decided that no

[117] Barnouw, p. 239.

[118] Barnouw, p. 239.

[119] Smulyan, pp. 83–84.

[120] Barnouw, pp. 31–33, and Frank J. Kahn, pp. 7–16.

[121] Barnouw, p. 94.

[122] Inglis, pp. 63–64.

more licenses would be issued. After a federal court ruled that same year that the 1912 law did not give the Commerce Department the authority to assign powers and frequencies, the interference problem became intolerable. This "chaos of the airways", as it was called, finally led to the establishment in 1927 of the Federal Radio Commission (FRC) with explicit authority to assign powers and frequencies.[123]

The 1927 law broke new ground in federal regulation of private enterprise. The new legislation decreed that all existing radio transmitting licenses would automatically terminate 60 days after its passage. Thereafter, any sort of radio transmission, whether telegraphy or telephony, whether amateur, point-to-point commercial communications, or broadcasting, would be not a right, but a privilege that would be granted by the federal government only when the proposed transmitting activity was shown to be to the advantage of the public and only for a limited period.[124] In 1934 the Federal Communications Commission (FCC) was created to replace the FRC.

In the U.S. the spectrum was regarded as belonging to everyone. The 1912 radio act required licenses, but did not give the government the authority to deny anyone a license, so that broadcasting, like hunting or fishing, was everyone's right, though a license could be required. When increasing interference threatened to devalue the resource for everyone, some means of allocating radio frequencies and restricting broadcast power seemed necessary. Complete government control of the medium, as was the case in many European countries, was not seriously considered. Another possibility not considered was legal establishment of a market in which rights to spectrum could be traded and where prices would adjust themselves so that demand would just match supply. To some extent, however, such a market arose on its own because a license once granted was seldom revoked and could be transfered to a new owner.[125] In the next two sections, in looking at other countries, we will see a wide variety of forms of government regulation of broadcasting.

4.3 THE ESTABLISHMENT OF BROADCASTING IN OTHER COUNTRIES

4.3.1 The British Broadcasting System

Despite a preeminent position in the science and application of radio, England was slow to establish regular broadcasting. English engineers, such as Oliver Lodge, Oliver Heaviside, and John Ambrose Fleming, were leaders in investigating the relevant phenomena, and until the First World War the English-based Marconi companies dominated the world market for point-to-point wireless communications.[126] The

[123] Inglis, pp. 64–65.
[124] Stephen B. Davis, pp. 171–176.
[125] Aitken 1994.
[126] Pocock, p. 2.

country had a great many amateur radio operators.[127] The Marconi company was eager to provide the service, and, a year before Sarnoff's broadcast of the Dempsey–Carpentier fight, it scored a public relations coup on behalf of broadcasting.

On 15 June 1920 the Marconi company arranged to broadcast a performance of the Australian soprano Nellie Melba, at the time perhaps the world's most celebrated artist (and today memorialized in peach melba and melba toast, besides gramophone recordings). Her voice was heard throughout the British Isles, in much of Europe, and even in Newfoundland. At a station in Norway the signal was so strong that it was relayed further by telephone, and at the Eiffel Tower station a phonograph record was made of her performance.[128] H.M. Dowsett, author of a 1925 book on broadcasting, wrote, "The renown of the singer, the world-wide attention which was given to her performance, the great distances at which good reception was obtained, all combined to give to the Melba Concert the atmosphere of a great initiation ceremony, and the era of broadcasting for the public amusement … may be said … to have been definitely launched on its meteoric career from this date."[129]

For each of its experimental broadcasts, however, the Marconi company had to obtain a special permit from the British Post Office.[130] Finally, in 1922 regular broadcasting was authorized, because, according to the English radio engineer Henry J. Round, "the situation in America forced the hands of the authorities here to allow it."[131] The reluctance of the Post Office to act resulted partly from a wish to profit from the experience in other countries, particularly the United States. Though a stimulus to British action, U.S. broadcasting served more to provide warnings than an example to be emulated, and what resulted was a broadcasting system so different that the U.S. and British systems have ever since been taken to be contrasting types.[132]

One warning was alarm at the "chaos of the ether" being experienced in the U.S. It convinced British authorities of the need for strict control of the number of stations and transmitting power.[133] In May 1922 the Postmaster General announced that he would license eight stations, each with 1500 watts of power. When some two dozen radio manufacturers sought licenses, they were persuaded to combine to form a single broadcasting organization, the British Broadcasting Company (BBC), subject to government regulation.[134] The BBC was a modification of the European pattern of government control of communications in being a public corporation that

[127] Dalton, vol. 2, pp. 37–39.

[128] A. Briggs, pp. 46–47.

[129] In A. Briggs, p. 47.

[130] Dalton, vol. 2, p. 53.

[131] In A. Briggs, p. 59.

[132] A. Briggs, p. 59.

[133] A. Briggs, pp. 67–68.

[134] Dalton, vol. 2, pp. 68–69. In 1926 the BBC as a company was dissolved, and it was replaced as a corporation operating under a royal charter and controlled by a board of governors [Wood, pp. 32–33].

operated at arm's length from the government.[135] By the end of 1924 the BBC, which was supported by license fees paid by listeners and by royalties on receivers, had nine main stations and ten relay stations.[136] Another warning derived from the U.S. was dissatisfaction with advertising, which the BBC prohibited.

Soon after regular broadcasting commenced, Britain, like the United States, experienced a radio craze. In December 1922 there were only 35,000 licensed listeners, but by the end of 1923 there were over half a million and probably just as many unlicensed ones.[137] In 1923 a British journal carried the following complaint: "[The wireless-in-the-home business] is becoming the national pastime. It is one of those epidemics that you sicken for, catch, and spend an inordinate amount of money getting rid of."[138]

Besides the absence of advertising, British programming was different because the BBC had an avowed intention of elevating public taste. Thus musical programs, which predominated in Britain as in the U.S., presented mainly classical music.[139] Announcers, chosen from the upper classes, spoke the King's English and wore evening dress at the microphone.[140] (Women were thought unable to achieve the impersonal touch required of an announcer.) There were many informational and high-cultural broadcasts: talks on books or cinema, discussions, adult education, radio plays, and many programs for special listening groups, such as women, farmers, fishermen, and schoolchildren. Fairly early, news reporting assumed importance. Regular evening broadcasts were preceded by the Big Ben chimes (a sound that would thus become familiar worldwide), and daytime bulletins began during the General Strike in May 1926, when almost all newspapers were closed.[141] The BBC did, it is true, present some variety shows and other lighter entertainment. Another popular type of broadcasting, sports announcing, had a slow start, even though one of the first broadcasts, chosen by the Marconi company to generate great interest, was the Carpentier–Lewis prizefight.[142] Until late in the decade the press prohibited the BBC from prompt reporting of sports results, and the Football Association opposed broadcast of soccer games.[143]

In short, the BBC saw its mission as public service rather than public entertainment. It prided itself on treating the radio audience as humans capable of growth and development, rather than as targets of commercial messages, and its program managers shared with doctors and lawyers the attitude that they should give the public what was good for them rather than what they asked for.[144] Yet listener responses and, more

[135] Lewis and Booth, p. 56.

[136] Bussey, p. 21.

[137] S. Briggs, p. 54.

[138] In S. Briggs, p. 55.

[139] Lewis and Booth, pp. 61–62.

[140] Lewis and Booth, pp. 62–63, and Wood, p. 31.

[141] Lewis and Booth, pp. 57–59.

[142] Dalton, vol. 2, p. 68.

[143] S. Briggs, p. 170.

[144] Lewis and Booth, pp. 58, 69.

importantly, competition from commercial stations based on the Continent (described below) gradually effected a change in BBC programming.

4.3.2 Broadcasting in Other European Countries

In the U.S. the electromagnetic spectrum was regarded as common property, to which all had a right of access, though technical limitations required a governmental role of ensuring fairness. Quite a different attitude predominated in Europe; in most countries, as in England, the spectrum was regarded as government property to be used only by governmental agents.[145] Nevertheless broadcasting took many forms in different countries.

As in England, the governments of Sweden and Denmark quite early took complete control of broadcasting: in 1925 in Sweden (with the formation of *Radiotjänst*, now *Sveriges Radio*), and in 1926 in Denmark (when all private interests in radio were transferred to the public *Statsradiofonien*, now *Danmarks Radio*).[146] In Italy a royal decree of 1923 put broadcasting in the public domain, and government control was effectively exercised throughout the period of Mussolini's rule.[147]

Another government with complete control of broadcasting was the Soviet Union. Regular broadcasting began in August 1922 and was regarded from the outset as a political instrument. The recorded speeches of Lenin (an enthusiastic supporter of radio) were broadcast beginning in December 1922. Because of a shortage of receivers, group listening was encouraged in "houses of culture", stores, and dormitories.[148] In 1929 an external broadcasting service of Radio Moscow began transmitting in German, English, and French.[149]

Hungary was quite unusual in that when regular radio broadcasting began there in the mid 1920s, the country was starting its fourth decade of a similar service carried over wires. In 1893 the engineer Tiridar Puskas began sending transmissions—most of them news—five or six times a day to receivers in subscribers' homes. Puskas later contracted with the Ministry of Posts, Telegraph and Telephone (PTT) to provide the programs over telephone lines for a monthly fee. Studios and transmitting equipment were improved, and the programming (which came to include theatrical and operatic performances) increased in variety, quality, and quantity. The service was much used in the Budapest area. It was supervised by the PTT, which also supervised radio broadcasting when it began.[150]

Regular broadcasting in Belgium began in 1923 with *Radio Belgique*, with programming in French; several years later *N.V. Radio* began providing program-

145 Aitken 1994.

146 Emery, pp. 174, 197.

147 Emery, pp. 260–264.

148 Emery, pp. 381–382.

149 Wood, p. 41.

150 Emery, pp. 394–395.

ming in Flemish. These stations were supported by advertising fees and voluntary contributions from listeners. In 1931 the commercial stations were taken over by a public corporation—under the Minister of Posts, Telegraphs, and Telephones—which had been granted a monopoly on radio broadcasting. Most of its financial support came from an annual license tax on receivers and from a sales tax on radio tubes and other parts; advertising was not permitted.[151] In Norway the evolution of broadcasting was similar; the number of private stations grew from one in 1924, to 13 in 1929, and in 1933 the newly formed Norwegian Broadcasting Corporation (*Norsk Riksringkasting*) assumed public control of the stations.[152] Germany too underwent a somewhat similar evolution, as the government assumed increasing control of broadcasting in the course of the 1920s, and complete control shortly after Hitler came to power.[153]

In the Netherlands a pluralistic system arose under government regulation. In April 1920 the Philips company started weekly broadcasts of music,[154] and by the end of the 1920s, five groups were providing broadcasting: a group of radio manufacturers and radio listeners (HDO, *Hilversumche Draadloze Omroep*), a group of radio amateurs, and three religious organizations (Catholic, orthodox Protestant, and liberal Protestants). Only HDO was supported by advertising.[155]

France, too, nurtured a pluralistic system. Regular broadcasting began in November 1921 from the military station at the Eiffel Tower, and in 1923 the government extended its monopoly on postal and telegraphic services to cover radio. However, the state sold 10-year concessions to private stations.[156] In 1933 there were 14 state-owned stations and 10 private stations; the former were supported mainly by government appropriations, the latter by advertising revenues.[157] International commercial broadcasting existed as early as 1925, when three French stations (Radio Normandie, Radio Paris, and Radio Toulouse) began sending sponsored programs, mainly light entertainment, across the English Channel, and these programs attracted huge numbers of listeners.[158]

The European country whose broadcasting in the 1920s and 1930s most resembled that of the U.S. was Spain. In 1917 Don Antonio de Castilla and others founded *La Compañía Ibérica de Telecomunicación* for the manufacture of transmitting and receiving equipment, and in 1921 this company began experimental broadcasts. In 1923 the government adopted a code for the licensing of broadcasting stations; the broadcasting of advertising was specifically authorized (though limited, by a 1924 regulation, to five minutes in each hour of broadcasting). The first successful station

[151] Emery, pp. 124–125.

[152] Emery, pp. 186–187.

[153] Emery, pp. 295–297.

[154] Dalton, vol. 2, p. 53.

[155] Emery, pp. 140–142.

[156] Thomas, p. 1.

[157] Emery, p. 241.

[158] Browne, p. 51, and Lewis and Booth, p. 62.

was *Radio Ibérica*, an outgrowth of *La Compañía Ibérica de Telecomunicación*; its transmitting power and popular programming made it one of the best known stations in Europe. There followed *Radio Barcelona, Radio Cadiz, Radio San Sebastian*, and many others. Radio became an important part of Spanish culture. In 1933 there were more than 200 radio manufacturers and dealers in Madrid alone, and in 1934 there were more than 60 broadcasting stations. The government did not begin providing broadcasting until after the civil war.[159]

In Luxembourg a radio amateur, François Aneu, began broadcasting in 1924. The popularity of the music and plays he transmitted aroused the interest of a group of entrepreneurs in establishing a commercial broadcasting station in Luxembourg that would attract a large international audience. The group received government authorization in 1930, agreeing to certain programming guidelines and to giving the government a share of the profits. Radio Luxembourg began broadcasting in 1931 and increased its transmitting power to 200 kilowatts in 1933. It broadcast in many languages, and though there were news and other informational programs every day, most of the programming was music. It distinguished itself from other stations by featuring the performances of well-known musicians and, as a result, became known as "Station of the Stars". Soon it was by far the most popular station in Europe and in 1935 reportedly had more listeners in the British Isles than BBC did.[160]

4.3.3 Broadcasting in Asia, Africa, Australia, and the Americas

In 1922 two radio stations, mainly the work of the American businessman P. Osborn, commenced broadcasting from Shanghai department stores. In 1927 the Kuomintang government set up stations in Tientsin and Peking, and shortly afterwards several provincial governments established stations. The Kuomintang party began operating the Central Broadcasting Station in Nanking in 1928, and in 1932 when this station began using a 75-kilowatt shortwave transmitter its broadcasts reached all of China and most of Southeast Asia.[161]

In Japan in 1925 private interests—local newspapers, press agencies, radio-equipment dealers, and individuals—set up broadcasting stations in Tokyo, Osaka, and Nagoya. The following year the Ministry of Communications forced these stations to merge into the Japan Broadcasting Corporation (NHK), a monopoly under strict government regulation. Program content had to be submitted before broadcast, and discussion of political issues was forbidden. Receiver license fees paid for broadcasting, and advertising was prohibited. The first nationwide broadcast was of the accession ceremony of Emperor Hirohito in 1928.[162] At about the same time,

[159] Emery, pp. 345–352.

[160] Emery, pp. 158–161, and Wood, pp. 43–44.

[161] Lent, p. 13.

[162] Lent, p. 62, and Emery, pp. 480–483.

broadcasting began in Korea and Taiwan, in both cases under the control of the Japanese rulers.[163]

In many regions of Southeast Asia, the colonial rulers set up radio stations in the 1920s. In the 1930s broadcasts in the native languages began in several countries: Thailand (which alone in Southeast Asia was not subjected to colonial rule) in 1931, Indonesia in 1933, and Singapore in 1936.[164]

In India regular broadcasting began in 1927 when the Indian Broadcasting Company (IBC), a private concern, set up stations in Bombay and Calcutta. IBC's revenues came from advertising (restricted by the government to ten percent of the time of any program) and license fees.[165] Programs were classified either as European or Indian.[166] In December 1927 the colonial government decreed that no topics of political or industrial controversy be discussed in broadcasts.[167] (At the time there was widespread opposition to English rule—Gandhi's passive resistance movement was in its second decade—as well as incendiary friction between Hindus and Moslems.) Financial difficulties forced liquidation of IBC in 1930, and the government assumed direct control of broadcasting.[168] The mid-1930s saw a marked rise in interest in broadcasting, and in 1939 there were stations operating in six major cities.[169]

Where broadcasting existed in Africa in the 1920s and 1930s, it was almost always run by—and presented in the language of—the colonial power.[170] In South Africa and Kenya, both with large European settler populations, broadcasting became established in the late 1920s.[171] Kenyan broadcasting was mainly in English. In South Africa the postmaster general permitted a commercial station, the African Broadcasting Company (ABC), because of the difficulty in collecting listeners' fees, and by 1934, ABC had achieved popularity and profitability, despite its avoidance of the Afrikaans language. In Egypt broadcasting began with several commercial stations in the late 1920s, which gave way in the mid-1930s to a national broadcasting corporation offering two services, one in Arabic (14 hours a day) and one, aimed at foreigners, in French and English (four hours a day).[172]

Australia's first regular broadcasting was provided under a sealed set system; each broadcaster leased to listeners sets fixed to a single wavelength. The system proved unpopular and was soon abandoned, and in 1924 the postmaster general began licensing two classes of stations—ones receiving most of their revenue from

163 Lent, pp. 14, 44.

164 Lent, pp. 124, 164, 156.

165 Luthra, p. 23.

166 Luthra, pp. 31–36.

167 Luthra, p. 43.

168 Luthra, pp. 50–61.

169 Luthra, p. 66, and Emery, p. 452.

170 Emery, p. 437.

171 Head, pp. 55, 141.

172 Head, p. 18.

listener fees (A stations) and ones financed by private means including advertising (B stations). In 1932 the Australian Broadcasting Company began operating all the A stations under contract with the government; it ran eight metropolitan stations and four regional ones to provide wide coverage in the rural areas. The 40 B stations then operating were financed entirely by advertising.[173]

In New Zealand amateur broadcasters had by 1925 created sufficient interest in the medium to induce the government to establish a public system of broadcasting paid for by receiver license fees. In 1932 the New Zealand Broadcasting Board was established, which gave the country a BBC style of organization.[174]

The development of Canadian broadcasting paralleled that of U.S. broadcasting until the early 1930s when severe restrictions were placed on advertising and the Canadian Radio Broadcasting Commission (CRBC) was established as a government-subsidized entity.[175] Providing motivation were complaints about advertising, fear of cultural annexation to the United States, and the failure of commercial broadcasters to provide service to sparsely populated areas.[176] In its first year, the CRBC established five public radio stations, which broadcast Canadian programs with the intent of knitting the country together.[177]

In most of Latin America in the 1920s, countries tended to adopt the U.S. style of broadcasting, and the U.S. radio industry found there a large market for its equipment.[178] Promoting these developments were U.S. companies, such as Westinghouse, RCA, General Electric, and International Telephone and Telegraph (ITT), and the U.S. government, through consuls and attachés. For example, ITT, which was founded in 1912 to operate a telegraph and telephone system in Puerto Rico and Cuba, set up radio stations in these countries in the early 1920s, and the demonstration broadcasting system set up by Westinghouse for the 1922 celebration of the Brazilian centennial continued operating after that event.[179] In most countries broadcasting was supported almost entirely by advertising. And the popularity in Latin America of U.S. stations, notably KDKA—received from the U.S. by medium-wave or shortwave, or from local rebroadcast—meant that U.S. influence extended to programming.[180] In the mid-1920s there were broadcasting stations in half a dozen Mexican cities, and by 1930 more than 30 stations operated, a dozen of them in Mexico City.[181] In Brazil, 12 stations were broadcasting daily in 1927; Buenos Aires, Argentina, had 20 stations by 1930; and Montevideo, Uruguay, had 19 stations by the same year.[182]

[173] Emery, pp. 492–495, Lent, pp. 274–275, and Potts, pp. 16–18.

[174] Lent, pp. 288–289.

[175] G. Douglas, p. 84.

[176] Emery, pp. 46–47.

[177] Emery, p. 51.

[178] Schwoch, p. 106.

[179] Schwoch, pp. 97–98, 107, and Davis, p. 77.

[180] Schwoch, pp. 110–111.

[181] Schwoch, pp. 106–107.

[182] Schwoch, pp. 103–104, 110–111.

In the early history of broadcasting one may discern four general patterns: a monopoly on broadcasting by a governmental or quasi-governmental agency (as in Britain or the Soviet Union); a pluralistic system, with a governmental agency as one provider of broadcasting (as in France); a pluralistic system with government playing no role other than regulation (as in the U.S. or Spain); and the imposition of a government monopoly after a period of a pluralistic system (as in Belgium or Norway). In every country, of course, the establishment of radio broadcasting was a complex process that can only be hinted at here, as different social settings shaped the emergence and continued evolution of the broadcast medium. Developments of the 1930s are a subject of Chapter 6.

4.3.4 International Cooperation

On an international scale, as on a national scale, effective use of the radio spectrum for broadcasting requires allocation of frequencies and limitation on transmitted power. International cooperation on broadcasting was facilitated by earlier cooperation on other forms of communication. Interest in coordinating telegraph service between countries led to the founding in 1865 of the World Telegraph Union (now the International Telecommunications Union), which gradually extended its jurisdiction to include all international wire and wireless communications.[183] And wireless telegraphy, which of course preceded broadcasting by two decades, had stimulated international cooperation.

In 1903 the German government hosted the first international conference on wireless. The second conference, held three years later and again in Berlin, allocated specific parts of the spectrum for commercial and military use. The third conference, held in London in 1912, adopted more detailed allocations and rules.[184] These conferences helped establish a basic principle; the radio spectrum is public property that must be regulated by governments.[185] The 1912 conference in particular led to regulatory legislation in several countries.

With radio broadcasting in the early 1920s came vastly greater problems of interference from beyond national borders. A European conference was finally held in 1925—when Europe already had some 150 stations on the air—that allocated wavelengths to countries on the basis of area, population, and volume of telegraph and telephone traffic.[186] A much broader agreement was reached two years later at a conference in Washington DC; 80 nations signed the resulting International Radio-Telegraphy Convention.[187]

Not surprisingly, Europe, where the problems of interference were greatest, led the way in achieving and enforcing international agreements. A meeting of 26

[183] Emery, p. 511.

[184] Inglis, pp. 44–45.

[185] Inglis, p. 45.

[186] Dalton, vol. 2, p. 91.

[187] Bussey, p. 28.

European countries in Prague in 1929 resulted in new agreements and the provision for their enforcement by the Bureau Internationale de Radiotelephonie in Brussels. Continuing problems, caused especially by a marked increase in transmitting power, resulted in 1933 in the "Lucerne plan".[188] It was by then clear that technological advances and changes in broadcasting service would continue to require international negotiation.

4.4 RADIO ENGINEERING

4.4.1 Electron Tubes

Among the technical challenges posed by radiotelephony, four stood out: generating a continuous wave of high frequency, modulating it so that it bears an audio signal, separating the signal from the carrier wave at the receiver, and amplifying the electric currents involved in order to extend the range of transmission. All of these challenges were eventually met by the electron tube, but only after a period of intense investigation and development of its capabilities by laboratories of several large corporations.[189]

Both Fleming's diode and de Forest's triode were, as we have seen, devised for detection of telegraphic signals, and they could fairly easily be used to demodulate a radiotelephonic transmission. We have seen also how interest in a telephone repeater stimulated the development of the electron tube as an amplifier, and how wartime demand for wireless communications involved large companies in advancing the radio art.

A specialization of tube type marked the advance of electron-tube technology, as engineers designed tubes for particular functions, such as rectification, amplification, or oscillation, and for particular power levels and frequency ranges. Even for a given application, the number of tube-types increased; for example, RCA marketed 17 different receiving tubes in 1925, 74 different ones in 1933.[190]

In 1926 Gilles Holst and Bernard Tellegen of Philips introduced the pentode in order to solve a problem with the use of the screened grid tube as a high-level amplifier.[191] And in subsequent years a large variety of multi-element tubes, some having seven or eight electrodes, were developed. Another notable advance was the introduction in 1930 by Stuart Ballantyne and H.A. Snow of Boonton Research Corporation of the variable-mu (gradual cut-off) tube, designed to prevent cross-modulation when a strong unwanted signal is very close in frequency to a weak signal.[192] The pentode and the variable-mu tubes were immediate successes; at a

[188] Bussey, pp. 28–29.

[189] Maclaurin, p. 89.

[190] Stokes, p. 18.

[191] Stokes, p. 54, and Thrower, p. 10.

[192] Thrower, pp. 63–66.

major trade show in Chicago in 1931, 73% of all models displayed used pentode tubes and 94.5% used variable-mu tubes.[193]

Until the late 1920s, radios were powered by batteries, usually both dry-cell batteries and acid storage-batteries. The radio astronomer John Kraus described a vacuum-tube receiver he had as a boy in the early Twenties: "The tube filament was lighted by a 6-volt automobile storage battery. … About once a week my father and I … took it downtown to the battery service station where we left it overnight. Hundreds of batteries in row upon row were undergoing recharging at the battery station for other people with radio receivers. … A bulky 45-volt battery was also required for the tube's plate voltage supply. … a new one was required about once a month. This battery could not be recharged. …"[194]

In 1922 GE announced the UV-199 tube with a "low-drain" filament, which made it possible to power radios with smaller batteries. Many manufacturers, beginning in 1923, offered portable radios, but these did not become common, principally because of their high price and bulkiness.[195]

More significant was the development of tubes that could be powered by house current. In 1923 Westinghouse engineers showed that by heating the cathode indirectly one could eliminate the hum otherwise produced in tubes powered by alternating current.[196] It took several years to develop AC tubes that gave reliable service and could be manufactured at reasonable cost, but RCA achieved this in 1927.[197] As a result the radio became a home appliance that could be plugged into the wall.

Though, as we saw in Chapter 1, the Poulsen arc and the Alexanderson alternator were successful continuous-wave transmitters, by 1919 it was clear that the best generator of continuous waves would be the electron tube.[198] Tubes used as oscillators became more and more powerful: in 1915, 25-watt tubes were available; during the war, 250-watt tubes were developed; in 1921, 10-kilowatt water-cooled tubes were being manufactured; and in the mid-1920s the power level reached 100 kilowatts.[199] Other lines of advance were the development of metal tubes, which made it possible to manufacture larger tubes,[200] and the development of smaller, more rugged tubes for portable and car radios.[201] As often in electrical engineering, improvement in electron-tube technology drew on knowledge and techniques from outside the discipline. For example, in order to achieve the high vacuum, both Arnold and Langmuir used the vacuum pump invented by Wolfgang Gaede in Germany in

193 Henney, p. 21.
194 Kraus, p. 6.
195 Schiffer, pp. 63–86.
196 Thrower, p. 13.
197 G. Douglas, p. 49.
198 Aitken 1983, p. 359.
199 G. Douglas, p. 44.
200 Maclaurin, pp. 170–172.
201 Stokes, p. 47.

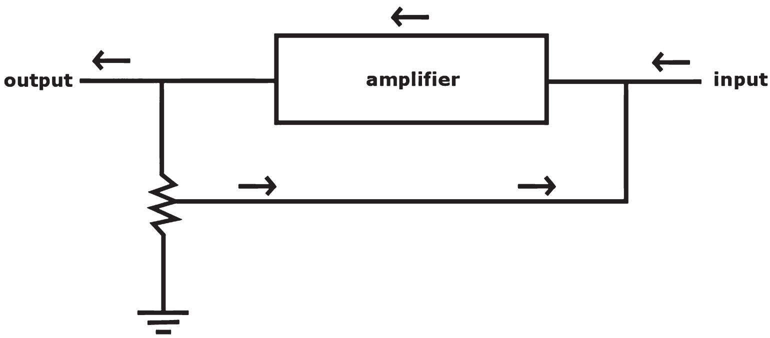


Figure 4.4. Schematic drawing of the principle of the regenerative circuit.

1910.[202] Another example is the method of copper-glass sealing invented by W.G. Housekeeper.[203]

4.4.2 Edwin Howard Armstrong

In November 1919 the Radio Club of America held a dinner at the Hotel Ansonia on 78th Street in Manhattan to honor Edwin Howard Armstrong on his return from military service in France.[204] Though only 29-years-old, Armstrong was already recognized as a preeminent radio engineer; in 1917 the Institute of Radio Engineers awarded him its highest honor for his invention of the regenerative circuit, and earlier that year the French named him Chevalier of the Legion of Honor for his invention of the superheterodyne receiver.

Armstrong was born in New York City on 18 December 1890 and studied electrical engineering at Columbia University under the celebrated Michael J. Pupin. Radio was Armstrong's passion, and about a year before he graduated in 1913 he devised a circuit that revolutionized the art of radio. Using a triode as an amplifier, he fed back part of the output to the input, and thereby obtained much greater amplification. (See Figure 4.4) Armstrong made a further discovery with this circuit; just when maximum amplification was obtained, the signal changed suddenly to a hissing or a whistling. He soon realized this meant that the circuit was generating its own oscillations, and thus that the triode could be used as a frequency generator.[205] The first of these discoveries—of a powerful amplifier—vastly increased the sensitivity of radio receivers, while the second—of an oscillator—led to the use of the electron tube in transmitters and also in receivers for an added function, heterodyne reception.

[202] Maclaurin, p. 90.

[203] Eoyang, p. 46 (which references Fleming 1934 p. 191).

[204] Lessing, p. 127.

[205] Lessing, pp. 66–68.

In 1901 Reginald Fessenden introduced the heterodyne principle to the wireless art.[206] (He also coined the term, from the Greek words for "other" and "force".) With audio frequencies the phenomenon was well known (and exploited every day by piano tuners): if two tones of frequencies A and B are combined, one may hear a tone with frequency A minus B.[207] Fessenden suggested that it be employed in a radio receiver by mixing the incoming radio-frequency wave with a locally generated wave of slightly different frequency, the combined wave then driving the diaphragm of an earpiece at audio frequencies. (Thus mixing a 101 kHz input with 100 kHz generated in the receiver yields a frequency of 1 kHz, which is in the audible range.) Lacking an effective, inexpensive local oscillator, Fessenden could not make a practical success of the heterodyne receiver. With the recognition that an electron tube could serve as an oscillator, the situation changed, and heterodyne receivers began to be built during the world war.

In April 1917 the U.S. entered the war, and Armstrong joined the army, having been offered a captaincy in the Signal Corps.[208] He soon left for Europe with an advance unit to set up the army's communications system. Armstrong had earlier made a thorough study of heterodyne amplification, presenting his findings in October 1916 to the Institute of Radio Engineers.[209] Shortly after his arrival in England, he met with Captain Henry J. Round of British Army Intelligence, who explained to him the progress made in the reception of very weak signals at high frequencies. Armstrong later described the moment of inspiration:

> *The third link came months later as I happened to be watching a night bombing raid [in Paris] and wondered at the ineffectiveness of the antiaircraft fire. I may say that night bombing was not very dangerous in those days, either for the man on the ground or the man in the airplane. Thinking of some way of improving the methods of locating the position of airplanes, I conceived the idea that perhaps the very short waves sent out from them by the motor ignition systems might be used. The unique nature of the problem, involving the amplification of waves shorter than any ever contemplated and quite insoluble by any conventional means of reception, demanded a radical solution. All three links of the chain suddenly joined up [the two other links being Armstrong's earlier study and the information from Round] and the superheterodyne method of amplification was practically forced into existence.*[210]

The essential idea of the superheterodyne is to convert the high-frequency signal to one of intermediate frequency by heterodyning it with an oscillation generated in the receiver, then amplifying that intermediate-frequency signal before subjecting it

[206] Aitken 1983, pp. 58–60.

[207] Thus a middle-C tuning fork, which vibrates at 256 hertz, when sounded together with a 250-hertz middle C from a mistuned piano, produces a 6 hertz "beat".

[208] Lessing, p. 88.

[209] E.H. Armstrong, "A study of heterodyne amplification by the electron relay", *Proceedings of the IRE*, vol. 5 (1917), pp. 145–168.

[210] E.H. Armstrong, "Vagaries and elusiveness of invention", *Electrical Engineering*, vol. 62 (1943), pp. 150–.

to the detection and amplification usual in receivers. For the discovery of the superheterodyne, Armstrong must share credit with others working largely independently (notably Lucien Lévy in France and Walter Schottky in Germany).[211] The same is true for the discovery of the regenerative circuit, but in both cases it was Armstrong's work that brought the discoveries into widespread use.

RCA marketed the superheterodyne beginning in 1924.[212] It gave improved sensitivity and could be tuned by turning a single knob. Not long after RCA began licensing other manufacturers to make the superheterodyne, it became—and remains today—the standard type of radio receiver.[213] Armstrong went on to other achievements. In 1922 he introduced the superregenerative circuit (which found wide use in special-purpose receivers, such as police radio and ship-to-shore radio, and in radar systems), and in the late 1920s and early 1930s he almost single-handedly developed wideband FM technology (described in Chapter 6).

4.4.3 Interference

The development of increasingly powerful oscillator tubes, mentioned above, led to more powerful transmissions, making the airwaves more crowded. There were other sources of interference, notably the navy's arc transmitters (which generated harmonics of the operating frequency) and the regenerative receiver when misadjusted (so that the amplifying tube acted as an oscillator).[214] Another problem was that receivers were not very selective, so that even stations well separated in broadcasting frequency might be received together.

A combination of regulatory means (restricting the number and transmitting power of stations, as discussed in the preceding section) and technical means greatly alleviated the interference problems. Technical means included stabilizing transmitting frequencies, developing directional antennas, expanding the usable spectrum, and increasing receiver selectivity (which will be described in the next section).

Not all stations had instruments able to measure the transmitting frequency accurately, and even if a transmitter was tuned accurately at one time, the frequency would fluctuate slightly because of temperature and humidity changes.[215] Moreover, many stations were unconcerned whether they maintained a fixed frequency or not. Notorious for wandering in wavelength was the Los Angeles station of the evangelist Aimée Semple McPherson. After warnings, the station was closed down by the Commerce Department, whereupon McPherson telegraphed Secretary Hoover:

[211] Alan Douglas, "Who invented the superheterodyne?", *Proceedings of the Radio Club of America*, vol. 64, no. 3 (November 1990), pp. 123–142.

[212] G. Douglas, p. 46.

[213] Inglis, p. 43.

[214] Aitken 1994.

[215] Aitken 1994.

PLEASE ORDER YOUR MINIONS OF SATAN TO LEAVE MY STATION ALONE STOP YOU CANNOT EXPECT THE ALMIGHTY TO ABIDE BY YOUR WAVE LENGTH NONSENSE STOP WHEN I OFFER MY PRAYERS TO HIM I MUST FIT INTO HIS WAVE RECEPTION STOP OPEN THIS STATION AT ONCE[216]

In 1917, A.M. Nicolson of Western Electric built a crystal-controlled oscillator (the mechanical vibration of the crystal controlling the electrical oscillation of the circuit), and in 1924, AT&T's broadcasting station WEAF began using the technique to maintain its operating frequency.[217] The problem of frequency stability was only gradually solved as the crystal oscillators improved in design and became more widespread in use.[218] Radio itself provided a means of disseminating frequency standards; in 1923 the National Bureau of Standards began broadcasting standard frequency signals.[219]

Early transmitting antennas were typically either a simple tower or long wires strung between poles, and the importance of a good grounding system was just beginning to be appreciated.[220] Engineers developed antennas and antenna-arrays that transmitted most of the power in one direction, and in the early 1930s such directional broadcast antennas gradually came into use.[221] Particularly important was the invention in the late 1920s by Hidetsugu Yagi and Shintaro Uda of a directive short-wave antenna; the Yagi antenna, as it is now called, has found wide use for amateur radio, radar, and television.[222] There were improvements also in the antennas used for radio reception. As early as 1923, a company in Dundee, Michigan set up a community antenna system and charged people $1.50 a month to be connected, but the practice did not become common.[223]

When radio broadcasting began, amateurs in the United States, England, and other countries were restricted to the shortwave region (wavelengths of 200 meters and less), thought then to be useless for long-distance communication. Amateurs soon showed this to be quite mistaken.[224] In the early 1920s the American Radio Relay League collaborated with similar amateur organizations in Europe to explore the limits of long-distance radio. In 1923, two-way communication was established between American and French amateurs, and the same year British and American amateurs conducted a 10-day trial that showed conclusively that transatlantic communication was possible using shortwaves at low power.[225] The following year a

216 Barnouw, pp. 179–180.

217 Fagen, pp. 318–319.

218 Aitken 1994.

219 Aitken 1994.

220 Inglis, p. 67.

221 Henney, p. 22.

222 James E. Brittain, "The Yagi-Uda antenna", *Proceedings of the Radio Club of America*, vol. 59 (1985), no. 2, pp. 7–10.

223 Barnouw, p. 154.

224 Barnouw, pp. 151–152.

225 Wood, pp. 22–23, and Dalton, vol. 2, pp. 133–137.

16-year-old British schoolboy established two-way communication with New Zealand.[226]

These results surprised radio engineers, but they were quick to begin investigating the higher frequencies. RCA began to make use of shortwave for transoceanic messages (abandoning longwave), and shortwave began to be used as a link to allow simultaneous broadcast elsewhere. For example, in October 1924 a station in Cape Town, South Africa, rebroadcast a KDKA program.[227] In the early 1930s shortwave and telephone-cable allowed prominent Europeans (including George Bernard Shaw, Benito Mussolini, Leon Trotsky, Pope Pius XI, H.G. Wells, and the Prince of Wales) to be heard live over radio in the United States; in 1931, NBC broadcast 159 incoming international programs, while CBS broadcast 97 such programs.[228]

4.4.4 Advancing the Radio Art

With the growth of broadcasting came a host of technical improvements without which radio might have remained a technology for enthusiasts only. Particularly innovative was AT&T's New York station WEAF, which we have already met as the station that introduced advertising to radio. When AT&T went into broadcasting, which it did in the summer of 1922 with station WBAY (soon renamed WEAF), it was determined to draw on its engineering expertise and talent to raise the technical level of the art. It introduced the condenser microphone (which was quite noise-free), the "volume indicator" (allowing the transmitter operator to maintain a constant audio level), and the simultaneous use of several microphones by means of a mixer or fader.[229] In 1923 it built what is considered the first modern radio studio, with two large rooms for announcers and performers separated by a control room with soundproof glass windows.[230] (See Figure 4.5) Using telephone lines to bring the signal to its studio, WEAF made frequent broadcasts from distant locations, such as the fall 1922 broadcast from Chicago of the Princeton-Chicago football game.[231]

The separation of the studio from the transmitting station led to a specialization among radio engineers; transmitter engineers, in charge of generators, transmitters, and antennas, dealt with high voltages and power, while studio engineers, concerned with microphones, acoustics, and studio controls, dealt principally with low voltages.[232] The specialization contributed to the rapid advance of the radio art, particularly in the operational techniques in the studio. Microphones were improved, signals from several microphones were carefully combined to achieve better tonal quality, and the acoustic properties of the studio were studied and adjusted for particular

[226] Wood, p. 23.

[227] Barnouw, p. 152.

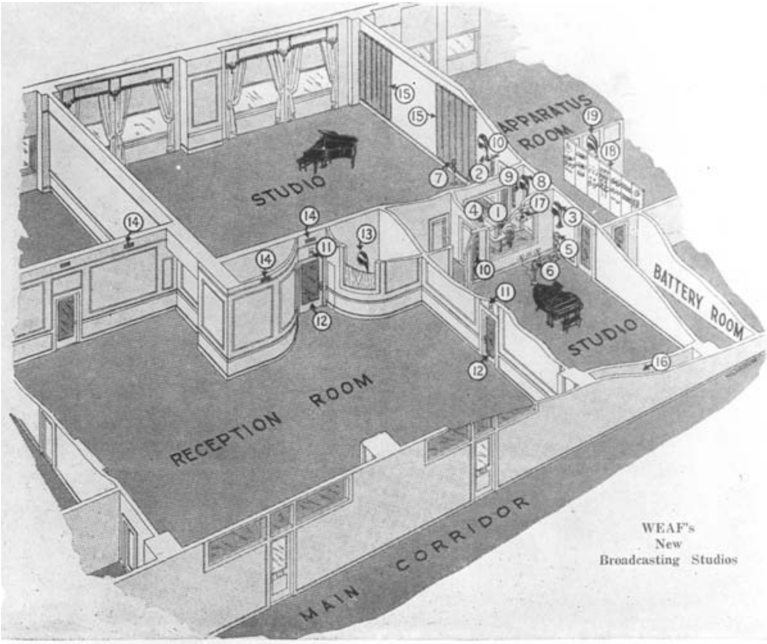
[228] Barnouw, pp. 248–250.

[229] G. Douglas, pp. 36–37.

[230] G. Douglas, p. 37.

[231] G. Douglas, p. 87.

[232] Dalton, vol. 3, p. 57.



Schematic diagram of WEAF studios at 195 Broadway, 1923.

Figure 4.5. Drawing of the WEAF studio (photo courtesy of AT&T Archives).

programs.[233] For broadcasting recorded music, an important advance of the mid-1920s was the use of the newly developed electrical phonograph-pickup. This allowed the electrical signal to be fed directly, after amplification, to the transmitter; earlier, with the acoustic phonograph, one had to use a microphone placed at the horn loudspeaker.[234]

In the early 1920s people usually listened to radio by wearing headphones.[235] The rise of radio broadcasting generated a great demand for loudspeakers, which at first could be met only by combining a telephone receiver with a horn of the type used with phonographs (providing acoustic amplification as a megaphone does). The low volume and poor sound quality of this arrangement prompted a major development effort in several countries. There resulted great advances in audio-frequency amplifiers, in electroacoustic transducers, and in the physical design of loudspeakers.[236] Most influential were GE researchers C.W. Rice and E.W. Kellogg, whose famous 1925 paper not only summarized the state of the art but also presented a

[233] Dalton, vol. 3, pp. 57–64, and Banning, pp. 121–122.

[234] Dalton, vol. 3, p. 64.

[235] Derived from telephone headsets of the type used for land-line work, headphones for wireless receivers underwent considerable development in the period from 1905 to 1925. See Hunt, pp. 73–74, and McNicol, pp. 330–332.

[236] McNicol, pp. 332–341.

new loudspeaker design so good that it soon dominated the market.[237] This so-called electrodynamic speaker first reached the market in 1926 in the Radiola Loudspeaker Model 104.

Another achievement of the mid 1920s was single-control tuning. Radio receivers typically contain two or three circuits that must be tuned to a particular station; in the early 1920s each circuit had to be adjusted individually. In 1925 several manufacturers began selling receivers with single-control tuning, and soon this feature was standard. The level of inventive activity—and the avidity with which inventors sought patents—is indicated by the number of U.S. patents, filed for in the period from 1920 through 1929, having to do with single-control tuning: 57 different patents for a basic solution and many more for improvements on these schemes.[238]

The elimination of static (atmospheric noise) was another area of intense activity, but success was quite limited until the development of FM radio in the 1930s (described in Chapter 6).[239] A few other advances of radio engineering in the 1920s deserve mention. Transmitter efficiency was increased by use of the constant-current system of modulation invented by Raymond Heising in 1921. In the early 1920s AT&T developed the "side band system" for more efficient transmission (in which both the carrier and one side band are eliminated); it was claimed that the system requires only about one-quarter the power otherwise needed.[240] The straight-line frequency tuning capacitor was introduced, which allowed better separation of stations at the high frequency end of the dial.

Two problems with early radios—the tendency of distant stations to fade and swell, and "blasting", which happened whenever one encountered a local or powerful station in tuning the radio—were solved by an effective form of automatic volume control (AVC), invented by Harold Wheeler in 1925.[241] Since AVC caused an apparent broadening of a station's signal, receiver manufacturers provided visual means for accurate tuning, either through a gauge or a light indicator, such as RCA's "Magic Eye". A new feature of radios in 1930 was tone control, whereby the listener could get more effective base by reducing the treble response.[242] In the early 1930s radio-phonograph combinations, dual speakers, and remote control all became available.

These and many other engineering achievements contributed to the growing popularity of radio, reducing the cost of both transmitters and receivers, making receivers easier to use, and improving the sound quality of the broadcasts.

[237] Hunt, pp. 79–82. Hunt points out that Hans Riegger and Edward Wente each independently developed the same type of loudspeaker, but that the publication of their results, in, respectively, *Wissenschaftliche Veröffentlichungen aus dem Siemens-Konzern* and a patent specification, was little noticed.

[238] Harrison 1979.

[239] McNicol, pp. 206–217.

[240] Blake, pp. 326–327.

[241] Frederik Nebeker, "Harold Alden Wheeler: a lifetime of applied electronics", *Proceedings of the IEEE*, vol. 80 (1992), pp. 1223–1236.

[242] Henney, p. 20.

4.5 HOW GOOD IS THIS RADIO?

4.5.1 Quantification in Radio Engineering

At the time of the radio craze in 1922, many people were most interested in range of reception, that is, in what were the most distant stations they could receive. With the increase in number of stations and their distribution over frequencies from 550 to 1350 kHz (following the second national radio conference in 1923), it became important to receive only the station selected, free from interference from stations on neighboring frequencies. As the programming itself became the reason people listened to radio, it became important that the receiver faithfully reproduced the sound in the broadcasting studio. And there were, of course, many other qualities people wanted in a receiver, such as volume of sound, ease of operation, reliability, quality of the cabinet, low price, and portability.

Some of these, such as the last three, could readily be judged by the prospective purchaser, and it was straightforward to compare two radios for distance of reception or volume of sound. But the degree of interference and, especially, the sound quality of the radio receiver were more difficult to judge and seemed fairly subjective. One might guess that the phonograph industry, which had then existed for more than two decades, might have devised an objective means of judging how faithfully a sound was reproduced; it had not done so, partly because the task was difficult and partly because that industry, before it faced competition from radio, did little research and development.[243] As with other areas of subjective judgment, one could, of course, trust the experts, in this case, musicians. Indeed, several radio manufacturers employed musicians to perform "tone tests" to guide their engineers in the design of receivers (though one may suspect that this was done more for its use in advertising than for its utility in receiver design).

There is a long tradition in engineering of turning to quantification in order to judge, and thence to improve, engineering design. Galileo's 1638 study of strength of materials and the quantification of the analysis of vertical water wheels in the decades after 1750 are two prominent examples.[244] In 1883 William Thomson, later Lord Kelvin, said,

> *In physical science a first essential step in the direction of learning any subject is to find principles of numerical reckoning and methods for practically measuring some quality connected with it. I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind. …*[245]

[243] G. Douglas, pp. 157–158.

[244] Galilei, *Two New Sciences* (1974/1638), and Reynolds, esp. pp. 196–265.

[245] Thomson, pp. 73–74.

At the time Kelvin was addressing an audience of engineers, and in some of his own engineering work he showed the value of quantification, notably in studies of submarine telegraph-cables.[246]

From its beginnings, radio posed new problems of measurement. New instruments were required to measure wavelength or frequency, to measure radiated power, and to measure decrement of wireless signals. Even for quantities, such as current and voltage, which had long been measured, there was a need for new instruments, partly because of the extremely low levels of current and voltage that needed to be measured. The importance of "methods for practically measuring" (Kelvin's phrase) is evidenced in one of the milestones of radio science: *The Principles of Electric Wave Telegraphy* (1906) by J.A. Fleming, inventor of the diode electron tube. A second edition, with the augmented title *The Principles of Electric Wave Telegraphy and Telephony*, appeared in 1910.[247] In this volume, the second chapter, on "High frequency electrical measurements", fills 101 pages and begins with a section on "The essential difference between high and low frequency electrical measurements". Fleming writes, "The measurement of high frequency electric currents and potentials and other specific qualities of electric conductors and insulators … to a considerable extent calls for the employment of special instruments and methods", and the chapter goes on to discuss such instruments and methods.[248]

Many of the articles in the early years of the *Proceedings of the IRE* dealt with measurement techniques,[249] and the importance of quantification in the development of radio engineering is shown also by the attention given to it by one of the most illustrious radio engineers, Frederick Terman. He published two landmark volumes in the history of electronics: *Radio Engineering* (1932) and *Measurements in Radio Engineering* (1935).[250] Terman explains in the preface to the latter that these are companion volumes, the one dealing with the physical principles of radio, the other with measuring equipment and techniques.[251]

There is an interesting passage in the preface to Fleming's *The Principles of Electric Wave Telegraphy and Telephony*: "The quantitative aspect of the subject is, however, of special importance at the present time. There comes a stage in the development of the technical applications of scientific discoveries when exact measurement is the very life and soul of further achievements, and when empirical

[246] This quotation, or part of it, has been used many times as an epigraph in engineering books and articles, which in itself is evidence of the importance engineers attach to quantification.

[247] Fleming 1910.

[248] Fleming 1910, p. 111.

[249] "A method for determining logarithmic decrements", "A direct-reading decremeter and wave meter", "A null method of measuring energy consumption in a complex circuit", "The measurement of radiotelegraphic signals with the oscillating audion", "The measurement of radio frequency resistance, phase difference, and decrement", and "On measurement of signal strength" are examples.

[250] Terman 1932, and Terman 1935.

[251] The latter volume reappeared in an enlarged form in 1952: Frederick Terman and Joseph Pettit, *Electronic Measurements* (McGraw-Hill, New York; 1952).

methods and personal skill have to be replaced by careful predetermination and precise measurement."[252]

Accepting Fleming's premise—that there is a stage of development "when exact measurement is the very life and soul of further achievement"—one might argue that, at least as far as radio receivers is concerned, this stage occurred in the years around 1930 rather than the years around 1910, when Fleming wrote these words. The early history of radio receivers is, after all, the story of qualitative improvements: Hertz's spark gap, Edouard Branly's coherer, Fleming's diode detector, H.H. Dunwoody's crystal detector, de Forest's triode detector, Reginald Fessenden's heterodyne receiver, and Armstrong's regenerative receiver. These were fundamentally different designs with readily apparent differences in reception, so that precise measurement of receiver properties had little role either in the design of these receivers or in the choice of one over another. Indeed, what became the standard receiver design, Armstrong's superheterodyne, patented in 1920, was developed by an engineer not much given to quantitative reasoning.

In 1930, however, when the superheterodyne had become the standard receiver circuit, radio manufacturers were competing by making small improvements in quality of reception and by reducing the cost of receivers. Here quantification of the relevant qualities, including the technical means to make precise measurements, was, in Fleming's words, "the very life and soul of further achievement". Requiring precise measurement was not only the performance of individual components, but also the overall performance of radio transmitters and receivers.

Work in other areas—notably telephone engineering and acoustic engineering—was useful. For example, two devices developed by telephone engineers were valuable in testing radios: the thermophone (a frequency generator) and condenser-type microphone. Nevertheless, radio engineers, working for the government and in the private section, needed to devise their own test-and-measurement techniques.

Much of the early work in radio measurement took place at government laboratories. The U.S. Navy took an early interest in wireless and was an important contributor to radio test-and-measurement.[253] Beginning in 1911, which was the year of the Radio Ship Act requiring many ships to carry wireless apparatus, the National Bureau of Standards (NBS) sought methods and developed instruments for measuring quantities associated with radio transmission and reception.[254] Its first tasks were the standardization of a wavemeter and the development of a decremeter (to measure the rate of decay of the bursts of energy emitted by the transmitters of those days). In 1913 a Radio Laboratory Section of NBS was formed, and its activities increased markedly with the outbreak of war in Europe in 1914. In these years the Radio Laboratory produced what became one of the most influential books in the history of radio: NBS Circular 74, entitled *Radio Instruments and Measurements* and issued

[252] Fleming 1910, p. viii.

[253] Navy Department, pp. 90–131.

[254] Snyder and Bragaw.

in 1918.[255] Written under the direction of John Howard Dellinger (Chief of the Radio Laboratory), Circular 74 presented in 330 pages the theoretical basis of radio measurement as well as the instruments and methods of measurement.[256] Britain's counterpart to the National Bureau of Standards, the National Physical Laboratory, was another site of important work.[257]

At least as important as the government-sponsored work, however, were the efforts of scientists and engineers employed in industry. Radio research at AT&T began more than a decade before the organization of Bell Laboratories in 1925, and General Electric supported research in radio.[258] Other large companies that contributed to the improvement of radio test-and-measurement were Westinghouse and RCA, whose Technical and Test Department was established in 1924. Three small companies that had a large impact were General Radio Company, Hazeltine Corporation, and Radio Frequency Laboratories.

General Radio Company was unique in the 1920s in specializing in the manufacture of test instruments for the radio industry.[259] In 1915 Melville Eastham started General Radio specifically to manufacture instruments. In the mid 1920s, as the number of radio manufacturers increased and as the importance of measurements became more and more obvious, the company grew rapidly as it introduced a wide variety of instruments. Before the end of the decade, General Radio had marketed "the first commercial vacuum-tube voltmeter to measure radio-frequency voltages, the first standard-signal generator to measure the sensitivity and selectivity of radio receivers, and the first power output meter to measure the electrical power available to drive their loudspeakers."[260] And in the mid-1930s "came the first commercial sound-level meter to measure the fidelity of the sound produced by the loudspeaker, the first wave analyzer to measure the distortion that prevents faithful reproduction, the first radio-frequency bridge to measure the characteristics of antennas, and the famous General Radio Type 650-A Impedance Bridge, which became an industry standard for measuring components and which set the amazing longevity record … of 26 years without a redesign."[261]

The second small company that had a large impact on radio test-and-measurement was Hazeltine Corporation.[262] Founded in 1924 by Louis Alan Hazeltine, designer of the Neutrodyne receiver, this company prospered as a licensing and consulting firm. The company always placed emphasis on quantitative testing, and several of its employees, including Harold Wheeler, Art Loughren, and

[255] National Bureau of Standards 1918.

[256] Wireless Press made a clothbound version available, and in 1924 a second, revised edition was published.

[257] Pyatt.

[258] See Fagen 1975 and Birr.

[259] The information on General Radio Company comes principally from Donald B. Sinclair 1965 and Thiessen.

[260] Donald B. Sinclair 1965, p. 20.

[261] Donald B. Sinclair 1965, p. 20.

[262] The information on Hazeltine Corporation comes principally from Wheeler 1978 and Wheeler 1982.

L.J. Troxler, excelled in the design of test equipment. Wheeler writes, "From the beginning of the Company laboratory in Hoboken, my creative work was about evenly divided between the end product and the testing of its performance. The latter offered an opportunity for much ingenuity in the development of methods and the design of equipment for accuracy and ease of operation."[263]

The third small company was Radio Frequency Laboratories (RFL) of Boonton, New Jersey. Like Hazeltine, RFL was a consulting and licensing company. It was formed in about 1923 by two outstanding engineers, Lewis M. Hull and Charles Stuart Ballantine, both of whom later served as president of the Institute of Radio Engineers. One of the services RFL performed for its licensees, which included such prominent companies as Stromberg-Carlson and Colonial Radio, was the quantitative testing of popular radio receivers.

Engineers from all three of these companies played a large role in the adoption of standards for the testing of radio receivers, a subject to which our text now turns.

4.5.2 Standardization of Measures of Receiver Performance

The establishment of standards for engineering practice had long been a principal activity of both the American Institute of Electrical Engineers (AIEE) and the Institute of Radio Engineers (IRE).[264] In the 1920s standards for some of the components used by radio engineers were specified by AIEE committees, while the IRE took responsibility for specifying standard tests of the overall performance of radio receivers.

Nineteen-twenty-eight was the first year the IRE published standards for testing a radio receiver.[265] The Receiving Sets Subcommittee of the IRE Standardization Committee, which formulated these standards, included two engineers from Hazeltine Corporation, founder Alan Hazeltine and Chief Engineer William A. MacDonald. Hazeltine, who at the beginning of his career worked in the General Electric Testing Department, practiced a scientific approach to design, including laboratory experiments and measurements. MacDonald had pioneered in test-and-measurement for radio with a paper, "Importance of laboratory measurements in the design of radio receivers" first presented at an IRE meeting in November 1926 and published the following year in *Proceedings of the IRE*.[266]

In that paper MacDonald wrote: "It is obvious that an exact knowledge of the individual and over-all characteristics of a radio receiver should be accurately known, yet experience shows that many manufacturers, including some of the largest, are practically unaware of the exact performance of the apparatus they

[263] Wheeler 1982, p. 348.

[264] See McMahon, esp. pp. 79–92, 154–156.

[265] Wheeler 1982, pp. 351–355.

[266] W.A. MacDonald.

produce." MacDonald did not here consider tests of overall performance, but described 13 fundamental measurements of receiver subsystems. (The instruments required were a precision wave meter, a radio frequency oscillator, an audio frequency oscillator, and a vacuum-tube voltmeter.) Two GE engineers, who apparently took umbrage at MacDonald's statement that some of the largest manufacturers were "unaware of the exact performance of the apparatus they produce", published a description of some of the test procedures—namely, the tests of overall performance—in use at General Electric.[267]

A paper that appeared the following year confirmed both MacDonald's claim that quantitative tests of radio receivers were sorely needed and the objection of the GE engineers that Hazeltine Corporation was not the only company developing such tests. Written by A.F. Van Dyck and E.T. Dickey of the RCA Technical and Test Department, the paper "Quantitative methods used in tests of broadcast receiving sets" described procedures in use at RCA.[268] The authors wrote:

> *In radio receiving set engineering, numerous obstacles to quantitative measurement work were present which required the development of new methods and new apparatus. … As a result of this lack of means of measurement, receiving set tests during the first twenty-five years or so of the radio art were conducted in a necessarily crude, practical way, chiefly by so-called "listening tests," wherein the receiving set was operated exactly as in actual service, and observations made by ear.*

It was in that year, 1928, that the IRE published its "Standard tests of broadcast radio receivers".[269] The members of the Receiving Sets Subcommittee—Dellinger was the chairman—did not seek a single "figure of merit" to guide purchasers of radios. Instead they sought to specify measures of three fundamental properties of receivers—sensitivity, selectivity, and fidelity—with the expectation that such measures would help engineers improve radio design and would aid radio distributors and dealers in the "selection of apparatus for specific service conditions".

Sensitivity of a receiver at a given broadcast frequency was defined as the input signal in microvolts necessary for a standard output; the sensitivity characteristic of a receiver is a graph of the sensitivity for various value of carrier frequency. (See Figure 4.6.) Selectivity was defined as the ability of a receiver to distinguish between signals on two slightly different frequencies, and it is expressed as a curve giving the signal strength required to produce standard output for frequencies around a selected frequency. Fidelity was defined as the degree to which a system accurately reproduces at its output the audio signal which is impressed upon it. To measure fidelity at a given carrier frequency, the engineer varied the modulation frequency from 40 to 10,000 hertz while keeping the field intensity fixed and measured the ratio of output voltage at the modulation frequency of measurement to the output voltage at the modulation frequency of 400 hertz.

[267] "Discussion on importance of laboratory measurements in the design of radio receivers (W.A. MacDonald)."

[268] Van Dyck and Dickey.

[269] Institute of Radio Engineers 1928.

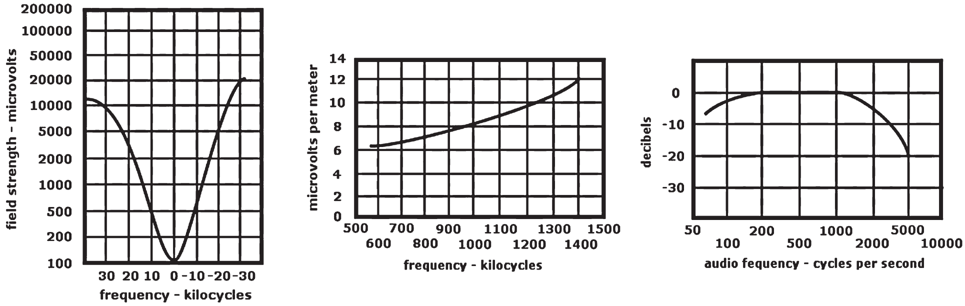


Figure 4.6. The sensitivity characteristic of a receiver is a graph showing, for each value of the carrier frequency between 550 and 1450 kHz, the input signal in microvolts necessary for standard output from the receiver. The selectivity of a receiver is given by a set of graphs, one for each carrier frequency. Each graph shows how the response of a receiver falls off for frequencies away from the selected frequency (by graphing the ratio of input required for standard output at a frequency off resonance to the input required at resonance as a function of the number of kilocycles off resonance.) The fidelity of a receiver is given by a set of graphs, one for each carrier frequency. Each graph gives, for each audio frequency between 40 and 10,000 Hz, the ratio of output voltage at that frequency to output voltage at 400 Hz.

The Receiving Sets Subcommittee gave much attention to standardizing the procedures for these tests. A set of standard test frequencies for sampling the carrier-frequency range was specified; modulation was set at 30%; a "standard dummy antenna" was defined; and so on. The procedures for these tests were refined and other tests were specified in subsequent publications by the IRE Standards Committee. The Receiving Sets Subcommittee became the Technical Committee on Radio Receivers, E.T. Dickey became chairman, and a revised report on standard tests was published in 1931.[270] The following year Harold Wheeler became chairman and considerably revised reports were published in 1933 and 1938.[271] The tests discussed and agreed upon by these committees have, with only minor changes, remained in use for decades.[272]

Thus, the performance of radio receivers was quantified, and quantified in a standardized way. What difference did this make to the radio industry?

Measurement was important in the design of radios, making it easier for engineers to design the system as a whole and to optimize overall performance while keeping the projected cost of a receiver at a particular level. Measurement helped also in understanding how a subsystem worked and how its performance was related to that of other subsystems; it made clear that in some cases there are trade-offs, as with selectivity and fidelity (a receiver that is extremely selective will necessarily have poor fidelity at high audio frequencies, and, conversely, a receiver with excellent fidelity at these frequencies cannot be extremely selective).

270 Institute of Radio Engineers 1931.

271 Institute of Radio Engineers 1933a, Institute of Radio Engineers 1933b, and Institute of Radio Engineers 1938.

272 Wheeler 1982, pp. 351–355.

For the engineering community as a whole, measurement made possible unambiguous communication. As Van Dyke and Dickey wrote in 1928, "It is the belief of the authors that the day is not far distant when it will be possible for radio engineers to use one universally comprehensible language in speaking of receiving set measurement and performance."[273]

Measurement made it easier to monitor the manufacturing process, permitting such things as statistical quality control and reliability estimation. Being able to describe the output of a manufacturing process quantitatively may allow one to set production standards in order to maximize efficiency (aiming to get a high percentage of manufactured sets with acceptable performance without raising manufacturing costs greatly).

Finally, for the purchasers of radios, measurement made it easier to evaluate and compare radios. And the improvements in radio design and manufacturing meant that in the 1930s, the radio industry produced high-quality, low-cost receivers. In 1925 the average price of a radio was $85; in 1940 it had fallen to $40. In the same period, the percentage of homes with radios increased from 10 to more than 80%, and this despite the economic hardship of the Depression.

Thus by the end of the decade there were tests of receivers that were objective in the sense that the results depended only upon the receiver being tested and not by whom or where the tests were performed. This benefited consumers, manufacturers, and engineers, and was an important step in making radio engineering more scientific.

4.6 RADIO'S GOLDEN AGE

4.6.1 A Radio in Every Home

As explained above, RCA was established without thought of radio broadcasting, yet already in 1922 it made $11 million from its sales of radio receiving equipment, far exceeding its business from marine and transoceanic communication.[274] At the beginning of the 1920s, radio-parts manufacturing was a bigger business than radio-set manufacturing, as most amateurs preferred to build the sets themselves. In 1923 there were some 5000 radio-parts manufacturers in the United States. As radios became more common, radio-set manufacturing became a bigger and bigger business. The number of radio manufacturers, however, peaked at about 200 in mid-decade and then stabilized at about 80 in the late 1920s and early 1930s.[275]

RCA, Crosley, Atwater Kent, Philco, Zenith, Magnavox, and Stromberg-Carlson were leading manufacturers. Though plants making radio parts were geographically scattered, radio-set manufacture was concentrated around New York and Chicago. (In 1930 approximately 1/3 of production took place within 25 miles of New York

[273] Van Dyck and Dickey, p. 1530.

[274] Barnouw, p. 115.

[275] Eoyang, pp. 75, 101–103.

City, and 1/3 within 30 miles of Chicago.)[276] Annual sales of radio equipment in the U.S. totaled $60 million in 1922, more than doubling in each of the two following years and reaching $843 million in 1929.[277] Radio broadcasting, too, was big business, grossing $172 million in 1929.[278]

In 1930 the Justice Department brought an anti-trust suit against RCA, GE, Westinghouse, and AT&T, demanding that the companies disentangle themselves and end their patent-pooling agreement. This prompted RCA to begin making radio patents available to all and to reduce the royalties it required.[279] This was one factor in the decline in the average price of radio receivers, and despite the Depression the number of homes containing a radio increased from 40% in 1930, to 72% in 1934.[280] Both radio manufacturing and radio broadcasting remained healthy businesses through the 1930s.

Radio did not lead the way in making home entertainment into big business; rather; it followed the phonograph. The relationship between the two industries has changed over time. Initially, the phonograph helped prepare the way for radio. By 1920 many U.S. homes contained a phonograph, and annual record sales grossed $105 million.[281] Radio was able to take advantage of the performers and audiences cultivated by the phonograph industry. Of course, broadcasting went beyond music. Sports, news, and weather reporting were popular because of the timeliness of the information. Certain programs, such as variety shows and discussions, appealed because they were broadcast live. But many of the new forms of programming might have been provided on phonographs: audio plays (translating the German term *Hörspielen* rather than using the English "radio plays"), lectures, exercise programs, and advice on running a farm or home. The high price of phonographs—usually 75 cents for two 4-minute sides—is probably the principal reason these forms were not thus provided.

Radio, however, did not confine itself to the new forms of information and entertainment, and the phonograph industry felt threatened. The new competition spurred innovation in phonograph technology, notably the use of electronic amplification, which provided better fidelity and much greater volume of sound.[282] Because jazz was not often played over the radio, record companies in the 1920s turned increasingly to jazz.[283] Nevertheless, the phonograph industry went into a steady decline beginning in 1927 that did not end until a decade or so later with the coming of jukeboxes and disk jockeys.[284] Since then the phonograph and radio industries

[276] Eoyang, pp. 130–132.

[277] George H. Douglas, p. 75.

[278] Eoyang, p. 167.

[279] Barnouw, pp. 252–257.

[280] Eoyang, p. 67.

[281] Lubar, p. 174.

[282] G. Douglas, pp. 157–158. The electrical phonograph began to be marketed in 1926 [Lubar, p. 175].

[283] Barnouw, p. 129.

[284] G. Douglas, p. 159. More than 100 million records were sold in 1927, but only some 6 million in 1932 [Lubar, p. 177].

Figure 4.7. Radio in the home (photo courtesy of the Library of Congress, LC-USZ62-108097).

have been less antagonistic than symbiotic, with the former providing programming material, the latter stimulating sales of particular records and promoting rapid change in musical tastes.

A radio was much more exciting than a phonograph, offering both more choices and unpredictability. By the end of the 1920s radio had become, in the words of historian David Nye, "a substitute hearth, clustering the family together to hear crackling reports from great distances, baseball games, and the latest music."[285] As Nye goes on to say, "Radio drew the family circle together to hear about the outside world; broadcasts both stimulated and silenced conversation." (See Figure 4.7.)

We have already reviewed, in the first two sections of this chapter, the rise of radio broadcasting in the economically prosperous 1920s. Yet when the Depression set in after the stock market crash at the end of 1929, radio continued its growth.[286] Three factors help to explain the continued growth. First, with the Depression came steep declines in employment by vaudeville and theater companies, the recording industry, and the motion picture industry, and this made more talent available to radio, raising the level of professionalism in radio programming.[287] Second, though people in the 1930s had to forgo things they had enjoyed in the 1920s, almost no

[285] Nye, pp. 282–283.

[286] Radio broadcasting grossed $172 million in 1929, declined slightly the following year, then continued its growth [Eoyang, p. 167].

[287] Czitrom, pp. 79–80, and Eoyang, p. 168.

one gave up listening to radio.[288] Third, it was in the early 1930s that advertisers in large numbers turned to radio: its share of total advertising expenditure grew from 1.4% in 1928, to 6.6% in 1931, to 12.3% in 1935.[289]

4.6.2 The Expansion of Programming

Radio programming underwent a rapid evolution in the 1920s and early 1930s. As mentioned earlier, classical music accounted for a large part of broadcast time in the 1920s. Some stations broadcast little else; for example, beginning in 1921, KYW in Chicago broadcast opera exclusively, afternoon and evening, six days a week, to great popular acclaim.[290] Later in the decade, NBC, guided by its musical advisor Walter Damrosch, made great efforts to bring classical music to the masses.[291] A result was that, while in 1920 only a minority of Americans had attended an opera or an orchestral performance, by 1930 classical music had become a widespread form of entertainment.[292]

Commercialization of broadcasting made listener preferences more important, and, as a result, programming time given to classical music, particularly opera, decreased, while that given to jazz increased.[293] Other types of music became familiar. Hawaiian music was often heard, and to the surprise of many station managers, "hillbilly" or "barn dance" music (what we now call country music) became extremely popular.[294] The media historian Daniel Czitrom has written, "For both artist and audience, radio broke down the formidable geographical and racial barriers that had separated the various rich veins of American folk music."[295]

Here, and elsewhere, the establishment of the networks was having an effect. According to the historian Susan Smulyan, "Relatively unknown recording artists … gave way to already celebrated urban vaudevillians; regional sponsors were replaced by national sponsors; listeners' letters ceded influence to the new art of audience surveys."[296] It is significant that in the late 1920s when most programming was unsponsored, it was the sponsored programs (such as the Happiness Boys, the Eveready Hour, and the Ipana Troubadours) that were most popular with listeners.[297]

Broadcasters worked to cultivate the female audience. In 1925 Anna J. Peterson broadcast recipes over KYW in Chicago, and in 1926 the Buttericks company told

[288] Nye, p. 283.
[289] Smulyan, p. 131.
[290] Barnouw, p. 88.
[291] G. Douglas, p. 160.
[292] G. Douglas, p. 153.
[293] Smulyan, p. 97.
[294] Smulyan, p. 23.
[295] Czitrom, p. 85.
[296] Smulyan, p. 94.
[297] Smulyan, p. 97.

how to make winter attire over WJZ in New York. The relatively young profession of home economics assisted in devising programs to attract women listeners.[298] Three radio personalities offering advice to women became extremely popular: Aunt Sammy, Betty Crocker, and Ida Bailey Allen.[299] The greatest success in gaining women listeners came in the 1930s, with the soap opera (so called because several sponsors were manufacturers of laundry soap).

Another type of programming to undergo rapid development was news reporting. In the 1920s newspaper editors thought of radio as an ally, stimulating interest in events that people would want to read about in the papers,[300] but the early 1930s saw a bitter clash as the press sought to prevent radio stations from subscribing to wire services. In the 1930s, the Depression, the New Deal, and European crises stimulated interest in news. Lowell Thomas, whose nightly news report began in 1930, became extremely popular, as did *The March of Time*, begun in 1931, which combined news and drama by using actors to recreate, in the studio, news events of the preceding week. Radio certainly made political leaders better known. For example, in 1931 NBC broadcast 28 appearances by the President, 37 by cabinet members, and 71 by congressmen.[301] In 1939 a survey found that 70% of U.S. citizens relied on radio as their prime source of news and 58% thought it more accurate than the press.[302] It should, however, be pointed out that extensive and detailed news reporting over the radio did not become common until the very end of the 1930s; H.V. Kaltenborn's 102 broadcasts in 18 days concerning the 1938 Munich crisis set a memorable example.[303]

The largest change in programming in radio's first 15 years was the rise of serial drama, an innovation described in the first section of this chapter. From 1931 to 1940, radio drama (including situation comedies, dramatic serials, and documentaries) increased from 15 to 23% of evening programming, and from 9 to 65% of daytime programming (almost entirely in the form called soap operas).[304] The gain in evening programming came at the expense of music, which declined in the evening hours from 56 to 25% of program time. The gain in daytime programming for drama came at the expense of talk shows, which declined from 63 to 16% (although talk shows increased in evening programming from 15 to 34%).[305] Some radio drama aimed at a young audience: in 1932 came *Buck Rogers in the Twenty-Fifth Century*, considered one of the first great children's serials of the air.[306]

The first 15 years of broadcasting saw a professionalization of the process. In addition to improvements in sound quality, there were more elaborate productions,

[298] Smulyan, p. 88.

[299] Smulyan, pp. 89–91.

[300] G. Douglas, p. 98.

[301] Barnouw, p. 250.

[302] Czitrom, p. 86.

[303] Smulyan, p. 156.

[304] Czitrom, p. 84.

[305] Czitrom, p. 84.

[306] Dunning, pp. 101–102.

with more actors, better use of music and sound effects, and more careful scripting and rehearsing.[307] (In early radio, ad-libbing was common.) There was careful allocation of time to program and commercial breaks, and there was increased use of audience surveys.[308] There was the emergence of radio stars and also the coming of celebrities from vaudeville or the record business to radio. The first 15 years of broadcasting also saw the emergence of other uses of radio.

4.6.3 Educational and Other Uses of Radio

When full-length movies began to be made at the time of World War I, many people thought they would have great educational value. A clergyman said that a motion picture "teaches history by lightning", and D.W. Griffith, pioneering film director, wrote in 1916, "Six moving pictures would give these students more knowledge of the history of the world than they have obtained from their entire study."[309] When radio broadcasting began, there were even higher expectations of its educational value.

By the end of 1922 the Commerce Department had granted 690 broadcasting licenses, and 74 of them had gone to educational institutions.[310] Most of the programming on the educational stations was general information (including weather and crop reports, advice on home economics and child rearing, and religious services) and entertainment, but there were attempts at offering formal education over the air.[311] Station WHA of the University of Wisconsin at Madison offered instruction for adults in many subjects and, during the Depression, produced the *Wisconsin School of the Air* (heard by more than 40,000 schoolchildren in the 1934-35 school year). Station KSAC of the Kansas State College of Agriculture and Applied Science, established in 1924, offered 10-week courses in its *College of the Air* and received 11,000 enrollments in its first year.[312] The networks, too, made some effort to use the new medium for educational purposes; for example, CBS's daily *American School of the Air* sought to educate children through radio drama.[313]

The late 1920s were hard on educational stations. The FRC reallocations of 1927 and 1928 left almost all educational stations with only part-time frequency assignments, and in most cases only daylight hours, and many sold out.[314] The FRC requirement of the early 1930s that each station have frequency control equipment (so that broadcast frequency would not stray) was a hardship for weakly financed stations.[315] This and the straitened economy of the Depression years caused other

[307] Smulyan, pp. 118–119.

[308] Smulyan, pp. 116–117, 119.

[309] Griffith, pp. 30, 32.

[310] G. Douglas, pp. 34, 142.

[311] G. Douglas, pp. 142–143.

[312] G. Douglas, pp. 147–148.

[313] MacDonald, p. 26.

[314] Barnouw, pp. 218–219.

[315] Smulyan, pp. 130–131.

educational stations to close. In 1930 the National Committee on Education by Radio was formed "to save or to recover for the uses of education a fair share of the radio broadcasting frequencies".[316] Few proponents of educational radio were pleased with the situation in the mid-1930s; the networks offered little educational programming, only 38 of some 200 educational institutions to receive licenses by the end of 1936 were still operating, and formal education over the air had all but disappeared.[317] Yet their hopes had not been entirely misplaced; the news reporting and some other network programs had obvious educational value, and many of the educational stations that had survived were very successful.

From its earliest days, radio was valued as purveyor of timely information, especially weather forecasts and financial reports. Though urban dwellers had other means of acquiring such information, as from posted storm warnings or stock tickers, radio made timely information available over the entire nation. From the early 1920s the U.S. Department of Agriculture supplied weather and crop reports to radio stations, and in 1922, 35 of 36 licensed stations were broadcasting USDA market reports, 20 of them weather reports.[318] In the spring of 1923, Frank E. Mullen started a regular KDKA program of market and weather reports for farmers, and four years later Mullen began to produce for NBC the *National Farm and Home Hour*.[319]

Radio made it possible to communicate with trains and automobiles, just as it had done with ships at sea. In 1928 the police department in Detroit, Michigan began dispatching squad cars by radio. In November 1930, police departments in 29 cities had radio systems, and another 22 cities were in the process of setting up such systems.[320] (See Figure 4.8.)

At about the same time began the relationship between radios and ordinary cars that would decades later keep the radio industry vigorous in the age of television. In 1928 William Lear (known today mainly as the designer of the Learjet) built a radio that could be placed in an automobile and convinced a battery manufacturer in Chicago, Paul Galvin, to begin manufacturing it. The Galvin Manufacturing Company, which in 1929 adopted the name Motorola, succeeded spectacularly in opening up this new market for radio.[321] In 1930 only 34,000 car radios were sold, in 1932 the number reached 140,000, and the following year it jumped to 724,000.[322] (It was reported in 1932 that free-wheeling—then the rage of the automotive world in order to save gasoline—was causing problems with the charging system in cars equipped with radios.)[323]

Radio soon came to play a number of other roles. As early as 1910 the military wireless station atop the Eiffel Tower was sending out daily time signals. The

[316] In Barnouw, p. 261.
[317] G. Douglas, pp. 142–152.
[318] Smulyan, pp. 21–22.
[319] Morris, pp. 481–482.
[320] Henney, p. 20.
[321] G. Douglas, pp. 50–51.
[322] Eoyang, p. 69.
[323] Henney, p. 21.

Figure 4.8. Police radio (photo courtesy of the Schenectady Museum & Suits-Bueche Planetarium).

German station at Nordreich started a time service shortly afterwards, and in 1912 a conference was held in Paris to plan a worldwide time-signal service. Marine navigation depended upon accurate knowledge of the time, and for centuries the principal goal of navigational science was the development of an accurate ship chronometer.[324] Radio quickly met this need with high accuracy and over most of the globe. Radio direction-finding (discussed in Chapter 1) made possible a radio compass. Radio provided many other navigational aids, some of which are described in Chapter 5.

Radio links extended the telephone system. In 1920, AT&T established telephone service to Catalina Island, 30 miles off the California coast, using a radio link.[325] In 1931 RCA completed an inter-island communication system, using ultra-high-frequency radio, in Hawaii.[326] Illustrating a move to shorter wavelengths, in 1931 a microwave (18-centimeter wavelength) telephone circuit was established across the English Channel. Commercial radiotelephone service between passenger ships and shore began in 1929 and was commonplace for service in the North Atlantic by 1933.

4.6.4 The Social Impact of Radio

Any technological system arises in a particular social setting that partly determines its form and function. In turn, the technological system comes to influence the social setting. Much of this chapter has dealt with the shaping of radio broadcasting. Following is a brief consideration of the social impact of the new technology.

[324] Part of this story is told in Dava Sobel's *Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of His Time* (New York: Walker and Company, 1995).

[325] Barnouw, p. 106.

[326] Henney, p. 20.

In winning rapid acceptance, radio drew on pre-existing interests in music (especially the type purveyed by the phonograph industry), news, weather, and sports. Radio, in turn, increased popular interest in these forms of entertainment and information. People heard a great deal more music than ever before, people knew more about national and international affairs than earlier, and people followed professional and college sports more closely than an earlier generation could have imagined possible. Besides music, news, and sports, radio offered variety shows, serial drama, and talk shows, creating a world of entertainment that gave people things to be interested in and to talk about. Radio helped people understand a rapidly changing world, provided role models, and, at least to some degree, increased tolerance for social differences.

Radio gave the U.S. a nationwide culture; people in every state were spending part of each day listening to the same music, news, and other programs. It is true that some printed materials (especially magazines),[327] traveling shows (vaudeville, plays, circuses, chautauquas), phonograph recordings, and early silent films catered to a national audience before radio broadcasting, but radio reached many more people, occupied them for many more hours, and every day gave millions across the country the feeling of being present at the same event.

Radio did a great deal to diminish the rural-urban separation. In 1916 William H. Wilson, a sociologist who studied rural communities, wrote, "The widest divergence between city and country is a spiritual one; by this I mean a contrast in the general attitude of either population toward life as a whole."[328] Radio reduced that divergence, principally by making urban culture available everywhere, but also by doing the same for some aspects of rural culture, notably country music.[329]

The economic impact of radio should not be forgotten. The U.S. economy of the 1920s saw the first economic boom driven by mass-market consumer products. Radio was an important product; in 1925 more than 1300 different models of radio receiver were being manufactured.[330] In the Great Depression the radio industry was a relatively stable part of the economy; the number of radios manufactured in 1934 was only 8% below the 4.4 million manufactured in 1929, and gross income from radio broadcasting fell only 21% from 1929 to 1932.[331] A great many women found employment in radio manufacturing; indeed in radio-tube plants, women laborers outnumbered the men.[332]

Another economic effect of radio, in the late 1920s and 1930s, was stimulation of consumer demand through advertising. The products most advertised on radio

[327] Nationwide magazines flourished at the turn of the century, and by 1920 there were 15 magazines with circulation exceeding a million (Lubar p. 32).

[328] In William Benton, publisher, *The Annals of America* (Encyclopaedia Britannica, Chicago; 1968), vol. 14, p. 6.

[329] G. Douglas, pp. 177–179.

[330] Eoyang, p. 209.

[331] Eoyang, pp. 75–76, 167. Because the average price of a radio fell from $134 in 1929, to $37 in 1934, the aggregate value of radio production fell from $592 million in 1929, to $151 million in 1934.

[332] Eoyang, p. 133.

were those people bought often: low-priced, packaged consumer goods, mainly food, drugs, toiletries, and tobacco.[333] Radio advertising in the U.S. turned out not to reduce, and may indeed have stimulated, expenditures for newspaper and magazine advertising, which increased markedly in the period from 1927 to 1931.[334] The role of radio as an essential home appliance and as an advertiser for consumer goods is further discussed in Chapter 6.

In some areas, radio's social influence was not as great as hoped, nor was it entirely beneficent. Many pioneers of radio broadcasting, who believed that radio would elevate musical tastes, were disappointed. Most of the proponents of educational radio were disappointed. And many social critics, especially the people wanting large political or social changes, were disappointed. In 1926 H.V. Kaltenborn, journalist turned radio commentator, wrote that "radio has been extremely timid about permitting the broadcasting of anything that contravenes the established order."[335] Birth control, prostitution, and race relations were among topics considered improper for radio. The historian of broadcasting Erik Barnouw writes, "Along with mah-jongg and Florida real estate and the hip flask, radio was reflecting the nation's determination not to look at its problems."[336]

Probably the most common criticism of commercial radio was that its programming appealed to the "lowest common denominator" of the listening audience. A 1934 study by Jerome Kerwin of the University of Chicago complained that "in order to secure the large audiences which the advertisers want and will pay for, it is necessary to stage the least elevating types of program during the best listening hours." The opposition, in Kerwin's critique, between radio's potential to uplift the audience and its potential to entertain it is clear, as in his conclusion that "practically every program … suggests a surrender to the current standards of taste."[337] Some may have felt that people should have more choice in programming than what the commercial stations and the few non-commercial educational or religious stations offered; others may have felt that radio was an opportunity to elevate the tastes of the public if government controlled what programming was offered.

It was also argued that radio made people into passive, home-staying consumers of entertainment. Participation in the activities of fraternal orders declined markedly in the late 1920s and 1930s. Through radio, people heard more music, but were less likely to make music themselves. Radio was probably a factor in the steep decline in sales of musical instruments in the 1920s. For example, piano production in the U.S., which totaled 111 million dollars in 1922, fell steadily in the 1920s, totaling only 42 million dollars in 1929 (and fell even more rapidly in the years immediately

[333] Smulyan, p. 167, and Eoyang, pp. 175–176. Eoyang points out that food, drugs, toiletries, and tobacco, though claiming less than 30% of consumer purchases, accounted for some 2/3 of radio-advertising expenditures.

[334] Eoyang, pp. 172–173.

[335] In Czitrom, p. 81.

[336] Barnouw p. 91.

[337] Quoted in Smulyan, p. 135.

following).[338] (This is surprising in view of the economic prosperity of the decade and the prominence of music in the popular culture.)

The 1920s saw the beginning of the shift from the print media to the broadcast media as society's principal channel of information. Like the spread of printing almost five centuries earlier, the growth of broadcasting has brought with it multitudinous economic, political, and cultural changes. It is difficult, even with the perspective that the passage of more than half a century has given us, to assess the social influence of radio. One effect is clear; radio set the pattern—in mode of financing, in the business structure of networks of affiliated stations, and in programming—that would be adopted by television in the late 1940s.

Usually regarded as a poor cousin to television, radio was for many people of the 1920s and 1930s more personable and evocative than television would be to their grandchildren in the 1970s and 1980s. The radio listener continually creates, in his imagination, a vision of the people and events he is hearing about. The radio announcer Paul Harvey tells of a painting showing a boy, in wrinkled plus-fours and worn shoes, listening enrapturedly to a 1930s cathedral-style radio. The artist, Jim Daly, wrote, "There is no way for me to express the pleasure I received from listening to the old radio programs. In my mind those wonderful heroes were magnificent. No movie … no television program … not even real life, could have equaled what my imagination could conjure up. Amazingly, all those heroes looked a little bit like me."[339] Indeed, one of the reasons radio enjoyed a golden age in the 1930s and 1940s was that most people were optimistic about the future and believed in heroes.

338 Eoyang, p. 71.

339 Quoted in Rhoads, p. 7.

Chapter 5

Postwar Recovery and the Great Depression: Electrical Technologies in Industry and Commerce

5.1 ELECTRIFYING THE FACTORY

5.1.1 Electric Motors in Manufacturing

Electric power changed manufacturing procedures everywhere, and the most obvious way it did this was through the use of electric motors. A mechanized factory of the nineteenth century had a prime mover, either a waterwheel or a steam engine, that drove individual tools through an elaborate system of shafts and belts. The transition to the factory of the 1930s, in which electric power was delivered to the point of use in bench tools or hand tools, occurred over several decades and in three stages.

In the 1890s electricity began to be used as a means of transmitting energy to the factory, but not as a means of distributing energy within the factory. In other words, electricity drove one or several large electric motors that turned line shafts, and power reached individual tools through belts and perhaps other shafts. In the next stage of development, "group drive" predominated; machines were arranged in groups around relatively short line-shafts, each driven by an electric motor. The final stage, achieved in many factories in the 1930s, was "unit drive": each machine was equipped with an electric motor.[1]

The process of decentralization of electric drive conferred benefits of two sorts. First, unit drive eliminated the shafts, pulleys, and belts that transferred mechanical power from the prime mover to the individual machines and that consumed perhaps

[1] Devine 1.

Dawn of the Electronic Age: Electrical Technologies in the Shaping of the Modern World, 1914 to 1945, by Frederik Nebeker

half of the power generated. second, unit drive greatly increased flexibility both in plant arrangement and in power and rotational speed delivered to each machine. There was the drawback, though, of higher capital costs; many more motors were required and total horsepower was usually several times that required with group drive. Electric power thus contributed to the long-standing trend in manufacturing toward higher capital costs but lower labor costs.[2]

Unit drive was possible because electric energy, unlike mechanical energy, could be divided easily and transmitted easily. But unit drive could work only if there were appropriate motors. They had to be affordable, reliable, and fairly efficient. They had to be available in sizes and speeds appropriate to a wide variety of tasks. In some applications, it was important that the motor started quickly, even with a heavy load. Sometimes it was important that the motor maintain a constant speed under varying load.[3] All these desiderata occasioned a great deal of activity: the tinkering of self-taught engineers, mathematical design by engineers with doctorates in physics, and systematic development by research departments of electrical manufacturers. Indeed, design of motors was a large part of electrical engineering innovation in the last decades of the nineteenth century and the first decades of the twentieth century.

Particularly troublesome was the mismatch between the high speed of most electric motors and the low speed required for many tools. Already in the 1880s there were variable-speed direct-current motors, but they were subject to failure through overload and required excessive size in order to achieve high power at low speed. What proved successful in a great many applications, especially for unit drive in factories, was the coupling of an alternating-current motors with newly designed mechanical gearing.[4]

Just as the redesign of factories accompanied the adoption of electric power (as we saw in Chapter 2), so were machine tools redesigned for the incorporation of electric motors. In 1904 an engineer commented: "No permanent advance in electrical operation of machine tools will be made until the motor and the tool are designed for each other. … What is needed (and this cannot be emphasized too strongly) is a complete redesign of present machine tools with motor operation alone in view." [5] This happened, however, only slowly: it was not until after World War I that machines designed specifically for unit drive were in wide use.[6]

In Western Europe and North America electrification of factories proceeded steadily in the first three decades of the century. In the United States at the turn of the century, steam engines provided 81% of the power to drive machinery, water wheels 13%, and electricity 5%; by 1920 electricity had overtaken steam, and in 1929 electricity provided 78% of all mechanical drive.[7] In the eight years from 1919

[2] Devine 1.

[3] Wengenroth.

[4] Wengenroth, and Rolt, p. 205.

[5] Quoted in Devine 1, p. 35.

[6] Devine 1.

[7] Devine 1.

to 1927, the number of electric motors in use in the U.S. increased from 9.2 to 19.1 million.[8]

Electricity not only replaced steam and water power, it also brought mechanical power to a great many workplaces for the first time. Humans, and sometimes animals, were the sole source of power in most manufacturing establishments as late as 1900. According to a history of power in the U.S.:

> *… steam power … is uneconomical in small units. Steam is generally not suitable for the 1 or 2 horsepower that might be needed by the most common size of manufacturing establishment before 1900 or for the fractional horsepower needed to operate the light, special-purpose machine that might be used to improve the productivity of a craftsman in a workshop.* [9]

Thus, for the first time, electric drive made it economical to use mechanical power in small-scale manufacturing.

As discussed earlier, the largest effect of the electrification of factories was that it gave managers great flexibility in organizing operations. But it led also to greater and more effective use of mechanical power. Factory workers became controllers of mechanical power, and because physical strength was less important, women were at less of a disadvantage in seeking such work. Electric power also gave rise to new industries.

5.1.2 Electrochemistry and Electrometallurgy

One of the most widely used metals today, aluminum is valued for its light weight, corrosion resistance, high electrical conductivity, and low cost. It is the third most abundant element in the earth's crust, but because it occurs in nature only in chemical compounds (bonded typically to oxygen and silicon, the two more abundant elements), it was not even isolated until 1825 and it remained a semiprecious material for decades thereafter. In 1886 Paul Heroult in France and Charles M. Hall in the U.S. independently developed an electrolytic process for making aluminum from the ore aluminum oxide. In 1894 the metal was selling for 50 cents-per-pound. Though the manufacturers had to create the market for aluminum, sales increased steadily. By 1908 the company Charles Hall helped found (Pittsburgh Reduction Company, later the Aluminum Company of America, or Alcoa) was selling one-and-a-half million pounds of the metal per month.[10]

In the Heroult and Hall process, aluminum oxide is dissolved in molten cryolite (the mineral sodium aluminum fluoride) and then subjected to an electric current that splits the compound, producing molten aluminum. Similar electrolytic processes were then developed for other metals, such as magnesium, beryllium, and lithium; all of these are lighter than aluminum, and hence were valued for aircraft construction and many other applications.[11]

[8] Bennett 1993, p. 2.

[9] Hunter and Bryant, p. xxii.

[10] Devine 3.

[11] Fink.

By the 1920s there was a wide range of electrochemical processes that were commercially important. There was electroplating, which was first industry of any sort based on electrical technology. There was electrolytic decomposition, as in producing hydrogen and oxygen. There was the electric-battery industry, which depended, of course, on the generation of electric current chemically. Electrochemical techniques came to be used to produce a great many products: phosphorus and phosphoric acid (used in making other chemical, matches, and fertilizers), caustic soda (used in making other chemicals, paper, and soaps), and chlorine (used as a bleach and in treating water). For many metals normally produced by other means, such as zinc and copper, electrolytic techniques were adopted in order to use lower grade ore or to obtain more complete extraction of the ore. More frequently, smelter-produced metals—copper, antimony, iron, lead, nickel, tin, and many others—were refined electrolytically.[12]

From the turn of the century on, electrochemical companies were a principal user of electric power. The Niagara Falls Power Company, which began selling electricity in 1895, had a generating capacity of 60,000 horsepower in 1902, and at this time three-quarters of its production went to 16 electroprocessing companies.[13] By the time of World War I, the electroprocessing industries of Tyneside (the region along the Tyne River in northern England) accounted for 2% of the total electricity sales in the United Kingdom.[14]

The electrochemical industry expanded rapidly in the interwar period—worldwide output almost trebled in the 10 years after 1923—and saw many technical advances.[15] For example, techniques of chromium plating improved significantly. There was no chromium plating industry in 1919, yet in the 1930s chrome objects became commonplace.[16] (By the end of the 1930s, even molded plastic could be electroplated.)[17] The most significant advance was the move to continuous, rather than batch, production and toward remote, semi-automatic, and automatic control.[18] We will consider electrical and electronic control in manufacturing separately below, but here may note that it was the electrochemical industries that pioneered in techniques of continuous processing, which then were adopted in many other types of bulk materials processing.[19] Milk, for example, instead of being pasteurized in large tanks, flowed continuously through two sets of coils, where it was heated in the first and cooled in the second.[20]

Besides the electrochemical processes already mentioned, electrothermal processes were important in metallurgy. Electric furnaces were of three different types:

[12] Devine 3, and Vinal.

[13] Devine 3.

[14] Hannah, p. 33.

[15] Fink.

[16] Vinal, and Fink.

[17] *Scientific American*, April 1938.

[18] Bennett, p. 1.

[19] Schur, p. 74.

[20] Bennett, p. 36.

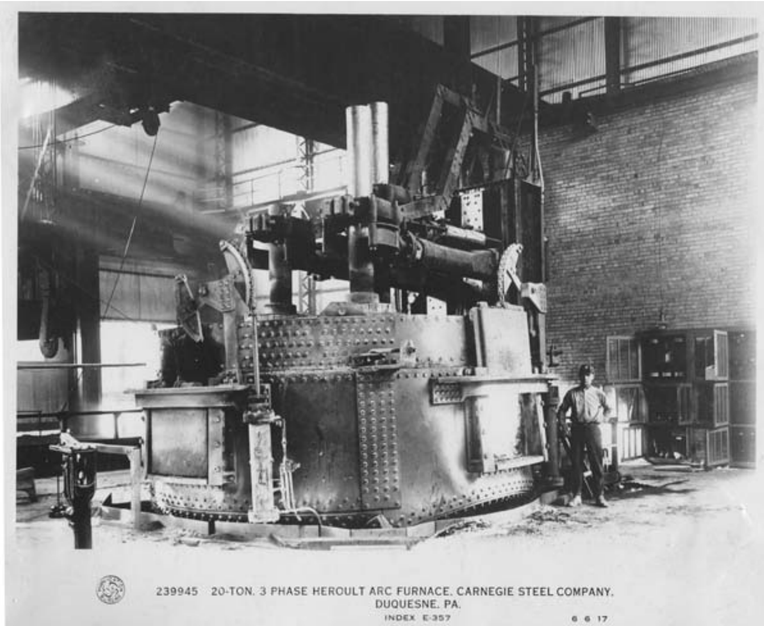


Figure 5.1. 20-ton Heroult direct-arc furnace (photo courtesy of the Schenectady Museum & Suits-Bueche Planetarium).

arc, resistance, and induction. All had the advantage of being able to reach higher temperatures than combustion methods could. They were also cleaner, being free from smoke and ash, and more controllable, delivering the heat more precisely to the area intended.[21]

Arc furnaces used the high temperature of an electric arc, either from an electrode to the material to be heated or between two electrodes situated near the material to be heated. (See Figure 5.1.) In the interwar period, arc furnaces were important in the manufacture of ferro alloys, such as steels having particular properties. Indeed, many of these alloys could be produced in no other way.[22]

In resistance furnaces, heat is generated by sending current through a resistive material, often the material being processed. The first commercially successful resistance furnaces in the United States were built by Eugene D. and Alfred H. Cowles in the 1880s to produce a variety of materials, notably aluminum–copper alloys. In 1891, Edward G. Acheson used a resistance furnace to produce silicon carbide crystals as an abrasive, which he called Carborundum. A decade later, in 1902, the annual production of silicon carbide reached approximately four million pounds. Another man-made abrasive was fused alumina, which in the U.S. began to be produced commercially in 1901. These and other man-made abrasives, which

[21] Vinal.

[22] Vinal, and Fink.

were unknown before the resistance furnace, were essential to the development of improved machine tools in the first decades of the century.[23]

An induction furnace functions in the manner of a transformer—alternating current in one winding produces a changing magnetic field, which produces current in a secondary winding—where the secondary winding (a single turn) is either the conductor to be heated or the metal container of the nonconductive material (such as glass) to be heated. Induction furnaces became common in the first two decades of the century, being used in forming and annealing metals and in processing non-metallic substances such as rubber and plastics. Because the skin effect (the tendency of alternating current to be concentrated at the surface of a conductor) is more pronounced at higher frequencies, one can control the depth of induction heating by controlling the frequency; use of a low frequency gives heating in depth, while use of a high frequency can limit the heating to a few thousandths of an inch into the material. Induction furnaces were used both for smelting and annealing, especially with non-ferrous metals.[24]

5.1.3 Electrification of Industry

The steam engine and mining were closely related. The first practical steam engine, patented by Thomas Savery in 1698, was built to raise water from mines. In 1712 Thomas Newcomen demonstrated a more practical steam engine at a coal mine in Worcestershire; it became widely used in mines in England and on the Continent. And in the 1760s James Watt developed an engine that was much more efficient; he showed this with two large engines, one of them built to drain a coal mine. Watt, together with his business partner Matthew Boulton, went on to sell hundreds of steam engines that found many different applications and thus helped to bring about the Industrial Revolution.[25]

In mining, steam engines also helped to ventilate the mines and to run elevators, but underground operations were still done by hand in the 1870s. The difficulties and hazards of either placing steam engines in mine galleries or transmitting power mechanically from the surface had prevented mechanization of underground mining.[26] In 1877 the leading German electrical manufacturer Werner Siemens embarked on an extensive program to explore the use of electricity in mining. The Siemens company soon demonstrated a solenoid-operated rock drill, then a rotary rock drill. In addition, they designed an electric locomotive for use in mine tunnels and installed a railway system in a Saxony coal mine in 1882.[27]

The presence of inflammable gases in many mines, however, retarded the adoption of electrical equipment, since sparks or arcing might occur in switches, motors,

[23] Devine 3 and Vinal.

[24] Devine 3 and Vinal.

[25] Williams, pp. 157–160.

[26] Devine 3.

[27] Jones, p. 43.

or other devices.[28] As engineers learned how to design equipment that was safe, electricity began to be used for illumination (including battery-powered portable lights), for pumping water, and for ventilation.[29]

The heavy operations of rock cutting, loading, and hauling were more slowly electrified. By World War I in the U.S., half of the bituminous coal mined underground was cut by machine.[30] In the decade after the war, the loading of coal began to be mechanized, first with the "pit-car loader" (a mobile inclined-plane made of a motorized conveyor belt) and then with the "mobile loader" (equipped with a pair of claws for reaching into a pile of broken coal).[31] By 1920 most hauling was done with electric power.[32]

Surface mining, too, was transformed by electrical technology. A 1931 article on the U.S. cement industry reports: "In a typical [new] installation raw materials are taken from the quarry by electric shovels, hauled by electric trains to electrically-driven crushing plants whence the materials go through various grinding, handling, and mixing processes, all electrically controlled." The finished product was pumped electrically to storage silos.[33] Electrical equipment came to be important also in drilling for and pumping oil.[34]

Electrically-driven pumps also became important in refrigeration. Indeed, the electric motor made air-conditioners, refrigerators, and freezers practical in many more applications than formerly. The basic operation of these devices is the following: a refrigerant, such as Freon, absorbs heat as it passes from liquid to vapor, is compressed by an electric pump, and gives off heat to the environment as it returns to the liquid state. An electric fan may be used to assure air flow in one or both of the regions of heat exchange, and the device is typically controlled electrically, as by a thermostat or humidistat. The next chapter, considers refrigerators in the home, and air conditioning in homes and offices, noting some important industrial applications of refrigeration.

Refrigeration and rapid means of transportation—railroads and steamship lines—combined to make possible something never before achieved: worldwide specialization of agricultural production.[35] Beef from Argentina, lamb from New Zealand, bananas from Central America, and vegetables from California became items sold internationally. Refrigerated ships took Washington apples, California oranges, and Florida grapefruit to London's Covent Garden Market.[36] The refrigeration of ships and railway cars was usually achieved nonelectrically until the time of

[28] Jones, pp. 180–181.

[29] Devine 3.

[30] Devine 3.

[31] Devine 3.

[32] Devine 3.

[33] Rogers.

[34] Very often there was no power network near oil fields, so diesel engines were used to drive generators on site [Committee on General Power Applications].

[35] Rosenberg, p. 26.

[36] Boorstin, p. 327.

World War I for ships and not until after World War II for railways.[37] Refrigerated trucks began to be built about 1930.[38]

Beginning about 1920 refrigeration was present at almost every stage in the movement of fruits and vegetables from farm to dining table: in railway cars, in food processing plants, in trucks, in markets (notably self-service refrigeration units in the supermarkets of the 1920s), and in kitchens. Partly as a result, the consumption of fresh foods markedly increased.[39] Refrigeration was important in the brewing and meat-packing industries, and for cold storage warehouses. In dairy farming, electrical technology was important for refrigeration, sterilization, and for automatic control of the processing of milk.

Air conditioning had extremely important industrial applications. The processing of many products required cool temperatures. Even more important was the control of humidity. Many factories processed materials that absorbed moisture from the air: textiles, tobacco, pasta, black powder, candy, flour, and many more. When the humidity changed, such materials could change in appearance (chocolates turn gray) or handling characteristics (cotton threads broke and cigarette machines jammed). Pioneering in factory air-conditioning was Willis Carrier, who began installing such systems in 1902, and soon this type of air conditioning was of much greater commercial importance than comfort air-conditioning.[40]

Heating, too, was an industrial function that came to be done more and more by electricity. Space heating and water heating were, in many situations, best done electrically. Besides the electric furnaces used in metallurgy, there were electric furnaces used for baking, drying, curing, glazing, and other purposes.

A technique that assumed importance in the interwar years was dielectric heating. When a nonconducting material is exposed to alternating electric and magnetic fields, the molecules are repeatedly pushed and pulled, generating heat. This is similar to the induction heating of metals mentioned above, but because there is no skin effect with nonconductors, dielectric heating gives in-depth heating. It came to be used for vulcanizing rubber, drying certain foods, and drying paper.[41] One noteworthy application was to the manufacture of plywood. The term “plywood” came into use in the 1920s to dissociate the improved product from its predecessor, called ‘veneered wood’. The bonding of the layers of plywood took many hours using conventional sources of heat; dielectric heating reduced the time to half an hour.[42] As a result, plywood became less expensive and found many more applications.

Several forms of electric welding became common in the first two decades of the century. In arc welding, an arc forms between the work and a carbon or metal rod (the intense heat melting the metal at the surface); in resistance welding, an electrical current generates heat at the junction of the two metals. The new welding

37 Volti.

38 Anderson, p. 230.

39 Platt.

40 Cooper.

41 Schurr, p. 76.

42 Wellman, p. 201.

methods made it possible to fabricate efficiently from steel slab many machine parts that formerly were cast. For example, in 1928 the cylindrical frame of an electric motor began to be made by bending a steel strip and fusing the ends with resistance welding; the welded frame was less expensive and structurally more uniform than the cast-steel frame.[43] Arc welded structures replaced a great many riveted structures, in automobiles, railroad cars, airplanes, and elsewhere; its importance in shipbuilding and repair was mentioned in Chapter 2.

Just a few of the many other electrical technologies in manufacturing are mentioned below. Magnetic separators became important in processing of some ores. Electrostatic precipitation, which takes advantage of the fact that particles suspended in the air typically have an electric charge, came to be widely used for the removal of smoke, dust, or moisture. X-ray machines were used to examine castings and other metal parts, either by taking an x-ray photograph of pieces bearing identifying numbers or by viewing them by fluoroscopy (that is, on a translucent screen coated with a material that fluoresces when struck by x-rays). There was a trend to substitute electromechanical processing for thermal or chemical processing, as in mechanical fiberization for papermaking or in the separation of components of liquid and gaseous mixtures for chemical production.[44]

The long-term tendency to substitute electrical techniques for non-electrical techniques required, of course, more and more electric energy. At the turn of the century, most factories that used electric power generated it themselves. Along with the interconnection of power networks, discussed in Chapter 3, came the abandonment of many private power stations. In 1909, 64% of the power supplying electric motors in U.S. factories was generated on site; just 10 years later, 57% was purchased from electric utilities.[45] So along with the wider distribution of electric power (delivered to point of use), came centralization of power generation.

5.1.4 Electrical and Electronic Control of Machines

A long-standing trend in manufacturing is to use more and more machines and, for a given level of output, to employ fewer and fewer people. The ideal of machines not only of carrying out the work but also of guiding themselves is ancient. In his *Politics* Aristotle wrote: "… if every instrument could accomplish its own work, obeying or anticipating the will of others … if the shuttle would weave and the pick touch the lyre without a hand to guide them, chief workmen would not need servants, nor masters slaves."[46] In the twentieth century in the fabricating industries, the introduction of mechanical power and special-purpose tools was indeed often followed by automatic control. In the development of process industries, electrical instruments had a larger role; there the pattern was first sensors, then recorders, then centralized remote-control, and finally automatic control.

[43] Thomson.

[44] Schurr, pp. 75–76.

[45] Devine 1.

[46] Quoted in Bennett, p. viii.

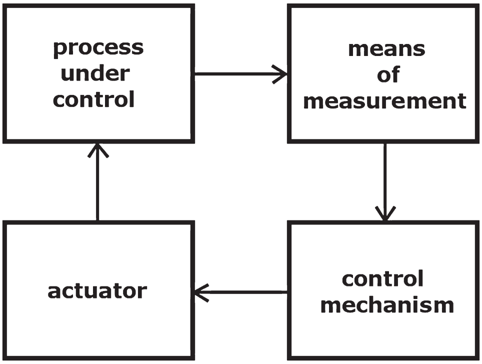


Figure 5.2. The basic scheme of automatic control.

Vital to most control systems is feedback, the return of part of the output as an informational input. Automatic feedback control comprises three elements: a measuring instrument to convert a physical attribute to a signal, a controller to generate a command from the signal, and an actuator to carry out the command.[47] (See Figure 5.2) The first controllers—thermostats, for example—were on–off switches that acted when the measured value rose above or fell below a preset value. There appeared increasingly sophisticated control: two or more inputs, complex circuits to convert inputs to command, and actuators capable of graded action. Following are several examples, in both process and fabricating industries.

First, consider the instruments used as sensors. Thermometers, pressure gauges, hygrometers, and flow meters date from the seventeenth century, and instruments that measure and record are almost as old. A great range of instruments were developed for use in scientific—and later, industrial—research, some of which will be considered in Chapter 8. This section concerns instrumentation in the factory.

Instruments were valuable in a factory because if a process could be characterized quantitatively, and if those quantities could be measured, then accurate control of the process was much easier to achieve. In the first decade of the century, electrical measurement of temperature became fairly common; as early as 1902, thermocouples were marketed as standard items, and Cambridge Instrument Company began selling an automatic temperature controller in 1909.[48] In the interwar years, managers could purchase accurate, reliable, and inexpensive instruments to measure a great range of physical attributes; in the 1930s there were more than 600 U.S. companies manufacturing several thousand different industrial instruments.[49] Many of these instruments were electronic, most often by virtue of the use of an amplifying tube to make them more sensitive. An example was the Tagliabue–Heppenstal moisture indicator: leads were driven into a piece of lumber, an ammeter and electronic amplification allowed measurement of conductance, hence of moisture level. By 1931 this was a standard way to test dryness of lumber.[50]

[47] Bennett 1991, p. 70.

[48] Sydenham, p. 433.

[49] Bennett, p. 29, and Perazich 1938, p. 9.

[50] Onstad.

A next step was the automatic recording of measurements. This made it easier to monitor and analyze the production process. From the turn of the century on, managers used automatic recorders to measure the performance of machines, to clock hours worked, and to check that work practices were followed.[51] Recording instruments found intense application in the process industries after World War I.[52]

Sometimes the indicators of the monitoring instruments were placed in a central location. Then actuators, such as a solenoid-operated valve or a motor-driven fan or an electric heating element, might be operated from the same location. We have already seen that electric utilities set up such central control rooms, and in the 1920s they became common in many industries.[53]

Often it was possible to go a step still further. If a production process could be monitored by instruments and if deviations from desired values could be eliminated by specifiable actions, then the process might be controlled entirely automatically. The simplest example was a heater or oven controlled by a thermostat, which dates from the late eighteenth century.[54] In the 1920s, and 1930s, much more sophisticated systems automatically controlled such variables as the voltage or current coming from a dynamo; the degree of combustion in furnaces; the thickness of sheet metal during cold rolling; the temperatures, pressures, and flows in separating the components of crude oil; temperature control of the grinding and cooling operations in making pulp for paper; temperature and humidity control in lumber drying; and accurate control of time-temperature cycles for heat treating of metals.[55]

Automatic control was used to great advantage in the Fourdrinier machine that converts suspended wood pulp to paper in a continuous process. The machine, whose most obvious feature is a series of large cylindrical rollers, consists of as many as 10 sections, and the speeds of operation of these sections must be maintained in proper relationship to one another (there being a slight progressive increase in speed from the wet to the dry end of the operation). In about 1920, both Westinghouse and GE began installing sectional drives that regulated their speeds automatically. This gave a higher quality paper and allowed the machines to run at twice the speed possible earlier.[56]

The most important advance in iron and steel technology of the interwar years was the wide strip mill, which used similar control apparatus for a series of graduated rollers that converted a thick ingot of steel into a continuous sheet that was both smooth and of uniform thickness.[57] Partly as a result of this advance, sheet metal came to be used in large quantities for automobiles, refrigerators, washing machines, and much more. The steel industry also adopted automatic control of open-hearth

[51] Bennett, p. 1.

[52] Perazich 1938, p. 14.

[53] Bennett, p. 31.

[54] Mayr, pp. 70–75.

[55] Perazich, pp. 54–72.

[56] Lorant, pp. 129–137.

[57] Landes, p. 475.

furnaces, which increased output 13% while reducing fuel consumption (per ton of steel) by 16%.[58]

In the 1920s automatic controllers became widespread in the process industries, including—besides the ones already mentioned—chemicals, food, textiles, glass, ceramics, brewery and distillery, sugar, and paint and varnish. In the United States, some 75,000 automatic controllers were sold to industry from 1925 to 1935.[59] The petroleum industry succeeded in meeting the greatly increased demand for gasoline in the 1920s by adopting continuous refining, aided by automatic controllers; in 1926, for example, the Jenkins process of refining crude oil could be operated almost entirely automatically.[60] The chemical industry underwent great changes; a trade journal reported in 1929 that "just as CONTINUOUS PROCESSING is everywhere replacing batch handling as soon as it can be applied profitably, automatic control is taking the place of manual operation as rapidly as it proves itself."[61] In the 1930s the processing of milk was automated.[62]

So far this discussion has considered only process industries. Automatic control became important in fabricating industries as well. For example, in the late 1920s, automatic arc welding became possible; an electric motor fed the electrode at the rate required to maintain a constant arc-voltage between electrode and work, and another electric motor moved the arc along the seam. For simple, continuous welds, an automatic welding machine was three to six times as fast as an expert manual welder.[63] Automatic welding was rapidly adopted in automobile manufacture.

Characteristic of the fabricating industries are machine tools, devices such as drills, lathes, and punch presses that shape solid materials. In the interwar period these came to incorporate control systems.[64] For example, in 1927 the Cincinnati Milling Machine Company began selling a milling machine with a hydraulic system for automatic movement of the machine's sliding table.[65]

One might argue that cam-following tools, such as lathes, were the first programmable automatic machines, since one could easily change the master cam controlling the machine. Cam control, however, was successfully applied only to woodcutting tools because all the force to position the cutting tool had to be supplied by the cam itself.[66] What was needed here, and in many other cases, was a power amplifying device. Such devices, called servomechanisms—the word was coined in 1926—were extensively developed in the interwar years.

A servomechanism is a power amplifying device that uses feedback to achieve proportional amplification. A mechanical torque amplifier (encountered in the

[58] Perazich 1938, pp. 17–18.

[59] Bennett, p. 28.

[60] Lorant, p. 103.

[61] Quoted in Lorant, p. 187.

[62] Noble, p. 59.

[63] Koch.

[64] Rolt, p. 237.

[65] Devine 2, p. 45.

[66] Devine 2, p. 45.

description in Chapter 3 of the differential analyzer) or a three-element electron tube are amplifiers that depend on the amplifying element for the proper relationship between input and output. In servomechanisms, by contrast, the proper relationship is achieved by feedback; that is to say, feedback is used to insure that output indications (at high power) accurately reproduce input indications (at low power).[67]

An early example was a servomechanism for a metal-cutting lathe that incorporated J.C. Shaw's 1920 invention of an electrical sensing device that required only a very light contact with the master cam.[68] Servomechanisms were used in the 1930s to maintain alignment of the paper passing through printing presses.[69] Servomechanisms were used for speed control of steam turbines, stabilization of ships by gyroscopes, automatic ship steering, and automatic stabilization and guiding of aircraft.[70]

Automatic control changed the factory environment. A historian of machine tools has written:

> *Though working principles remain the same, the contrast between the smooth exterior of the modern machine tool and the exposed wheels and shafts of its skeletonic ancestor is very striking. … Its changed appearance is due to the fact that by the use of power controls all its moving parts can be more fully enclosed and shrouded.* [71]

Labor requirements of factories changed, as many workers became machine-tenders, and many jobs were eliminated. In most cases, industries adopting the new machines were able to increase the quality of the goods and to lower the price by reducing labor costs, wastage, and energy costs.[72]

In the United States the instrument industry grew rapidly in the early decades of the century. For industrial instruments alone, annual sales increased from $600,000 in 1909, to $34 million in 1929, and for the period from 1920 to 1936, U.S. industry spent a total of $300 million on indicators, recorders, and controllers.[73] In the 1920s and the 1930s, there was a movement from instruments that simply measure, to instruments that measure and control; automatic controllers made up 7.7% of sales in 1923, and 33.3% in 1935.[74]

In 1933 the engineer Charles R. Underhill asserted:

> *We are living in the electronic age. Millions of electronic devices already are at work. Electronic tubes increasingly control the machines of industry. The electric eye, with its associated electronic tubes and apparatus, is rapidly replacing the human eye in many branches of industry. …* [75]

[67] Hazen.

[68] Woodbury, p. 98.

[69] Bennett, pp. 9–10.

[70] Hazen.

[71] Rolt, p. 237.

[72] Bennett 1991, p. 73.

[73] Perazich 1938, pp. 24, 71.

[74] Perazich 1938, p. 39.

[75] Underhill, p. vii.

Many of the early regulators were electromechanical systems—in the sectional drives of paper machines, for example, there were mechanical linkages between motors—but these tended to be replaced by entirely electrical regulators. For example, for sectional drives General Electric introduced in 1937 a completely electrical regulator that used electronic amplification, and such regulators became standard in the 1940s.[76] We saw in Chapter 3 that the electric power industry pioneered in the use of electronic control, as in the thyratron voltage regulator.

Underhill explains the advantage of electronic systems as follows:

> *All of the highly developed electromagnetic switching, controlling, regulating, and protective devices have contacts that burn; pits, bearings, slip rings, brushes, and other surfaces, that wear and must be replaced; mechanical adjustments which must be made and which will work or wear loose. …* [77]

Electronics involves the free passage of electrons in vacuum, gas, or semiconductor. The electron stream is then controllable in ways not possible with electron flows in conductors; hence it is often possible to achieve effects (such as switching, amplification, or oscillation) that were previously achieved mechanically or electromechanically. We should note that free electron passage was exploited for purposes other than communications and control: arc lighting, discharge lighting (both considered in Chapter 6), arc welding, and arc furnaces.

Electronic devices had obvious advantages. They were rapid in operation. Only a small actuating energy was required, and it might be provided by a wide range of different physical effects, including changes in resistance, inductance, capacitance, phase, frequency, temperature, sound, and light. Electronic devices were capable of amplification, accurate in response, quiet in operation, and free of moving parts and contacts.[78] The quick response made possible new types of control or allowed the faster operation of existing machines. For example, in automatic paper cutting a control impulse may have a duration of one-thousandth of a second or less.[79] The low activation energy made electronic devices extremely sensitive and opened up new possibilities for automatic control. The absence of mechanical inertia was valuable whenever control equipment was subject to motion, as were the voltage regulators on ships.[80] And the absence of moving parts usually meant that less maintenance was required.[81]

There were, of course, some disadvantages: tubes were fragile; they were subject to burn out; and in some applications they were too expensive. Tube designers gradually alleviated all of these difficulties: for many applications much more rugged metal tubes were developed; tube lifetimes increased; and manufacturing costs diminished.

[76] Bennett, pp. 8–9.

[77] Underhill, pp. 174–175.

[78] Committee on General Power Applications.

[79] Gulliksen.

[80] Gulliksen.

[81] Gulliksen.

Some industrial electronics already discussed are the spark-gap oscillators used for high-frequency induction heating and the mercury-arc and thermionic rectifiers used in power systems. The thyratron was used for precision control of electric motors (as in milling machines) and of resistance welding (in aircraft, automobile, and railroad construction). In automatic spot welding and in many automatic devices, there was need for a time-delay switch or relay. In the early 1930s, five types of electromechanical time-delay relays were in use, but they all had shortcomings not shared by the electronic time-delay relays just then coming into use.[82]

In the interwar period most control systems involving feedback used only an on-off controller (as in home thermostats today). The principal reason for this limitation was the difficulty of amplifying electrical signals, which was usually necessary to operate an actuator (amplification of an on-off signal is easily achieved by an electromagnetic relay). As electron tubes became more reliable and better suited to control purposes, they began to find wide use in control systems, often for amplification.[83] In the process industries, controllers designed in the 1930s provided for response proportionate to the deviation from the set point, also to take into account the derivative of the deviation (its instantaneous rate-of-change) and its integral (its cumulative effect).[84]

Speed of operation and lack of mechanical inertia were other reasons for the move to electronic systems.[85] Yet the changes came slowly, as, according to Bennett, "It was many years before the electronic valve and electronic amplifier became accepted as reliable, robust devices, simple and cheap enough for general industrial use." [86]

One of the main types of electron tube was the photocell. Its ability to convert light energy to electrical energy and to generate a signal proportional to the intensity of the incident light suggested to many at the end of the 1920s that a wide variety of industrial applications would be found.[87] These applications—such as automatic counting on production lines, temperature measurement, and automatic control of lighting—however, developed only slowly. In the 1930s the phototube made it possible to measure some qualities for the first time—smoke density or paper transparency, for example—and to perform some operations automatically—such as the inspecting, grading, and sorting of wrist pins in the automotive industry.[88] Another early application was in automatic paper cutting, the photocell detecting whenever the cut deviated from the spot printed to indicate the proper position.[89] In the 1930s photoelectric control was applied to school and factory lighting, to the roasting of

[82] Gulliksen.

[83] Bennett, p. 21.

[84] Bennett 1991, p. 70.

[85] Bennett, p. 21.

[86] Bennett, p. 23.

[87] Bennett, p. 21.

[88] Perazich 1940, pp. 28–29.

[89] Gulliksen.

coffee and the baking of bread (the darkness being monitored by a photocell), to the counting of traffic, to detecting counterfeit stock certificates, to matching colors, and to a great many other uses.[90] Chapter 6, which reviews the development of sound movies, shows that it was this application that first led to mass production of the photocell.

5.1.5 Mass Production and Popular Culture

In the interwar years most people looked favorably on mass production, because it raised the standard of living by lowering the price of goods. For the first time, large numbers of people could afford a sewing machine or an automobile. Henry Ford was a national hero, and Fordism was celebrated in Europe, Asia, and South America. The Battersea Power Station (designed by Giles Gilbert Scott), built in the years from 1930 to 1934 and located near the center of London, became for Englishmen a symbol of modernity.[91]

There were, however, many people, particularly among the intellectuals, who decried the broader effects of mass production. These people associated mass production with huge business enterprises, specialization, regimentation, standardization, uniformity of thought, and authoritarianism. Probably most troubling was that the subdivision of the production process in factories like Ford's made the work extremely monotonous, sometimes turning the laborers into mere machine-tenders. The interwar years saw frightening depictions of a future in which these features dominated: Fritz Lang's film *Metropolis* (1927), René Clair's film *A nous la liberté* (1931), Aldous Huxley's novel *Brave New World* (1932), Diego Rivera's frescoes (1932–1933), and Charlie Chaplin's film *Modern Times* (1936).[92]

People worried, too, that mass production caused unemployment, and in the early 1930s many people blamed it for the depression. Others, however, argued that the new production techniques were in fact a stimulus to the economy. Both views are considered in the section below on the economy and electrical technology. There was the fear that automation—though it was not called that until 1948—would make the capacities of most people superfluous to the economy. In 1923 R.B. Williams, involved in the U.S. paper industry, coined the word "automatization" in arguing that automatic machinery would alleviate the shortage of labor for paper mills.[93] The 1920 play "R.U.R." (Rossum's Universal Robots) by the Czech playwright Karel Capek questioned the ability of humans to use wisely or even control the new technological possibilities. It was here that Capek coined the word "robot" from the Czech "robota", meaning work.

One objection to mass production was that the standardization of products diminished everyday life. For Ford standardization was indeed a precondition of

[90] Underhill, pp. 223–240.

[91] Watkin, p. 557.

[92] Hounshell, pp. 316–320.

[93] Lorant, pp. 137–138.

mass production: "You can have any color you want as long as it's black". But Ford's competitors General Motors and Chrysler pioneered techniques of "flexible mass production" that allowed them to provide purchasers with many options, and before the end of the 1920s Ford began to adopt such techniques.[94] The success of manufacturers in providing a plethora of consumer goods, weakening this objection to mass production, is explored further in Chapter 6.

There were many artists and designers who welcomed machine production, and the public often received their work enthusiastically. The French artist Fernand Léger, for example, believed that mass production had changed life for the better, that the working man would receive his share of the benefits, and that the machine was not a tyrant but an instrument of liberation.[95] His 1920 depiction of "The Mechanic" suggests self-confidence, individuality, and at least modest prosperity.

The International Exposition of Modern Decorative and Industrial Arts, held in Paris in 1925, stimulated an international movement of "machine aesthetics". The industrial designer, unlike the artist or craftsman making luxury goods for individuals, created "art for the masses" (in the words of Frederick Kiesler). Such industrial designers, working with a wide variety of everyday objects, helped make the 1930s the Streamlined Decade.[96]

Particularly influential was the Bauhaus school, founded by Walter Gropius in 1919 in Weimar, not far from Berlin. A tenet of the Bauhaus school was that the appearance of a manufactured object should be primarily determined by two things: its function and its suitability to mass production. Gropius felt that the obligation of artists in a democratic society was to work from the ground up rather than the top down, and this they could do, for the first time ever, because of mass production. Besides its much greater reach, mass production could be artistically liberating, and Bauhaus member Marcel Breuer argued that design for mass production was an entirely new artistic form. A celebrated example of Bauhaus architecture was commissioned by the electrical firm AEG for its new turbine factory. The closure of the Bauhaus school in 1933 by the Nazi Party probably increased its worldwide influence, as many Bauhaus members took up work in other countries.

In 1935 Sears, Roebuck and Company hired the industrial designer Raymond Loewy to redesign the Coldspot refrigerator. Loewy's design, with rounded corners, no visible legs, and the motor concealed, was so popular that sales increased from 65,000 to 275,000 in one year.[97] The following year Henry Dreyfuss redesigned the Hoover 150 vacuum cleaner.[98] The new aesthetic combined with new materials and processing, such as sheet metal, plastics, and chrome plating, to give the material culture of the interwar years a distinctive look.

[94] Hounshell, p. 329.

[95] Russell.

[96] Hounshell, pp. 308–309.

[97] Harvey Green, p. 113.

[98] Harvey Green, p. 65.

5.2 PROCESSING INFORMATION

5.2.1 Information-Intense Businesses

In the late 1830s in New York City, Lewis Tappan set up a business to sell wholesalers credit information on country storekeepers who wanted to buy their goods. Tappan's business thrived. A decade later, R.G. Dun joined the company and directed its expansion nationwide. By 1859 Dun was sole owner of what became R.G. Dun and Company, later Dun and Bradstreet. In the 1870s the company received information from 10,000 investigators in 69 branch offices and answered some 5000 inquiries every day.[99]

In the late nineteenth and early twentieth centuries, there was steady growth in businesses providing information services: education, research and development, publishing, communication services, accounting, banking, real estate, insurance, and advertising. And within companies that produced non-informational goods and services, there was a steady increase in the number of people employed who processed information. These trends continued, and in 1967 information activities accounted for about 46% of the U.S. gross national product, 25% in the "primary information sector" (information as product) and 21% in the "secondary information sector" (the bureaucracies of non-information businesses).[100]

Electrical technologies played a large part in the growth of this fourth sector of the economy. At the beginning of the century the other three sectors—agriculture, industry, and services—were all considerably larger.[101] With the increase in trade and growth in the size of firms, the handling of information became ever more important. With large firms and large government came bureaucratic organization, and bureaucracies came to rely more and more on new means of communicating and processing information: telegraph, telephone, dictating machine, typewriter, cash register, duplicating machine, calculator, punched-card machines, and so on.[102]

Quite apart from its role in producing goods and services, information became increasingly important in commercial transactions. Any transaction involves information acquisition: what quantity of what means of payment is exchanged for what goods or services. Centuries ago buyer and seller acquired such information at the point of sale. Since the late nineteenth century the following trends have been apparent: (1) more information accompanies each sale; (2) information exchange precedes the sale (catalogs, contracts, advertising); (3) more and more transactions are purely informational in the sense that they do not involve physical transfer of goods or services; and (4) informational flows are carried increasingly by electrical and, later, electronic means.

Consider first the telegraph. The business historian Alfred Chandler has written:

[99] Boorstin, p. 55, and Beninger, p. 257.

[100] Beninger, p. 22.

[101] Beninger, p. 23.

[102] Beninger, pp. 278–283.

> *The revolution in the processes of distribution and production rested in large part on the new transportation and communication infrastructure. Modern mass production and mass distribution depend on the speed, volume, and regularity in the movement of goods and messages made possible by the coming of the railroad, telegraph, and steamship. These changes in production and distribution began as soon as steam and electricity were used extensively in transportation and communication. As the basic infrastructure came into being between the 1850s and 1880s, modern methods of mass production and distribution and the modern business enterprises that managed them made their appearance.* [103]

Railroad managers made great use of the telegraph to monitor and control performance, and beginning in the 1880s other geographically dispersed firms relied on the telegraph for internal communications.[104] The telegraph made it easier for firms to expand their markets and to disperse their production activities. In 1866, three telegraph companies merged to form Western Union, which became, in Chandler's words, "the first nationwide multiunit modern business enterprise in the United States." [105] Hence, the telegraph industry provided a model for other businesses to emulate besides stimulating commerce by the service it provided.

A major innovation in distribution of agricultural products was the commodity exchange, which made possible the selling of crops before they were delivered or even before they were harvested. Commodity exchanges (such as the Chicago Board of Trade or the Merchants Exchange of St. Louis) made great use of the telegraph and spread across the U.S. at the same time as the telegraph network expanded. The transatlantic telegraph greatly facilitated worldwide networks for distribution of products, both agricultural and manufactured.[106] For example, long-distance shipping of fresh fruits and vegetables, made possible by the refrigerator car, created a national market. Its effective functioning depended upon the telegraph, and in 1915 the U.S. Department of Agriculture started a market news service that used Western Union wires to provide information on shipments and prices.[107]

The stimulus that the telegraph gave to commerce is clearly seen in the increased activity of wholesalers and other middlemen. Their activity, managing flows of goods and services in one direction and payments in the other direction, consisted largely of information exchange. Chandler has written: "… once the railroad and telegraph permitted the wholesaler to market in a broad geographical territory, the volume of sales which a single firm handled jumped from an annual value of tens and hundreds of thousands of dollars to tens of millions of dollars."[108]

The technology of telegraphy advanced in the 1920s and 1930s. Western Union increasingly used multiplexing (sending more than one message at a time over a

[103] Chandler, p. 207.

[104] Yates, pp. 23–25.

[105] Chandler, p. 197.

[106] Beniger, pp. 249–253.

[107] Boorstin, p. 327.

[108] Chandler, p. 218.

wire) and began to use electron-tube amplifiers. Messages were processed in the form of punched paper-tape, so that a message might occur in written form only twice—from the sender and for delivery to the addressee—even though it was relayed many times.[109] In the United States the annual telegraph business was worth $40 million in 1899, $107 million in 1919, and $196 million in 1929, but declined significantly in the 1930s because of competition from another communications device that also expanded markets and stimulated economic activity.[110]

One of the first uses of the telephone, invented in 1876, was to link the town office of a firm to its factory. In the 1890s, many companies installed private branch exchanges.[111] The telephone became important both for internal communication (where, for some time, pneumatic tubes were a competing technology) and external communication. In the thriving U.S. economy of the 1920s, there was a 70% increase in telephone use.[112]

The skyscraper would not have been practical without the elevator. It has been argued, more surprisingly, that the skyscraper would not have been practical without the telephone. With any large office building a huge number of messages must go in and out every day; if each one had to be carried by a messenger, it might not be feasible to stack up so many offices as there are in a skyscraper.[113]

It is likely that the telephone, by facilitating business contacts, contributed to the growth of cities; throughout the world urban concentration and the intensity of telephone use have been roughly proportional. On the other hand, the telephone contributed to urban sprawl by allowing separation between office work and other aspects of a business, such as manufacture, shipping, or sales. It allowed also the dispersion of office work, so that a business's legal office, accounting office, and sales office could be located apart. The separation of office work from other functions, however, often led to urban concentrations as cities increasingly became white-collar transactional centers while production, warehousing, and retailing moved to suburban or rural locations.[114]

Chapter 7 considers many of the interwar advances in telephony—automatic switching, international service, radio voice-circuits, improved sound quality, and others—and the establishment of teletype service, but two other forms of electrical communication, telegraphic fire-alarm systems and stock tickers, are worthy of mention in this section. Automatic fire-alarms, which date back to the 1850s, became a vital part of firefighting in cities everywhere. The stock ticker, which dates back to the late 1860s, played a large role in facilitating investment in stocks. The device itself underwent improvement after it notoriously fell hours behind in the frantic trading in October 1929 (and its slowness received blame for adding to the panic). Western Union quickly built 10,000 new tickers capable of 500 characters-a-minute

[109] Corwith.

[110] Bright, p. 13.

[111] Yates, p. 21.

[112] Strom, p. 229.

[113] Pool, *et al.* Fischer (pp. 26–27) discounts this argument.

[114] Gottmann.

(the old tickers could handle 300 characters-a-minute), and these "500" tickers met the needs of the stock market until the 1960s.[115]

For more efficient processing of information within offices many new devices came into use. Addressing machines, such as the Addressograph, which used small metal plates to imprint names and addresses, were in wide use by 1920. By 1910 photostats were in use, and even earlier an inexpensive means of making multiple copies of a document—the mimeograph machine—was invented and marketed by A.B. Dick. Dictaphones were in wide use by 1910.

The most prominent machine in most offices of the early decades of the century was the typewriter, which began to be mass-produced as early as the 1870s. In the United States in 1900 there was one typewriter for every 640 people, and in 1910 annual sales totaled $2 million, shared by 87 U.S. firms and 22 foreign companies selling in the U.S. The typewriter business helped establish a much larger office-equipment industry, as typewriter manufacturers began making calculators, tabulating machines, and the like.[116]

Rivaling typewriters in popularity were adding machines and calculators (the distinction being that the latter machines were capable of all four arithmetic operations—addition, subtraction, multiplication, and division). From 1899 to 1919, the number of companies in the U.S. making adding machines and calculators increased from 18 to 65, and annual sales increased from $6 million to $83 million (surpassing the total sales of typewriters by $30 million).[117] Many of the manufacturers of adding and calculating machines marketed their machines in several countries, and thus helped create an international market for office machines. In the early 1920s, Burroughs, which was probably the largest company, had some 25 marketing subsidiaries around the world (and in 1930 it produced 100,000 machines). Other successful firms that marketed their products internationally were Felt & Tarrant (U.S.) and Brunsviga (Germany).[118]

The need for adding machines and calculators followed on the increased economic activity of the times, which had generated an increased need for bookkeeping. The adding machines and calculators, in turn, influenced business practices. An observer wrote in 1926:

> *… [adding and calculating] machines are today the chief factor in the development of better bookkeeping practice. Their greatest service lies in giving the world a way of controlling business by figures. Adding and calculating machines are not only adapted to current bookkeeping practice, but they are teaching men the value of business records.* [119]

Perhaps the most visible of early information-processing machines was the cash register. By 1920 people encountered the device every day in stores and restaurants

[115] Oslin, pp. 312–313.

[116] Cortada, pp. 13–21.

[117] Strom, p. 179.

[118] Cortada, pp. 37–42, and Strom, p. 180.

[119] Quoted in Cortada, p. 32.

throughout North America and Europe. Almost all of the cash registers in the United States and most of them elsewhere were built by a single company, National Cash Register (NCR), whose business practices and marketing methods came to be copied by many firms, including International Business Machines. John H. Patterson, head of NCR, emphasized salesmanship and extensive advertising. He avidly sought foreign markets; in 1922, NCR had branches in 50 countries and employed 28,000 people outside the United States. And Patterson sought continual improvement of the product.[120]

One of the most significant improvements of the cash register was the incorporation of an electric motor. This was part of a broad movement toward the electrification of many sorts of business machines. In 1901 Frank C. Rinche introduced an adding and listing device powered by an electric motor, and a motor-driven calculator (the Ensign) was marketed in 1905.[121] The same year Charles F. Kettering, a young engineer at NCR, developed an electric cash register that was an immediate success.[122] Electric typewriters began to appear before World War I, and mimeograph machines, which date back to the 1870s, came to be electrified.[123]

The early twentieth century saw a rapid increase in office work. The appearance of offices changed in two striking respects. The first has been discussed: the greatly increased number of office machines. The second was the greatly increased proportion of women among office workers. In the late nineteenth almost all office workers were men, and the feminization of clerical work coincided historically with its mechanization. Many women were hired as typists, although as late as 1904 only 21% of government typists were women.[124] In implementing the Hollerith punched-card system with the 1890 census, women were reportedly "more exact in touch, more expeditious in handling the schedules, more at home in adjusting the delicate mechanisms of the electrical machines", and eventually 80% of those employed as census "computers" were women (though a more important reason for this may be that women, having fewer options, were more willing to take such work at the wages offered).[125]

There were many other effects of the mechanization of office work. Cash registers, which provided a record of every transaction, and adding machines, which made it easy to add long columns of numbers, encouraged businessmen to maintain detailed accounting and to think quantitatively.[126] The instrumentation described in the previous section also gave managers quantitative information that made it easier for them to assume greater control of the manufacturing processes. Managers, at least, welcomed these changes; in the 1920s, the amount of electric energy used by U.S. manufacturers for information processing and support services increased at an

[120] Cortada, pp. 64–78.

[121] Cortada, pp. 30, 36.

[122] Leslie, pp. 20–22.

[123] Cortada, p. 20.

[124] Strom, p. 177.

[125] Strom, p. 178.

[126] Boorstin, p. 205.

annual rate of 8.3%.[127] The large volume of commercial records led to a new industry, the microfilm industry, to archive the records, and this industry, pioneered by the Eastman–Kodak company in the late 1920s and 1930s drew on technical advances in film and cameras made for the movie industry.[128]

5.2.2 International Business Machines

Beginning in 1933, Francis Townsend, an elderly physician, led a popular movement for government-administered old-age pensions. Partly in response, Congress passed the Social Security Act in 1935, mandating a payroll tax, paid by both employee and employer, to finance the pensions. Supervision of data collection was the responsibility of the Social Security Board (later Administration), which acquired IBM machines so that what the *New York Sunday News* called "the world's biggest bookkeeping job" became a straightforward task. The registering of citizens began in January, and 16 million applications were processed in just over two months. At a Social Security office, the information on an application was entered on a series of punched cards (a gang punch put the basic information of name, address, and SS number on all the cards). The cards could then be used for a variety of purposes. IBM machines even punched the payment checks. The increased reporting that Social Security required of companies induced many of them to adopt punched-card systems.

Office machines such as calculators, typewriters, and duplicators could be introduced singly because they expedited existing procedures. By contrast, the IBM machines used by the Social Security Board were part of a system that had to be adopted whole and that led to a reorganization of office work. The system, invented in the 1880s, was used successfully in business and government for more than a half-century and, by creating a large data-processing market, prepared the way for electronic computers.

In 1879, Herman Hollerith, recent graduate of the Columbia School of Mines, became a special agent for the U.S. census of 1880. Census-office personnel had already devised some mechanical aids to tallying the information, but Hollerith sought to mechanize large parts of the process. If the information was placed on cards by punching holes in particular positions, he reasoned, then machines could do the counting. In 1884 he went into business for himself and began filing for patents on machines for punching, sorting, and counting cards. The sorting and counting machines were electrical devices; a pin passing through a punched hole completed a circuit, which opened a lid (so that cards would enter a particular compartment) or advanced a counter. (See Figure 5.3.) The Hollerith system, used for the 1890 U.S. Census, increased the speed and accuracy of counting and permitted analysis of the data in new ways.[129]

[127] Sonenblum, p. 308.

[128] Burke, p. 116.

[129] Pugh, pp. 4–13, and Norberg.

Figure 5.3. Hollerith machines (photo courtesy of the IBM Corporate Archives).

In the 1890s Hollerith sought other government customers—in the United States and abroad—and commercial customers. In 1896 he began supplying equipment to the New York Central Railroad and incorporated his business as the Tabulating Machine Company. (The machines were called tabulating machines because they were used to prepare tables of data.) Hollerith continually improved his machines; he built a sorter that was fully automatic and a tabulator that could total the quantities in particular fields of the cards (so could add as well as count). The U.S. census of 1900 employed 1021 punches, 20 sorters, and 311 tabulators, and census offices in Canada, Norway, Austria, Russia, and Italy soon adopted the Hollerith system.[130] Affiliates of the Tabulating Machine Company were established in Britain in 1904 (called British Tabulating Machine from 1907 on) and in Germany in 1910 (called Deutsche Hollerith Maschinen Gesellschaft, or Dehomag); the latter soon expanded its operations to include Scandinavia and Switzerland.[131]

In 1911, when Hollerith had some one hundred customers, his company merged with the Computing Scale Company and the International Time Recording Company to form the Computing-Tabulating-Recording Company (CTR). In 1914 Thomas J. Watson, former sales manager of the highly successful National Cash Register Company, became general manager of CTR, and the following year he became president. Under Watson's leadership CTR became one the century's most successful companies, familiar around the world as IBM, International Business Machines Corporation, the name it assumed in 1924.

[130] Cortada, pp. 48, 53.

[131] Pugh, pp. 17–18.

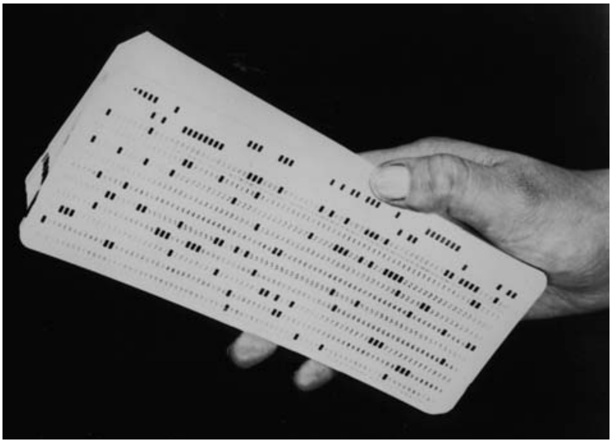


Figure 5.4. The 80-column IBM card, introduced in 1928, which replaced an earlier 45-column card (photo courtesy of the IBM Corporate Archives).

While Hollerith excelled at inventing and improving machinery, Watson excelled at building a sales organization able to find and retain customers. Watson considered it vital that his employees feel good about themselves and their company. He saw that they were well-trained and well-dressed, and he instilled company spirit through evangelical sales meetings and company songs.[132] He recognized, too, the importance of product development. When Watson took charge of CTR, it faced serious competition from Powers Accounting Machine Company, which had a tabulator that printed the results, rather than merely displaying them on dials or counters.

Watson immediately set up an R&D department at CTR. Able to translate the complaints or wishes of customers into technical tasks, he often assigned two or three inventors the same task and then selected the best solution.[133] He did this, for example, with the development of a printing tabulator, which CTR introduced in 1920. Another advance made the machines more versatile. Early tabulators had to be rewired when any change was made in the columns to be counted or added. An improved tabulator had a plugboard, so that the changes could be made quickly. A further improvement was the capability of exchanging plugboards without the plugwires in place; users could then have prepared plugboards for dozens of different applications.[134]

In 1928 the company introduced the 80-column card; no longer just a punched card, it was called by Watson the "IBM card" and became one of the most familiar artifacts of the middle decades of the century (see Figure 5.4). IBM built "reproducers" able to punch cards in the new format from cards in the old format, or vice versa. Also in 1928 the company introduced a tabulator able to subtract, and in 1931

[132] Pugh, pp. 34–35.

[133] Pugh, p. 47.

[134] Pugh, pp. 38–40.

an alphabetic tabulator (able to print letters as well as numbers) and a multiplying punch (able to multiply two numbers on a card and punch the result in a blank field of the same card). In the latter, multiplication was done electromechanically by a circuit containing relays.[135]

An important customer for punched-card equipment was the life-insurance industry. At the turn of the century life insurance was already big business—the largest firms had millions of policies—and some companies had begun to use punched-card equipment. A more efficient sorter developed in the 1890s by an actuary at Prudential Insurance Company prompted Hollerith to improve his, and after hearing an insurance company complaint about the time required for rewiring a tabulator Hollerith introduced the much faster plugboard system. Eager for machines that would create documents, the insurance companies supported two of Hollerith's competitors, J. Royden Peirce and James Powers, who pioneered in tabulators with printing capability. Peirce developed machines specifically for life insurance companies (including ones that could print alphabetic as well as numeric data), and Powers (whose Accounting Machine Company became part of Remington Rand in 1927) in 1913 began marketing a Printing Tabulator that was widely adopted in the insurance industry. It was particularly the threat posed by Peirce and Powers that prompted Watson to set up an R&D department at CTR in 1914. In Britain the Prudential Assurance Company (unrelated to the Prudential company in the U.S.) purchased the British Powers company, thus gaining direct influence on the technical developments.[136]

In these ways—making or stimulating particular innovations—the insurance business helped to shape tabulating equipment. Conversely, the tabulating equipment influenced the insurance business. At first the life insurance companies used punched-card machines simply to mechanize tasks, such as sorting, counting, and adding, that were being done manually. By reducing the costs of information processing, each company hoped both to gain a larger share of the existing market and to expand the market. The new equipment was soon put to new uses, as in allowing more extensive analysis of data and hence better design of products offered to the public. The printing tabulators, able to produce reports and records from preprinted blank forms, and the alphabetic tabulators in many cases eliminated steps in the processing of information.[137] The reciprocal interaction, which has been called co-evolution, continued in the computer era beginning in the 1950s.[138]

The railroads, an important early customer of tabulating machinery, used it for many types of accounting and for analysis of traffic data. In 1935 the Rock Island Railroad was punching 1.3 million cards a month. Other businesses used it to analyze sales data and to assist with inventory control and purchasing. For example, in the 1920s a system for chain store inventory management devised by Walter V. Davidson

[135] Pugh, pp. 48–51, and Norberg.

[136] Yates 1993.

[137] Yates 1993.

[138] Yates 1993.

came into wide use. And, as we have already seen, punched-card techniques were especially useful with payroll. Government use increased during World War I, when punched cards were used to keep track of recruits and to manage tax collections. In 1919, CTR had about 650 customers and was making about 110 million cards every month (the sales of which accounted for three-quarters of the company's revenues).[139]

Under Watson's leadership, CTR (later, IBM) continued to grow. Total sales increased from \$2.2 million in 1914, to \$44.7 million in 1938. Powers Accounting Machine Company (later, Remington-Rand) grew also, but its volume of business was about $\frac{1}{5}$ or less that of the industry leader.[140] There were numerous technical advances: the interpreter (printing, at the top of a card, the information already punched in the card), the verifier, a tabulator that printed the results, the IBM 80-column card, the reproducer (transferring data from one card to another), the multiplying punch (which recorded on an output card the product of two numbers read from input cards), the collator (able to insert or remove cards in a deck), and others.[141]

Watson's efforts for better products and better customer service were rewarded by IBM's reputation for reliable machines and excellent service.[142] The IBM historian Emerson Pugh has summarized his impact:

> *Watson is destined to be remembered for dress code, company songs, alcohol prohibitions, paternalistic policies, authoritarian practices, and salesmanship. But … he should be remembered even more for his ability to adapt to changing times. He successfully modified the company's products and business methods to prosper during two world wars and the Great Depression. He pioneered professional careers for women in his industry. And contrary to popular mythology, he showed remarkable ingenuity and flexibility as he readied the company for its post-World War II thrust into electronic computers.*[143]

By 1920 there was a sizeable office-machine industry, manufacturing typewriters, addressing machines, duplicators, calculators, tabulating machines, and more. This industry grew during the interwar years and in the 1950s, stimulated by wartime development of electronic computers, emerged as the data-processing industry. The punched-card equipment created the market for computers, as the first users of computers were usually those already using tabulating machines. The computer not only took over the functions performed earlier by punched-card machines, but also, in many cases, adopted pre-existing processes. One may therefore say that punched-card machines created and shaped the information-processing industry.[144]

[139] Norberg, and Cortada, p. 58.

[140] Norberg.

[141] Cortada, pp. 46, 56.

[142] Pugh, p. 51.

[143] Pugh, p. 36.

[144] Cortada, p. 44, and Pugh, p. xv.

5.3 ELECTRIFYING TRANSPORTATION

5.3.1 Streetcars and Subways

In 1842, just a dozen years after the opening of the first public steam-powered railway, Robert Davidson demonstrated a battery-driven electric locomotive on the Edinburgh–Glasgow line, but it proved too expensive for commercial use.[145] At the 1879 Berlin Exhibition, Werner von Siemens demonstrated an electric locomotive, drawing power from a center rail, and two years later the first public electric railway began operation in Lichterfeld, near Berlin.

Before electric traction was widely adopted, however, a number of difficulties had to be alleviated. Providing power to a moving vehicle was one; batteries were impractical and electrified rails, as at Lichterfeld, were dangerous. Motors had to be designed that could start and stop frequently and run at varying speeds. The power from the motor had to be conveyed efficiently to the axles. In the course of the 1880s, two engineers in the United States, Frank J. Sprague and Charles Van Depoele, solved these and other problems.[146]

Because most cities already had horse-powered streetcar systems, it was relatively easy to adopt the new technology, and in the 3-year-period following 1888, more than 100 U.S. cities did so.[147] By 1902, 94% of urban transit lines in the U.S. were electrified (and electric-powered subways made up part of the remaining 6%).[148] In the mid-1930s in the eastern United States, about 40% of the urban working class took the streetcar to work.[149] Interurban streetcar lines, connecting cities and reaching far out into the countryside, grew rapidly in the period from 1900 to 1915; in the U.S. they soon reached a total length of 15,000 miles.[150] Both the urban streetcar and the interurban lines, however, gradually gave way to the automobile in the thirty years or so following World War I.

Surviving somewhat longer were trolley buses, which received power from overhead electric lines. They appeared first in the U.S. in suburban Los Angeles in 1910, and in the 1930s appeared in cities throughout the country, in many places having been converted from electric streetcar systems. Trolley bus use reached its peak in the early 1950s.[151]

Subways proved more permanent. Here the example was set by London. In 1890 the Prince of Wales, later Edward VII, inaugurated the world's first electrified subway lines, the City and South London; its great success led within a decade to two more lines, the Waterloo and City and the Central.[152] Underground electric-rail

[145] Hannah, p. 2.

[146] Atherton, pp. 165–174.

[147] Burwell, p. 210.

[148] Chandler, p. 193.

[149] Harvey Green, p. 29.

[150] Burwell, pp. 210–211.

[151] Burwell, pp. 212–213.

[152] Bobrick, p. 111.

lines opened in Budapest in 1896 (the first on the Continent) and in Boston in 1897 (the first in North America).[153] The first line of the Paris Métro opened in 1900. Its entrances, designed by Hector Guimard, became world famous, fostering the Art Nouveau style (also known as *le style Métro*); 140 of Guimard's entrances were built between 1900 and 1913.[154] By 1936, the following cities, besides those already mentioned, had subway systems: Glasgow, Philadelphia, Madrid, Barcelona, Buenos Aires, Tokyo, Sydney, Osaka, Berlin, and Moscow.[155]

In 1931, Moscow had some 25,000 streetcars in service, and Stalin complained about their "overburdening the streets, retarding traffic and creating an incredible noise". The Central Committee of the Communist Party quickly decided to build a subway and to make it—with beautiful architecture, opulent materials, bright lighting, and good ventilation—a striking contrast to the dark and dirty subways of capitalist cities. Directing the project was a 40-year-old Ukrainian named Nikita Khrushchev. The first line opened in 1935, and the stations did indeed have a beauty unmatched in subways elsewhere. Khrushchev received the Order of Lenin for his achievement. By 1943 more marble had been used in 22 subway stations than in all the palaces of the Czar in the 50 years before the Revolution. The subways represented technological achievement, and the stations were secular cathedrals.[156] Lazar Kaganovich, who had overall charge of the reconstruction of Moscow, commented, "Our metro is a symbol of the new society that is being built."[157]

5.3.2 The Diesel-Electric and Turboelectric Drives

Electrically-powered locomotives got their start in a niche market, one that existed because in subways and tunnels the air pollution from steam locomotives was unpleasant and could be dangerous. In 1895, the Baltimore & Ohio Railroad began using electric locomotives for a tunnel in the city of Baltimore; the New York state legislature banned coal-fired locomotives from the underground Grand Central Station after July 1908; and other railways electrified parts of their lines because of tunnels.[158]

Besides the absence of smoke, electric locomotives had other advantages. They were quieter. They were more economical to operate. The electric motors could deliver power greatly in excess of their ratings for short periods, as in starting a train or in moving up a steep grade. There were, however, disadvantages. Though maintenance on the locomotives was less, maintenance on the fixed plant (the electrified track) was greater. More importantly, electrified track required a very large capital investment.

153 Bobrick, p. 223.

154 Bobrick, pp. 154–156.

155 Bobrick, p. 270.

156 Bobrick, pp. 272–281, and Josephson.

157 Quoted in Josephson, p. 532.

158 Burwell, p. 217.

In Europe, railway electrification was much more widely adopted than elsewhere. One factor was that many European railways were state owned, which made it easier to finance the initial construction of electrified lines.[159] The Apennines and the Alps partly explain why Italy and Switzerland pioneered in the electrification of railroad lines. Electric traction was capable of a steeper grade than was steam traction, and the mountainous terrain gave both countries abundant sources of hydroelectric power. By 1902, Italy had begun electrifying mainline track, and in 1931 electric trains handled 20% of the traffic. Large-scale electrification of the Swiss railways began at the end of World War I, and by 1931 all major lines were electrified. Sweden and Austria were two other countries where mountainous terrain stimulated the development of electric railroads. For western Europe as a whole, 6% of railroad mileage was electrified in 1931, while in the United States less than 1% was.[160]

In 1928, the Pennsylvania Railroad began the largest railroad electrification project in U.S. history. By the end of 1935, the entire line from New York City to Washington, DC was electrified.[161] However, the high capital cost of electrification, together with the alternative of the new diesel-electric locomotives, led U.S. railroads to abandon plans to electrify their lines. Indeed, the Pennsylvania Railroad electrification, completed in 1938, was the last major electrification project by any U.S. railroad.[162]

The successful alternative to track electrification was analogous to the early electrification of factories, before there were electric utilities from which to buy power; just as it was more efficient to use electricity as an intermediary between large steam engines and mechanical power at the workbenches, it proved more efficient to use electricity as an intermediary within a locomotive. By placing the prime mover (a combustion engine) and the generator in the locomotive, one could gain the advantages of electric motors without the costs of electrifying track. The prime mover that made this scheme practical was the diesel engine.

Patented by Rudolf Diesel in 1892, the diesel engine was an internal combustion engine that did not require an electric ignition system (as air was compressed to above the ignition temperature of the fuel). First used as stationary engines, the diesel seemed unpromising for transportation because of its great weight, difficulty in changing speeds, and inability to start under substantial load. Lightweight alloys, produced by electric processing, alleviated the first problem. The second and third were solved by coupling a constant-speed diesel motor with an electric generator that in turn powers electric motors.

In the 1920s the railroads faced increased competition from cars, buses, and trucks and therefore avidly sought more efficient engines as a cost-cutting measure. There resulted considerable improvements in the steam locomotives.[163] Older tech-

[159] Burwell, p. 223.

[160] Gordon.

[161] Burwell, p. 218.

[162] Burwell, pp. 218–220.

[163] Braun, p. 97.

nologies often undergo sudden technical advance when faced with new technologies, as happened with gas lighting in the 1890s. Much more effective was the development of the diesel-electric locomotive: diesel-electric engines converted fuel to motive energy with 33 to 40% efficiency (making them only slightly less efficient than all-electric system), while steam engines could achieve only 10% efficiency.[164]

A diesel-electric railway car was built in Sweden as early as 1913. A significant advance was the introduction in about 1928 of the mercury-arc rectifier; it allowed the wider use of DC motors, which were less expensive to maintain than AC motors. Europe's first high-speed diesel locomotive, the "Flying Hamburger" (which had an average speed of 124 kilometers per hour), came into service between Hamburg and Berlin in 1933. The Canadian National Railway began using the diesel-electric locomotive as early as 1930. In the 1930s, the conversion to diesel-electric began in earnest in many countries, and by 1960 almost all steam locomotives were retired.[165]

The new diesel-electric trains helped popularize streamlining. The style spread from airplanes to trains, automobiles, appliances, and countless other objects. (The first streamlined automobile in the U.S. was the Pierce-Arrow in about 1933; there was great excitement when the Airflow Chryslers and DeSotos were unveiled in 1934.)[166] Also making the railroads modern in the 1930s was their use of air-conditioning (the electric power coming from an axle-driven generator).[167]

Ship builders also looked to electric engines. The *Lexington* and the *Saratoga*, two U.S. aircraft carriers completed in 1927, had turbo-electric propulsion (central electrical control of four shafts, driven by eight electric motors of 22,500 horsepower each).[168] In 1932, the French transatlantic liner, the *Normandie*, was launched; more than 1000 feet in length, it was powered by a turbo-electric plant consisting of four sets of impulse turbines, each connected to a 6000 volt alternator, the current passing to four 40,000 horsepower motors (each driving a propeller).

Though ship propulsion remained, in most cases, non-electrical, electrical technologies of many other sorts transformed the operation and navigation of ships. Intraship and intership communication, lighting, heating, ventilation, hoists, remote control of bulkhead doors and rudders, and automatic stabilization are a few of the functions, many of which were mentioned in Chapter 2. Chapter 9 reviews other shipboard technologies, and Chapter 10 discusses how radar became a vital navigational tool, both for a new form of vision from the ship and for positional information from distant beacons.

[164] Klein, pp. 17–19.

[165] Klein, pp. 17–19.

[166] Hall.

[167] *Electrical Engineering*, vol. 51 (1932), p. 278.

[168] Hezlet, pp. 183–184.

5.3.3 Automobiles, Aircraft, and Elevators

Born on an Ohio farm in 1876, Charles F. Kettering worked for two years on a telephone line crew before earning a degree in electrical engineering at Ohio State University. In 1904 he accepted a position as "electrical inventor" with the National Cash Register Company (NCR) of Dayton, Ohio, which then had nearly a monopoly on the rapidly growing cash-register business in the United States. Kettering soon set to work on an electric cash register.[169]

Customers had long complained how tiring it was to press the keys of mechanical cash registers, but earlier efforts to electrify the register, both at NCR and elsewhere, had not succeeded. Kettering designed a small motor capable of high torque in short spurts and a clutch mechanism to engage and disengage the counting wheels at precisely the right moments. He made further improvements, arriving at a "universal motor" able to run on a wide range of voltages and frequencies, hence well suited to NCR's foreign markets. (By 1910 foreign sales accounted for about half of NCR's business.) The electric register was an immediate success. Kettering later remarked, "We have never placed a machine upon the market which has caused less trouble or opened up a greater field for increased business." [170]

For a different cash register, Kettering designed another electric motor, one capable of either continuous or intermittent operation. Such experiences so impressed him with the value to the company of basic research that he initiated a series of fundamental investigations of electric motors. This work profited both NCR and Kettering personally. In 1909 he resigned from the company and turned his attention to another product that he believed could be greatly improved by the incorporation of an appropriate electric motor.[171]

Electrical technology was already a vital part of gasoline-powered automobiles. A major innovation of the Belgian engineer Étienne Lenoir, who built the first commercially successful internal-combustion engine in 1860, was the use of an electric spark plug, powered by a battery, to ignite the air–fuel mixture.[172] By the turn of the century the German engineer Robert Bosch developed a magneto (an electric generator containing permanent magnets) to replace the battery.[173]

Moreover, a major competitor to the gasoline car was the electric car. (The other major competitor was the steam-powered car.) Indeed, in the United States in 1899 electric passenger cars outsold gasoline cars 1575 to 936. By 1904, however, 85% of new cars were gasoline powered.[174] The limited range (50 to 80 miles on a battery change), high price (much above that of a gasoline car), and low power of electric cars led to their gradual disappearance from most roads.[175] Beginning in 1910, however, the electric-car business revived briefly. Technical advances, such as

[169] Leslie, pp. 1–21.

[170] Leslie, pp. 21–22, and Cortada, p. 71.

[171] Leslie, pp. 22–37.

[172] Flink, p. 11.

[173] Leslie, p. 39.

[174] Burwell, p. 214.

[175] Flink, p. 10.

improved batteries (notably Edison's nickel-iron battery), played some role, but more important was the cultivation of a niche market—well-to-do, female town-dwellers. Electric cars were clean, quiet, reliable, easy to operate, and, most importantly, simple to start. (Starting a gasoline car was physically difficult and even dangerous.) Annual sales of electric cars climbed to 4500 in 1910, and reached 6000 in 1912.[176] It was at this point that Charles Kettering changed automotive history.

At the time that he left NCR, Kettering was already working on an improved automobile ignition system. He and a partner formed the Dayton Engineering Laboratories Company (Delco), and soon several car manufacturers, including Cadillac, adopted the Delco ignition. Kettering then decided to devise a self-starter, something scores of other inventors had already attempted, but as part of an integrated system for starting, headlamps, and ignition. He designed the starting motor so that it could be operated in reverse, once the engine was running, as a generator to recharge the battery and thus power the headlamps and ignition. He built a voltage regulator to allow for high engine speeds and a "low voltage cut-out" to disconnect generator and battery when the voltage generated fell below battery voltage.[177]

In February 1911, Kettering installed a complete unit in a Cadillac, and the first person outside Delco to ride in the self-starting car was Kettering's former associate at NCR, Thomas J. Watson, who was astonished by the experience, at first thinking that the absent-minded inventor had forgotten to crank the car. In November, Delco received an order for 12,000 of the systems from Cadillac.[178] Following its introduction in the 1912 Cadillac, the self-starter, marketed as the "ladies' aid", gained rapid acceptance. Gasoline cars equipped with self-starters soon captured the niche market that electric cars had cultivated.[179] (Electric vehicles held onto another niche market—delivery trucks for city use—well into the 1920s, and two other niche markets much longer—electric golf-carts and electric vehicles for factories and warehouses.)[180] In the years that followed came other electrical innovations. Besides headlights and signal lights, there were electric indicators, such as the electric fuel-gauge; the electric horn; electric controls, such as the automatic choke; the activation of the starter by pressing the accelerator (rather than a separate starter pedal); air conditioning (which became available in the 1930s); electric windshield wipers and washers; and, as mentioned earlier, radios. In 1939, the Music-Aire horn, which played a tune, was introduced.[181]

The most striking change in automobile design in the 1920s was the move to the closed steel body. In the United States, 90% of the cars built in 1919 were open (that is, without solid sides and tops for the passenger compartment, though they were usually equipped with a canvas canopy roof); of those built in 1927, only 18%

[176] Schiffer, pp. 125–152.

[177] Leslie, pp. 38–48.

[178] Leslie, pp. 48–50.

[179] Flink, pp. 162, 212.

[180] Schiffer, pp. 164, 173.

[181] Hall.

were open.[182] This change is explained largely by reduction in price: in 1922 a car with a closed body cost 50% more than a similar one with an open body, while in 1926 the premium was only 5%.[183] The reduction in price is explained largely by improved production techniques, the most important of which was automatic electric welding.

Thomson Electric Welding Company introduced an automatic welder in 1924; it could turn out 600 wheel rims per hour.[184] In the 1930s, almost all of the some 5000 welding operations required for the assembly of the Model A at Ford's River Rouge plant were machine assisted.[185] One of these operations was described thus: "Here the rear panel and two quarter panels are placed together in a huge balloon flash welding machine, a man pushes a button, the machine closes, there is a shower of sparks and the three sections are welded into one by means of 72″ seams in seven seconds."[186] Automatic welding played a large role in unit body construction—a single structure serving as both body and chassis—that was pioneered by the French manufacturer Citroën in 1933 and that appeared in the U.S. market with the 1936 Lincoln Zephyr.[187]

Freight elevators were already in wide use in the 1850s when Elisha Graves Otis, by inventing a safety mechanism, created a market for passenger elevators. Most elevators were run by steam engines until the 1880s, when hydraulic elevators (powered by water pressure from street mains, a tank on the roof of the building, or a pressure tank in the basement) became more common. Otis Brothers began selling electric elevators in 1889. Earlier elevators, both steam and hydraulic, were started and stopped by pulling down or up on a hand rope. Electric elevators made possible push-button control and, in many buildings, the elimination of the elevator attendant. By 1905 the majority of elevators manufactured were electric.[188]

The first escalators were built in the 1890s, and four types were demonstrated at the Paris Universal Exposition in 1900.[189] One of the systems demonstrated there, built by H. Ward Leonard, had a crucial innovation: automatic control of the motor speed, so that variation in the number of riders did not cause changes in speed. An escalator was able to carry more than 8000 people per hour, some 30 times the capacity of an elevator. Thus escalators were favored where traffic was heavy, as in department stores or train stations. There was an escalator at London's Earl's Court underground station in 1911. ("Escalator" was the brand name of the moving stairways manufactured by the Otis company, but in 1950 it was judged to be a generic term.)

182 Flink, p. 213.

183 Abernathy, p. 19.

184 Abernathy, p. 185.

185 Abernathy, p. 186.

186 Quoted in Abernathy, p. 133.

187 Abernathy, pp. 193–194.

188 Millbrooke.

189 Pursell, p. 87.

Mention might be made of another form of electrical transportation: moving sidewalks, which were featured at the 1893 Columbian Exposition in Chicago. Five years later one was installed in Harrod's department store in London, and many people hoped that they would solve the growing traffic problem of cities. But the device was almost forgotten for more than a half century (though in recent decades many examples have appeared, especially in airports).[190]

An important part of a country's transportation infrastructure are the pipelines through which fluids, such as water, oil, or natural gas, flow. Here, too, electricity became important, especially to power the pumps that move the fluid. In the United States more than 100 billion kWh of electricity is used each year to transport water alone; this is 5% of all the energy used for transportation services.[191] Beginning in the 1930s, electricity made possible remote control of pumping stations, so that a dispatching office many miles away could monitor and control the pumps with as much information as could be obtained at the stations.[192]

5.3.4 Control in Transportation

In many areas, electrical technologies for control followed on the heels of applications of electric power. Transportation was one such area.

Elevator control proved challenging. For elevators little used, Otis's "automatic continuous noninterference system" worked well without the need for an elevator operator: the elevator handled one call at a time, not responding to any other call until the elevator was unoccupied. Heavily-used elevators, on the other hand, were controlled by an operator from within the car. In buildings with a bank of elevators, there could be an elevator dispatcher, who watched an indicator board and transmitted instructions, often by buzzer, to the operators within each elevator. In 1924 Otis simplified the job of the elevator operator by introducing Signal Control, whereby elevator speed and stopping were controlled automatically, the operator operating buttons only to select floors and close car doors. *Scientific American* wrote that Signal Control gave elevators "electric brains". Finally, in 1950 the Otis company introduced Autotronic Elevatoring, which eliminated the need for attendants in heavily used elevators.[193] An important automatic control mechanism was the photocell system that prevented elevator doors from closing on passengers; these first appeared in the early 1930s.[194]

The commercial aviation industry grew steadily in the interwar years. By the end of 1929 more than 80 air-transport routes had been established in the U.S.[195] The introduction in 1933 of the Douglas DC-2 and the Boeing 247 gave the industry

[190] Braun, p. 228, and Pursell, p. 89.

[191] Burwell, p. 225.

[192] Committee on General Power Applications.

[193] Millbrooke.

[194] Underhill, p. 228.

[195] Pursell 1995, p. 236.

a great boost, and by the end of the decade the airlines were moving more than three million people a year. Many electrical technologies were involved: motors, lights, heating devices, radio communications, and instruments.

In the 1930s an aircraft might contain a hundred different instruments.[196] The pilot's instrument panel was one of the most complex and concentrated sets of data indicators to be found anywhere.[197] There was remote sensing of engine conditions: tachometer, oil- and fuel-pressure indicators, and indicators of the temperatures of water, oil, and cylinders. There were electromagnetic compasses and, especially important, turn indicators (which incorporated electric gyros). There were radio altimeters (a primitive form of radar) and sonic altimeters.[198] Radio direction-finding (discussed in Chapter 1) made possible a radio compass. The first commercial radio compass went on the market in 1921, and radio compasses were in widespread use on ships in the mid-1920s.

Indeed, on September 24, 1929 James H. Doolittle (famous today for his World War II bombing raid on Tokyo) demonstrated the possibility of instruments-only flying. Doolittle equipped an airplane with an accurate altimeter and a radio-beacon guidance system (which indicated exactly where to land). He enclosed the rear seat, where he sat, with canvas. In the front seat sat another pilot ready to take over if any problems should become apparent. Doolittle, without any visual information from outside, made a successful 15-minute flight. In 1937 an instrument landing system, which made it possible to land in conditions of low visibility, went into operation at Berlin's Tempelhof airfield.

Automatic control in airplanes attracted attention in July 1933 when Wiley Post made a solo flight around the world. Post credited his success to "Mechanical Mike", the new Sperry A2 autopilot, which was installed in his Lockheed Vega 5B. The autopilot allowed Post to rest during the seven-day flight.[199] (Post made headlines again two years later, when he and his friend Will Rogers died in a crash.) In addition to directional control, autopilots provided automatic stabilization (relieving the pilot of the constant task of maintaining straight and level flight).[200] This function was introduced as early as 1920, when the Aveline-Stabiliser was demonstrated on a Handley-Page aircraft at Cricklewood, North London. The Boeing 247, introduced in 1933, has an automatic pilot, and soon autopilots were common in commercial aircraft.[201]

Air traffic control was facilitated by a variety of electrical technologies, such as runway lights and beacon lights. Radio made possible enroute communications, concerning traffic and weather, between pilot and terminals. For flying standard routes, radio beacons, in use in the early 1930s, indicated to the pilot when he was on course. For flying off the usual airways, the pilot could use a radio homing device to see if he or she was flying directly toward the selected airport.[202]

[196] Perazich 1939, p. 9.

[197] Sydenham, p. 423.

[198] Green.

[199] Bennett, p. 18.

[200] Bennett, p. 19.

[201] Bennett, p. 19.

[202] Green.

In 1920 there seemed no prospect of making an airplane gyrocompass, and operation of a magnetic compass was disturbed by the plane's motion and by the currents in its electrical wiring.[203] Hence radio beacons were a welcome solution to the problem of accurately determining bearing. Radio navigation has a crucial advantage over most other means of taking a bearing: the accuracy of the bearing increases as the distance to the goal decreases. As J.E.D. Williams, historian of navigational science, writes, "It this *homing* quality of radio which made air navigation in cloudy conditions practical, leading eventually to the routine of automatic landing of airliners with hundreds of passengers aboard when the visual range is no more than that required to navigate the taxiways after landing."[204]

It was a system patented by Otto Scheller in 1907 that was adapted for use in the United States in the 1920s. Two antennas aligned in slightly different directions transmitted different signals. A pilot, equipped with only an ordinary radio receiver, heard one signal when he was to the left of the intended airway, a different signal when he was to the right, and a continuous tone when he was on course. By the end of the 1930s, the network of radio-range airways stretched across the North American continent.[205] J.E.D. Williams has written:

> *For the first time for centuries, navigators without visual reference to terrain required neither protractor nor dividers, and were indifferent to latitude and longitude. It was, arguably, the greatest revolution in navigations since the chronometer. Most of the navigator's routine became pre-flight planning. The flight plan, range by range, became the only navigation document.*[206]

In the 1930s the Germans designed and installed guidance systems for the approach to landing: a track guidance system similar to the Scheller system; marker beacons below the approach, each transmitting vertically; and some indication of glide slope by means of a signal-strength meter. Toward the end of the decade, the U.S. Army Signal Corps devised an improved system—the glide path was marked by a radio beam, and a visual display told the pilot his position relative to that path—and in 1948 a version of it, called Instrument Landing System, was adopted internationally.[207]

Running a railroad was a complicated business: scheduling traffic, maintaining smooth operations when deviations from schedules occurred, assuring safety, arranging for efficient use of freight and passenger cars. Indeed until the 1880s most railroad companies delayed expansion because managers considered any system much more than 500 miles in length to be too complex to manage.[208] Systematic administration, together with improved means of communication and control, gradually removed this impediment to expansion. We have already mentioned the importance

[203] J.E.D. Williams, pp. 139–141.

[204] J.E.D. Williams, p. 176.

[205] J.E.D. Williams, pp. 187–189. The network was created by the Aeronautics Branch of the Department of Commerce, forerunner of the Federal Aviation Administration.

[206] J.E.D. Williams, p. 189.

[207] J.E.D. Williams, pp. 191–192.

[208] Beniger, pp. 232–233.

of the telegraph and telephone to the railroads and their use of punched-card equipment—the New York Central Railroad was Hollerith's first commercial customer. Here we consider another technology important to railroads: electrical control systems.

With electric or diesel-electric locomotives, a control system was necessary for an individual motor, for the set of motors of a locomotive, and for linked locomotives. Remote control proved extremely valuable in sorting freight cars in switching yards. This was a time-consuming process: railroad traffic studies in the 1920s revealed that a freight car spent three-quarters of its life in terminal yards. Efficiency was improved by George Westinghouse's introduction in 1891 of remotely controlled electro-pneumatic switches. Even more important was the invention in about 1921 of remotely controlled electro-pneumatic car retarders (installed on the tracks to control gravity-assisted switching).[209] A railroad historian has written, "Few inventions have so transformed the work of railroads. Lives and limbs were saved, yard time for cars reduced, many collisions avoids, freight speeded to market. Car retarders also made it possible for the yards to be open in all types of weather. …"[210]

Electrical technology made an enormous contribution to railroading through signaling and control of track switches. Soon after its invention, the telegraph was used to report train departures and arrivals, and in the 1850s trains began to be controlled by wire. Dispatchers were thus able to modify schedules, to reroute trains, and to report delays, and they were able to do these things immediately.[211] As railways expanded in mid-century, there was a rapid increase in the number of track junctions, which made signaling a much more complicated operation. In 1856 in Great Britain, John Saxby patented a system for controlling signals and switches by one operation, thus delegating some control to the hardware.[212] By 1900 several automatic signaling systems were in use. Because appropriate electric motors were not then available, the earliest systems were powered by compressed air controlled electrically (by means of a solenoid valve).[213]

At an 1841 meeting in Birmingham, England railway signalmen agreed on the color code of white for safety, green for caution, and red for danger. In the United States, too, this was the most common code—for lights as well as semaphore signals (movable arms at the top of poles)—until the turn of the century. The tendency to mistake no signal for the "all clear" signal (white) prompted the New York, New Haven and Hartford Railroad in 1899 to adopt green for "all clear" and yellow for "caution" (keeping red for "stop"). Other railroads gradually followed suit, and the same color code was later adopted for automobile traffic lights.[214] From the turn of the century on, light signals gradually replaced semaphore signals.[215]

[209] Aldrich, and Brignano, pp. 178–180.

[210] Brignano, pp. 178–180.

[211] Brignano, pp. 48–52.

[212] Brignano, pp. 65–69.

[213] Brignano, pp. 114–116.

[214] Brignano, pp. 137–138.

[215] Brignano, pp. 133–134.

Railroad crossing acquired automatically triggered flashing lights and electrically-powered gates.[216] Automatic doors came into use, especially for subways. As early as 1901, mechanisms to automatically stop a train when it was in danger began to be installed.[217] In 1923 the signalling system of the New York subway lines run by the Interborough Rapid Transit Company consisted of 111 electro-pneumatic control centers operating 2313 signals and 975 switches.[218]

An achievement of the late 1920s was Centralized Traffic Control (CTC). Earlier, the necessary coordination resulted from the actions of many individuals who followed published schedules in operating trains, switches, and signals manually. Any deviation from plans, such as adding cars or changing times, required communication by telegraph or telephone to many people. CTC placed the control of switches and signals over a large area in the hands of one person. In many systems, the order to activate a particular switch or signal reached its desired destination by bearing a coded address that was recognized by a "selector" associated with the intended switch or signal. CTC made it possible to increase greatly traffic on existing track and thus lower costs.[219]

An early application of electron tubes outside of radio was Lloyd V. Lewis's vacuum-tube amplifier (about 1917) placed on locomotives for picking up signal currents carried in the tracks.[220] This type of signaling to locomotives increased the capacity of lines because it allowed trains to resume speed as soon as the block ahead was clear, rather than having to wait until the next wayside signal came into view.[221] Greater safety, too, resulted from the new technology.

5.4 FOSTERING ECONOMIC GROWTH

5.4.1 Postwar Recovery and Electrification

World War I devastated the economies of the European belligerents. Those economic activities directed to exclusively wartime needs came to an end, and markets for civilian products had to be reestablished. International trade had been disrupted, and many countries had suffered extensive destruction of factories, roads, railroads, and communications. And during the war, governments had borrowed money to an extent far beyond any historical precedent.

There was great postwar inflation. In Britain prices in 1920 reached three times prewar levels; in France, five times prewar levels. The currencies of central and eastern Europe lost $\frac{9}{10}$ or more of their prewar value. Austria, Hungary, Poland, Russia, and Germany all experienced hyperinflation, with prices thousands, millions, or billions of times prewar values. Though inflation drastically reduced indebtedness

[216] Brignano, pp. 148–153.

[217] Brignano, p. 156.

[218] Brignano, p. 134.

[219] Brignano, pp. 183–188.

[220] Brignano, p. 159.

[221] Aldrich.

within these countries, it did not ease the burden of debts or reparations due to foreign creditors, since these required payment in gold or hard currencies, and it bred a general sense of insecurity.[222]

Gradually, however, conditions improved. By the middle of the decade, European manufacturing had reached prewar levels, and it continued to climb until 1930.[223] In 1928–1929, national income in Britain was 113% of its prewar level, in Germany 109%, in France 124%, and in Sweden 139%. International trade only slowly revived, partly because throughout the 1920s and 1930s, nations increasingly had recourse to tariff protection against foreign businesses. World trade reached only 112% of the prewar level in 1928–1929 and fell to 92% during 1936–1938, this despite an overall rise in output of manufactures, which reached 149% of the prewar level in 1928–1929, and 188% during 1936–1938. Also disquieting was that in most countries unemployment remained at high levels. In Germany unemployment stood at 18% in 1926; in Denmark and Norway unemployment averaged almost 20% during 1925–1929; and in Britain it was never less than 9% of the workforce anytime in the decade.[224]

Overproduction of most farm products led to much lower prices. Most businesses, on the other hand, found ways, such as mergers or trade associations, to maintain high prices. In the postwar period, governments intervened in many matters—setting tariffs and quotas, controlling currencies—once left to the market.[225] On the whole, however, economies grew faster than populations, and the 1920s saw larger increases in productivity than almost any other decade in history.

Taking a larger view, consider that over the past half-century, the economies of some 15 developed countries have grown at an annual rate of about 3% (corresponding to a rise in total product by a factor of fifteen in the course of a hundred years). Population in these countries has grown at about 1% per year (almost tripling in a century), and per capita product has grown at about 2% per year (becoming more than five times as large over a century). Accounting for a large part, in some cases as much as 80%, of this growth in per capita product has been increased productivity (output per unit of input), since increases in labor and capital inputs have been quite limited.[226]

Increased productivity comes partly from better ways of organizing work, but mainly from improved or new methods. The economic historian Jacob Schmookler concluded, "Long-term economic growth is primarily the result of the growth of technological knowledge. …"[227] He points out that this growth results either from the diffusion of existing technological knowledge, a process described in Chapter 3, or from the creation of new knowledge, a process to be considered later in this section.

[222] Landes, pp. 361–362, and Clough, pp. 95–96.

[223] Clough, pp. 15, 133.

[224] Landes, pp. 365–369.

[225] Landes, p. 359.

[226] Kuznets, pp. 303–306.

[227] Schmookler, p. 196.

In the quarter century from 1913 to 1938, productivity (output per man-hour) rose at an annual rate of 2.1% in the United Kingdom, 2.35% in France, 1.3% in Germany, 1.5% in Belgium, and 2.45% in Switzerland. In the same period, real income rose by an average of just 1% per year in Germany and the U.K., even less in France. Yet this was a period of devastating war, postwar inflation, and economic depression, so these figures provide, according to the historian David Landes, "testimony to the power of continued technological change to stimulate investment and raise productivity in the most adverse circumstances."[228]

The U.S. fared better economically. In the period from 1913 to 1938, productivity rose at an annual rate of 3%. Much of the improvement occurred in the 1920s, when productivity increased 5.2% annually.[229] The years from 1922 to 1927 saw the highest peacetime growth rate ever for the U.S. economy, 7% per year.[230] In the 1920s, real incomes increased an average of 35%, while incomes climbed only 5% over the entire previous 20 years.[231] The average output per unit of capital input increased faster during the period from 1919 to 1929 than in any other period between 1899 and 1953.[232] Labor costs, too, declined per unit of output.[233]

The productivity increase resulted from many small innovations in manufacturing processes.[234] Many of the innovations—we have already mentioned improved plant layouts, continuous processing, and automatic control—resulted from increased application of electricity. Perhaps most significant was the 50% increase in mechanical power per worker in the period from 1919 to 1929.[235] In the case of the paper industry, it is possible to give an estimate of the magnitude of the contribution by electrical technology; a study concluded that about half of the output-capital growth was due to increased application of electricity.[236]

Despite a gradual increase in total energy consumed, this period saw a decrease in energy intensity, that is, energy consumed per unit of output. This trend and the rising productivity were both in part a result of the increasing share of energy provided by electricity.

Electricity consumption in Europe more than doubled from 1920 to 1929 (53 to 113 billion kilowatts) and almost doubled again in the next decade.[237] In the United States in the 1920s total energy use increased an average of 1.2% per year, electricity use 7.3%; in manufacturing the annual increase was greater—9.1%.[238] The principal cause for this increase was the substitution of electric power for other sources of

[228] Landes, pp. 419–420.

[229] Landes, p. 420.

[230] Perrett, p. 337.

[231] Perrett, p. 324.

[232] Lorant, p. 1.

[233] Sonenblum, p. 404.

[234] Lorant, pp. 202–213.

[235] Link, p. 306.

[236] Lorant, p. 143.

[237] Purnell's, p. 1152, and Landes, p. 431.

[238] Schurr, p. 343, and Sonenblum, p. 308.

mechanical energy in manufacturing. In 1903 in the U.S. electricity provided just 7% of the mechanical energy used in manufacturing; in 1920, it was 52%, in 1929, 78%, and in 1937, 84%.[239] Though electricity generated by manufacturers themselves continued to increase, the trend was toward greater use of utility-generated electricity.[240]

Improved productivity in power generation reduced the cost of electricity. In the U.S. the efficiency of energy conversion at steam-electric plants increased from 5% in 1900, to 30% in 1940. In the period from 1919 to 1927 alone, the amount of coal needed to produce one kilowatt-hour of electric power decreased from 3.20 to 1.84 pounds.[241] This, plus improved production methods, explain the decrease in energy intensity; in the U.S., the energy use per unit of output declined by 40% from 1920 to 1937.[242]

Electrification made increased productivity possible both by improving particular steps in manufacturing and by allowing improved organization of production as a whole.

The use of instruments to monitor and control factory processes led to two types of savings: operating economies and economies in the use of capital equipment.[243] Accurate control of operating conditions reduced the inputs of raw materials and fuels needed. With many furnaces, by monitoring CO2 levels one could achieve more complete combustion and thus lower fuel costs. In one case fuel costs fell 15.5% as a result. At that time, reducing fuel consumption by 1% in a large boiler could save $10,000 annually. There was often a reduction in labor requirements, in the number of workers required or the skill levels required or both. There was frequently a reduction in breakdowns on the production line and in defective goods. For example, careful control of temperature in porcelain kilns and in glass annealing furnaces significantly reduced the incidence of defective products.[244]

Instrumentation often permitted increased speed of machinery, which meant that less equipment was needed for a given rate of output. Equipment carefully maintained, with the help of monitoring by instruments, had a longer life. Central monitoring and control helped ensure continuity of operations, by carefully controlling the operating conditions and by rapid identification of equipment malfunctioning or in danger of malfunctioning. Less idle time meant greater capacity. For example, installation of automatic control of temperature and humidity in a lumber-drying kiln raised the annual capacity of the kiln 46%.[245]

The most important effect of electrical technology on manufacturing was that it led to improved organization of production. Chapter 2 reviewed how electric motors allowed more efficient arrangement of factory production: increased flow of

[239] Sonenblum, p. 390.

[240] Sonenblum, p. 378.

[241] Bennett, p. 2.

[242] Sonenblum, p. 414.

[243] Perazich 1938, p. 69.

[244] Perazich 1938, pp. 69–75.

[245] Perazich 1938, p. 72.

production (especially through the use of overhead traveling cranes and movable power tools), improved working environment (illumination, ventilation, cleanliness), improved machine control, and ease in plant expansion. Since materials handling is a major part of the cost of manufacturing, great savings resulted for the more efficient layout of operations and the better means of materials handling.

The reorganization of factory work may, indeed, have been the main cause of the unprecedented productivity growth of the interwar period.[246] What electric power offered was precision in the application of power: precision in space (the mechanical or thermal power generated at the point of use), precision in time (the power generated only when needed), and precision in intensity (a power level exactly suited to the task).[247] Other electrical technologies, such as instruments and control systems, contributed to the productivity increases. Improved transportation and communications facilitated business activities of all sorts.

The general rate of technical advance in an economy depends greatly on improvements in production technology, because the rate at which a new consumer or producer product is sold is usually quite sensitive to price (typically there are older products that serve the same purpose) and the price at which a product can be offered can often be lowered greatly by more efficient production technology.[248] Ford's assembly-line techniques turned the automobile from a luxury item into an item of mass consumption. In recent decades the falling price of computers has led to their use in more and more businesses.

The new techniques of production required less human labor per unit of output, and the interwar period was one of chronic unemployment. To some extent, electrical technologies compensated by increasing economic activity generally, by stimulating demand (as by radio advertising), and by providing new products (such as the control equipment mentioned above or the consumer appliances considered in the next chapter).

5.4.2 New Products and Industrial Research-and-Development

The second half of the nineteenth century saw the emergence of industrial research in the German chemical, pharmaceutical, and optical industries. In the electrical industry, the two leading entrepreneurs were also champions of industrial research. Werner Siemens, whose work on electrical units is commemorated in the name for the unit of conductivity (the siemens), stressed the practical value of scientific research and put a large part of his profits into research and development.[249] Thomas Edison set up a research laboratory with the intention of constantly making inventions—"a minor invention every ten days and a big thing every six months or

[246] Schurr, pp. 4–5.

[247] Devine, p. 38.

[248] Cortada (p. xviii) argues this point for information-processing technology.

[249] von Weiher, pp. 38–40.

so"—and he succeeded in doing this, both at Menlo Park, New Jersey, and at his later laboratory at West Orange.[250]

In the early twentieth century in the U.S., three electrical companies stood out for their support of industrial research. In 1889, several Edison companies merged to form Edison General Electric Company, and in 1892 a further merger, with the Thomson-Houston Electric Company, produced the General Electric Company (GE).[251] In 1900, GE established a research laboratory under the direction of Willis R. Whitney; it grew in size to a professional staff numbering 44 in 1906.[252] In 1907, John J. Carty supervised a consolidation of research and development engineers of the Bell Telephone System (including the Western Electric Company) at 463 West Street in New York City, which took the name Bell Telephone Laboratories at the end of 1924.[253] Other companies, too—such as Westinghouse and, in the 1920s, RCA—began investing in research and development.

Before World War I a research department was regarded as a big-business luxury, and in 1920 only 8000 people were employed in industrial research.[254] The wartime success of directed research was influential; in 1916 John J. Carty said that out of the war "comes a growing appreciation of the importance of industrial scientific research, not only as an aid to military defense but as an essential part of every industry in time of peace."[255]

A government study of industrial research in the U.S. found that in 1938, 50,000 people were employed in industrial research, four times the number so employed in 1921 and more than the number employed in mining copper and iron ore or in manufacturing radios and phonographs. The increase occurred despite a substantial decline in industrial research in the years 1931 to 1933, when many companies reduced their research staffs and more than 100 companies discontinued their research activity altogether. The study concluded: "This remarkable growth… reflects the emphasis that industry is placing on improved and less costly production methods, on the improvement of products, on the utilization of waste products, and on the creation of new goods and services."[256]

Industrial research was concentrated in the largest companies—in 1938, just 54 companies employed half of the total number of researchers—and in relatively new industries, such as chemicals, petroleum, rubber products, and motor vehicles. The electrical industries employed more than ⅕ of all researchers; the main areas of research were electrical communications (telegraph, telephone, and radio broadcasting), electrical machinery, radio receivers and phonographs, and electric power.[257]

250 Reich, p. 43.

251 Reich, pp. 45–48.

252 Reich, pp. 66–75.

253 Fagen, pp. 42–52.

254 Landes, p. 482.

255 Carty.

256 Perazich 1940, p. xi, 6.

257 Perazich 1940, pp. 19, 66.

In the United States, research in electrical technology was dominated by Bell Telephone Laboratories, GE, Westinghouse, and RCA.

A research laboratory benefited a company in several ways: relevant, recent results of science and technology were brought to the company's attention so that it would not be surprised by new developments; products and processes were improved; new products were designed; patents were acquired that could prevent competitors from exploiting new technology; difficulties with materials or production methods were investigated; and the firm could more readily gain a progressive image.[258] In many cases, companies at first directed most R&D toward improvements in production and later redirected the work more toward product improvement.

The economic historian Jacob Schmookler presents a substantial body of evidence showing that the amount of invention in different areas is governed by the extent of the market. He then explains this empirical finding as follows: "(1) invention is largely an economic activity which, like other economic activities, is pursued for gain; (2) expected gain varies with expected sales of goods embodying the invention; and (3) expected sales of improved capital goods are largely determined by present capital goods sales."[259] Invention should not, then, be an exogenous variable in economic theory (as it would be if, for example, inventions were by-products of non-market-directed scientific advance), but rather an endogenous variable.[260] Earlier, invention was a nonroutine economic activity; in this century, it has increasingly become a routine economic activity.[261]

A thorough study of innovation in the automobile industry, however, arrived at a different result. William Abernathy concludes:

> *Some of the most important innovations in the industry were made under weak demand conditions and made apparently to stimulate demand." He argues that manufacturers turned to new technology when sales lagged, and that "In the automobile industry, the most important explanatory factor in innovative activity seems to be the competitive strategies of the major firms …."*[262]

He finds the following pattern: "… [each innovation] at first was available only in expensive cars, then in many cars, and ultimately became a standard aspect of all cars. With wide adoption, each wave of new features became "packed down" in the product technology and taken for granted by customers, and fresh innovations were again needed for competition."[263] Examples of this include electric starters, electric lights, closed steel bodies, automatic choke, streamlined bodies, and improvements in electronic ignition.

Technological advance had a major economic impact only when certain conditions were satisfied. There had to be a large potential demand, though not necessarily

258 Reich, pp. 4–5.

259 Schmookler, p. 206.

260 Schmookler, pp. 207–208.

261 Schmookler, p. 208.

262 Abernathy, p. 63.

263 Abernathy, p. 64.

a pre-existing demand (as shown in the cases of radio receivers and electrolytically produced aluminum). The technological means of meeting that demand had to adequate in reliability, ease-of-use, and cost of manufacture; in most cases this was achieved only after a lengthy series of improvements to the original invention. And there had to be the human capital of engineers, managers, entrepreneurs, and salespeople to call upon to turn a technological possibility into a commercial success.[264]

The growth industries—that is, ones growing much faster than the rest of the economy—provide clear evidence of the economic impact of new technology. At the turn of the century, the growth industries were electric power and communications. In the next generation, they were the automobile, chemical and petroleum, and electric-appliance industries.[265] In the United States, well over a third of value of all manufacturing in 1948 was in branches that did not exist or were extremely small in 1880.[266]

More usual, however, was technological innovation in existing industries, and this was the aim of most industrial research. Here market forces obviously played an important role in directing technological advance. Businessmen found that product improvement was often a more effective competitive weapon than low price, advertising, or aggressive marketing. In particular, the manufacturers of relatively standardized machines—such as generators, motors, streetcars, subway systems, telephone equipment, elevators, pumps, and printing presses—gave much attention to product innovation.[267]

The historian Harold Passer has written about General Motors and Westinghouse in the 1890s: "The competition in reality was between the engineering staffs of the two companies. If the engineers of one company were able to design a motor that met the customers' wants better than the second company's motor, the engineers of the second company had to improve their motor or run the risk of losing their market." [268] Alfred Chandler has written, "In such industries coordination meant more than maintaining a high-volume of flow of goods through the processes of production and distribution. It meant coordination between customers with technologically complex requirements and manufacturers with even more complex producing equipment." [269] And as already discussed Thomas J. Watson worked hard to strengthen research and development at IBM and to tie it closely to manufacturing.[270]

Several conditions of the interwar period boosted industrial research. One is that in the 1920s, diversification became a common strategy for corporate growth. Though managers sometimes purchased or merged with a company having a different product line, the usual method was diversification from within. The managers

[264] Kuznets, pp. 326–327.

[265] Kuznets, pp. 325–326.

[266] Kuznets, p. 319.

[267] Chandler, p. 410.

[268] Quoted in Chandler, p. 410.

[269] Chandler, p. 411.

[270] Pugh, p. xvi.

then looked to their R&D organizations to develop the new products.[271] Until the 1920s, General Electric and Westinghouse concentrated on manufacturing light and power equipment; they then began diversifying by producing of a wide variety of household appliances.[272]

Another condition of this period was the greatly increased use of instrumentation in manufacturing. This made it much easier to gain practical advantage of information gained in the laboratory (where, for example, one might find more efficient conditions of temperature, pressure, and flow).[273] The new instruments also stimulated the research. For example, John Kraus, in the mid-1930s, used a microphone, sound level meter, and piezo-electric pressure sensor to redesign a refrigerator pump so that it would make less noise.[274]

The usual, and often unnoticed, product of industrial research was improvement in existing processes or products. For example, in the U.S. at the end of the 1930s, power stations used 1.5 pounds of coal per kilowatt-hour generated, down from 3 pounds in 1920, and 6.4 pounds in 1902.[275] Electric lamps made in 1936 gave some 30% more light per watt than lamps made in 1920, and refrigerators made in the late 1930s consumed just ⅓ of the power of comparable refrigerators a decade earlier.[276] As industrial R&D became established practice, people came to expect continual technical improvement in products and manufacturing processes. This inertial technical change (along established technological trajectories), though it usually receives less attention from historians than technical breakthroughs, may be of enormous economic significance, as discussed below.

5.4.3 The Great Depression and the Economic Infrastructure

The economy of the Western world experienced six economic crises in the half-century preceding 1929, but the depression that began in that year far exceeded them in economic contraction, unemployment, and human suffering. In economic cost, the Great Depression, as this crisis came to be called, was comparable to the Great War.[277] The historian David Landes has written,

> *Everywhere there was the unforgettable pain of these years of privation and humiliation. … The children of later, more affluent decades will never quite understand the shock of this experience; but the sociologists of political behaviour tell us that nothing—not religion, nor race, nor economic interests—has shaped the subsequent allegiances of the depression generation so indelibly as the calvary of*

[271] Chandler, pp. 473–474.

[272] Chandler, p. 475.

[273] Bennett 1991, pp. 78–79.

[274] Kraus, pp. 55–57.

[275] Perazich 1940, p. 37.

[276] Perazich 1940, p. 39.

[277] Anderson, p. 325.

unemployment and the dole. The numerical data cannot possibly convey the poignancy of the suffering. … [278]

The data, though insufficient, is necessary. From 1929 to 1931, shares of industrial firms lost 60% of their value in the U.S., 55% in France, and 45% in Great Britain. The number of bankruptcies increased sharply, as did unemployment.[279] In 1932, the number of registered unemployed in Europe reached 15 million, 6 million of them in Germany.[280] The banking systems in Austria and Germany collapsed; those in the U.S., Great Britain, and France were badly shaken.[281]

The crisis was triggered by the U.S. stock-market plunge in late October 1929. The crisis spread worldwide, because the U.S. was the leading national economy—at that time producing 45% of the world's industrial goods—and because it provided one of the two principal capital markets of the world (the other being Great Britain's).[282] In addition, the war had made many European economies vulnerable. During the war the European belligerents borrowed huge sums of money, much of it from the U.S. After the Versailles Treaty the victorious nations expected to be able to pay their debts with German reparations. As it happened, Germany paid only a part of what she owed and much of that only because of new loans from the U.S. So this heavy indebtedness helped pull down the European economies.[283]

The stock market collapse of late 1929 caused a commercial slump. The second great blow to Western economies was the financial crisis that began in mid-1931. In May of that year came the collapse of the Credit-Anstalt, Austria's largest bank, which controlled directly or indirectly ⅔ of Austria industry. A welcome move was President Hoover's one-year moratorium on intergovernmental debts in June, but it was not enough to stop the series of bank failures that spread from country to country.[284] Germany ceased payment of reparations, and all European nations, with the exception of Finland, in effect repudiated their debts to the U.S.

While factories almost everywhere curbed output, many farmers increased production in an effort to compensate for falling prices. The result was a continued price fall; at the end of 1932, agricultural prices were ¼ the average level of the period from 1923 to 1925.[285] The non-industrialized parts of the world, including South America, Africa, and much of Asia, suffered greatly in the 1930s, because efforts to shelter the economies of the industrialized nations caused the price of primary products to fall more than the price of manufactured goods.[286]

The totalitarian regimes of Hitler and Stalin, however, achieved substantial economic growth in the mid-1930s. Chapter 3 described the rapid development of

278 Landes, p. 398.

279 Landes, pp. 372–373.

280 Clough, p. 10.

281 Landes, pp. 380–387.

282 Anderson, p. 326.

283 Landes, p. 363.

284 Landes, pp. 375–376.

285 Anderson, pp. 327–328.

286 Landes, p. 392.

electric power in the Soviet Union in this period, and in Germany total production of electricity increased from 25.7 billion kWh in 1933, to 61.4 billion kWh in 1939 (and continued increasing in the first four years of the war).[287] A principal means that Hitler and Stalin used to supply people with work and to revive the economy was production of arms.[288]

The severity of the economic crisis provoked extreme political measures. In general, economic nationalism and extreme measures to stimulate the economy fostered authoritarian regimes.[289] Germany suffered the most economically—at one point only ⅓ of German workers had regular employment—and partly as a result Hitler came to power in early 1933.[290] In Japan, too, economic hardships helped the political forces of militarism to gain power.[291] In these and many other countries the state took a much larger part than earlier in regulating the economy, trying to achieve both economic growth and social harmony.[292] In the United States, a new level of government activism began with the 1932 election of Franklin Delano Roosevelt to the presidency.

The economic success of the totalitarian regimes influenced people inside and outside of these countries. Hitler's success in reducing unemployment from 6 million in 1933, to 2.8 million two years later, greatly increased popular support for him.[293] The success of Stalin's Five-Year Plans gained adherents for the Communist Parties in many countries, and such state direction of the economy became the model for many leaders of Third World countries. Another consequence of the Depression was that the democracies became preoccupied with economic problems at home and were slow to recognize the dangers posed by certain regimes.[294]

Besides arms production, a few industries prospered, including the radio industry and aviation. Many thought that mass production had caused the Depression, since production had grown more rapidly than consumption. While some proposed curtailed production and sharing of the work, others saw the answer in the cultivation of mass consumption through marketing and advertising.[295]

Electrical technology in some ways helped alleviate the crisis. Movies, records, and radio helped give people a sense of shared difficulty, a community in adversity. Electrical appliances stimulated consumer demand. Information processing was a vital element in economic growth as it assumed essential roles in more and more businesses. Moreover, the data-processing industry itself grew to substantial size, in the late 1980s accounting for 5% of the U.S. gross national product.[296] The increas-

[287] Ludwig, p. 177.

[288] Anderson, p. 340.

[289] Black and Helmreich, p. 308.

[290] Landes, p. 398, and Anderson, p. 332.

[291] Hobsbawm, p. 35.

[292] Landes, p. 399.

[293] Grenville, p. 164.

[294] Grenville, p. 172.

[295] Hounshell, pp. 321–322.

[296] Cortada, p. xvii.

ing mechanization of office work (with typewriters, tabulating machines, dictaphones, and so on) usually increased, rather than decreased, the number of office workers, principally because it made it profitable to carry out operations that were too expensive if done manually.[297]

In Britain, from 1930 to 1935, industrial output rose 19% overall, but electrical engineering increased by 133% and electric power by 73%. In the period from 1930 to 1937, 5% of total national investment in Britain went to electric power.[298] Britain faired well, for in the period from 1929 to 1937, industrial output worldwide, excluding the U.S.S.R., rose only 3%, which is an annual rate of just 0.4 percent.[299]

In the larger picture of the first half-century, the capital-intensive and technologically advanced industries became the drivers of economic growth. They helped make Germany the most powerful nation in Europe before World War II, and the U.S. the largest producer of industrial goods in the world (in the late 1920s the U.S. produced 40% of the world's industrial output).[300] In the mid-1930s growth resumed in most countries. During the war there was in most countries an enormous increase in productiveness, which after the war was turned to a higher standard of living.

In the 1930s the most powerful nation economically, the U.S., wanted to stay out of foreign wars. The most powerful nation in Europe, Germany, harbored feelings, in many of its citizens, of unjust treatment after the Great War. The most powerful nation in Asia—Japan—wished to expand its realm of economic activity, and other Asian nations were not militarily strong enough to prevent it from doing so. The next chapter looks at the most powerful nation, where electrical technologies played important roles in the creation of a consumer culture, and the subsequent chapter turns to the most powerful nation in Europe, where communications technologies helped a nationalistic regime gain the following of most of the citizens.

In 1930, it was announced that John D. Rockefeller, Jr., in cooperation with R.C.A. and N.B.C., would build a "temple of electronics" in midtown Manhattan; three blocks were razed to make room for the new Radio City.[301] General Electric engineers designed a control system for the lighting of the Rockefeller Center Theater that could follow a number of present sequences.[302] In 1938 tourism was the country's third largest industry—after the steel and automobile industries—and the most popular tourist attraction was Rockefeller Center, drawing 20,000 out-of-towners every day.[303] It helped make Americans aware of the marvels of electronics, and during the Depression provided for many people an image of a more prosperous world.

[297] Strom, p. 183.

[298] Landes, p. 396.

[299] Landes, p. 390.

[300] Kuznets.

[301] Henney, p. 20.

[302] Bennett, p. 20.

[303] Susman, p. 46.

Chapter 6

Electrical Technologies and the Consumer Culture

6.1 ELECTRICITY IN THE HOME

6.1.1 Electric Lighting

At 9:59 on Wednesday evening the twenty-first of October 1931, newspaper photographers began taking pictures of New York's Broadway. What was remarkable was the street's darkness. Most of the great illuminated signs were turned off for one minute—as were traffic lights and many street lights—in honor of Thomas Edison, who had died three days earlier. The *New York Times* reported the next day.

> *All along the Eastern seaboard, from Maine to Florida, towns and hamlets, city and country, forgot for the moment the business of living to pay homage to the dead. Further West, where Chicago's "Loop" was bathed in brilliance … the lights went out at 8:59, and all the Mississippi Valley, from Cairo to the Gulf, was deep in shadows. In Denver it was 7:59 Mountain Time when for a minute only the stars were luminous. Out on the Pacific Coast … the lights of San Francisco and of Hollywood and of Seattle and Tacoma were dimmed at 6:59.*[1]

Before electricity, the night was lit only by flames. Because flame lighting was costly, dirty, and dangerous, the world was almost everywhere a dark place at night. What a visitor from the nineteenth century would perhaps have found most striking about American life in 1931 was how bright homes, public building, and streets were at night. Many of the people who honored Edison that evening in 1931 could remember that darker world. Electricity began to be used for public lighting in the 1870s, but only gradually did it extend its reach into homes, first into the homes of the wealthy, then into middle-class homes, and finally, in many urban areas by the end of the 1930s, into almost all homes. In the United States, only 24% of homes had electricity in 1917,

[1] *New York Times*, 22 October 1931, pp. 1, 3.

Dawn of the Electronic Age: Electrical Technologies in the Shaping of the Modern World, 1914 to 1945, by Frederik Nebeker

but 80% did in 1930.[2] Despite the Depression the trend continued in the 1930s. Electrification rates were somewhat lower in most other industrialized countries. In 1939, 62% of Canadian homes were electrified.[3] In Britain less than 6% of residences were wired for electricity in 1919, but by the end of the 1930s, ⅔ were.[4]

A decade after gratitude to Edison produced that 1-minute blackout, a World War and fear of the bomber produced blackouts every night and all night in many of the cities of Europe. Though people could still use electric lighting indoors, these blackouts were so bothersome and depressing that cities held celebrations when they were no longer necessary. In 1945 an American reporter in London wrote, "I was told afterward that in a poll taken to discover what people considered the greatest hardship of the war, the blackout won hands down. I didn't wonder. This blackout was inhuman. …" [5]

The rapid increase in the proportion of homes electrified depended upon strong consumer interest. Everyone wanted electric lighting, and as the years passed there were more and more attractive electric appliances, such as vacuum cleaners and refrigerators. The previous public use of electric lighting played a role; in the words of one historian, "Brilliant levels of illumination in downtown stores and public places had the effect of making people feel they were living in the dark." [6] Vigorous promotion by the electricity providers—who hoped to increase and balance their load—helped too. The most important factor may have been the continual reductions in the cost of electric power, made possible by more efficient generation and distribution of power. In the first seven decades of the twentieth century the cost declined by a factor of fifty.[7]

In the 1920s and 1930s many homes with electricity used it almost exclusively for lighting. For example, in Britain, as late as 1935, ⅓ of new homes were wired for lighting only; that is, they were not provided with sockets.[8] Such homes typically made occasional use of electric appliances, especially an iron or a fan, by placing an adapter in a light socket. Throughout this period, "octopus wiring" could be found in many kitchens (with cords from several appliances going to a multiple-socket adapter screwed into a drop-cord light socket), which reminded people that not long before lighting was the only anticipated home use for electricity.[9]

Electric lighting was probably the strongest pillar of the electrical industry. It was indeed the principal reason for setting up central power stations in the last decades of the nineteenth century and first decades of the twentieth century (most factories and trolley systems generated their own electricity), and even in the United States in the late 1930s lighting still accounted for 30% of the sales of electric

[2] Cowan 1976.

[3] Dodd.

[4] Hannah, pp. 188, 365.

[5] Behrman, p. 424.

[6] Platt.

[7] Schurr, p. xiv.

[8] Hannah, p. 193.

[9] Donaldson, p. 323.

power.[10] Arc lighting was the first form of electric lighting to be exploited commercially, but in the interwar period incandescent lighting completely dominated, with arc lighting and gas lighting disappearing in most places and fluorescent lighting only slowly spreading. Many large electrical manufacturers relied for a large share of their profits on sales of incandescent bulbs.

It is possible to estimate the economic importance of the incandescent bulb. In the United States in 1939, 55 factories employed 12,000 people to manufacture electric lights valued at $85 million. To these figures, however, one must add the retail trade in electric lights, the production of electric power for lighting, and the manufacture and installation of wiring and light fixtures. All together, electric lighting was a 1.2-billion-dollar business, employing a half-million people.[11]

In the United States in the interwar period, as earlier, General Electric (GE) exerted a large degree of control over the electric light industry because of its excellence in design and manufacturing capabilities, ownership of patent rights, and aggressive business practices.[12] In 1927, of all incandescent lamps sold in the United States, GE made 65.3%, licensees of GE (mainly Westinghouse) made 29.6%, and all others (including importers) made 5.1%.[13]

A cartel, the International Union for Regulating Prices of Incandescent Lamps, effectively controlled the international market. Prices were regulated, sales territories were agreed upon, and technical advances were shared. The strongest force behind the establishment of this cartel in 1921 was the German company Osram, which was formed in 1919 by combining the lamp works of A.E.G., the German Welsbach Company, and the Siemens group.[14] GE though not officially a member of the cartel, acted as if it were.[15] The large profits resulting from this restraint of competition were a principal support for many companies who were also active in other, more volatile, and less profitable areas of electrical manufacturing.

The research departments of major manufacturers, notably GE in the U.S. and Philips in Holland, steadily improved the incandescent bulb and the bulb-production machinery. Notable was the 1912 success of GE engineer William Coolidge in perfecting a means of making tungsten ductile, so that it could be drawn into a strong, flexible filament.[16] (The ductile tungsten lamp delivered the final blow to gas and arc lighting.)[17] There was also the development of new tube types, for an ever-increasing number of applications.

In 1912 an incandescent bulb had an efficiency of only 5%; that is, 95% of the energy consumed by the bulb came out in the form of heat rather than light. At the GE Research Laboratory, Irving Langmuir spent three years, beginning in 1909,

[10] Bright, p. 6.

[11] Bright, pp. 3–9.

[12] Bright, p. 235.

[13] Bright, p. 261.

[14] Bright, pp. 304–305.

[15] Bijker, p. 205.

[16] Bright, pp. 194–195.

[17] Bijker, p. 203.

studying the behavior of gases in incandescent lamps. He found that filling a bulb with an inert gas such as nitrogen reduced the evaporation of tungsten from the filament. The gas lowered the efficiency of the bulb by conducting heat away from the filament, but this loss was more than offset by the efficiency gain from being able to operate the filament at a higher temperature (2500 °C rather than 2100 °C). Langmuir found also that the heat loss could be reduced by coiling the filament in a tight helix. As a result of such work, the gas-filled lamps made in 1917 were much more efficient that earlier lamps. Efficiency increase was greatest, almost 100%, for high-power lamps, 25% for 100-watt lamps.[18]

Further improvement in efficiency followed from the development of non-sag tungsten (which allowed a closer spacing of the turns of the helical filament).[19] The appearance of bulbs changed with GE's introduction, in about 1920, of the tipless bulb. Previously, in the production process when the exhaust tube was removed from the round end of the bulb, a tip remained. Consumer demand forced other manufacturers to follow suit.[20] Another GE innovation was a practical method of frosting the inside of the bulb, to reduce the glare of the filament, introduced in 1925.[21] The proliferation of bulb types continued. (See Figure 6.1.) There were highly efficient lamps for street lighting and neon lighting for advertising (described in Chapter 7). There were photoflash lamps (pioneered by Philips), floodlights, and searchlights.[22] There were lamps for tanning, paint drying, signaling, and decorative purposes. (See Figure 6.2.)

The lighting industry thrived in the interwar period. In the United States, the annual per capita production of large incandescent lamps (excluding flashbulbs, Christmas lights, auto lights, and others) increased from 2.2 in 1919, to 4.0 in 1939, with the total per capita lumen-hours increasing almost fourfold because of the longer life and greater luminosity of bulbs.[23] Though it was usual for light to come from a bare bulb in ceiling fixture or wall fixture, the lighting industry promoted the use of shades and the sale of portable light fixtures (both floor and table lamps). In the 1930s there was a movement toward indirect lighting; concealed lights directed upward made the ceiling the source of light.[24]

There were advances in the engineering science as well, notably in the measurement of lamp characteristics. Before the 1920s, the performance of electric lights was, as a rule, judged by visual comparisons. The development of photometric instrumentation and standards for comparison was a challenging process similar to that undertaken for radio receiver performance, which we considered in Chapter 4.[25] By the late 1930s the instruments and measurement protocols were sufficiently standardized that laboratories around the world could compare test results meaningfully. Lighting labo-

[18] Bright, pp. 317–323.

[19] Bright, pp. 324–325, and Perazish 1940, p. 39.

[20] Bright, pp. 325–326.

[21] Bright, pp. 326–328.

[22] Bright, p. 311.

[23] Bright, p. 4.

[24] Brown 1953.

[25] Clayton, pp. 93–94.

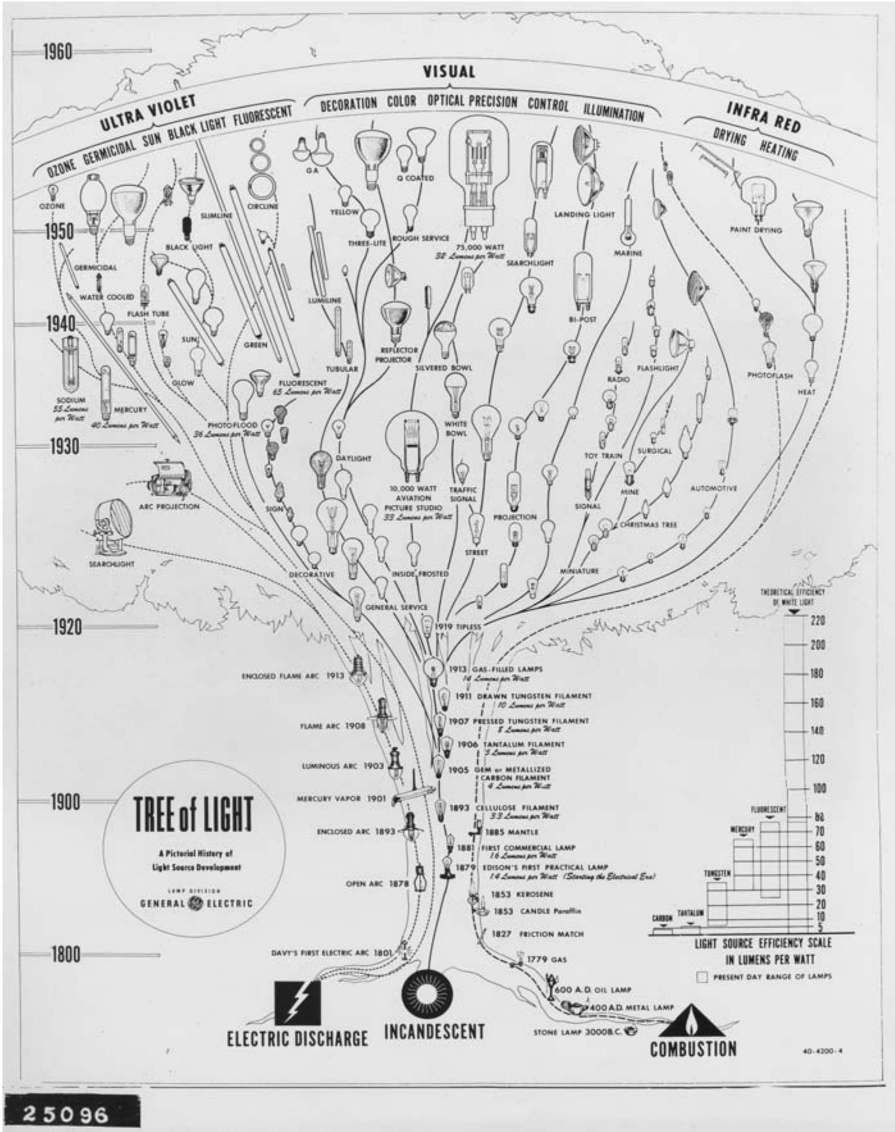


Figure 6.1. General Electric chart of the evolution of lighting (photo courtesy of the Schenectady Museum & Suits-Bueche Planetarium).

ratories, such as that at Wembley belonging to the British company GEC, studied many other aspects of lighting design in addition to lamp performance, including the type and level of illumination required for different purposes, the effective distribution of lamps, and the use of reflectors and diffusers.[26]

[26] Clayton, pp. 97–100.

Figure 6.2. A 1932 publicity photo of two General Electric incandescent bulbs: a 50,000 watt lamp and a "grain of wheat" lamp for use in surgical instruments (photo courtesy of the Schenectady Museum & Suits-Bueche Planetarium).

Chapter 1 described the early design and manufacture of electron tubes owing a great debt to the established field of electric lighting. The debt increased in the interwar years. First, there was direct transfer of technology, both in the devices themselves (filaments and glass enclosures) and in the machinery for mass production. Second, there was transfer of expertise, as many engineers who had worked to improve incandescent bulbs turned to the design of electron tubes. And third, many business organizations established for lamps, with production and marketing facilities in place, added electron tubes to their product line.

6.1.2 The Modern Kitchen

Homes were wired for electricity mainly because people wanted electric lighting. Other uses for electricity became common only after practical appliances were developed by engineers and made affordable through mass production. Many of the early appliances assisted in food preservation or preparation.

In the United States in the last decades of the nineteenth century it became increasingly common for a house to contain an icebox, which used ice delivered by the iceman to keep food cool. Stores and restaurants also used iceboxes. The ice was made in the town's ice plant, which contained a large mechanical refrigerator. Such machines were used also for brewing, meat-packing, cold storage, and industrial ice-making. They were, however, not practical on a small scale because the motive force came from steam engines, which required constant maintenance, and because there were no satisfactory means of automatic control.[27]

The development of reliable, small electric motors solved both problems; they could run for years without maintenance, and it was then possible to design automatic control of temperature and of refrigerant flow. (The refrigerator worked by allowing a refrigerant to absorb heat inside the unit in changing from liquid to gas and using an electrically driven compressor to return the refrigerant to the liquid state as heat was released outside the unit.) Engineers found that the thermostat itself (which closed a circuit when the temperature fell below a set value) could not tolerate the current flow required for the motor, but it could control the latter by means of a electromagnetic relay (a switch actuated by an electromagnet). They also devised automatic regulation of the refrigerant flow, which needed to be adjusted as load on the system changed.[28]

In the ice plants themselves electric power began replacing steam power early in the twentieth century; electric motors cost less initially, occupied less space, required less maintenance, and cost less to operate.[29] But in the next decades electric power became the undoing of the ice industry, as it made small-scale refrigeration efficient, dependable, and inexpensive.

Several home refrigerators came on the market in the 1890s, but the machines available before 1917 were expensive to buy and troublesome to use.[30] Perhaps the first mass-produced home refrigerator was the Kelvinator, introduced in 1918.[31] Automatic control was crucial to its widespread adoption. Edmund J. Copeland, a founder of the Kelvinator Corporation, developed a sophisticated thermostatic switch that sensed temperature of both evaporator and refrigerant. It was installed on the first Kelvinators in 1918.[32] In the late 1920s, metal, rather than wooden, cabinets became common, making the refrigerator lighter in weight (by half or more), lower in cost, and easier to clean.[33]

With the mass production of refrigerators came lower prices. From 1922 to 1924, the price of the most commonly used refrigerator fell from $450 to $250.[34] General Electric engineers at Fort Wayne, Indiana spent almost 15 years developing a compression refrigerator for home use, the Monitor Top (so-called because the top recalled the Civil-War ironclad gunship), which GE began mass producing in 1926 (see Figure 6.3). Mounting the motor and compressor on the top of the refrigerator allowed heat to escape easily, but the mechanism nevertheless came to be placed at the bottom of the cabinet because users preferred the higher position of the food

[27] Donaldson, p. 189.

[28] Donaldson, pp. 189–204.

[29] Anderson, p. 208.

[30] Anderson, pp. 100–101.

[31] Cowan 1985.

[32] Anderson, p. 196, and Donaldson, p. 216.

[33] Donaldson, p. 219.

[34] Donaldson, p. 211. At that time a refrigerator might cost more than a car; in the 1920s the price of a new Ford Model T was as little as $290 (Abernathy, p. 32).

Figure 6.3. The GE Monitor Top refrigerator (photo courtesy of the Schenectady Museum & Suits-Bueche Planetarium).

compartment.[35] Sales vastly exceeded the 10,000 a year expected by the company: just five years later, the millionth Monitor Top was presented to Henry Ford in a ceremony broadcast by radio.[36] The annual production for all U.S. manufacturers grew from 5000 refrigerators in 1921, to one million in 1931, and then to almost three million six years later.[37] By the end of 1941, 45% of U.S. homes had refrigerators, the market being dominated by GE, Westinghouse, Kelvinator (owned by American Motors), and Frigidaire (owned by General Motors).[38]

In 1944, twice as many U.S. homes contained refrigerators as contained iceboxes (one or the other was found in 85% of homes). Vital to the widespread acceptance of refrigerators was the fall in price: the average price in 1920 was $600; in 1930, $275; and in 1940, $154.[39]

The intense effort to develop effective and reliable home refrigerators yielded many gains, notably in energy efficiency. Refrigerators made in 1940 used only ⅓ of the power used by those made a decade earlier.[40] Engineering research for home refrigerators benefited the refrigeration industry as a whole, as progress made in home refrigeration with leak-free joints and seals, more effective refrigerants, better

[35] Anderson, pp. 197–198.

[36] Cowan 1985.

[37] Boorstin, pp. 329–330.

[38] Cowan 1985. If one considers only homes with electricity, the market penetration of refrigerators was greater: in 1940 62.8 percent of the homes with electricity had a refrigerator (Tedlow, p. 326).

[39] Anderson, pp. 213–221.

[40] Perazich 1940, p. 39.

electric motors, and automatic control was applied in the design of industrial equipment and home air-conditioning.[41]

The history of refrigeration technology illustrates the force called market-pull. Besides the improvements in electromechanical refrigerator already mentioned, the market for home refrigerators stimulated the invention of quite different types, notably a refrigerator that ran on natural gas—a flame rather than a compressor driving the cooling cycle—marketed by the Swedish firm Electrolux. Even more innovative were some of the designs for new refrigeration systems proposed by the physicists Albert Einstein and Leo Szilard, who filed more than 45 patent applications in the seven years of their collaboration. Among their inventions was what is known as the Einstein-Szilard electromagnetic pump; promising reliability because of its lack of mechanical moving parts, it was developed by AEG in the late 1920s but did not find practical application until used in cooling nuclear reactors many years later.[42]

In the United States refrigerators became common at about the same time as automobiles and self-service markets (which could offer lower prices by making greater sales per employee). There resulted what has been called the "automobile-refrigerator complex" (buying larger quantities at more distant self-service markets), which put an end to the practice of visiting the market every day.[43] Another appliance, the home freezer, accentuated this trend.

Though freezing had long been used for preserving whole fish, in 1924 Clarence Birdseye got the idea of freezing dressed, ready-to-cook fish. He developed techniques for rapid freezing, placing the item to be frozen between two metal plates containing refrigerant (so that they could be cooled continuously). Also important was Birdseye's idea of packaging the food—seafood, poultry, vegetables, fruit, or whatever—before freezing it.[44] General Foods Corporation purchased the quick-freezing patents of Birdseye and in the early 1930s undertook a campaign to create a market for consumer-package frozen foods. The campaign focused on the larger urban areas, one at a time, giving established wholesalers exclusive jurisdictions, encouraging retailers to sell the products by renting to them at low cost a specially developed display case, and making heavy use of advertising. By the end of 1940 there was national distribution of frozen foods, and the production of commercially packaged frozen foods increased from 200 million pounds in 1937, to 570 million pounds in 1941, to 1 billion pounds in 1945.[45]

People could keep frozen foods in the ice-making compartments of their refrigerators, and in the late 1930s separate freezers began to be sold in large numbers. The home freezer provides an exception to the rule that urban households adopted new appliances faster than rural households: a 1952 New York study found that 85% of farm families had a food freezer while only 7% of urban families did.[46] In the

[41] Donaldson, pp. 228–229.

[42] Dannen.

[43] Flink, p. 164.

[44] Anderson, pp. 203–204.

[45] Anderson, pp. 275–277, and Volti.

[46] Vanek.

nineteenth century, most people's diets varied considerably with the seasons; frozen foods, together with long-distance refrigerated transport, helped to level out the seasons in this respect.

In the interwar years the kitchen coal-stove or wood-stove all but disappeared in the United States, as gas and electric stoves became usual.[47] Both GE and Westinghouse introduced an electric range before World War I. By the end of the 1930s in Britain electric cooking accounted for about ¼ of domestic electricity sales.[48] Small appliances for cooking, such as hot plates, electric skillets, table cookers, and immersion heaters, also became popular.

A principal advantage of many electrical appliances was that they operated automatically or nearly so, allowing one to attend to other things while they were in use. In about 1927 Toastmaster introduced a "completely automatic toaster", "No Turning, No Burning". The electric toasters sold before then had to be watched when used, and usually the bread had to be turned manually. Other automatic appliances popular in the 1930s were coffee percolators, waffle irons, and corn poppers. In England an automatic teamaker, incorporating an electric clock, was introduced in 1933.

It was in the interwar period that canned food began to be used in large quantities, and electric can openers sold in large numbers.[49] Other popular electric appliances were electric mixers, beaters, liquidizers, choppers, slicers, and grinders. The late 1930s saw the automatic roaster and the electric juice-maker.[50] An electric dishwasher began to be sold as early as 1932, but sales grew slowly.[51] In the early 1930s, Morris M. Cohn, sanitary engineer in Schenectady, New York, and engineers at GE had the idea that an electric device could replace the garbage can, just as the vacuum cleaner was replacing the broom, and in 1935, GE began marketing its "Disposal" to grind food wastes for removal through the sewer. The device (also known as "the electric pig") did not sell in large numbers until the 1950s.[52]

6.1.3 Cleanliness and Comfort with the Aid of Appliances

As inventors and engineers found new ways to make electricity useful in the home, electrical manufacturers sought to stimulate demand. As early as 1908, at the Manchester Exhibition in England, there was a model house, and in its kitchen, "… the all potent … electricity is working wonders … unsullied by soot or smell, it is roasting, stewing, boiling, chopping. …" [53] The following year an English power

[47] Cowan 1976.

[48] Hannah, p. 193.

[49] Cowan, p. 186.

[50] Gorowitz, p. III.47.

[51] Gorowitz, p. III.35.

[52] Hoy.

[53] Quoted in Hennessey, p. 140.

company opened "Electra House", an all-electric house, that contained a vacuum cleaner, knife cleaner, sewing machine, and other electrically powered appliances.[54] In 1934 Westinghouse opened its House of Tomorrow in Mansfield, Ohio, which contained at total of 864 "electric servants".[55]

Such promotion must have had some effect, for by the late 1920s in the United States a great many homes had electric lighting throughout the house, a half dozen electric appliances in the kitchen, a radio and a phonograph in the parlor, and other electric devices in other rooms. According to a 1932 report, "It is the rule rather than the exception that a … house will contain, among other things, a $500 piano or automatic player piano, a $150 radio, a $50 talking machine, and a $50 icebox (the latter now rapidly being displaced by $200 electric refrigerators). … The home without electric lights and gas is a freak, save in the remoter country districts."[56]

Very often the first electric appliance a family would acquire was the iron.[57] Before there was electricity in the home, ironing was one of the most unpleasant chores: it had to be done near a hot stove, and irons were heavy and frequently had to be reheated on the stove. Electric irons eased the chore and were relatively inexpensive, and by the end of the 1920s they were found in almost all electrified homes in the U.S.[58] In the 1930s, irons began to come equipped with automatic temperature control, switching the current on and off in order to maintain one of five or so possible temperatures. Another innovation of the 1930s was the steam iron, which produced steam and released it through holes in the sole plate. Ironing machines, too, were sold for home use.

After electric lamps and irons, the most popular appliances in the United States in the late 1920s were, in order of decreasing use, vacuum cleaners, washing machines, fans, toasters, portable heaters, radios, stoves, and refrigerators.[59] Just as with the refrigerator, the widespread acceptance of vacuum cleaners, washing machines, fans, and many other appliances required a small, reliable, and relatively inexpensive electric motor. The mass production of these "fractional horsepower" motors was a momentous achievement of the interwar period. The growth may be exemplified by production figures for the General Electric plant in Fort Wayne: it produced about 575 small motors per week in 1911, 8000 per week in 1920, 36,000 per week by 1930, and 58,000 per week by 1937.[60]

In 1901 the Englishman H.C. Booth patented a vacuum cleaner, but the mechanism was so bulky that it was usually either operated by professionals or placed in the basement of the building with tubes going to the rooms. In 1908, in the United States, James Murray Spengler developed a truly portable vacuum cleaner that was successfully marketed by H.W. Hoover, and in 1930, 44% of U.S. homes had a

[54] Hennessey, p. 140.

[55] Westinghouse.

[56] Pitkin 1932, p. 189.

[57] Hannah, p. 195.

[58] Cowan 1976.

[59] Linkous, p. 283.

[60] Linkous, p. 284.

Hoover or other vacuum cleaner.[61] Along with the vacuum cleaner came carpeting that could not easily be taken outside for beating, either because of its size or because it was fastened to the floor.[62] In many countries the lack of carpeting and the belief that carpets could be properly cleaned only by taking them outside for beating constrained the market for vacuum cleaners.[63]

One of the heaviest household tasks was washing clothes. Designing a machine for this task was challenging, as one needed an appropriate motor and a means of repeatedly reversing the direction of motion of the agitator (so that the clothes would not become wrapped around it). These problems solved, U.S. manufacturers turned out large numbers of machines in the 1920s. In 1926, 900,000 washing machines were sold, and in 1935, despite the Depression, 1.4 million were sold. Already in 1930, 35% of U.S. homes had a washing machine, and in 1940, just over half did.[64]

These early machines greatly reduced the physical labor, but still demanded much of the housewife's time as they did not go through the wash cycle automatically and did not spin dry.[65] In many early machines, the motor that powered the washing machine could be attached by a belt to the rollers of the wringer. Later a separate spin dryer or a spin-dry phase in the washing machine replaced the hand- or electrically-operated wringer. The introduction of the automatic washer in 1937 meant that washing machines no longer required an operator to change the phases of the wash cycle.

As with the refrigerator, mass production of the washing machine lowered its price; the average machine in 1926 cost $150, that in 1935 just $60.[66] Before 1930 it had been common for laundry to be done outside the home. The adoption of the washing machine was thus an unusual instance of a task again being done in the home after having been commercialized to a large degree.[67]

One of the most striking changes in household technology was the adoption of central heating instead of heating rooms separately by stoves or fireplaces. Central heating used oil, natural gas, or electricity rather than wood or coal. Electrical technology was important in the acceptance of oil burners, which came with continuous spark ignition, electric thermostatic control, and electrically powered air flow and oil flow.

A similar change was the provision, in several rooms of the house, of hot water that was centrally heated. Both central space heating and water heating became common in U.S. homes in the 1920s.[68] The water heating was often done electrically. In general, electric heating was well suited for short-term and localized heating.

[61] Vanek.

[62] Braun, p. 89.

[63] Hannah, p. 195.

[64] Braun, p. 89; Vanek; and Harvey Green, p. 7.

[65] Cowan 1976.

[66] Braun, p. 89.

[67] Strasser 1991.

[68] Cowan 1976.

Supplementary heating with electric heaters became common, as did electric heating pads and electric blankets.

Chapter 5 discussed mechanical means of cooling and dehumidifying air that were developed for use in various industries. Air-conditioning for comfort did not become important until industrial applications had brought forth dependable, economical, and automatic air conditioners. Evaporative cooling (lowering the temperature by evaporating water into air moving into a room) was technically simpler and less expensive than refrigerating air. Around the turn of the century it was tried in public buildings in several countries, but was effective only in very dry climates, such as the southwestern United States. Small evaporative-cooling units for home use began to be marketed there around 1930.[69]

In about 1903, a theater in Cologne, Germany installed an advanced air-conditioning system that released refrigerated air from overhead vents and took in return air through vents in the floor, and in 1909 a theater in Rio de Janiero began operating a refrigerated-air system.[70] In 1924, Hudson's Department Store in Detroit found that air-conditioning attracted customers, and thereafter restaurants, hotels, and stores gradually adopted air-conditioning.[71] In the 1920s, air-conditioning began to appear in U.S. theaters; 14 Chicago theaters, for example, were air-conditioned in 1925.[72] (Because theaters could be sweltering in the summer months, it had been the practice for Vaudeville theaters to close for the summer.)[73] The desirability of air-conditioning in railroad passenger cars—where open windows admitted blasts of hot, soot-filled air—stimulated the development of much smaller air-conditioning units, and by the mid-1930s air-conditioning was common on U.S. trains.[74] It was, above all, the new movie theaters of the late 1920s and 1930s that made Americans want air-conditioning in their homes and work-places.[75]

For the leading suppliers of industrial air-conditioning, such as Willis Carrier's company, each installation had been custom designed. In the move to mass-produced products, these companies were challenged by electrical manufacturers, such as GE and Frigidaire.[76] The latter, for example, introduced a home air-conditioner in 1929.[77] In the interwar years, air-conditioning passed from curiosity to normality, from troublesome, unreliable systems to automatic, reliable systems, and—for certain businesses and in the homes of the wealthy—from luxury to necessity.[78]

Many other appliances, such as the sewing machine (both floor and portable models), the electric clock, the electric curling iron, and electric model-trains, were

[69] Donaldson, pp. 286–287, and Rotsch.

[70] Donaldson, pp. 286–287.

[71] Rotsch.

[72] Donaldson, pp. 286–288.

[73] Fred Allen.

[74] Cecil Elliott, p. 323.

[75] Boorstin, p. 357.

[76] Gail Cooper.

[77] Donaldson, p. 294.

[78] Donaldson, p. 301.

successfully marketed. The electric razor, for example, was introduced by Jacob Schick in 1928. Philips developed an electric razor with a circular cutting head and put it on the market in 1938; this razor, the Norelco, eventually became a worldwide success.[79] GE engineers developed an electric razor-sharpener in 1932 and an electric blanket in 1936.[80] Westinghouse announced the Preciptron, an electrostatic air cleaner, in 1935. There were also electric tools, such as drills and sanders, for the handyman.

The plethora of new products made the role of advertising important for marketing. Important, too, were continual technical improvements, such as making the appliances smaller (so more easily handled and stored), less expensive (resulting both from simplified design and better production methods), and easier to use (as automatic temperature control on refrigerators and irons). Advances in resistance coils, small motors, and thermostatic and other switches found application in many different appliances.

In general, domestic appliances were adopted more slowly in Europe than in the U.S., though there was great variation from country to country. In Germany, washing machines did not become common until after World War II.[81] In the early 1930s, the use of electric appliances in Switzerland, where electric power was relatively inexpensive, was comparable to that in the U.S., whereas the use-rate in France was, for many appliances, less than ⅓ that in the U.S.[82] Electricity consumption for domestic use increased just 30% in France in the 1930s, while it doubled in both Germany and in the United Kingdom.[83]

The social effects of household technology are difficult to specify. Several studies indicate that electrical appliances did not cause any reduction in the number of hours spent on housework. The work, though, certainly became less onerous, and standards of cleanliness rose and, for most people, the size of homes increased markedly. Also, it became much less common to employ servants, and tasks earlier done outside the home returned to the home. The net effect seems to have been that housewives spent as much time on housework before electrification as after.[84]

In the U.S. at the beginning of the century, the second largest occupation group (after farmers) was live-in servants. A "lower middle class" household was defined for census purposes as one employing fewer than three servants.[85] Following World War I there was an increasing scarcity of servants in both Europe and North America, and when middle-class housewives had difficulty finding servants, they became more interested in washing machines and vacuum cleaners. The new technology made housewives more productive, allowing them to employ fewer servants or none at all. In those homes that had never employed servants, the new technology made

[79] Philips, p. 39.

[80] Gorowitz, pp. III.35, III.46.

[81] Braun, p. 89.

[82] Landes, p. 439.

[83] Landes, pp. 439–440.

[84] Cowan, p. 191.

[85] Drucker 1994.

possible higher standards, as clothes were washed more often, the house was cleaner, and food was better prepared. Indeed, standards of living that earlier were achieved only in homes with several servants became common in servantless homes.

There is no doubt that social practices often change radically after the adoption of new technologies, yet new technologies, increasing as they do the range of choices, sometimes facilitate the maintenance of traditional ways. Household technologies, for example, allowed women to take employment outside the home and still keep house in much the same way as earlier. Household technologies may also have reinforced traditional role assignments (to husband, wife, male child, or female child) by making it easier for one person to do a task without help from others.[86]

In the same period that electric appliances were being adopted, there was a women's movement to professionalize homemaking, exemplified by such books as *Principles of Domestic Engineering: The Business of Home Management* (1915) and *Household Engineering: Scientific Management in the Home* (1920).[87] Lillian Gilbreth, famous from the biographical book *Cheaper by the Dozen*, was a leading practitioner of Taylorism, the movement to rationalize factory production mentioned in Chapter 5. She worked to extend those methods to the home and to establish home economics as a discipline. The willingness to try new methods, especially to adopt new labor-saving devices, was encouraged.[88]

The proliferation of household technology in the interwar period certainly helped to make popular Le Corbusier's conception of the home as a "machine for living", as mechanisms to carry out a wide variety of tasks became common.[89] What came to be one of the most important tasks—entertainment—is the subject of the next section.

6.2 MASS ENTERTAINMENT

6.2.1 Music for the Masses

In the early twentieth century, mass production techniques and vastly improved transportation and communication prompted more and more businessmen to aim at mass markets. This was true of those offering cultural goods as well as those offering material goods. The 1920s saw the beginnings of new forms of mass entertainment.

The aristocratic audience for music had already expanded greatly in the nineteenth century to include millions of the bourgeoisie, as new theaters and concert halls provided music in public settings. The expansion continued in the twentieth

[86] Thrall. Most people believed that an effect of household technology was that it reduced the time children spent doing chores. This may indeed have been a long-term consequence, but a comparison of households in a Boston suburb in the 1960s did not find the expected negative correlation between amount of household equipment and time spent by the children doing chores.

[87] Dodd, and Harvey Green, p. 10.

[88] Braun, p. 91.

[89] "The house that works".

century as composers and performers used new media to reach people of every social status in movie theaters and in homes. The great increase in the social role of music depended mainly on three new devices: radio, electrical phonograph recording, and sound movies. These electronic media—all used electron tubes in one or more capacities—soon delivered most of the music people heard. (After World War II other electronic technologies, including tape recording, television, portable radios, and compact-disk players, further increased the social role of music.) As described in Chapter 4, radio, by the end of the 1930s, in the United States and many other countries, was bringing music and other programming into most homes. This section considers the electrical phonograph; the next section, sound movies.

When Thomas Edison invented the phonograph in 1877, people were astonished that it was possible to make a permanent record of speech or music. There was a brief phonograph fad, but neither Edison nor others seemed to be able to make a lasting business of the invention.[90] About 15 years later, Emile Berliner made two innovations that gave the device its modern form: the stylus moved laterally (rather than up and down) and the recording was done on a thin disk (rather than on a cylinder).[91] The crucial advantage of Berliner's method was that the records could be mass-produced easily, as duplicates of a record could be readily molded in a suitable material (originally vulcanite, a hard rubber). In the first decade of the century arose a large record industry, dominated in the United States by three companies: Columbia, Victor, and Edison. Already in 1904, one home in 20 in the United States had a phonograph, and an Enrico Caruso recording made in 1902 sold more than one million copies.[92]

In the early 1920s record sales began to fall as the industry faced competition from player pianos—just then at the height of their popularity, being sold at the rate of a million a year in the U.S.—and from radio.[93] The record companies responded by proclaiming the virtues of their medium—as in the slogan "The music you want, when you want it"—and by working to improve their product.[94] Though phonographs might be driven by electric motors, they were then essentially mechanical devices: motion of the record caused vibration of the pickup stylus; a mechanical linkage connected the stylus to a diaphragm; and the resulting motion of the diaphragm produced the sound waves in air. The new competition prompted the phonograph industry to develop a new system of electrical recording, which drew on

[90] Lubar, pp. 167–172.

[91] Edison had considered both lateral stylus-motion and disks as a recording surface. The latter he rejected probably because the speed of the stylus in the groove varied, being much slower near the center of the disk than near the rim, whereas with cylinder recording the speed is constant. (This disadvantage did not, in later disk systems, greatly affect sound quality.) What made lateral motion preferable for Berliner was that, with his duplicating method, it produced an amplification of sound: when the recording was made, small forces sufficed to move the stylus laterally over the wax-covered surface; application of acid then cut the lateral undulations into the underlying metal; then in playback (either of the master or of a pressing of it) much more acoustic energy was created as the stylus was pulled along the groove. Berliner's disks could be listened to with a reproducing funnel rather than, as with Edison's cylinders at the time, with ear tubes [Read and Welch, pp. 119–123].

[92] Lubar, pp. 167–172, and Read and Welch, pp. 119–123.

[93] Bachman, and Lubar, pp. 174–177.

[94] Millard, p. 174.

advances made by telephone and radio engineers, such as electronic amplification and improved microphones. An electronic system developed at Western Electric by Joseph Maxfield and Henry C. Harrison and first marketed in 1925 by the Victor company (as the Orthophonic) became standard.[95]

The electronic system worked as follows. In the recording studio, a microphone converted the music to an electrical signal, which was amplified before going to an electromechanical cutting head that made the recording. (The cutting head moved in response to the changing magnetic field created by the electric signal.) In playback, an electromagnetic pickup converted the motion of the stylus to an electrical signal, which was amplified before being converted to sound energy in a loudspeaker. (The pickup worked by electromagnetic induction; current was generated in a conductor—the stylus—subjected to a changing magnetic field—caused by the lateral motion of the stylus.) Whereas the frequencies reproduced well by the acoustic phonograph extended from 160 hertz (cycles per second) to 2000 hertz, the new phonographs had a range of 100 to 5000 hertz. (This range was still much less than that of human hearing, 20 to 20,000 hertz.) Even more importantly, the new phonographs had a much greater volume—for the first time recorded music could be as loud as the original—and the new recordings had a longer playing time. The public received the new records enthusiastically. Acoustic phonographs gradually disappeared, and the new phonograph industry boomed, with annual production in the U.S. of 100 million records in 1927.[96]

Electrical recording benefited too from radio broadcast techniques, such as the mixing of multiple microphones. It recorded large orchestras quite effectively, while acoustic recording had worked well only for soloists.[97] Phonographs, like many radios, came to have tone control, which allowed listeners to alter the balance of frequencies, often by turning up the bass.

Of the many technical advances not related to telephone or radio engineering, two may be mentioned. In the early electric phonographs, the pickup stylus created the electrical signal by moving a coil in a magnetic field. Engineers found that the pickup could be more sensitive by using as transducer a piezoelectric crystal, which generates a potential difference when subjected to a mechanical force. (We saw in Chapter 2 that piezo crystals were used in the first sonar system.) The signal thus generated was small, but powerful and noise-free amplification made the method feasible. With a lighter-weight tone arm, a smaller motor sufficed to run the turntable, so in the late 1930s a less expensive rim-driven (rather than centrally-driven) turntable began to be manufactured.[98] The other outstanding technical advance was stereophonic recording.

Human hearing is binaural (the sounds reaching one ear differing slightly in intensity and arrival time from those reaching the other), so equipment that plays a single soundtrack cannot reproduce the experience of listening to a live performance.

[95] Millard, pp. 141–143.

[96] LeMahieu, and Lubar, p. 177.

[97] Bachman, and Braun, p. 165.

[98] Millard, p. 191.

Experiments in the use of two or more microphones and two or more earphones or speakers—in order to recreate "auditory perspective", the spatial distribution of sound—go back to a demonstration of two-channel sound transmission at the Paris Electrical Exposition in 1884.[99] In 1933, Bell Labs engineers demonstrated three-channel sound transmission: on a stage in Philadelphia, where Leopold Stokowski's Philadelphia Orchestra performed, were three microphones, whose signals actuated three loudspeakers similarly placed on a concert stage in Washington, DC.[100]

The 1930s saw the development of several systems for stereophonic phonograph recording. The one that eventually succeeded commercially (though not until the 1950s) was invented in about 1930 in England by Alan Blumlein of Electric and Musical Industries (later EMI) laboratories and independently in the United States by Arthur Keller of Bell Laboratories. Two channels of sound were cut in the same groove, one laterally, the other vertically. Both inventors soon modified their systems by rotating the cutting directions 45 degrees, because lateral and vertical cutting produced slightly different-sounding recordings.[101] The stereo phonograph was not introduced as a consumer product because of the unfavorable business conditions of the 1930s, but stereo did come to movie theaters, first in Paris in 1932 (for a sound version of Gance's 1927 classic *Napoléon Bonaparte*) and later to great popular acclaim in 1941 with Disney's *Fantasia* (again featuring Stokowski and the Philadelphia Orchestra).[102]

The greatest cultural change made by the medium of records was that music became much more frequently experienced. Here the phonograph worked in team with two other electronic media: the radio and the movie soundtrack. The mass marketing of music had begun in the late nineteenth century with sheet music and piano rolls. But a piano or player-piano was expensive, and use of the former required some musical training. By the end of the 1930s in the United States almost all homes had a radio or phonograph or both, and most people saw one or more movies every week. The electronic media, though often rivals for the entertainment dollar, frequently worked together. The radio popularized particular songs, which then enjoyed high record sales. Sound movies, too, stimulated record sales. The movie *Holiday Inn* helped make Irving Berlin's song "I'm Dreaming of a White Christmas" popular enough to sell 30 million records.[103]

Some critics deplored the effects on musical taste that mass marketing had. A British observer, Martin Cooper, asked rhetorically "Can a whole new uneducated public be aesthetically enfranchised without lowering aesthetic standards?", and commented that in Britain"… [American influence] has already begun the scaling down of aesthetic values so as to be within the intellectual grasp of the average city dweller. …" [104] Movies and radio, as a rule, aimed at the largest possible audience,

99 Fagen, p. 68.

100 Lyon.

101 Keller, pp. 53–54, and Millard, p. 192.

102 Keller, pp. 54–55, and Lyon.

103 Millard, p. 177.

104 Martin Cooper, pp. 77–78.

but records more easily allowed differentiation of the market. There were recordings of the finest orchestras, of opera, of marching bands, and of popular singers. Initially it was through records that Afro-American music, especially jazz and blues music, reached audiences worldwide; in the interwar years this music was seldom played on the radio, but was widely marketed in what were called “race records”.[105]

Electronic amplification even changed the way live music was performed. The guitar, for example, became more popular in jazz bands because it could be provided with its own microphone. Electronic amplification also made popular a quiet style of singing, called crooning, practiced by Rudy Vallee, “Whispering” Jack Smith, Little Jack Little, and many others.[106] Many of those accustomed to traditional vocal technique deplored the new styles, including Martin Cooper, quoted above, who wrote, “The devastating influence of the microphone on singers is not, of course, a specifically American phenomenon, but it is mainly in Hollywood and as film actors or actresses that indifferent singers have been built up into kings and queens of song.”[107]

Electronic amplification made practical the public enjoyment of recorded sound, as using an electric phonograph for a dance party. A public address system could, of course, carry music, and in the 1920s a company called Muzak went into the business of providing background music for workers in factories and offices.[108] There was bigger business, though, in the jukebox.

In the late nineteenth century there were coin-operated weighing machines and gum dispensing machines. In 1889, Louis Glass equipped an Edison phonograph with a nickel-in-the-slot operating device and placed this forerunner of the jukebox in a San Francisco saloon. The machine was so well received that by mid-1891 more than a thousand coin-operated phonographs were in use. Such machines were battery-operated because at that time electric current was not available in many places. Many of the machines were in so-called “phonograph parlors”, which, with the addition of other coin-operated entertainment devices, evolved into the penny arcade. Machines that could automatically change the record cylinders or disks, according to customer choice, began appearing in 1905. The coin-operated phonograph business peaked shortly after the turn-of-the-century, in part because of the growth of the home-phonograph market and in part because the lack of effective amplification limited the appeal of the coin-operated machines.[109]

Shortly after the advent of the electrical phonograph in the mid-1920s came a much more attractive phonograph-playing machine, the “jukebox”, a name acquired in 1930s. Customers were attracted by the big sound made possible by electronic amplification—both fidelity and volume were greater than what radios or phonographs in the home offered—by the cabinets of translucent plastic brightly backlighted, by the impressive record-changing mechanisms, and by the opportunity to

[105] Chambers, pp. 141–143.

[106] Lubar, pp. 179–180.

[107] Martin Cooper, pp. 69–70.

[108] Lubar, p. 189.

[109] Read and Welch, pp. 105–118, 493.

choose the music and often to adjust the volume.[110] In 1939 the Seeburg company offered a "wireless" jukebox system, in which selections made at any of many small units, which were plugged in at ordinary sockets, were signaled—over the building's wiring—to the central record-playing unit.[111] The Depression, together with the soaring popularity of radio, had hit the record industry hard—record sales in the U.S. fell from 100 million in 1927, to 6 million in 1932—but jukeboxes helped revive the industry. Indeed, in the late 1930s half of all records produced in the U.S. went to the some 500,000 jukeboxes in use.[112]

The interwar period saw the beginnings of electronic music, which may be defined as music produced or modified, not merely reproduced or amplified, by electronic means. Its emergence was part of a movement in twentieth-century music toward new modes of musical expression and toward giving composers control over more aspects of music, including pitch, intensity, timbre, rhythm, and spatial arrangement.[113]

Before there was electronic music, there was electric music. In 1906 in Mount Holyoke, Massachusetts, Thaddeus Cahill, an inventor who had patented an electric typewriter, demonstrated his 200-ton instrument, the Telharmonium. It contained 145 alternating-current generators, one for each tone, and telephone receivers converted the electrical signals to sound.[114]

In the 1920s and 1930s there followed a series of instruments that used electric circuits, designed to oscillate at particular frequencies, to generate music. Some of them attempted to reproduce the timbres of existing instruments, others—and these attracted more attention from composers—to produce new timbres. Among the instruments producing new sounds were Leon Theremin's Thereminvox or Aetherophone (1920), Jörg Mager's Sphärophon (1926), Maurice Martinot's Ondes Martenot (1928), Bruno Helberger and Peter Lertes' Hellertion (1928), Friedrich Trautwein's Trautonium (1930), and N. Langer and J. Halmagyi's Emicon (1930). Theremin's instrument, which generated the oscillations electronically, was manufactured by RCA, which sold about 250 of them in the early 1930s, and filmmakers later used its eerie sounds for many movies. (See Figure 6.4.) Composers who wrote for the new instruments included Percy Grainger, Paul Hindemith, Arthur Honegger, Darius Milhaud, and Richard Strauss.[115]

Most notable of the instruments designed to reproduce existing timbres was an electronic organ (called the Novachord) invented by Laurens Hammond in 1929. He

[110] Jukeboxes were visually loud, and with good reason. The engineer Arthur Keller (p. 113) writes of a meeting with someone from Wurlitzer, a major jukebox manufacturer: "… I felt compelled to ask whether jukeboxes had to be so ugly? This question did not faze our visitor. He surprised me by simply saying "Yes!" He then explained that it was intentional. Anyone who walked into a room containing a jukebox was attracted to it and felt compelled to do something to it!"

[111] Lynch, p. 14.

[112] Lubar, p. 177; Lynch, p. 13; and Millard, p. 169.

[113] Gamer.

[114] Nicholl.

[115] Gamer, and Nicholl.

Figure 6.4. Theremin's instrument, manufactured by RCA, which a person played the instrument simply by moving her hands near the two antennas (photo courtesy of the Library of Congress, LC-USZ62-129162).

began selling them in 1935, and in the first two years he sold 3000.[116] Here electromagnetic induction produced the oscillations. For each note of the keyboard there was a small disk, driven by an electric motor, with teeth around its edge. The teeth passed a coil-wound, permanent magnet, inducing feeble currents in the coil. If, then, the teeth passed the magnet at a rate of 440 times per second, middle A (440 hertz) was generated.

There were also instruments that produced the vibrations in conventional ways, by means of strings or reeds, but used an electronic system (including pickup, amplifier, and loudspeaker) to permit control over the quality and intensity of the tones. These included electric pianos (Superpiano 1927, Neo-Bechstein 1931, Elektrochord 1933), electric organs using vibrating reeds (Rangertone 1931, Orgatron 1935), electric violins, and—with the greatest success—electric guitars.[117]

Electrical technology brought other innovations to musical performance. In 1926 a performance of Rimsky-Korsakov's *Scheherezade* by the Philadelphia Orchestra was accompanied by Thomas Wilfred on his Clavilux, a "color organ". In January 1932 the rhythmicon (a machine invented by the composer Henry Cowell and the engineer Leon Theremin able to reproduce any rhythmical combination) was used in a performance in New York City.

116 Lubar, pp. 190–191.

117 Gamer.

6.2.2 Movies

In 1893, Edison invented the Kinetoscope, which allowed a single viewer to see moving pictures in a peep-show cabinet. In France, the Lumière brothers invented a combined camera and projector and held a public showing on 28 December 1895. The following year Edison and others in the U.S. began producing projectors. At first, motion pictures were presented as part of vaudeville shows, interesting mainly as a technical marvel. Around 1905, movie houses for working class people, called nickelodeons because they charged a nickel a show, began appearing, and in 1910 there were some 20,000 of them in the northern U.S. cities. At that time some 100 U.S. film companies were producing more than 2000 films a year, and another 2000 films a years were imported from Europe. In 1912, the average daily movie attendance in the U.S. was five million.[118]

Newsreels were an early feature; already by 1910 they had the "magazine" format that they retained for the next 50 years.[119] In the years around 1910 many longer, multi-reel films began to be made. D.W. Griffith's three hour movie *Birth of a Nation*, released in 1915, showed the narrative power of the new medium and helped establish cinema as a respectable entertainment. As a means of holding public attention, Hollywood studios promoted the star system, with publicity men generating interest in the lives and personalities of actors and actresses.[120] (At first, though, the film studios, like the early radio stations, tried to keep performers anonymous; in both cases, great public interest in the performers as people ended the anonymity.) In 1920 movie attendance in the U.S. reached a weekly average of 40 million and continued to climb.

Although Edison originally conceived of motion pictures as an enhancement of the entertainment provided by the phonograph, the two inventions followed separate courses, each achieving great success in its own sphere. The goal of combining the two, however, continued for four decades to attract the efforts of inventors in many countries. It attracted these efforts because the goal seemed technically attainable and commercially valuable. Yet, as in the case of other elusive goals such as television or the picture-phone, both perfecting the technology and gaining its acceptance proved more difficult than imagined. The principal technological needs were good sound quality (in both recording and playback), sound amplification (sufficient for a movie theater), and exact synchronization of sound and visual action.

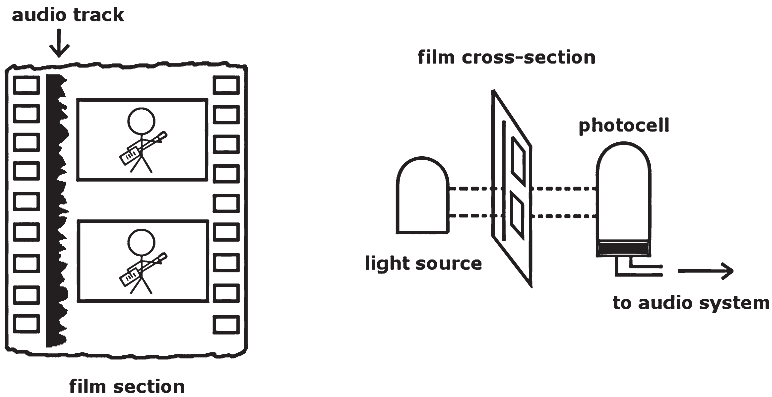
In Berlin at the turn-of-the-century, Ernst Rühmer recorded sound photographically by using an audio signal to modulate the current to an arc lamp. Fox Film Corporation brought some of these "Photographophone" films to the United States, but they were not a commercial success.[121] In 1909, Edison noted that there were more than 40 patents combining phonograph and motion picture film, and four years later he introduced the "kinetophone", a combination of film projector and

[118] Lubar, pp. 199–204.

[119] Lubar, p. 203.

[120] Rotha, pp. 129–130.

[121] Kellogg.



Fiure 6.5. Schematic drawing of how sound is produced when movies are shown.

phonograph (equipped with a large acoustic horn). According to one historian, "Although it made a great impact when it was first introduced, it died a painful death at the hands of theater audiences who howled in derision when the sound got out of synchronization." [122] Other prominent inventors who worked on synchronizing sound and moving image were Charles Kettering (discussed in Chapter 5 as inventor of the automatic starter for the automobile), Vladimir Zworykin (who will be discussed in Chapter 7 as television pioneer), and Lee de Forest (covered in Chapter 1 as inventor of the triode electron tube).

In about 1919, three Germans invented a sound-on-film process (known as Tri-Ergon) that evolved into the system that prevailed in Europe in the 1930s. During recording, sound was converted first to an electrical signal and then to a light signal, which was placed photographically on the edge of the film. (See Figure 6.5.) In playback the steps were reversed; a beam of light was directed at the soundtrack, and a photocell on the opposite side converted the fluctuating light signal to an electrical signal, which was amplified and then converted to sound in a loudspeaker. The moving-coil loudspeaker, which as we saw in Chapter 4 changed radio in the mid-1920s, answered the need for effective theater amplification.

The photocell, a type of electron tube, was a crucial component of this system. In a typical radio tube, electrons are able to escape the cathode because it is heated; that is to say, thermal agitation provides the energy to free electrons from the solid state. In contrast to this thermionic emission is photoelectric emission; with some materials, light waves striking the surface release electrons. This photoelectric effect, discovered by Heinrich Hertz in 1887, could be used to convert light energy to electric energy. An evacuated or gas-filled tube, called a photocell, contains a large cathode coated with a photosensitive material and an anode, maintained at a positive voltage to attract electrons freed from the cathode. (See Figure 6.6.) Thus when light strikes the cathode, a current is generated that is roughly proportional to the intensity

[122] Millard, p. 116.

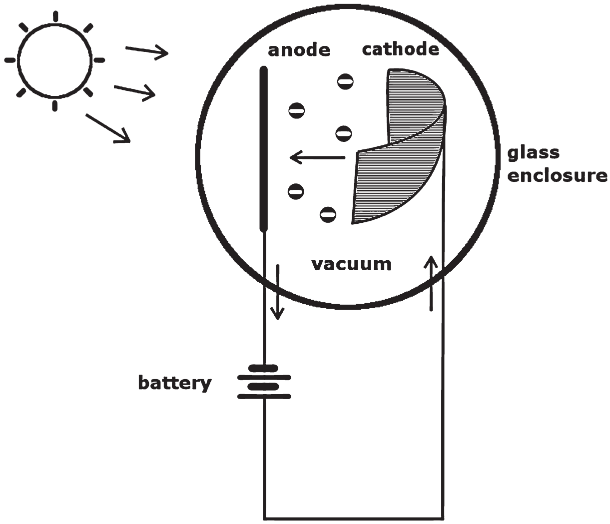


Figure 6.6. Schematic drawing of the operation of the photocell.

of the light. The current is so weak that in almost all applications electronic amplification is required.

The sound-on-film method used a camera that simultaneously recorded image and sound. The two tasks seemed incompatible: in taking the image, the film needed to move in steps (24 of these "frames" per second, each time the film being held stationary as the shutter opened and closed), while in recording sound, the film needed to move continuously. There was the same problem in the film projector. The Tri-Ergon company solved the problem by developing a camera that recorded the sound at a point of the film some distance from the picture aperture. In the region where the sound was recorded, a flywheel smoothed out irregularities in the motion of the film. A similar mechanism was used in the projector. Manufacturers of sound cameras worldwide purchased from Tri-Ergon the license for this smoothing mechanism.[123]

There were, however, several rival systems for making a soundtrack. The most important in the U.S. were an RCA system that recorded sound by varying the width of the track and two systems (by Western Electric and Movietone respectively) that recorded sound by varying the opaqueness. The RCA system stemmed from work done by GE engineers during World War I to record radio signals (for reference and decoding) photographically on a moving tape, and in the early 1920s, GE engineers showed that the technique could be used for synchronized film and sound.[124]

Warner Brothers was the first studio to achieve commercial success with sound movies: *Don Juan* in 1926, for which the sound accompaniment was music only,

[123] Salt, pp. 188–189.

[124] Barnouw, p. 153.

and *The Jazz Singer* in 1927, which had only a few spoken lines ad-libbed by Al Jolson, who played the lead. The next year Warner Brothers released the gangster film, *The Lights of New York* as the first "100% Talking" movie.[125] The sound system, called Vitaphone, used 16-inch 33 ⅓ rpm discs.[126] Because of difficulties with synchronization, this system was eventually abandoned in favor of sound-on-film systems, which soon thereafter achieved commercial success, beginning with Fox Movietone News in 1927.

Rapid technical advances in the other two sound-on-film systems left Movietone behind in the early 1930s. Both of its rivals continued to be used as they were compatible for the end user: the width of the soundtrack and its location on film were standardized, so the same sound projector worked for both.[127]

The established film producers were reluctant to take up sound movies. In the first place, many doubted that sound movies would ever become common, as many earlier attempts to introduce them had failed. It was reported that Sam Warner, when told of a demonstration of the Western Electric sound system that Warner Brothers would later dub Vitaphone, commented, "… haven't you been around the show world long enough now to know that a picture that talks is something to run away from?"[128] Others in the industry believed that the talkies were a passing phase, attractive only as long as they were a novelty.[129] Secondly, film makers wanted to recover more of their investment in the existing technology before investing a large amount in new technology. The cost of conversion was enormous, estimated at $23 to $50 million for Hollywood's studios, which at the time had a total value of about $65 million.[130] Thirdly, whereas silent films could easily be marketed in many countries, a sound movie could be easily marketed only where the language of the film was spoken.[131] (This new language constraint on film marketing was especially detrimental to countries, such as Sweden, with small home markets where the film industry had depended on export.)[132]

Silent films were not, of course, experienced in silence. Besides the hisses, cheers, and comments of the audience, the movie house almost always provided an organist, pianist, or small band for musical accompaniment. The conversion from silent movies to talkies eliminated the jobs of about 20,000 musicians in the United States, a quarter or a third of all musical employment at that time. Indeed, the large savings in labor costs in the showing of movies was a principal motivation for Warner Brothers, which owned a nationwide chain of movie theaters, to invest in sound movies.[133]

125 Wohleber.

126 Coe, p. 100.

127 Salt, pp. 212–213.

128 Wohleber, p. 42.

129 Scherwood.

130 Millard, p. 158.

131 Braun, p. 168.

132 Braun, p. 170.

133 Kraft.

Still, sound movies radically changed the movie experience by allowing dialog, singing, and sound effects. It became much easier to convey ideas and personalities. Stories could be more complicated, move faster, and show character development.[134] And this time sound movies did catch on. By the end of 1928, 1000 cinemas in the United States were wired for sound, and in 1930 only 5% of Hollywood films were silent.[135] From 1927 to 1930, the number of U.S. filmgoers doubled, and though movie attendance declined with the coming of the Depression, even in 1935, 40% of U.S. adults saw a movie at least once a week.[136]

Sound movies, as it turned out, hastened the movement toward vertical integration in the film industry. In the early years the tasks of production, distribution, and exhibition were performed by different companies. Some film producers, having become more prosperous, began to gain control of the exhibition of movies. The cost of equipping movie theaters for sound was so great that many independent exhibitors sold out. A few film producers sought to build more extensive media empires, by acquiring control of music publishing and phonograph companies as well. Two such empires were Warner Brothers and RCA. Warner Brothers acquired some 650 movie theaters, Brunswick Records, and seven major music publishers. RCA bought a film producing company and a chain of vaudeville and movie theaters to form Radio-Keith-Orpheum (RKO) and purchased the Victor Company to become RCA Victor.[137] The distribution systems of U.S. companies extended to many other countries.

Though movies have not changed radically in form from 1930 to the present, there have been a great many improvements in film technology, and many of these have noticeably influenced film style. Sometimes a stylistic feature clearly followed from a technical advance. For example, the introduction of an effective editing machine in 1930 (the "sound Moviola") led to a decrease in average shot-length. Another example is the introduction in about 1933 of techniques making it possible to add a separately recorded music track to the dialog track without loss of sound, which led to extensive use of background music.[138] More often the influence was less direct, as with the many incremental improvements in lighting, sound, and other methods.

It was no doubt the climate of Southern California that made Hollywood the capital of film making, since in the early years of the industry most shooting took place outdoors. Efforts were made to improve studio lighting, first to make indoor filming feasible, then to allow the director greater control of light for dramatic effect. Indeed, as soon as effective lamps were available, directors often chose artificial illumination—because of its controllability—even when natural illumination was possible. Lights developed for theaters, still photography, and as military search-

[134] Lubar, pp. 205–206.

[135] Wohleber.

[136] Braun, p. 170, and Lubar, p. 207. In the U.S. more than 90 million movie tickets were sold each week in 1930 [Virga, p. 276].

[137] Millard, pp. 158–161.

[138] Salt, pp. 212–214.

lights were adapted for studio lighting; carbon-arc lamps and incandescent tungsten lamps were used most. Technicolor filming, which began in the mid-1930s, made new demands on studio lighting. Throughout the history of film lighting there has been the constant demand of film makers for brighter lights.[139]

By 1930 several practical means of making color movies had been developed, but the higher cost of production severely limited their use. Even in the 1940s, only 10% of feature films were in color.[140] In 1922 in the United States Perfect Pictures introduced three-dimensional movies (with *The Power of Love*), an innovation destined for periodical revival over the next 70 years or more.

In the interwar period, improvements in sound were especially noticeable to moviegoers. In the first years of talkies, the sound quality was so poor that, according to a contemporary report, "The tinkle of a glass, the shot of a revolver, a footfall on a hardwood floor, and the noise of a pack of cards being shuffled, are all about alike."[141] One area of improvement was microphones: condenser microphones, mentioned in Chapter 1, were adopted, and these came to be suspended from booms, which could be moved and extended while in use.[142] (Earlier, microphones had to be hidden in props, such as lamps or flower arrangements.) Another area was loudspeakers. Though also used in radios, phonographs, and public-address systems, it was their use in movie houses that principally stimulated improvement in the 1930s. The importance of good physical design, particularly the shape of the enclosure, was recognized. In 1931, Western Electric introduced a three-way speaker system; the audio signal was divided into three frequency bands—high, middle, and low—and sent to three separate speakers (a "tweeter", a mid-range driver, and a "woofer"), each one designed for its frequency range.[143] Frequency filters were used to improve sound quality, cutting off low frequencies (notably the 50 or 60 Hz signal from the AC power supply) and frequencies above 9000 Hz (to avoid noise from the grain of the film and from the amplifiers).[144]

In the 1930s new instruments and machines greatly improved film processing. These included sensitometers (to measure the sensitivity of film), densitometers (to measure optical density), and the 1932 Bell & Howell Model E printer, which automatically copied picture and sound in one operation.[145] Stimulated by the greater demands on studio lighting that color films made, photographic exposure meters (an application of the photocell) also came into general use.[146]

[139] Handley.

[140] Braun, p. 171, and Lubar, p. 207.

[141] Reported in *Harper's*, circa 1929 (Allen 1939, p. 4).

[142] Salt, p. 212.

[143] Millard, p. 189. After World War II hi-fi enthusiasts put together sound systems from the best components available to them; the speakers they used were often ones built for cinemas, since high-quality speakers were rare in radios or phonographs.

[144] Happé, p. 178.

[145] Crabtree.

[146] Handley.

The 1930s saw the beginnings of a new way of exhibiting movies. Richard M. Hollingshead, Jr., opened the first drive-in movie theater on 6 June 1933 in Camden, New Jersey. He obtained a patent on the idea, opened a second drive-in the following year in Los Angeles, and began selling his idea to other entrepreneurs. In the 1950s, drive-ins became common thoughout most of the U.S.[147]

Movie technology had important spin-offs. Most important were the hundreds of industrial devices incorporating photocells. A few of these predated sound movies, but it was the standardization and mass production of the photocell for sound movies that led to proliferation of such devices. Phototubes for opening doors, for counting, for density measurement, and for register control (as on printing presses or trimming machines) were among the many applications, and in the 1930s photocells became the basis of electronic imaging in television cameras. Another consequence was assistance in establishing the microfilm industry. Though people had experimented with microphotography for decades, it was only after the rise of the movie industry (which provided engineering experience with film manufacture and film transport) that microfilm became a widely-used technology.[148] Film equipment also became a consumer product; in the 1920s, Bell & Howell, Eastman Kodak, and other companies began producing movie cameras for home use, first 16 mm film, and later also 8 mm film.[149]

Movies, like books, opened up to people new realms of experience, and they proved extremely popular. A movie theater might show several hundred different movies in a year, and seeing two movies at one sitting (a double feature) became common. The feature film was usually preceded by one or more short subjects, such newsreel, cartoon, travel film, or, on Saturday, a serial drama.[150] At the beginning of the 1920s members of Chicago's working class spent more than half of their entertainment budgets on movies.[151] For individuals, movies became one of the most interesting activities, and for communities the movie house became a center of public life. The art deco super cinemas of the early 1930s were often a major source of community pride.

According to a cultural historian, "The movies gave to America in the Twenties what genteel culture was no longer capable of providing—manners and morals, heroes and heroines. At the movies one could still learn how proper, wellborn, old Americans behaved, and also—what genteel culture never taught—how they misbehaved."[152] A psychologist wrote in 1932, "Next to the automobile, the motion picture fascinates the American most keenly. He sees a show on the average of about once a week, year in and year out. …" (He added, "But the radio is swiftly gaining on the motion picture and, in the opinion of some observers, may equal it in vogue

[147] Flink, p. 161.

[148] Burke, pp. 116, 130.

[149] Robinson, pp. 45–47.

[150] Manchester, pp. 144–145.

[151] Cohen.

[152] Sklar, p. 18.

within a few years.")[153] People consciously patterned themselves—in clothing, hairstyle, and behavior—on movie stars, as "trousers like Dietrich's", the elegance of Fred Astaire, and the hair of Jean Harlow.[154]

In England by 1914 almost every town had a cinema, and by the late 1920s going to the movies was for many people the most important social event of the week.[155] Cinemas were erected throughout Britain, and, as a British historian noted, "an astronomical mileage of film helped to bind Britain into a more coherent and urban-centred culture" (though admitting that Hollywood values and fashions had been influential).[156] Another British observer wrote, "It was above all this mythological 'America' [of musicals and Westerns and of the Hollywood "superstars"] that transformed the cinema into a dream palace, a self-referring world that offered refuge and imaginative alternatives to urban and suburban life in Britain in the 1930s."[157]

For many people the movies provided escapist entertainment; as Franklin Roosevelt put it in 1936, "… it is a splendid thing that for just fifteen cents an American can go to a movie … and forget his troubles." It was the golden age of Hollywood musicals, and the sparkling Shirley Temple starred in 27 films by decade's end. Many movies were meant to be comforting to the middle-class, such as the comedies that ridiculed the behavior of wealthy eccentrics, as Howard Hawks' *Twentieth Century* (1934) or *Bringing Up Baby* (1938). The main cultural theme of the 1930s was the worth of the simple, everyday American life.[158] While films of the 1920s often glamorized urban life, those of the 1930s more often depicted small-time life and traditional virtues. The director Frank Capra, in such highly successful films as *It Happened One Night* (1934), *Lost Horizon* (1937), *You Can't Take It With You* (1938), and *Mr. Smith Goes to Washington* (1939), exalted the instincts of the common man.[159] A cultural historian concludes, "Small town and rural America, drawn out of its cultural backwardness by the electronic reach of the new media, gained in prestige during the Depression from all the emphasis on the virtues of little people and everyday lives."[160]

Hollywood movies had worldwide appeal. Especially in the uncertain times of the 1930s, people everywhere admired "the classless American who is his own master, determined to succeed on his own terms" as exemplified in many films by Gary Cooper, Clark Gable, Spencer Tracy, and Robert Taylor.[161] Also well received were the many depictions of women—in films of the 1930s—as career

[153] Pitkin, p. 190.

[154] Allen 1939, p. 121.

[155] Chambers, pp. 74–75.

[156] Hennessey, p. 170.

[157] Chambers, p. 85.

[158] Sklar, p. 24.

[159] Sklar, p. 24.

[160] Sklar, p. 24.

[161] Roberts, "Hollywood".

women.[162] In the years between the wars movies became a major component of cultures in all developed countries. The historian Erwin Panofsky has written:

> *Whether we like it or not, it is the movies that mould, more than any other single force, the opinions, the taste, the language, the dress, the behaviour, and even the physical appearance of a public comprising mroe than 60 per cent of the population of the earth. If all the serious lyrical poets, composers, painters and sculptors were forced by law to stop their activities, a rather small fraction of the general public would become aware of the fact and a still smaller fraction would seriously regret it. If the same thing were to happen with the movies the social consequences would be catastrophic.*

For the most part, movies, like radio, avoided controversy. There were some films of social or political protest, even from Hollywood, such as Frank Capra's *Mr. Deeds Goes to Town* (1936) and John Ford's *Grapes of Wrath* (1940). A good deal of controversy related to the view that movies promoted immorality, and many churches condemned movies for this reason. As early as 1922 the U.S. film industry began self-regulation, the vigor with which it pursued this effort waxing and waning with the level of criticism. It was especially activity by the Roman Catholic Church's National Legion of Decency that prompted Hollywood in 1934 to institute a new code to govern the making of films.[163]

Some of the social consequences of movies are clear enough. People had access to a new product, and its popularity was so great that there resulted a major new industry. There were losses too. Movies and other forms of mass entertainment contributed greatly to the tendency to replace activities, such as hobbies and clubs, with consumption of a commodity. One result has been an enlarged cultural community, but a cultural community held together only by the common consumption of products made in a few places only. (The threat to more local communities is discussed below in "A common culture" and "The Americanization of national cultures".) The cinema, along with the radio and the phonograph, certainly contributed to the decline of vaudeville, which was the popular entertainment of the masses from 1875 to 1925.[164]

Some of the social consequences are harder to pin down. It is probably true that movies, like literature, enlarged the knowledge and sensibilities of a great many people. Yet the continual stimulation may sometimes have partially desensitized people and greatly devalued the experience of viewing a theatrical performance. The historian Daniel Boorstin writes of this paradoxical effect: by making ephemeral experiences permanent, photography, recorded music, and movies have devalued the experiences themselves.[165] Marshall McLuhan, whose aphorism "The medium is the message" is well known, has argued that movies and, later, television changed the dominant mode of mass communication from the linear, sequential texts of the

[162] Roberts, "Hollywood".

[163] Susman 1973, p. 107.

[164] Fred Allen.

[165] Boorstin, pp. 361–410.

printed media to the multi-dimensional, simultaneous presentations of the audiovisual media, and he sees this as a watershed in human history.[166]

6.2.3 A Common Culture

The electronic media of radio, records, and movies were not the only ways electrical technology contributed to mass entertainment in the interwar period. In theaters, electric lighting and controls led to a new era in stage lighting. Electricity also made possible certain special effects, such as swords that sparked, and it was used surreptitiously in vaudeville animal acts to get a lion to snarl or a dog to leap from a ladder.[167] In addition to jukeboxes, there were many machines to entice nickels or dimes from the public.

In the early 1930s pinball machines—with sounds, flashing lights, and automatic scoring—rather suddenly appeared in drug stores, hotels, and coffee shops across the country.[168] In many places these machines could be found in penny arcades, along with grip testers and automatic fortune-tellers. The number of manufacturers reached 800, and so sophisticated were the electrical controls developed for pinball machines that the U.S. Navy reportedly experimented with them for possible use in torpedoes and anti-aircraft guns. In the 1930s slot machines became extremely popular, often only until laws forbidding them were passed, often despite such laws.[169] And another machine helped make horse racing a major business and one of the most popular spectator sports, a machine that in 1949 every major racetrack in the United States was using to compute betting odds, dispense tickets, and display race results.[170]

In the pari-mutuel betting system, invented by the Frenchman Pierre Oller in 1869, the payoffs are determined by what bets are placed, with the total of all bets, minus a percentage for the racetrack, distributed in an equitable way to those who bet on the winning horses. In about 1880, a New Zealand inventor by the name of Ekberg built a machine, which he called a totalizator, that would record and total bets. The Australian engineer George Julius built a much improved, electrically powered totalizator, which was first used in 1913. Julius's device combined ticket-printing machines, adding machines to record and total bets, and rotating-drum indicators to display sales and odds to the spectators. Julius organized a company that sold tote machines in several countries, including the United States.[171]

[166] Robert C. Davis.

[167] Fred Allen.

[168] Allen 1939, p. 123.

[169] Lubell. To make it easier to evade law enforcement, thousands of small slot machines, each about eight inches high and eight inches wide, were made. For the same reason, some companies worked to develop a machine controlled remotely by radiowaves (so that the bulk of the mechanism could be safely hidden away). Lubell reported in 1939 (p. 40) that "Some slot machine makers also manufacture phonographs, and they already have succeeded in applying the remote-control principle to their music boxes experimentally."

[170] Schmidt, pp. 2, 95–96.

[171] Estes, and Schmidt, pp. 42–43.

This system still required much manual operation and was so slow that final odds were not known until after the race. Because the final odds often differed markedly from those previously displayed and because the system was subject to cheating by pari-mutuel clerks, the public was losing confidence in the betting operations. On 26 April 1927 at a racetrack outside Baltimore, Harry Straus, an electrical engineer, bet on a horse showing nine-to-one odds. The horse won, but final odds, announced 10 minutes after the race, were about three-to-one. This disappointment prompted Straus to see if he could invent a machine that would give up-to-the-minute odds while the betting was going on.[172]

Straus gained the interest of GE, which assigned Arthur J. Johnston of the GE Remote Control Division to work with Straus. The two men sought to reduce the number of purely mechanical parts by using, as much as possible, relays and rotary switches that had been developed for automatic telephone switching. In its final form, their machine received signals from ticket-issuing machines, totaled wages made on each horse, and showed on an electrical indicator board (with a rectangular array of 24 light bulbs for each digit) the amounts wagered on each horse. The board showed also the current odds, which were updated every 90 seconds by clerks using mechanical desk calculators. At the end of the race, the board showed also the order of finish and the payoff amounts. An English version of the Straus-Johnson system went into use in 1930, while in the United States the system was successfully inaugurated in 1933.[173]

Both management and the public enthusiastically welcomed the totalizator. Betting could continue to the very start of the race, and one race could follow another more rapidly. Bettors could follow wagering trends and verify the odds themselves, and the general suspicion of dishonesty in the betting operation ceased. The system reduced the human labor required and eliminated the waste of preprinting tickets that were not used.[174] With the rapid adoption of the totalizator came increasing popularity for horse racing. *Encyclopaedia Britannica* wrote that "the popularity of racing itself derives largely from the totalizator's speed and efficiency …", a point put succinctly by the journalist Joe Hirsch, who said "The tote did for racing what Babe Ruth did for baseball."[175] At about the same time, another electrical device was introduced that helped win even more public confidence in horse racing: the "photo-finish" timing device, which had been developed by Bell Labs engineers.[176]

Related to the rise of mass entertainment were two other social movements of the interwar period: an increase in leisure time and the emergence of a youth culture.

[172] Schmidt, pp. 41–42.

[173] Estes; Kidwell and Ceruzzi, pp. 53–55; and Schmidt, pp. 45–46.

[174] Estes, and Schmidt, pp. 95–96. Both management and government liked the tote because it made it easy to deduct commissions and taxes from all wagers.

[175] Estes, p. 723, and Schmidt, p. 96.

[176] Boettinger, pp. 172–173.

In 1860 in the U.S. the work-week of a factory worker averaged nearly 70 hours; by 1900 it had fallen below 60 hours.[177] In the next several decades it fell even faster. In 1914 Ford instituted the 8-hour day for his factory employees. Household appliances reduced the number and duration of daily tasks, and the automobile shortened travel times. (The final savings in time might be small or even nonexistent, since, as noted above, appliances often led to higher standards of housework and the automobile caused people to travel more.) And rising incomes meant that a great many people for the first time had money to spend on leisure activities.

How to spend leisure hours—hardly a problem for most people in the nineteenth century—became a common subject of discussion. One listing of publications about leisure contains approximately 20 items from 1900 through 1909, 50 items from 1910 through 1919, 200 items from 1920 through 1929, and 450 items from 1930 through 1939.[178] Whereas people used to spend leisure hours in personal or family activities, such as taking a walk or cultivating a hobby, that cost little or nothing, people increasingly purchased products or entertainments for leisure hours. In the U.S. and other urbanized and economically developed countries, leisure industries arose.

There were the forms of mass entertainment discussed above: listening to the radio, playing records, watching movies, and so on. There was a great rise in interest in spectator sports and in participant sports, such as golf and tennis, that required purchases or use fees. In the years after World War I home workshops became much more common—the availability of electric handtools for woodworking and metalworking certainly contributed to this trend—and the do-it-yourself era arrived.[179]

This period saw also the emergence of a separate youth culture. Young people in the 1920s called attention to themselves with bobbed hair, short skirts, raccoon coats, sporty roadsters, and jazz records. F. Scott Fitzgerald wrote that in the early 1920s the young generation suddenly “danced into the limelight” and were emulated by the older generation, so that “The sequel was like a children’s party taken over by the elders. … A whole race going hedonistic, deciding on pleasure.”[180] The historian Mark Sullivan wrote “The twenties, reversing age-old custom, biblical precept, and familiar adage, was a period in which, in many respects, youth was the model, age the imitator.” [181] Young people stayed in school much longer; in the 1920s in the U.S. high-school attendance increased from 2.2 million to 5 million and the number of college students doubled.[182] The popular music of the late 1930s and 1940s, called “swing”, was also the music popular with the young, particularly young women known as “bobbysoxers” (whose characteristic attire was white buck shoes, white socks, pleated skirt, and blouse or sweater).[183]

[177] Current, *et al.*, p. 535.

[178] Susman 1973, p. 83.

[179] Heyn, pp. 274–276.

[180] Fitzgerald, p. 117.

[181] In Rather, p. 60.

[182] Current, *et al.*, p. 688, and Harvey Green, p. 127.

[183] Millard, pp. 178–184.

This cultural trend was not restricted to the U.S. In Germany in the postwar years it seemed to many that young people were running wild. (Part of the explanation is that teenagers made up a disproportionately large part of the population—a result of a high birth rate before the war, high mortality among older people during the war, and a low birth rate during the war). Young people, it was complained, had "large amounts of pocket money", which they used to "supply themselves with trashy literature, smoke cigarettes, and visit the cinema".[184] There were youth movements in Germany, France, and other countries that attracted much attention and in some cases gained considerable political influence.[185]

The youth culture shaped and was itself shaped by the new media of radio, records, and movies. These made it possible for the spoken discourse, music, or dramatic performance of one person or a small group of people to reach millions. Centuries earlier, the printing press had made it easy for the words of a single person to reach millions of people. The new media could reach all people, literate or not. Centuries earlier, books were prized possessions. In the 1930s in many countries almost everyone experienced radio, records, and movies.

Through the new means of mass entertainment, abetted by the increase of leisure and the predominant position of youth culture, there emerged in the 1920s and 1930s in the United States a single mass culture. Advertising, movies, and radio programs portrayed, for people of all economic and social standings, a common style of life. The cultural historian Robert Sklar has written "In the Thirties many cultures became one culture."[186] There were national, mass-circulation magazines such as *Time, Reader's Digest*, and *Saturday Evening Post*.

The media not only portrayed a common style of life, but also engaged the interest of people, one day after the other, in the same events. This shared consciousness the cultural historian Stephen Kern traces to World War I:

> *The sense of simultaneity experienced by diplomats during the July Crisis was magnified a thousand times during the war, as millions of soldiers were united by chain of command, electronic communication, and synchronized watches and united in spirit by the commonality of events. And their struggle was in turn witnessed by the millions at home, who learned about these multifarious events almost at the same time as they were happening, read about them in newspapers, viewed them in movie houses, and discussed them incessantly. Europe became a communications network that processed more information than ever before about more people involved in more events in widely distant places at the same time.* [187]

There were, of course, many sources of the common culture besides the new media. Economic growth, urbanization, industrialization, and the cultural crisis generated by the war contributed. Mass production meant that a large part of the

[184] Bessel, pp. 225, 247.

[185] Black and Helmreich, pp. 430–431. Shirer (1990, pp. 252–256) explains how, after coming to power, Hitler managed to Nazify the strong German youth movement; in 1932 membership in the Hitler Youth was just 108,000, while some ten million Germans belonged to other youth organizations.

[186] Sklar, p. 24.

[187] Stephen Kern, p. 295.

population had similar clothing, household possessions, and cars.[188] Already in the 1920s in the U.S. chain stores gained a quarter of the market for food, apparel, and general merchandise.[189]

Class differences, always less visible in the U.S. than in Europe, diminished still further in the 1920s. The weathly, the middle class, and the working class often listened to the same radio shows and attended the same sporting events. Movies were enjoyed by all classes in society, and very often the same films were equally popular with the highly educated, the affluent, the middle class, and the poor. A sociologist has written,

> *The meals that are cooked, the cleanliness, order and decor of the household, the garments worn by family members, home entertaining—all reflect the services of the housewife and all are guided by the standards and values of the national media. Even child-rearing techniques have become more uniform under the influence of the media. One of the changes Urie Bronfenbrenner pointed to in his study of trends in child rearing was a narrowing of class differences between 1930 and 1960.*[190]

A historian of media, Daniel Czitrom, has written, "For both artist and audience, radio broke down the formidable geographical and racial barriers that had separated the various rich veins of American folk music."[191] By the end of the 1930s soap operas made up 60% of network daytime broadcasting, and a contemporary study found that on average a soap-opera listener followed 6.6 different series. In Czitrom's words, the programs provided "a model of reality by which one is taught how to think and how to act."[192]

The success of the mass culture came in large part from its openness to inputs from many sources. Sklar has written:

> *Movies and radio forged a new mass culture in the Twenties by absorbing and amalgamating the traditions and cultures of all who created the new media and all who responded to them—ethnic and nationality cultures, the popular arts, and the outward forms at least of genteel culture, if not yet the inner acquiescence. No cultural phenomenon was more remarkable … than the power of immigrants and children of immigrants … to shape the unified culture that genteel America had spent itself in seeking.*[193]

The 1920s and 1930s were the first decades of mass entertainment. There was a democratization of entertainment; earlier, theater and concert music were mainly for the wealthy. There was a commercialization of entertainment, as, more and more, one spent money on leisure activities. There was a mechanization of entertainment, with a variety of machines—radios, phonographs, jukeboxes, movie projectors, pinball machines, and others—involved. Finally, there was a privatization of

[188] Sklar, pp. 16–17.

[189] Current *et al.*, p. 678.

[190] Vanek, p. 366.

[191] Czitrom, p. 85.

[192] Czitrom, p. 85.

[193] Sklar, pp. 18–19.

entertainment; though some products—movies, jukeboxes, totalizators—brought many people together, most products—radio, records, and magazines—were enjoyed at home. These trends, which became evident in the interwar years, have continued for the rest of the century.

6.3 THE CONSUMER CULTURE

6.3.1 A Plethora of Consumer Goods

In the last half of the nineteenth century the railroad and the telegraph helped transform the U.S. economy from a multitude of local markets to a single continent-spanning market. Efficient large-scale production and effective nationwide marketing led to great increases in sales of particular products.

Consider, for example, the phonograph. In 1896, Edison introduced a simplified phonograph selling for about \$100, and quickly followed it with a smaller model selling for \$40. The next year Eldridge Johnson offered a version of Emile Berliner's gramophone for \$25. Edison responded by introducing a \$20 model in 1898 and a \$10 model the following year. By that time the Columbia Company was also selling a \$10 model, and there soon appeared less expensive phonographs, such as the \$7 Euphonic and the \$3 Toy.[194] The low prices, assisted by aggressive marketing, caused business to boom for the record industry. In 1897 only a half-million records had been sold; just two years later, the total reached three million. In 1904, one home in twenty had a phonograph. And—except for a dip caused by the 1907 depression—record and phonograph sales continued to rise until 1920.[195]

Such democratization of consumption—turning a luxury item for the wealthy into a mass-produced product for the average citizen—occurred with many products, including the sewing machine, the camera, the bicycle, and the automobile. This is to say that more and more companies turned from a traditional low-volume, high-margin business to a high-volume, low-margin business. Crucial in bringing about this transition were new marketing methods, such as department stores, chain stores, and mail-order houses. Other factors were the inflation during World War I, which narrowed the gap between salaried employees and wage earners, and the practice of installment buying—which first became common in the 1920s—which enabled people with smaller incomes to make large purchases.[196]

By 1920 household furnishings, ready-made clothing, cosmetics, wristwatches, bicycles, cigarettes, and prepared foodstuffs (such as breakfast cereals, packaged crackers and cookies, baking mixes, and canned foods) were being mass produced. More and more frequently, people purchased products rather than somehow providing for themselves, and increased prosperity permitted a great many discretionary purchases. Thus in the 1920s, the U.S. became what historians have called a "consumer society", defined as "a society in which not only the affluent but many

[194] Millard, p. 123.

[195] Millard, pp. 49, 65.

[196] Sklar, p. 86.

ordinary men and women bought items not just because of need but for the sheer pleasure of buying".[197]

Electrical technologies contributed in several ways to bringing about the consumer society. First, as shown in Chapters 2 and 5, mass production techniques depended greatly on electric tools, electric heating and air-conditioning, electric conveyance, and electric monitoring and control devices. Second, electric devices were among the most important consumer items. Third, electrical technologies played a large role in marketing, particularly advertising. And fourth, electrical technologies, notably radio and movies, helped create an expectation of consumption in the way they portrayed daily life.

Many of the most popular consumer items were electrical devices: light fixtures, fans, electric clocks, space and water heaters, washing machines, irons and ironing machines, sewing machines, vacuum cleaners, electric stoves and ovens, refrigerators, freezers, mixers, toasters, table cookers, and dishwashers. Every year there were new items to attract unspent dollars, such as Christmas lights, electric trains, electric razors, curling irons, electric kettles, and electric carpets. And the 1920s saw the emergence of a major new sector of the economy: consumer electronics. Radios and phonographs were by far the most important of the electronic products, but amateur radio equipment was also important, and there gradually appeared new products, such as the photographic exposure meter (first sold in large numbers by the Weston Electrical Instrument Company of Newark, New Jersey beginning in 1931), the car radio, the FM radio, home movie equipment, the electric organ, and the television receiver.[198] Installment buying, which by 1926 accounted for 15% of retail sales, was stimulated mainly by the automobile, but electrical appliances, especially the washing machine, the refrigerator, the radio, and the sewing machine, were also important stimulants.[199] For example, in the 1920s the Philadelphia Electric Company had a "Wire Your Home" campaign, and by 1927 almost a half-million of its customers were purchasing appliances on the installment plan.[200]

Electrical technology had aided marketing in the late nineteenth century with arc lighting (which illuminated business districts and the interiors of department stores), the telephone (which made it easy to place orders), the trolley (which gave greater access to commercial centers), and illuminated signs (which stimulated business). The 1920s saw more impressive signs, including neon signs. Vending machines—refrigerated ones appeared in the 1920s—made it easy to buy certain products.[201] And electrical technology assisted in the rise of advertising, providing both purchasable objects and advertising media.

[197] Current *et al.*, p. 683.

[198] The Bell & Howell Company, producer of motion-picture equipment, began cultivating the amateur market in 1919, and this part of their business grew extremely rapidly in the next decade. In 1932 Bell & Howell introduced the Filmosound 16mm projector, which turned out to be the company's most successful product. [Robinson, pp. 45–48.]

[199] James Playsted Wood, pp. 389–390.

[200] Strom, p. 229.

[201] Donaldson and Nagengast, p. 238.

A historian of advertising has written, "Advertising came triumphantly out of World War I. It was better, it was bigger, it was reputable. It had proved its ability to sway people's opinions and govern their actions." In the United States advertising expenditures rose from $1.5 billion in 1918 to almost $4 billion in 1929. Most people welcomed advertising—in part because it often gave them a flattering picture of themselves—and it made people want goods that formerly were luxuries reserved to the rich.[202] Advertisers believed they had a vital social role; in an economy dependent upon mass consumption, the advertiser was a powerful stimulant to consumption and an essential creator of new wants. An editor of *Printer's Ink* put it this way in 1926: "Whatever adds to a man's desire to own more wealth adds to the wealth of the nation."[203] Indeed, in the 1920s the main impetus for the economic growth came from the mass consumer market.[204]

Undoubtedly, advertising in the 1920s made people aware, as never before, of the great variety of goods available.[205] Products sold effectively by advertising included cigarettes (Lucky Strikes, Camels, Chesterfields), soaps (Palmolive, Lux), shampoo, shaving cream, deodorants, mouthwash (Listerine), toothpaste (Pepsodent, Ipana), cosmetics, tires (Firestone), correspondence courses, and cars. Manufacturers came to regard advertising as a vital part of their business, and for some products, such as cosmetics, advertising costs exceeded production costs.[206]

In an age of technological innovation, advertising had the important ability to establish new products on the market in a fraction of the time it would otherwise take.[207] New household technology, for example, would have been adopted much more slowly without advertising. Advertisements presented new products, explained their use, and showed ordinary people using them. When General Electric decided to mass produce the "Monitor Top" refrigerator in 1927, it allotted $18 million for the manufacturing plant and $1 million for an advertising campaign.[208]

Businessmen saw mutual advantage in cooperatively promoting new products through generic advertising. The electric refrigerator was promoted generically in the mid-1920s in the U.S. by two associations of manufacturers, the Society for Electrical Development and the National Electric Light Association.[209] Such cooperative advertising increased from $40,000 in 1919, to $6,000,000 in 1929.[210]

Advertisers soon recognized that most family spending was done by the wife and increasingly directed advertising toward women.[211] This recognition led also to the employment of many women in the advertising profession, and these women

[202] James Playsted Wood, pp. 363–365. The quotation is from p. 363.

[203] Pease, pp. 21–23.

[204] J.M. Roberts, "The New Era …".

[205] Sklar, p. 86.

[206] James Playsted Wood, p. 395.

[207] James Playsted Wood, p. 367.

[208] Donaldson and Nagengast, p. 225.

[209] Donaldson and Nagengast, Figure XXI following p. 116, and p. 220.

[210] Pease, p. 24.

[211] Pitkin, p. 191.

helped to communicate to industry the interests of women.[212] Household technology played a large role in this shift; one historian has written, "If the exercise of the wife's right to partake of the benefits of modern technology necessitated a realignment of the family's financial resources from husband to wife, advertisers happily condoned that."[213]

Many of the advertising campaigns manifestly worked, and advertising came to be seen as a major social force.[214] In 1930 the writer Sherwood Anderson complained, "People … no longer buy … newspapers, books, foods, pictures, clothes. Things are sold to people now."[215] Though great, the power of advertising can be overestimated. Manufacturers continually sought to produce what people wanted, and in the 1920s, they conducted market research in the form of "sample surveys" (which may be seen as forerunners of the public opinion polling that began in the mid 1930s).[216] A manufacturer would be unlikely to spend much on an advertising campaign unless trials had shown customer satisfaction with the product.

Though consumers were free to spend as they chose, they might choose unwisely because of misleading or false advertising. The 1930s saw the beginning of a consumer movement to reduce this risk. Extremely influential was a book published in 1927, which became a best seller: *Your Money's Worth: A Study in the Waste of the Consumer Dollar* by Stuart Chase and Frederick Schlink. The book was critical of the power of advertising, urging consumers to be skeptical and to seek product information from other sources. The authors formed a national Consumers' Club—it became Consumers' Research in 1929—as an independent agency to test and rate products.[217] A competing organization, Consumers' Union, was formed in 1936. The consumer movement contributed to the passage in 1938 of two laws (the Food, Drug, and Cosmetic Act and the Wheeler-Lea Amendment to the Federal Trade Commission Act) that gave the federal government the power to regulate advertising and labeling.[218]

Of particular importance for electrical products was an earlier organization, Underwriters' Laboratories (UL). It was formed by the insurance industry in 1894 for safety testing of consumer products. The hope was to reduce bodily injury, loss of life, and property damage caused by manufactured products. UL standards for safety became widely accepted by businesses (which wanted their products to be certified as safe), government agencies (which often required UL approval of products), and consumers (who expected to see the UL label on electrical products). Underwriters' Laboratories became independent of the insurance industry in 1917, supporting itself mainly by fees for testing, and became increasingly international (having in 1973 some 40 testing centers outside the U.S.). UL claims some credit

[212] Dodd.

[213] Dodd, p. 147.

[214] Ruth Schwartz Cowan, "The 'industrial revolution' …", p. 196.

[215] Sherwood Anderson, p. 40.

[216] Hobsbawm, pp. 142–143.

[217] Pease, pp. 98–100.

[218] Pease, p. 124.

for great improvements in safety; the number of people in the U.S. killed by electricity declined from 20-per-million in 1920, to 5-per-million in 1973 despite a 15-fold increase in the use of electricity.[219]

6.3.2 Standardization

Though new technologies were celebrated, the subsequent changes in daily life were frequently denounced. In 1929, Stuart Chase wrote, "… the machine has destroyed so many of our habits with a devastating thoroughness that we have been left a people lost in the wilderness, our time-honored folkways scattered and dispersed." [220] A special object of censure was standardization, which most people in the late 1920s believed to be a necessary consequence of mass production. The prime example of mass production, the Model T automobile, exemplified the relation; between 1908 and 1927 Ford's assembly lines poured out 15 million of them, all very similar in form and in "any color you want as long as it's black". It became popular to decry mechanization because of the belief that it made things, and then people, more uniform and less individualistic.

Though they might admit that this argument had some validity, proponents of mass production pointed out a number of mitigating factors: the huge number of different consumer products, the efforts of each manufacturer to differentiate his product from competing products, and the increasing ability of manufacturers to mass produce an item in many varieties.

Certainly a given product appeared with much less variety when it was mass-produced rather than home-made or made by a small manufacturer, but mass production led to a much greater variety of consumer products than the world had ever known. In the late 1920s the Sears-Roebuck mail-order catalog contained more than 100,000 separate items.[221] People had always enjoyed acquiring things and having choices; the plethora of affordable consumer goods gratified both desires.

In most markets numerous manufacturers competed, and each sought to make his products distinctive. A historian has written, "Frozen foods were the very embodiment of standardization; a package of peas bought in Indianapolis would be no different from one bought in Tacoma. Paradoxically, however, with standardization came variety. Consumers could soon choose from dozens of food products prepared in many different ways."[222]

Many manufacturers developed adaptable manufacturing techniques, allowing both continual changes in the product (annual models in the automobile industry) and—at any one time—a variety of models, with different prices, styles, features, and colors. GM in the 1920s pioneered this technique of market segmentation,

[219] Ashley, and Andover.

[220] Chase, p. 252. Chase added (p. 257) "The machine is probably the greatest destroyer of old standards that the world has ever seen", which is to say that machines have destroyed behavioral standards even as they have established material ones.

[221] Chase, p. 254.

[222] Volti, p. 56.

designing mass-produced products for particular groups of people ("a car for every purse and purpose").[223] As Stuart Chase wrote in 1929:

> *To hold that our commodities increasingly seek a dead level is absurd. They seek altogether too many live, new levels—with the hand of the super-salesman always on the bellows. If this be standardization, make the most of it. It is the standardization of infinite variety and perpetual change—and thus uncomfortably close to a contradiction in terms.* [224]

Advertising, as we have already said, was important in introducing new products. It helped, too, in achieving market segmentation. And it conferred on products flattering images of the type of person who used them. People increasingly saw purchases as a way to express, or even develop, their personalities. The aficionado of classical music might choose a Philco radio-phonograph console, while the Benny Goodman fan might buy the Majestic Knockabout, a portable radio. The car one drove, the records one listened to, the movies one saw, the appliances one bought (air-conditioner or ice-cream maker or bread-slicer)—all could be seen as expressions of personality.[225]

Paradoxically, the great variety of consumer goods depended upon the establishment of industrial standards, so that many manufacturers could produce for the same market. In some countries the lack of standardization in electricity supply (different voltages and frequencies) meant higher prices for electric appliances (since they had to be tailored for each type of supply) and hence slower adoption of appliances. For example, in England in the late 1930s there were a wide variety of non-standard AC systems and still more than a million DC customers.[226] Another requirement for the mass production and marketing of appliances was a standardized system of plugs and sockets, which the National Electric Light Association brought about in the U.S. in 1917, before which time there were twenty or so different types of wall receptacles.[227] In the first decades of the record industry, there were different recording forms (cylinder and disk), different methods of cutting the groove, different sizes of records, and different speeds. By the late 1920s the disk format, the lateral-cut groove, and the 78-rpm record (either 10 or 12 inches in diameter) were the standard, so that manufacturers of phonographs and of records produced for a single market.

Within a country, industrial standards were set by different mechanisms. The first or largest manufacturer might, through a dominating market position, impose his standards on others. A manufacturers' association, such as the National Electric

[223] Tedlow, p. 7.

[224] Chase, p. 254.

[225] Consumer preferences were certainly used in assessing people: a movie-industry executive wrote in 1953, "If [my acquaintances] will rate for me, in order of preference, the actors and actresses they like and dislike and the pictures they have seen them in, I immediately have a psychiatric analysis of them which I suspect is better than they can obtain in any reasonable time from a psychiatrist." [Raibourn, p. 804.]

[226] Hannah, p. 196.

[227] Schroeder.

Light Association, might take the leading role in defining industrial standards. Alternatively, that role might be filled by the engineers' professional society, as happened in Britain in some areas with the Institution of Electrical Engineers. There were significant efforts to make industrial standards extend beyond a nation's borders, notably by the International Electrotechnical Commission.

The achievement of a standardized form of a technology had important advantages. The more a technology was adopted, the more it was developed and improved by engineers. The more a technology was adopted, the better it became known and understood by consumers. There were often advantages, too, in belonging to a network of users, usually with increasing advantages the larger the network. And a standardized technology encouraged the provision of ancillary products.[228] Earlier chapters provided examples, including the competition among steam, gasoline, and electric cars around the turn-of-the-century, and between gas and incandescent lighting over several decades.

The electric refrigerator faced competition from both the icebox (which in the 1930s began to be called "the ice refrigerator") and the gas refrigerator. A 1936 advertisement touted the "modern ice refrigerator" as "using ice in an entirely new way" so that "the ice service man need come only once in several days" and pointed to the advantages of lower price and greater reliability ("It will not get out of order").[229] It is noteworthy that here, as in many other instances, the competition between two technologies increased business for both of them, as the mass-marketing of the electric refrigerator did not, in the early years, diminish business for the ice industry. An observer wrote in 1931, "… the propaganda on behalf of electric refrigeration taught the people the need of refrigeration, and thousands who had never used ice and who couldn't afford electric refrigeration bought ice boxes and became customers for ice men."[230]

The more serious rival to the electric refrigerator was one powered by natural gas. It operated on a different principle: heat was extracted when a refrigerant was absorbed into a liquid, rather than when a refrigerant vaporized, as in the electric refrigerator. This absorption refrigeration system had been invented in 1922 by two Swedish engineering students, Carl G. Munters and Baltzar von Platen. Because it ran continuously, it did not require automatic controls. Having virtually no moving parts, it was silent and highly reliable. The U.S. company Servel bought rights to this machine and began selling the Electrolux-Servel in 1926. Though the company continued to manufacture absorption refrigerators until 1956, such machines never commanded more than 10% of the market (though they found a market niche for use in recreational vehicles and in regions of the world without reliable electricity supply). The victory of the electric compression refrigerator may have been more the result of strong financial backing for development and promotion than of better technology.[231]

[228] Arthur.

[229] Advertisement in *Saturday Evening Post* 15 February 1936, p. 83.

[230] Quotation of J.W. Beckman in Donaldson and Nagengast, p. 228.

[231] Ruth Schwartz Cowan 1983, pp. 128–143, and Ruth Schwartz Cowan, "How the refrigerator …".

Once a technology has been adopted, it often is difficult for competing technologies to win converts, a phenomenon known as "technological lock-in". It may be that different historical circumstances would have led to the dominance of the gas refrigerator. The QWERTY typewriter keyboard is clearly an example of "lock-in", though it is not clear that other keyboards would be significantly better.[232] Very often one of several alternative technologies comes to dominate, but this is not inevitable. Gas and electric clothes driers, gas and electric stoves, gas and electric water heaters—these have coexisted in many countries on roughly equal terms for more than 60 years.

Consider the competition in the 1920s of the two talking machines, the phonograph and the radio. Sales of Edison phonographs declined 50% in 1924, sales of Victor phonographs declined 60%. The phonograph industry felt compelled to adopt electronic amplification to achieve greater volume, especially of bass notes. By the late 1920s it appeared that both products would survive, and several companies began to make radio-phonograph combinations (218,000 of which were sold in 1929).[233] Indeed, the two industries established a symbiotic relationship: the record industry provided material for radio programs, and broadcasting became an important stimulant to record sales.

6.3.3 The Americanization of National Cultures

The English historian Eric Hobsbawm has written, "Even in 1914 the USA had been the major industrial economy, and the major pioneer, model and propulsive force of the mass production and mass culture which conquered the globe during the Short Twentieth Century. …"[234] The 1920s were better economically for the U.S. than for Europe, and in 1929 the U.S. produced more than 42% of the world industrial output, while Great Britain, France, and Germany combined produced only 28%.[235]

In 1920, 10 times as many automobiles were registered in the U.S. as in all of Europe, and although European production increased more than U.S. production in the interwar years, in 1938 there were still three-and-a-half times as many cars in the U.S. as in Europe.[236] The 20 million telephones in the U.S. in 1929 were more than double the total for the rest of the world. Compared to most other countries, the U.S. adopted electrical household appliances rapidly, a trend helped by a vigorous electrical manufacturing industry, an effective advertising industry, and the great purchasing power of a large middle class. In addition, traditional ways were less fixed. In France, for example, many held to the practice of buying groceries daily, believing that refrigerators spoiled the taste of food. Certain conditions unlike those in most of Europe also contributed: the hot and humid weather in much of the U.S.

[232] Liebowitz and Margolis.

[233] Millard, pp. 136–146.

[234] Hobsbawm, p. 14.

[235] Hobsbawm, p. 97.

[236] Landes, p. 442.

in summer made air conditioning more attractive, and the great distance to stores for many people made refrigerators and freezers more attractive.[237]

Thus in the interwar period, the U.S. led the way toward a consumer society. In Germany and other countries, the postwar mood of enjoying life in the present rather than saving and building for the future, reinforced by the continued depreciation of the currency, hastened this movement.[238] In Switzerland a strong economy and a highly developed electrical industry resulted in an even more rapid adoption of many electrical appliances than in the U.S.[239] The Soviet Union, at the other extreme, may be said to have further distanced itself from a consumer society as Stalin emphasized industrial production, with the result that there were few attractive consumer products that rubles could buy.

A well-developed system of international trade helped spread the consumer culture. At the turn-of-the-century, the U.S. imported twice as much from Europe as it exported there. By the outbreak of World War I the ratio was almost even. The war left destruction throughout Europe and depleted investment capital, which was further depleted in many countries by the postwar inflation. By contrast, the war stimulated the U.S. economy, and the 1920s saw further economic growth. The U.S. became a source of investment capital and technological know-how for countries around the world. And in international trade U.S. firms were helped by having a very large home market.

The interwar years saw what has been called "the coca-colonization" of much of the world, as U.S. products became prominent in many countries. Numerous U.S. companies (such as Coca-Cola, Woolworth, and Ford) set up businesses abroad. In 1929, Coca-Cola was on sale in 76 countries, and that same year there were almost 400 U.S. owned businesses in Great Britain.[240] U.S. firms, such as Hoover, Hotpoint, and National Cash Register, marketed electric appliances overseas. Many new and aggressively marketed products—Wrigley's chewing gum, Gillette safety razors, Sun Maid raisins, the Kodak Brownie camera—were exported and sold in large numbers abroad.

These products helped convey the U.S. lifestyle to other countries. At the same time, increasing material prosperity and the increasing adoption of products, such as the telephone and the automobile, which earlier had been adopted in large numbers in the U.S., gave the appearance of following the U.S. lead (though here the effects resulted mainly from parallel evolution rather than direct influence). Marketers elsewhere copied the advertising campaigns of U.S. manufacturers, and the European vogue of Fordism and Taylorism heightened the impression of the U.S. as the country of the future.

What may have been most important in the Americanization of other cultures were the products that directly conveyed U.S. culture: popular fiction, comics, movies, records, and radio programs. U.S. magazines became popular in Britain,

[237] Braun and Kaiser, pp. 92–94.

[238] Bessel, p. 250.

[239] Braun and Kaiser, p. 94.

[240] Tedlow, p. 63, and Mayer.

and U.S. comics were sold and emulated worldwide. U.S. music—first ragtime, then jazz, then swing—became extremely popular in Europe, and U.S. record companies operated internationally.[241] It was movies, however, that were most influential.

The worldwide dominance of U.S. movies owes much to World War I. With the onset of war, film-making in Europe nearly ceased, while in the U.S. the film business expanded steadily. By 1918, U.S. films dominated the market in much of Europe and in parts of the Far East. In some countries there were practically no other films available.[242] A British historian has written:

> *But the success of D. W. Griffith's* The Birth of a Nation *(1915) had irreversible effects on the cinema throughout the world. The British public rapidly came to prefer the better made and more varied U.S. films to inferior native efforts. In 1920, out of a total of 878 films available only 144 were British, and six years later only 5 per cent of screen time was occupied by British material. …*[243]

Their success in foreign countries made U.S. filmmakers reluctant to take up sound movies, because it would then be more difficult to market their films in countries where English was not commonly spoken.[244] There remained, of course, a large English-language market for films, and Hollywood continued to thrive after the coming of sound movies. Indeed, sound movies worked to Hollywood's advantage in two ways, as exemplified by the history of the Danish film industry. In the era of silent films, Danish films had success throughout Europe, but with the arrival of sound movies the foreign market almost disappeared, partly because language then impeded export and partly because it then became more difficult to compete with Hollywood, as sound movies were more expensive to produce.[245] For U.S. filmmakers the large home-market made the costs bearable.

There were others reasons for the success of Hollywood. There was a high level of technical skill—in camera work, lighting, and sound—that depended upon advanced engineering.[246] The wealth of U.S. film-makers allowed them on occasion to acquire outstanding talent from other countries; noticing the excellent German films of the interwar period, Hollywood producers brought over many German directors, actors, and technicians.[247] Occasionally, however, non-U.S. filmmakers succeeded in direct competition with the Hollywood. The Hungarian-born, British-based filmmaker Alexander Korda had great success with *The Private Life of Henry VIII* in 1933, and followed it with a series of lavish costume dramas.[248]

Movies became by far the most universal of art forms, attractive to people of all social classes and accessible, by means of subtitles or dubbed sound, to people

[241] Chambers, p. 135, and Millard, pp. 65–79.

[242] Rotha, pp. 73–74.

[243] Chambers, p. 82.

[244] Braun and Kaiser, p. 168.

[245] Kaarsted, pp. 52–53.

[246] Rotha, p. 139.

[247] Rotha, p. 77.

[248] Chambers, pp. 83–84.

of all cultures. Extremely important was that fact that motion-picture technology provided no barriers to export as there were worldwide standards, in both video and audio systems. The width of the film strip, the scheme of sprocket holes, the size of picture frames, the width of the sound track, and the manner of recording sound were all standardized.[249] The popularity of U.S. films was the strongest force bringing about this standardization.[250]

In this worldwide market, Hollywood movies dominated. In 1947 they occupied 80% of British screen space.[251] Shortly after World War II, a British observer commented:

> *Visually America is the best-known country in the world. The towering New York skyline, the white clapboard houses of New England, the Golden Gate, the magnificence of the Rockies; these pictures have become, through cinematic repetition, part of the Englishman's pictorial equipment, and with Hollywood's aid he has developed an intimate acquaintance with such peculiarly American institutions as the drugstore, the tourist-cabin, the fraternity house and the railroad depot.* [252]

In Latin America, until domestic film industries began to compete in the 1940s, U. S. films completely dominated.

The Americanization of national cultures was aided by the emergence in many countries, as we saw earlier, of a youth culture. In the U.S. in the 1920s young people had the means and freedom to develop into a powerful cultural force influencing everyone: breaking with the past, abandoning convention and formalities, living for the present, celebrating life's pleasures, spending whatever money one had. The youth culture was reflected in the music and movies the U.S. exported, and young people elsewhere were more likely to become champions of American products and practices. In 1941 the journalist Henry Luce wrote:

> *American jazz, Hollywood movies, American slang, American machines and patented products, are in fact the only things that every community in the world, from Zanzibar to Hamburg, recognizes in common. … America is already the intellectual, scientific and artistic capital of the world.*[253]

It may be noted that the processes labeled Americanization—involving consumer goods, magazines, records, movies, and radio—operated most strongly within the U.S., giving most of its inhabitants a large measure of common culture. Indeed, movies and radio seem to have been more popular with immigrant families than with native-born families.[254] It may also be noted that in this period in the U.S.

[249] A few features of the technology existed in more than one standard. For example, until 1953 there were four different standards for the size and shape of sprocket holes [Raibourn]. Also, as mentioned above, there were two commonly-used means of recording a soundtrack (varying the width of the track or its optical density).

[250] Raibourn.

[251] Rotha, p. 126.

[252] Morpurgo, pp. 51–52.

[253] Luce, p. 324.

[254] Czitrom, p. 192.

"culture" acquired a new meaning. Replacing Matthew Arnold's conception of culture as appreciation of the highest intellectual and artistic achievements was a democratic conception of culture as the patterns of actions, thoughts, and feelings of all the people of a geographic area. For the first time people spoke often of "the American way of life" and of "the American dream", and there was widespread interest in popular culture and in public-opinion polling.[255] Mass consumption and mass entertainment, particularly by radio and movies, must have been principal forces behind this change.

Already at the turn-of-the-century, U.S. influence on Europe was noticeable enough to provoke critical comment. In 1901 the British author William Thomas Stead published *The Americanization of the World; or, The Trend of the Twentieth Century*, and in the next year the British author Fred A. Mackenzie published *American Invaders*.[256]

In 1927 the German Richard Müller-Freienfels wrote on "The Americanization of the soul". He argued that a chief characteristic of the United States was what he called "the mechanization of life", the general intrusion of technology into daily activities and the celebration of its virtues. He reported that when visiting people in the U.S., he was often shown wireless apparatus, vacuum cleaners, or mechanical contrivances in the kitchen, including "electrical machines [that] prepared the inevitable ice cream". The U.S. citizens, he thought, valued practicality and efficiency above feelings and emotions, and hence celebrated machines. He saw the same trend, though at a less advanced stage, in Europe: "In respect of the tyranny of technique, we are becoming more and more Americanized." Another characteristic of U.S. life that Müller-Freienfels highlighted was standardization, not only in the mass-produced products visible everywhere, but also in the people: "All the clean-shaven men, all these girls, with their doll-like faces, which are generally painted, seem to have been produced somewhere in a Ford factory. …" Whereas Europeans maintained separations between races, classes, and other social groups, Americans, he thought, chose agreement and similarity. "This reduction of all to a dead-level has of course its advantages, but it deprives life of much that is desirable, and, above all, of a perception of personal quality." Müller-Freienfels went on to decry the same tendency in Europe, especially in the cities.[257]

In the interwar period in Great Britain many social critics of widely varying political positions saw the U.S. influence as a threat to the English way of life.[258] The BBC, under Director General John Reith, saw itself as a bulwark against "mass culture", that is, "American culture". The British radio audience grew greatly in the 1930s, and the BBC found itself unable to resist the pressure for U.S.-style programs,

[255] Susman 1970.

[256] William Thomas Stead, *The Americanization of the World; or, The Trend of the Twentieth Century* (New York and London: H. Marckley, 1901), and Fred A. Mackenzie, *American Invaders* (London: G. Richards, 1902).

[257] Müller-Freienfels.

[258] Chambers, p. 36.

[259] Chambers, pp. 37–38.

though it fought a delaying, rearguard action.[259] Jazz was excluded from BBC programming, and popular American programs, such as Jack Benny or Bob Hope, were not broadcast in the evening hours.[260] Concern over the small proportion of British films being shown in the cinemas led the government in 1927 to establish quotas; that year cinemas had to give at least 5% of screen time to British films, and the quota rose to 20% in 1936.[261]

In Germany in the years just after the war there was a widespread perception of moral decline, and blame was frequently placed on the movies; one result was the censorship authorized by the Reichstag in the 1926 Law Against Dirt and Trash.[262]

In the consumer society, popular appeal replaced the judgment of critics as the arbiter of success, and foreign observers of the U.S. commented on this surrender of critical standards and saw it as especially American.[263] In 1927 the editor of the English journal *The Gramophone* wrote: "If the English public is encouraged to suppose that its opinion expressed *en masse* has any greater value than the similarly expressed opinions of the most degraded Hottentots, we may as well give up pretending to be anything else but one of the less prosperous colonies of the United States."[264] Another commentator wrote:

> *The way of life described in American films can make Europeans envious, and this envy has been the cause of much ill-feeling against the Americans. But the error of Hollywood is not that it has encouraged Europe to covet physical comforts that are in Europe either difficult or impossible to get, but rather that it has offered no mental standards to support the physical standards that it advertises so successfully. … It is the tragedy of America and of Europe that Hollywood has set itself the task of boosting American virtue at just that point where America's virtue has become America's vice: in the ease of American life.*[265]

For many critics, it was not the particular features of U.S. movies, music, or consumer goods that were objectionable, but rather the loss of national culture as the U.S. products became more and more popular. According to one observer: "Now the fashion for American Negro music has swept away these distinctions [of national musical style]. It has imposed comparative uniformity where there was once variety and made the whole world of entertainment music virtually an American appanage." [266]

It may be argued that international markets and mass communications were bringing about a globalized or cosmopolitanized culture, rather than an American culture. The substantial foreign input into U.S. products and the international success

[260] Chambers, pp. 38, 139.

[261] Chambers, p. 82.

[262] Bessel, pp. 221, 246–248.

[263] LeMahieu.

[264] Quoted in LeManieu, p. 376.

[265] Morpurgo, p. 58.

[266] Collins, p. 71.

of products from other countries support this view. It may be argued that social forces that appeared first in the U.S. because of greater freedom and greater prosperity were eventually felt everywhere, and the forces that were irresistible in the U.S. proved to be irresistible most other places.[267] Indeed, many of the changes associated with the U.S. were also associated with urban life—at times and in many countries specifically with Parisian life (as in the popular post-World-War-I song “How ‘ya gonna keep ‘em down on the farm after they’ve seen Paree”). It may be argued that “Americanization” was for many people a way of attributing to outside influence social changes that were perceived as undesirable.[268] These caveats notwithstanding, there is no doubt that the interwar period saw an unprecedented reach of one national culture and that electrical technologies played important roles in this process.

267 Mayer.

268 Mayer.

Chapter 7

Communication Technologies in Democratic and Totalitarian Countries

7.1 NEW COMMUNICATION TECHNOLOGIES

7.1.1 The 1936 Olympic Games: Technology in the Service of Propaganda

In August 1936 Berlin hosted the largest sporting festival the world had ever seen: some 4000 athletes from all over the world, representing 49 nations, gathered there to celebrate the tenth Olympic Games of the modern era. Adolf Hitler welcomed the opportunity to showcase the new Germany, which had made a remarkable economic recovery since his coming to power three-and-a-half years earlier. Many efforts were made to impress foreign visitors, and Nazi anti-Semitic policies were veiled for the occasion.[1]

Through advances in telecommunications, this Olympics was brought to people abroad as never before. Newspapers received teletyped reports from wire services and telegraphed or telephoned reports from their own correspondents. By the marvel of phototelegraphy, even pictures could be sent by wire. Radio carried the news even more rapidly and directly to the consumer. In movie theaters, newsreels and several full-length films allowed people everywhere to be spectators of the Games.

In 1934 Benito Mussolini had scored a propaganda success for Fascist Italy when Rome hosted the World Cup soccer competition. The Nazis sought to make the most of their opportunity, and they avidly applied new technologies to the task. Public-address systems and powerful lighting heightened the spectacle. Radio brought it into the homes of millions, not only by the existing radio stations, but also through a new high-power shortwave station that could be heard on all the

[1] Man.

Dawn of the Electronic Age: Electrical Technologies in the Shaping of the Modern World, 1914 to 1945, by Frederik Nebeker

continents.[2] Magnetic recording on steel tape, another marvel of the age, made it easy to record reports for broadcasting later and did so with little loss in sound quality. Such tapes were also played through public-address systems to allow people not at the Games to follow events.[3] The Nazis set up an official film agency headed by Leni Riefenstahl, whose own *Olympiade, Berlin, 1936* remains a much admired documentary; this agency strictly controlled the filming done by foreign cinematographers.[4] Still another technological marvel came to public attention through the Games: television. Though few Germans had receivers in their homes, the Olympics could be enjoyed in public television-viewing rooms in many German cities. German engineers also developed a means (the Zwischenprojektor) to convert motion pictures to television signals.

Germany undoubtedly gained many foreign admirers because of the Olympics, and domestically it was also well received. Part of the propaganda success of the 1934 World Cup for Mussolini had been that Italy won the competition, and Hitler expected German athletes to dominate the 1936 Games. They did win more gold medals than the athletes of any other nation, but Hitler was visibly dismayed at the large number of non-Aryan medalists, including a Korean runner who won the marathon and many black winners, including Jesse Owens, who took four gold medals.

7.1.2 New Types of Wire Communications: Teletype and Phototelegraphy

Though telegraphy was a mature industry—in 1920 it had been big business for 70 years—there was continual technological advance in the interwar period. For example, inductive loading of telegraph lines came to be widely employed. When lines were given increased inductance, electrical signals retained their shapes better, and hence could be sent in more rapid succession. Thus in 1924 Western Union laid a 2330 mile cable from New York across the Atlantic to Horta in the Azores that had continuous inductive loading: a strip of permalloy—an alloy of nickel and iron—wrapped around the copper conductor. (The alternative of increasing inductance at regular intervals was generally adopted for landlines.) The inductive loading permitted this cable to carry 1500 letters-per-minute rather than the 150-to-300 letters-per-minute with earlier cables.[5]

Automatic and multichannel telegraphy were more widely adopted. A message could be encoded as a series of holes in a strip of paper, the strip fed to an automatic sender, and the message received at the destination by an automatic printer. By 1920, 75% of Western Union's traffic was carried by automatic circuits. Multichannel

[2] Okamura, p. 172. The 1940 Olympic Games were scheduled for Tokyo, and the Japanese planned to have an even more powerful shortwave station (50 kW rather than 40 kW) to reach listeners worldwide.

[3] Morton, pp. 272–273.

[4] Man.

[5] Oslin, pp. 290–291.

telegraphy—especially duplex and quadruplex—had long been common. In the interwar period carrier systems were introduced in which a number of signals were sent simultaneously on different carrier frequencies. In the 8-channel Western Union system of 1933, for example, eight frequencies, spaced 300 Hertz apart, each carried its own message. Some carrier systems had 20 or more channels, with carrier frequencies extending from 3300 to 10,000 Hz. By 1940, the introduction of frequency-modulation techniques—with shift of frequency, rather than change of amplitude, constituting the signal—increased both accuracy and capacity for telegraph lines. As many as 288 messages could then be sent simultaneously over a single pair of wires.[6]

The telegraph business prospered in the 1920s. In the U.S. the number of messages almost doubled from 1920 to 1929.[7] The international business also increased, in 1927 commercial cable traffic was almost two-and-a-half times what it had been 14 years earlier (92.4 million words as compared to 38.0 million words).[8] One business made especially effective use of the telegraph; a 1936 advertisement states that 10,000 florists were members of the International Florists' Telegraph Delivery Association.[9]

The telephone gradually replaced the telegraph for most purposes, though the steady decline in number of telegrams sent in the U.S. did not begin until 1945.[10] In the interwar period long-distance phone rates continued their downward trend, but even in the late 1930s it was still much less expensive to send a telegram. One could send ten words and signature from New York to Chicago for 60 cents (a three-minute phone call cost several times that), and senders strove to compress or expand their message to fit, e.g. THINK FORGET TURN OFF GAS PUT OUT CAT PLEASE CHECK, or I LOVE YOU I LOVE YOU I LOVE YOU REGARDS.[11] There was also the widespread view that the telegraph, which provided a written message, was more official. For example, when in 1922 the Italian king telephoned from Rome to Milan offering Mussolini the premiership, he refused to act on the message until it was confirmed by telegram.[12]

As the telegraph business grew in the 1920s and 1930s, a town often gained branch offices—in hotels, the railroad station, or other public places—that were connected to the main telegraph office. In addition, many businesses had their own tie-lines to the main telegraph network or their own private lines, linking, for example, offices to factories. Because the skill to send and receive code could not be readily acquired, there was need for a device that made it easy to send and receive messages.[13]

6 O'Neill, p. 10, and Oslin, pp. 297–303.

7 Pierce 1977.

8 Oslin, p. 291.

9 *Saturday Evening Post*, 15 February 1936, p. 64.

10 Pierce 1977.

11 Hill.

12 Gunther, p. 200.

13 Oslin, p. 303.

With an electric typewriter, one could, of course, separate the keyboard from the typebars and paper carriage since the electrical connection between each key and its associated typebar could be arbitrarily lengthened. Providing a circuit for each of the 40 or so keys would, however, require a great deal of wire to communicate over any distance. A single circuit could serve if each key sent a code that activated only the associated typebar. This arrangement, supplemented by a printing apparatus for the sender, was called the teletypewriter.

The U.S. company that first provided a reliable and affordable teletypewriter was the Morkrum-Kleinschmidt Company, which formed in 1924 and soon changed its name to Teletype Corporation. In the mid and late 1920s, it sold thousands of machines to Western Union, AT&T (which provided telegraph circuits), and other companies. In 1930, AT&T bought the U.S. Teletype Corporation, and ITT purchased the foreign rights.[14]

These teletypes were connected either to a telegraph company such as Western Union or directly to another terminal on a private line. In 1931, AT&T introduced Teletypewriter Exchange Service (TWX), which provided central switching so that any subscriber could communicate by teletype with any other subscriber. The direct connection allowed two-way communication, and businessmen began to have "telegraph conversations". In 1937 TWX connected 11,000 stations.[15]

Teletypewriter service was much more popular in Europe than in the United States, perhaps as a result of the preference of many for written communication when a foreign language is involved.[16] An interesting use of teletype technology was teletypesetting, whereby a typesetting machine such as a Linotype was controlled from a remote position. This began to be used in 1934 by the *Scotsman* newspaper (linking London and Edinburgh offices) and by the London *Times*. Also occurring in the interwar period was the initial development of the radio teletypewriter.

One of the most impressive achievements of the interwar years was phototelegraphy, also called "facsimile telegraphy" or "facsimile transmission", though not yet "fax" (a post-1945 coinage). The quest to send pictures by wire dates back to the beginnings of telegraphy. In 1843 in England Alexander Bain devised an electrochemical recording telegraph capable of roughly reproducing line drawings, and in 1862 a system to transmit line drawings was being used between Paris and Amiens. By 1910 the daily press, at least in London, made use of images sent by wire. In the interwar period the triode amplifier, new photocells, electric filters, and carrier-current telegraphy led to great improvements in telephotography.[17]

Two basic ideals—fundamental also to television—were involved. First, one may regard a picture as made up of a finite number of picture elements or "pixels" (a word not coined until the 1960s), each one having a uniform brightness. Second, one may transmit an encoding of the pixels sequentially over a single channel and then reconstruct the image at the receiver.

[14] Oslin, pp. 304–305.

[15] Oslin, pp. 304–307, and Lubar, p. 93.

[16] Pierce 1977.

[17] *Americana*.

An early phototelegraph transmitter looked, and even functioned, something like an Edison phonograph. A photograph was mounted on a cylinder. Finely focused light illuminated one point of the photograph at a time. The cylinder rotated rapidly while the light moved slowly parallel to the axis of the cylinder, during which time a photoelectric cell registered the light reflected to it from each picture element. The phototelegraph receiver was a similar apparatus. Light-sensitive paper was mounted on the cylinder. A focused lamp, whose intensity varied with the signal strength, moved along the rotating cylinder. In order to achieve exact synchronization, which was essential, the drive motors in both transmitter and receiver were locally regulated by a tuning fork.[18]

In 1923, the Bell System engineer Herbert E. Ives, together with his colleagues, developed a practical system of phototelegraphy. (Ives then turned his attention to television, which he regard as merely a speeded-up form of phototelegraphy.)[19] Commercial use of Ives's system began in 1925.[20] In 1934 the wire service Associated Press put a large inter-city photograph transmission system into use.[21] Many other countries also began using phototelegraphy. In Japan the difficulty of encoding the written language into dots and dashes gave an extra reason to develop facsimile transmission, and innovative work was done there in the 1920s and 1930s.[22] It was Japan which, a half-century later, brought facsimile systems into general use worldwide.

7.1.3 Distant Vision: Television

The goal of viewing events taking place at a distant location is an old one, and feasible proposals for achieving it date back to the 1870s. Though a visual medium like movies, television was much closer in its development to two other media of instantaneous communication, phototelegraphy and radio.[23] Television took the basic ideas of phototelegraphy—regarding an image as composed of a number of picture elements, and transmitting the image by transmitting a sequential description of the picture elements—and added the requirement that enough images be sent each second so as to create, as with motion pictures, the illusion of continuous motion. After World War I, because of the development of radio technology, the means of simultaneously broadcasting such a signal to millions of people were already at hand. The difficult tasks were converting an image into a sequence of simple signals, reconstructing the image from the signals, and doing both fast enough to create the illusion of continuous motion.

In 1884, the Russo-German inventor Paul Nipkow described how a mechanical scanner (later known as the Nipkow disk) could work (see Figure 7.1), and in the

[18] *Americana*.

[19] Brooks, p. 185.

[20] O'Neill, p. 3.

[21] Henney, p. 23.

[22] NEC book [CHEE], pp. 22–23.

[23] Abramson, p. 3.

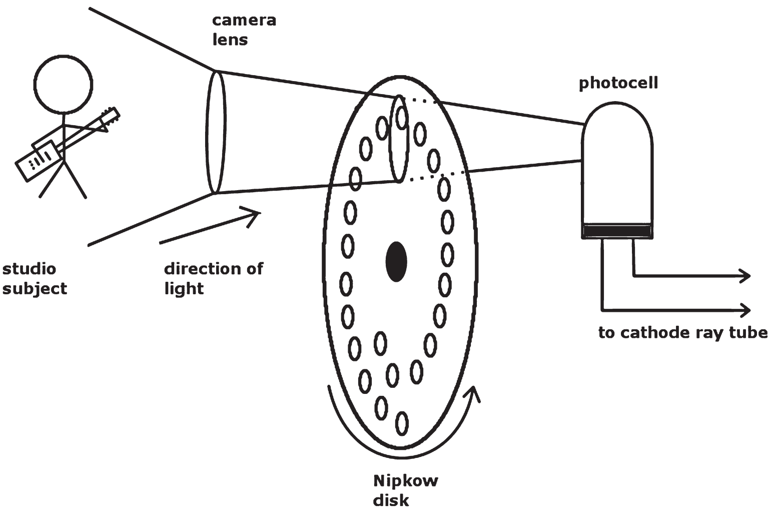


Figure 7.1. Schematic drawing of the Nipkow disk.

1920s, John Logie Baird in England developed a workable television system using the Nipkow disk. Baird's 1923 system, which was partly mechanical and partly electronic (since it used photocells and other electron tubes), provided only a crude image, constructed as it was of just eight scanning lines, each divided into 50 pixels.[24]

Baird was skillful at publicizing his work and in obtaining financial support for it. By late 1929 he had improved the system enough—there were now 30 scanning lines—to gain BBC approval to begin experimental broadcasts. Public interest was high and Baird sold many receivers.[25] There were other people also working on mechanical television systems. Herbert Ives, who, as mentioned above, demonstrated a much improved telephotography system in 1925, developed a wired television system in 1927.

Another line of work, as gradually became clear, had greater potential. In 1908 in Great Britain, A.A. Campbell Swinton had proposed an entirely electronic system of television, which used cathode-ray tubes for both transmitter and receiver. Though Campbell Swinton did not actually build the system, his proposal inspired most of the television inventions of the 1920s and 1930s.[26] The most important of many workers in this line was the Russian-born engineer Vladimir Zworykin.

Zworykin was educated at the military academy of St. Petersburg. In 1911, an outstanding professor at the academy, Boris Rozing, invited Zworykin, who was his student, to assist him in developing what Rozing called "electrical telescopy". Rozing had been working on it since 1902, and when Zworykin entered his

[24] Inglis, pp. 162–163.

[25] Inglis, p. 163.

[26] Abramson, p. 38.

laboratory in 1911 he saw Ferdinand Braun's cathode-ray tube in various modified forms. That same year Rozing was able to demonstrate in his laboratory the transmission of crude images. Zworykin's main task was to build better photoelectric cells, but achieved little success before his graduation in 1912.[27]

For the next decade other matters, including wartime service in the Czar's signal service and emigration from Revolution-torn Russia to the U.S., occupied Zworykin's attention, but in 1923, as an engineer in the Westinghouse research laboratory in East Pittsburgh, he got the opportunity to return to the quest to develop a practical television system. His plan was to use cathode-ray tubes for both transmitter and receiver. A satisfactory receiving tube could be built with known techniques; Zworykin used both electromagnets and electrically charged plates (that is, electromagnetic and electrostatic deflection) to move the electron beam appropriately across the fluorescent screen. A satisfactory television camera was much more difficult.[28]

Over the next several years, Zworykin labored at designing and building a television camera. In late 1928, he spent two months in Europe visiting French and German laboratories engaged in television development, and he brought back with him from France a picture tube that Fernand Holweck and Pierre Chevallier had developed. This tube relied on electric fields to obtain a tightly focussed electron beam; until then electromagnetic focusing and gas focusing (relying on ions created in a gas-filled tube) had seemed more promising. Retaining the principle of electrostatic focusing, Zworykin made major changes to the Holweck-Chevallier tube to obtain what became the predecessor of all subsequent picture tubes, to which he gave the name "Kinescope".[29]

In January 1929 Zworykin met in New York City with David Sarnoff, executive vice president of RCA. At the time RCA, General Electric, and Westinghouse were closely tied (as explained in Chapter 4), and all radio and television research conducted by GE and Westinghouse was on behalf of RCA. Sarnoff wished to put RCA in the forefront of television development, and Zworykin had little difficulty convincing him to support a project—estimated to cost $100,000 and to last two years—to produce a workable television system.[30]

The project took much longer and cost much more than estimated. Zworykin and his co-workers completed an improved camera tube, the iconoscope, in 1932. Two years later came the image iconoscope, a further improvement resulting partly from collaboration with engineers from Telefunken, RCA's German licensee.[31] (The first extensive use of Zworykin's image iconoscope was at the Berlin Olympics.)[32] In 1932, the RCA engineer Randall C. Ballard invented interlaced scanning (alternately scanning the odd-numbered lines and the even-numbered lines), which made

[27] Abramson 1995, pp. 12–17.

[28] Abramson 1995, pp. 44–45.

[29] Abramson 1995, pp. 71–78.

[30] Abramson 1995, pp. 70–77.

[31] Inglis, pp. 170–172.

[32] Braun, p. 162.

it possible to reduce the frame rate without causing flicker (hence to decrease the bandwidth requirement).[33] These and other advances prompted Sarnoff to announce in 1935 a million dollar development effort to introduce TV broadcasting, and test transmissions began that same year.[34]

In England, Electric & Musical Industries (EMI), with the cooperation of the Marconi Company, developed an all-electronic system (405 scanning lines composed the picture and the frame rate was 25 per second). In competitive tests against Baird's system, BBC found EMI's far superior and on 13 February 1937 ceased using Baird's.[35] The Emitron, a device quite similar to Zworykin's iconoscope, was developed independently by engineers at EMI. Perhaps the most outstanding of the EMI engineers was Isaac Shoenberg, another Russian refugee and former student of Rozing.[36] In other countries, notably Germany and France, television underwent impressive development. In Japan, Kenjiro Takayanagi demonstrated a television system as early as May 1928; it could show recognizable faces on a screen of 40 lines at 14 frames per second.[37]

In the mid-1930s there were still obstacles to successful commercialization of television: lack of detail in pictures, the high cost of receivers, the high cost of replacement tubes, the short range of transmitters, and the difficulty of connecting stations for network operation.[38] Particularly worrying was the question of how broadcasters would ever acquire or produce enough programming. It was pointed out that in 1934, the 300 feature films produced that year would fill only some 350 hours of TV time, and all the new plays shown on New York stages would fill only another 300 hours, yet a station would want to broadcast 5000 hours a year.[39]

It is true that in several countries television became a hobby for many people, reminiscent of the radio hobby in the years just after World War I. *Electronics* magazine reported in 1931 that Boston had an experimental station broadcasting to amateurs, who assembled their sets from parts bought in Kresge five-and-ten-cents stores; it reported also that New York City had four such stations.[40] Of course, like the earlier radio enthusiasts, these hobbists were not principally interested in what programming they were receiving.

Several European countries did begin regular broadcasting in the mid-1930s. In 1934, the Reichs Rundfunk began using a mobile television unit to record events each day for broadcasting on the evening news program ("Spiegel des Tages"). In

[33] Inglis, p. 160.

[34] Inglis, p. 176.

[35] Inglis, pp. 163–164. The British 405-line standard survived almost 50 years: in the 1960s when Britain adopted the 625-line European standard, British broadcasters duplicated many programs in the 405-line standard for the sake of viewers with older receivers, and they continued this practice until January 1985 [Fox].

[36] Braun, p. 162.

[37] Abramson 1995, p. 67.

[38] Henney, p. 23.

[39] Editors, p. 29.

[40] Editors, pp. 28–29.

England regular broadcasting began in 1936, and in 1937, 50,000 people in the London area saw the coronation of George VI on television, broadcast from Alexander Palace. In the U.S., the FCC was slow to approve anything but experimental broadcasting, an attitude that may be partly explained by the reluctance of the radio industry to allow television to disturb its lucrative broadcasting business.[41] Finally in 1939 the FCC allowed RCA to begin regular TV broadcasting. TV receivers were sold for $625 (one could then buy a new car for $900).[42] Sarnoff had predicted that from 20,000 to 40,000 receivers would be sold the first year in New York; only 800 were sold. There was considerable disagreement about technical standards within the industry, and agreement was not reached until 1941. U.S. entry into the war later that year meant, however, that commercial broadcasting did not begin on a large scale until five or six years later.[43]

7.1.4 Convenient Recording of Sound: Magnetic Recording

The first magnetic recorder was invented in 1898 by the Danish engineer Valdemar Poulsen, who was mentioned in Chapter 1 as the inventor of the arc transmitter. The operating principle was the same as that found in modern tape recorders: a microphone converts sound waves to an electrical signal, which, by means of an electromagnetic, controls the magnetization of a wire or steel tape (Poulsen used both); in playback the varying magnetization of the wire or tape generates, at the reading head, a varying electrical signal, which an earphone converts back to sound waves. Poulsen commercialized his invention as the Telegraphone, and it did find some use as a dictating machine, but the lack of a means of amplification and other difficulties limited its usefulness.[44]

In Germany in the 1920s several firms produced improved wire-recorders that used the electron tube for amplification. Magnetic recording was developed—as were phonograph and optical sound-on-film methods—for adding sound to motion pictures, but its principal applications were for dictating and telephone recording machines. Such machines came into wide use in many European countries in the 1930s. In the same period radio stations in Germany and Britain began using magnetic recording as a convenient way to record material for later or repeated broadcast. (The alternative, the transcription phonographs, were both awkward and expensive to use.)[45]

Wire was not an ideal recording medium; for reasonable sound quality, the wire had to move past the writing or reading head at high speed, and the wire often broke or became tangled. Steel tape had similar problems and also was quite expensive. People therefore sought alternatives, such as metal discs or cylinders or metal-coated

[41] Editors, p. 29.

[42] Editors, p. 29.

[43] Inglis, pp. 182–185.

[44] Read and Welch, p. 158.

[45] Morton, pp. 263–272.

paper surfaces. Collaboration between Allgemeine Elektricitäts-Gesellschaft (AEG) and the chemical company I.G. Farben produced a better medium: a tape of vinyl acetate covered with a layer of iron oxide. German engineers made other vital improvements, notably a shifting of the audio signal to a much higher frequency (where the magnetic material displays a more nearly linear response).[46] (This technique, called electrical bias, had been patented in the U.S. in the 1920s, but it was not then put into practice, nor was it known to the German engineers.)

The resulting product, the AEG Magnetophone, was presented to the public in 1935. It used the coated plastic tape, electron tube amplification, three electric motors (for the supply reel, for driving the tape, and for the take-up reel), and a forced-air cooling system for the motors. There were separate erasing, recording, and playing heads mounted together in a rigid, removable housing (making it possible to replace one head without losing the necessary, exact alignment with the others).[47]

AEG soon offered several different Magnetophone models, and they were quickly put to various uses, including office dictation, telephone recording, radio broadcasting, and military communications. One model even offered stereophonic recording.[48] By contrast, stereo phonographs were not commercially available anywhere until well after World War II, though patents for two-channel phonograph recording go back to the 1920s, and essentially the modern system was proposed was in the 1930s (by Alan Blumlein of EMI in England).[49]

7.1.5 Avoidance of Static: FM Radio

From the first days of wireless transmissions, engineers were bothered by the hissing, clicks, and grinding noises caused by atmospheric electricity. Many radio pioneers, including Marconi and de Forest, made great efforts to reduce this so-called "static". They did achieve some success, particularly with innovative antennas, but it was so modest in view of the efforts expended that most people considered the difficulty irremediable. Most engineers thought that static was simply a fact of life.

One who did not was Edwin Howard Armstrong. As discussed in Chapters 1 and 4, he was radio engineer who invented the regenerative receiver (which was the first to use the electron tube in a powerful way) and the superheterodyne receiver (which became the standard receiver and remains so to this day). These inventions already to his credit, in 1922 he commented, "The biggest problem that I can see is the elimination of static. This is a terrific problem. It is the only one I ever encountered that, approached from any direction, always seems to be a stone wall."[50] Yet he persisted, and a decade later achieved success with his system of wideband frequency-modulation radio.

[46] Millard, pp. 195–197.

[47] Morton, pp. 277–279.

[48] Morton, p. 279.

[49] Bachman 1962.

[50] Quoted in Lessing, p. 195.

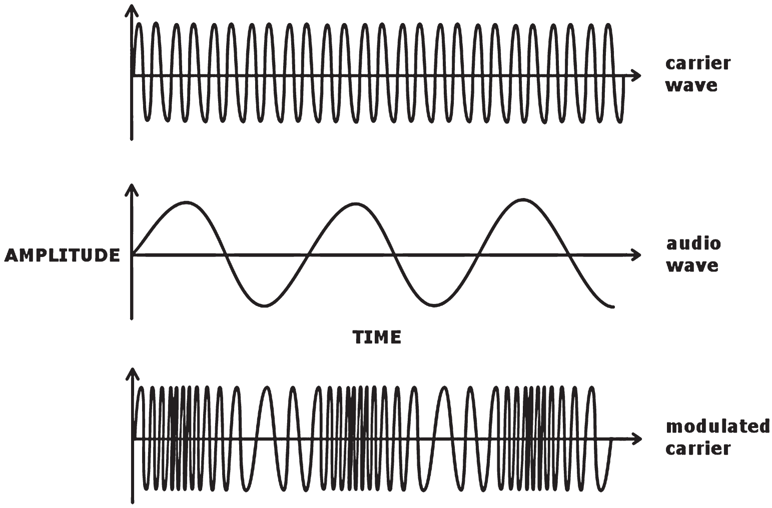


Figure 7.2. Depiction of, at the top, a radio-frequency carrier wave, in the middle, an audio signal, and, at the bottom, the frequency modulation of the carrier wave.

Frequency modulation is a different way of impressing an audio signal on a radio-frequency carrier wave. In the usual technique, known as amplitude modulation (AM), the amplitude of the carrier wave is regulated by the amplitude of the audio signal. (See Figure 7.2.) With frequency modulation (FM) the audio signal alters instead the frequency of the carrier, shifting it down or up to mirror the changes in amplitude of the audio wave.

Some engineers had had shown an interest in frequency modulation well before 1920. Most of them hoped that FM would allow an increase in the number of non-interfering stations by reducing the bandwidth required to transmit an audio signal. In a 1922 paper the engineer John R. Carson showed mathematically that FM would in fact require greater bandwidth than AM. This convinced Carson and almost all other engineers that developing an FM system was not worthwhile.[51]

In 1928 Armstrong turned to FM for a different reason: to solve the problem of static. He had already tried a transmitting system that sent out waves in two slightly different frequencies and many other schemes to avoid static—"more will-o-the-wisps than I ever thought could exist" as he put it.[52] He soon found it necessary to use a much broader bandwidth than AM stations used (today an FM radio channel occupies 200 kHz, 20 times the bandwidth of an AM channel), but doing so gave not only relative freedom from static but also much higher sound fidelity than AM radio offered.

In 1933, Armstrong obtained four patents for his FM techniques and set about gaining the support of RCA for his new system. RCA engineers were impressed, but the sales and legal departments saw FM as a threat to RCA's corporate position.

[51] Millman, p. 8.

[52] Quoted in Lessing, p. 196.

David Sarnoff, the head of RCA, had already decided to promote television vigorously and believed the company did not have the resources to develop a new radio medium at the same time.[53] Moreover, in the economically distressed 1930s, better sound quality was regarded as a luxury, so there was not thought to be a large market for products offering it. (For the same reason, the phonograph industry showed little interest in the 1930s in making stereo records.)[54]

Armstrong did gain some support from General Electric and Zenith, but it was largely on his own that he carried out the development and field testing of a practical broadcasting system. He gradually gained the interest of engineers, broadcasters, and radio listeners, and in 1939, FM broadcasts were coming from 20 or so experimental stations. These stations could not, according to FCC rules, sell advertising or derive income in any other way from broadcasting, but finally in 1940 the FCC decided to authorize commercial FM broadcasting, allocating the region of the spectrum from 42 to 50 MHz to 40 FM channels.[55] In October of that year it granted permits for 15 stations; the first to begin operation was WSM-FM in Nashville, Tennessee.[56] Zenith and other manufacturers marketed FM receivers, and by the end of 1941 nearly 400,000 sets had been sold.[57]

U.S. entry into the war brought a halt both to the granting of licenses for FM stations and to the production of FM receivers. After the war FM broadcasting was dealt a severe blow when the FCC made one of its most unpopular decisions, moving the FM spectrum allocation (to the range from 88 to 108 MHz) and thus making obsolete the 400,000 receivers as well as the transmitters of dozens of broadcasters. This allocation, however, allowed for two-and-a-half times as many channels, and the FM industry slowly recovered, though it did not enjoy rapid growth until the late 1950s.[58] In the late 1970s, FM broadcasting surpassed AM in share of the radio audience, and in the late 1980s, its share had grown to three times that of AM broadcasting.[59]

7.2 TELEPHONE TECHNOLOGIES AND SERVICES

7.2.1 Providers of Telephone Service

In the interwar period the largest and most complex machine in the world was the Bell telephone system. The telephone sets, transmission lines, and switching stations that extended over most of the inhabited areas of the United States were all physically connected. Attending to this spawling machine were hundreds of thousands of Bell employees, but its actions were entirely directed by the millions of users. The

[53] Inglis, pp. 121–123.

[54] Henney, p. 24.

[55] Inglis, pp. 124–127.

[56] Oslin, p. 288.

[57] Inglis, p. 129.

[58] Inglis, pp. 129–136, 140–142.

[59] Inglis, p. 144.

machine ran day and night, seven days a week. Every year many changes were made to improve its operation, yet it never stopped functioning. And—remarkable in an age given to celebrating technological achievements—it was almost taken for granted.

Long-distance telephone service, it is true, attracted attention. In the 1920s people were accustomed to being able to reach others in their region of the country by telephone, but calls across a thousand miles or more were exceptional. Even then, the usual means to communicate rapidly over such distances was the telegraph. Transcontinental calls became possible in 1915, as we saw earlier, but a three minute conversation between New York and San Francisco then cost more than $20. In 1945 the price had fallen to $2.50. Transatlantic telephony, as we will see below, became possible in 1927, but a call from New York to London then cost $75. In 1945 the price had fallen to $12.[60]

The cost of basic service declined too, and the telephone companies, most of whose early customers were businesses, eagerly sought to increase the number of private customers. (Similarly, a few decades earlier, electric utilities, which first served mainly companies, sought the business of residences in order to expand and better balance their provision of power.) In 1920, 35% of U.S. households had telephones. The percentage increased to 42 in 1929, but, because of the Depression, fell to 31% in 1933. By the end of the decade the loss was made up, and the 1940s saw rapid growth, with the percentage of homes having telephones reaching 62 in 1950.[61]

Deciding that the telephone system was a "natural monopoly", Congress in 1921 allowed the Interstate Communications Commission to waive antitrust limitations on the purchase of telephone companies, and in the next 13 years AT&T bought 223 formerly independent companies. In 1930, AT&T owned 80% of all telephones in the country, and most all of the remaining 20% were connected to the Bell system.[62] (From 1913 on AT&T offered interconnection to any independent telephone company that wanted it.) In 1929, AT&T's gross revenues exceeded one billion dollars; this was the first time any corporation reached that level.[63] In 1939 the assets of the company totaled approximately $5 billion; this was then the largest aggregation of capital controlled by a single company in the history of private enterprise.[64]

AT&T's growth came from advances on many fronts. The use of the electron tube as an amplifier not only made possible transcontinental service, but also allowed, through carrier telephony (discussed below), many conversations to be carried over a single pair of wires. The electronic amplifier, along with improved inductive loading, made it possible to use much finer wire (No. 19 gauge) than the previous standard (No. 6 gauge); as a result the amount of copper used per mile of wire could

[60] Lubar, p. 134.

[61] Fischer, p. 53.

[62] Fischer, pp. 50–51.

[63] Brooks, p. 177.

[64] Brooks, p. 205.

be 1/13 the amount used earlier.[65] In the five year period beginning in 1925 total capacity of the Bell system increased 150%, the number of electron tubes in use increasing from 7500 to 80,000.[66] Just four years later there were 350,000 amplifying tubes in the Bell system.[67] The increase in capacity greatly reduced operating costs per call; further savings resulted from improvements in techniques of metering and billing for long-distance calls.

AT&T service improved in many respects. Partly through better amplifiers, a greater range of the frequencies occurring in speech was transmitted: the bandwidth objective, which was 2300 Hz in the early 1920s, increased to 2800 Hz in 1924 and then to 3500 Hz in 1932.[68] Measures were taken to avoid crosstalk. (Crosstalk is an unwanted signal in one channel caused by the signal in another channel.) Conversations became clearer through the use of sidetone-reduction circuits that were incorporated into telephone sets in the interwar years.[69] (Sidetone is the acoustic output of a telephone set due to acoustic input to the same set.) Echo suppressors were developed in the early 1920s.[70] And, through cooperation between the Bell System and the National Electric Light Association, noise on telephone circuits caused by power lines was greatly reduced.[71]

The appearance of telephones changed considerably. A desk telephone formerly consisted of a stand with transmitter and receiver on the desk top and a box (containing ringer and speech circuit) on a nearby wall or the side of the desk. In the late 1930s better design and smaller components permitted "combined sets" (see Figure 7.3).[72] More striking was the gradual appearance of telephones with dials, associated with the introduction of automatic switching, which is discussed below. The modern dial number and letter arrangement was first used in Omaha, Nebraska phone system in 1921, and by 1930 dial telephones made up about one-quarter of all Bell telephones.[73] Equally striking was the introduction of the "French phone" or telephone handset.

The development of the handset in the years after World War I illustrates two important additions to engineering practice: the study of relevant human factors and the theoretical approach to engineering design. Until the 1920s telephones in the U.S. had separate transmitters (usually mounted on a wall or deskstand) and receivers (usually handheld). The idea of placing transmitter and receiver in a single unit that could be held in one hand was an old one, but had not been adopted by the Bell System because of technical problems (notably variation in the performance of

[65] O'Neill, pp. 7–8.

[66] O'Neill, p. 11.

[67] Braun, p. 150.

[68] O'Neill, p. 12.

[69] Fagen, pp. 103–108.

[70] Fagen, p. 273.

[71] Fagen, pp. 335–337.

[72] Fagen, p. 127.

[73] Fischer, p. 52.

Figure 7.3. Desk telephone having separate transmitter and receiver (photo courtesy of AT&T Archives and History Center).

the transmitter when its position was changed and acoustic feedback between transmitter and receiver). The technical problems were of less import in Europe, where telephone lines were generally much shorter than in the U.S., and the handset, or "French phone" as it was known, was widely used.[74]

In 1918 it appeared these problems could be overcome, and the Bell System undertook to develop a satisfactory handset. Engineers determined its shape using 4000 measurements of head dimensions, which were taken from a sample of adults representative of the U.S. population. Chapter 4 showed how the performance of radio receivers came to be understood and evaluated quantitatively. Similar advances in scientific understanding of a telephone transmitter made it possible to move beyond "cut-and-try" engineering to the quantitative evaluation of alternative designs without building them.[75]

Telephone companies sought to provide new services. As early as 1927 AT&T demonstrated a picture phone, something also developed in Germany.[76] In some places one could call to hear recordings of the weather forecast or of crop prices. Beginning in 1933 French telephone users could call an automatic time service. As mentioned in Chapter 4, telephone companies provided special lines (conveying a broader range of frequencies) between radio stations for the sharing of programming, and this became an important business for AT&T.

[74] Fagen, pp. 138–140.

[75] Fagen, pp. 142–153.

[76] Lubar, p. 134, and Kraus, p. 52.

7.2.2 The Negative-Feedback Amplifier

Positive feedback in an amplifier (sending some of the output back to the input in order to get greater amplification) makes immediate sense; we saw in Chapter 4 that this was the basis of Edwin Armstrong's regenerative receiver. By contrast, negative feedback in an amplifier (sending some of the output back to the input in negative phase so as to cancel some of the input) seems a stupid thing to do. Yet the negative-feedback amplifier was unquestionably one of the greatest achievements of twentieth-century technology and is now found in most types of communication or control systems.

At the turn of the century long-distance telephony was restricted by distortion—unwanted change of the signal waveform—caused by the telephone line. Inductive loading significantly reduced distortion and thus extended the range of telephony. But to call across the continent required signal amplifiers. After many unsuccessful designs, the electron-tube amplifier, as we have seen, solved the problem. But the use of amplifiers again made distortion a problem, because the repeaters were non-uniform in amplifying different frequencies, generated noise themselves, and—the worst problem—introduced harmonics of the frequencies present. The distortion became unacceptable when a signal passed through many repeaters or when multiple signals passed through the same line simultaneously (as with the carrier systems discussed below). The solution came in the form of the counterintuitive device—when first proposed, inductive loading, too, was counterintuitive—known as the negative-feedback amplifier.[77]

The engineer most responsible for the adoption of negative feedback was Harold S. Black. On the morning of 2 August 1927 this Bell Labs engineer was on his way to work in New York City, crossing the Hudson River aboard the Lackawanna Ferry and reading the newspaper. The lead stories that morning had not held his attention long, and he was again pondering. When Black began studying amplifier distortion in 1921, he—like others—hoped to solve the problem by designing electron tubes that would amplify linearly. However, Black—like the others—could make only slight progress.[78]

In 1923, just after hearing an inspiring lecture by the famous GE engineer Charles Steinmetz, Black adopted a new approach: not to prevent the amplifier tube from causing distortion, but to accept the distortion and somehow reduce it at the output. His first embodiment of this idea, the feedforward amplifier, did not work well in telephone systems of the 1920s, though it did find use with microwave radio in the 1970s. It was on that August morning four years later that Black had the idea, which came to him "in a flash", of the negative-feedback amplifier: one could greatly reduce distortion by returning part of the output signal to the input in the negative phase. He soon calculated that he could avoid self-oscillation with such a circuit and, within a few weeks, had built a working model.[79]

[77] Black, and Kline.

[78] Black.

[79] Black, and Kline.

Black found that the negative-feedback amplifier not only reduced distortion, but also stabilized the amplifier (that is, made its performance constant over time). Others at Bell Labs, especially Harry Nyquist and Hendrik Bode, contributed to the development and acceptance of the device. Nyquist found the conditions under which feedback circuits are stable (the allowable range of gain and phase shift expressible in terms of what is now called the Nyquist criterion) and invented the widely used Nyquist diagram, a graphical test for stability.[80] Bode developed design methods for stable amplifiers.

The negative-feedback amplifier had a greater bandwidth than other amplifiers, so more speech channels could be carried on a single telephone line (as explained below). It also helped eliminate the problem of cross-modulation—the signal in one channel influencing another channel—in multiple-signal lines.[81] Negative feedback came to be used in almost all types of amplifiers for both communications and control. For example, in the mid-1930s the recording and reproduction of music in phonographs began to make use of negative feedback, resulting in much improved sound quality.[82] In 1957 Mervin Kelly, director of Bell Labs, declared that Black's invention of the negative-feedback amplifier "ranks … with De Forest's invention of the audion as one of the two inventions of broadest scope and significance in electronics and communications of the past 50 years. …"[83]

7.2.3 Increased Transmission Capacity

The electronic amplifier solved the distance problem, but the cost problem prevented widespread use of long-distance telephony—in 1915, a three-minute call from New York to San Francisco cost $22.20. A solution was found in a vast increase in transmission capacity.

In 1920, a telephone call was, in most cases, carried on a pair of wires suspended about 12 inches apart on insulators on the crossarm of a telephone pole. The crossarm might support five pairs of wire, and the pole might bear half a dozen crossarms. Just after the turn of the century engineers devised a way to use each pair of two wire circuits for a third circuit (a "phantom circuit"), thus increasing capacity 50% without stringing more wire.[84]

These so-called open-wire lines were sometimes replaced, especially in urban areas, by cables; wire-pairs of much finer gauge were bundled in a protective sheath. The loss of signal strength was much greater (about 25 times as great, both from increased resistance of the finer wires and increased capacitance between wires), but was tolerable, especially as improved amplifiers became available. Cable, preferable everywhere for its relative immunity to weather conditions, had to be used in urban

[80] Editors of *Electronics*, p. 8.

[81] Editors of *Electronics*, p. 30.

[82] Bachman 1962.

[83] Quoted in Black, p. 59.

[84] Fagen, pp. 236–238, and O'Neill, p. 4.

areas because there the growth of the telephone system made open-wire systems quite impractical.[85]

By far the most important way of increasing transmission capacity was the introduction of carrier telephony, which allowed many telephone signals to be sent over the same line. The technique, also known as frequency-division multiplexing, is analogous to the simultaneous broadcasting of numerous radio programs; each signal is carried within a particular bandwidth not encroached on by other signals. Electron tubes and wave filters made the technique possible. Electron tubes were used as oscillators (to generate the carrier waves), as modulators (to impress the audio signal on the carrier), as amplifiers, and as demodulators. Also vital were wave filters, circuits that passed only the frequencies within a specified range. George A. Campbell of AT&T deserves much of the credit for the development of wave filters.[86]

AT&T introduced carrier systems as early as 1918 and 1920 (Types A and B), but the first system to be widely adopted was introduced in 1924 (Type C). On a single pair of wires, three two-way voice channels were carried at frequencies (in the 5 to 30 kHz range) above the voice frequencies, thus quadrupling capacity.[87] Continued improvements to carrier systems were made possible by the negative-feedback amplifier and by new electron tubes for use with higher frequencies (to 100 MHz and above).[88] (As the bandwidth of the medium increased, many more telephone signals could be carried, even allowing for some increase in the bandwidth of the latter.) Carrier telephony illustrates a more general trend toward convergence of techniques of wire and wireless communications.[89]

Another means of increasing transmission capacity was the introduction of coaxial cable. A coaxial cable is a sheaf of coaxial lines, each of which consists of a wire surrounded by an insulator within a conducting tube (see Figure 7.4). Because a coaxial line has lower attenuation and much greater capacity than a pair of wires, engineers of the 1930s developed the medium for broadband telephony. AT&T began using coaxial links in 1936, and five years later put into service a standardized coaxial system (Type L1) having a capacity of 480 telephone circuits or one television picture signal.[90] In 1940 a coaxial cable carried the television signal of the Republican National Convention (which nominated Wendell Willkie to run against Roosevelt) in Philadelphia to New York City for broadcasting there.[91]

For long-distance telephony, wire transmission is much more efficient than wireless (requiring milliwatts rather than hundreds of kilowatts), yet may not be practical.[92] We saw earlier that radio telephony was developed for communication

[85] O'Neill, pp. 6–7.

[86] Fagen, pp. 279–280.

[87] O'Neill, pp. 5–6.

[88] O'Neill, p. 2.

[89] Coggeshall 1962.

[90] O'Neill, p. 2.

[91] Brooks, p. 203.

[92] Fagen, p. 363.

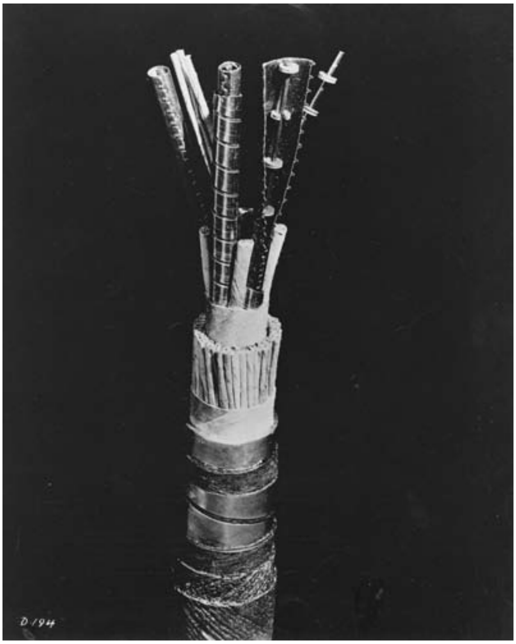


Figure 7.4. Coaxial cable (photo courtesy of AT&T Archives and History Center).

with ships, planes, and automobiles (and as early as 1916 wireless connection to the wire telephone network began to be possible).[93] In addition, because of the great technical challenges and costs of submarine telephone cables, radio telephony was developed for communication across large bodies of water.

As early as 1920, a wireless link across water became part of the regular telephone network when Catalina Island was thus connected with mainland California (though three years later two submarine cables took over the service).[94] The main goal for radio-telephone engineers, however, was regular service across the Atlantic. The technical advances that made this possible were the development of higher-power transmitting tubes, of more efficient means of sending the signal (notably the single-sideband, carrier-suppressed technique), and of techniques for noise reduction (as the use of the Beverage wave antenna).[95] In the early 1920s, it appeared that low frequencies (below 100 kHz) were the only part of the spectrum suitable. Public radiophone service, operating at 60 kHz, began on 7 January 1927, a three-minute call from the U.S. to England costing $75.[96]

It soon appeared that higher frequencies (in the range 5 to 25 MHz) were also practical and such links began supplementing the low-frequency links in 1929.[97] In

[93] Fagen, p. 370.

[94] Fagen, pp. 387, 391.

[95] Fagen, pp. 393–400.

[96] Fagen, pp. 391–393, 401, and O’Neill, pp. 1–3.

[97] O’Neill, pp. 1–3.

1930 a connection between New York and Buenos Aires went into service, and many more transoceanic links followed.[98] In 1937, just a decade after transoceanic telephony began, someone in the United States could reach 68 other countries and 93% of the world's telephones.[99] The high-frequency links proved more effective—there was less static and antenna directivity could be greater with the shorter wavelengths—and because demand for overseas circuits grew rapidly they were also favored because more bandwidth was available at high frequencies.[100] These links became standard and continued in use until the 1950s and 1960s when submarine cables and satellite links gradually replaced them.[101]

The frequencies employed reached as high as the microwave range (roughly 1000 MHz and up, corresponding to wavelengths 30 cm and below). In 1931, André Clavier of Le Matériel Téléphonique in Paris used a transmitting tube he had designed (a version of the Barkhausen positive-grid oscillator) to demonstrate microwave (18 cm) transmission across the English Channel, and two years later he set up a commercial microwave link there.[102] Britain inaugurated a microwave link for telephone and teleprinter service in 1934.[103]

All communications circuits have some level of noise (unwanted disturbances to the signal). Engineers gradually uncovered various causes of noise. Extremely important was the work of Walter Schottky at Siemens and Halske at about the time of World War I. He identified two sources of noise in electron tubes: thermal noise, caused by the heat motion of the molecules, and the shot effect, caused by the randomness of electron emission from the cathode.[104] Carrying Schottky's work further, J.B. Johnson and Harry Nyquist—AT&T engineers who were both natives of Sweden—identified and quantified a basic physical limit to amplification imposed by thermal noise.[105] Many others, too, contributed to the scientific understanding and engineering avoidance of noise.

7.2.4 Automatic Switching

Stringing a direct line between every pair of telephone users was quite impractical, so telephone connections, from the earliest days, were made through one or more centralized switching stations. At the time of World War I most switching was done manually at plug-and-jack switchboards. A local telephone call might proceed as follows, as recalled by Ben Hall: you "lifted the receiver and waited for the operator to say "Number, plee-yuz." You replied: "Three eight oh nine." The operator said:

98 Fagen, p. 410.
99 Fagen, p. 422.
100 Fagen, pp. 408, 422.
101 O'Neill, pp. 1–3.
102 Finn 1967.
103 Rigge.
104 Fagen, p. 910.
105 O'Neill, p. 12.

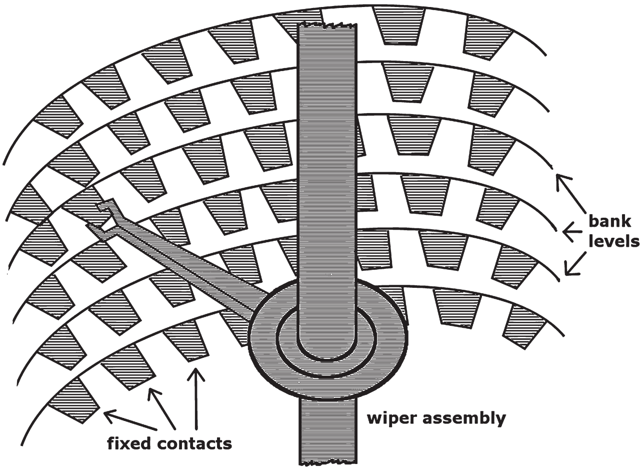


Figure 7.5. Schematic drawing of a Strowger switch.

"Thurree aye-yet oh niner. … Sorry the lion is busy." You said, "Thank you," and waited a decent interval before trying again. As soon as the lion was free, you got your connection."[106]

An operator at such a switchboard typically monitored 120 telephone lines, so the number of operators relative to the number of telephones was very high by today's standards—at the time of World War I, about 15 operators for every 1000 telephones.[107] The telephone system continued its rapid growth, requiring more and more operators, and when the war brought many more employment opportunities for women, AT&T management began to fear that they would not be able to staff the switchboards.[108]

More than two decades earlier a Kansas City undertaker, Almon Strowger, had patented an automatic switching device, and many independent telephone companies had adopted improved versions of Strowger's device. (See Figure 7.5.) In 1915, about 4% of telephones in the United States were connected to automatic switches. Strowger's system required the user to enter by "dialing" the number of the telephone he wished to reach. Bell System managers thought customers would object to the added task. Studies found, however, that people preferred dialing a number themselves to making connections through an operator (widespread belief that operators sometimes listened in on calls no doubt being a contributing factor to this preference).[109]

Not long after the war Bell engineers began installing automatic switches; in 1921 the office in Omaha, Nebraska became the first Bell office with fully

[106] Hall, p. 28.

[107] Pierce & Noll, p. 164, and Fagen, p. 550.

[108] Lipartito.

[109] Lipartito.

mechanical switching.[110] The movement from manual to automatic switching might have started earlier and might have proceeded much more rapidly than it did, but here, as in almost instances of the adoption of new technology, economic considerations determined the pace. There were, to be sure, formidable technical difficulties at every step of the way.

Rebuilding a ship at sea, plank by plank, would be an apt metaphor for the modernization of the telephone system: any new equipment must be compatible with the old, and changes must be made piecemeal without disrupting overall operation. A better metaphor would be turning the Mayflower into a modern ocean liner, all the while still cruising.

Fitting mechanical switching into a system that used mainly manual switching required many adjustments. In sending a call to an automatic exchange, the operator could dial the number or, what turned out to be more efficient, use a set of push-buttons to make the conversion. In the other direction—from an automatic exchange to a manual exchange—the operator could listen to the sequence of pulses, converting them to digits. This error-prone process was replaced first by a device providing a digital display for the operator, then by a "call announcer", which automatically converted the pulses into speech. The call announcer, introduced by Bell engineers in 1930, used the optical sound-on-film system then being developed for sound movies (with the spoken form of the numerals recorded on separate loops of film).[111]

In the Strowger system, also called the step-by-step system, the switches were under direct control by the users. When the user dialed the digit "four", four pulses were transmitted to a switch, a part of which moved four positions vertically or horizontally. The switch acted only as fast as the digits were dialed, and it was occupied by that user as long as the call lasted. In the first decades of the century, a different type of switching system was conceived. Called "common-control switching", it separated the control of switching from the switches themselves. Using current terminology, one could describe the common-control system as consisting of a collection of lines and switches and a computer, which receives from callers the numbers they wish to reach and decides how to route the calls. Central control of the switches gave the system greater flexibility, as did the ability to change easily the software, that is, the computer's operating instructions. Perhaps most important, the costly control apparatus could be used almost constantly, setting up one call after another, while with the step-by-step system the control was in the switches themselves, so this part of the control apparatus was idle from the moment the connection was made until the end of the call. The common-control system was, in a sense, a return to the earlier plug-and-jack system in that the "brains"—the operators—were separate from the switching network.[112]

The brain of the new system was made up of relays (mechanical switches controlled electrically) and other switches. When a call was initiated, it received the

[110] Fagen, p. 553.

[111] Morton, pp. 126–128.

[112] Pierce & Noll, p. 173.

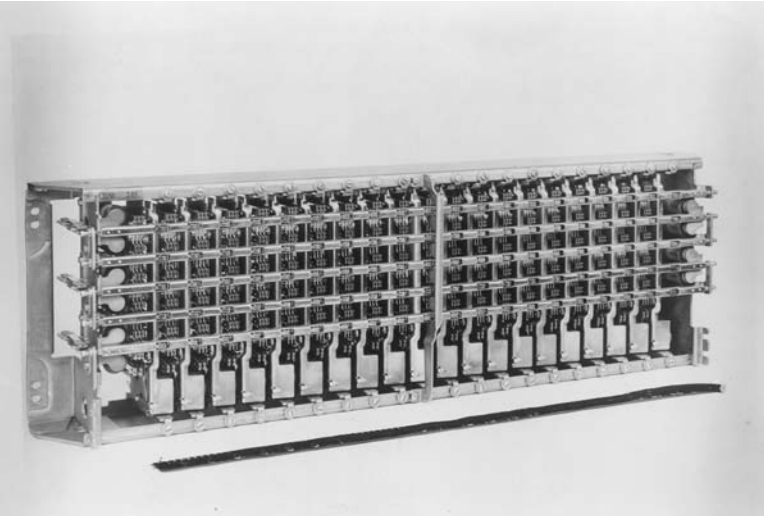


Figure 7.6. The No. 1 Crossbar Switching System (photo courtesy of AT&T Archives and History Center).

dialed number, stored it, searched for an idle transfer trunk, and activated several switches to make a proper connection. Western Electric engineers built a working prototype of such a system in the early 1920s, but it was not until the late 1930s that common control (in the form of the No. 1 Crossbar Switching System) was put into service.[113] (See Figure 7.6.)

Though local calls could be made entirely automatically, long-distance calls required operator intervention. Bell engineers made many improvements in the switching apparatus to reduce the burden on the operators, both to increase the number of calls an operator could handle and to reduce the delay experienced by the user. In 1920, one placed a long-distance call by telling the operator what number at what telephone exchange one wished to reach and then waiting for her to call back. The average time to make a connection was seven minutes in 1920. By the end of the decade, the average set-up time had been reduced to just over a minute, and customers usually stayed on the line while the connection was being made.[114]

As with many other engineering tasks, telephone switching gave rise to a new branch of applied mathematics, called traffic engineering or traffic mathematics. In 1903, the AT&T engineer M.C. Rorty began using probability theory to study problems arising in telephone networks, such as the number of transfer trunks between switching centers required to keep the occurrence of "blocking" (the unavailability of a line) to a very low level.[115] Such studies were carried much further by the Danish telephone engineer A.K. Erlang, whose 1918 publication in a British journal received

[113] Fagen, p. 575, and Pierce & Noll, p. 175.

[114] O'Neill, pp. 4, 12.

[115] Fagen, p. 539.

worldwide attention. Today the fundamental unit of telephone traffic (the Erlang) is named in his honor.[116]

In the Bell System the gradual introduction of automation allowed fewer operators to provide the same service: in 1902 there were 22 operators per thousand telephones; at the time of World War I, 15 operators; at the time of World War II, six or seven operators; and in 1970, just 1.7 operators per thousand telephones. Yet continued growth of the system resulted in increasing employment, from 30,000 operators in 1902, to 166,000 in 1970. Of course, much of the growth resulted from the lower cost of telephone service that the automation made possible.[117]

In any history of electrical technology, telephone switching deserves a place, because it was this task that led eventually to the invention of the transistor. In 1936, Mervin J. Kelly, director of research at Bell Labs, suggested to a young Bell Labs researcher named William Shockley that telephone switching might be done electronically rather than electromechanically. Shockley, after discussions with Walter Brattain, a Bell Labs researcher with interests in solid-state rectifiers, realized in 1939 that what was needed was an alternative to the electron tube (which required too much power and generated too much heat) and hoped to use semiconductors as the material for an alternative device. The research to this end was then set aside for wartime work, but it was not long after its resumption that Brattain and John Bardeen invented the transistor in 1947.[118]

7.2.5 Social Impact of the Telephone

It is almost always difficult to specify the social consequences of a new technology. With the telephone, a device that in many countries has come to be used daily by almost all adults, the difficulty is especially great. The telephone plays a role in almost all spheres of human activity; it usually acts indirectly (as it facilitates other actions); and it frequently contributes to both sides in a clash of opposing social movements. One consequence is unquestioned: a greater integration of human activity (see Figure 7.7).

The telephone has vastly increased the possibilities for personal contact, the communication being one-on-one, two-way, and instantaneous. Yet because the telephone conveys a voice only, some see it as an impersonal instrument that has contributed to the impersonality of modern life.[119] This critique seems less valid when the telephone is used—as it very often is—between people well-known to each through direct contact or when it is used between people so far apart geographically that they would have otherwise have no direct contact. In 1934 H.G. Wells wrote, "I require a pleasant well-lit room in good air … a secretary … and, within reach, an abundant library and the rest of the world all hung accessibly on to that secretary's telephone."[120]

[116] Pierce & Noll, pp. 166–167.

[117] Fagen, p. 550.

[118] Brooks, p. 203.

[119] Fischer, p. 25.

[120] Quoted in Brooks, pp. 200–201.

Figure 7.7. “Weavers of Speech” advertisement (photo courtesy of AT&T Archives and History Center).

Various psychological effects have been postulated. People have argued that the telephone makes its users more alert (increasing interpersonal contacts), or more anxious (threatening an unpleasant call at any moment), or more secure (permitting immediate contact when trouble occurs); that the telephone decreases privacy (putting us within the reach of others at all times), or increases privacy (facilitating one-on-one conversations); that the telephone augments involvement in public life, or diminishes it.[121] Almost everyone would agree that the telephone has made our world busier; the British novelist Norman Douglas has written, “We can hardly realize now the blissful quietude of the pre-telephone epoch.”[122]

The effects on human communities are equally difficult to assess. It is likely, for example, that the telephone contributed to suburbanization by reducing the advantages of central location. Yet the view that the telephone is delocalizing is contradicted by a 1933 study of telephone use which found that people used it principally to strengthen local ties and thus to resist the homogenizing tendencies of the mass media of radio and movies.[123] Some see the increase in extralocal ties as beneficial (allowing friends and family members far apart to converse and encouraging new personal ties), others as detrimental (as a blow to local community, heightening the placelessness of modern life).[124] There is evidence that the fewer contacts people had by other means, the more valued the telephone was; in the U.S. around the time of World War I a higher percentage of farm households had telephones than did

[121] Fischer, pp. 25–26.

[122] Quoted in Brooks, p. 200.

[123] Fischer, p. 25.

[124] Fischer, p. 25.

nonfarm households.[125] Indeed, at one point early in the century, Iowa had the country's greatest per capita access to telephone service.[126]

The importance of the telephone in commerce (discussed in Chapter 5) is unquestioned, but again the specific effects—whether, for example, it has helped large companies more than small—are debatable.

Finally, one might speculate on the political effects of the telephone. As a form of communication controlled by the users, not the government, it may have been a force for democracy.[127] On the other hand, the telephone can be used by the government to eavesdrop on its citizens. Both observations are supported by the example of Germany under Hitler or the Soviet Union under Stalin. Hitler intentionally hindered the growth of the telephone system by imposing heavy taxes, and Stalin opposed rapid development the country's telephone system, which he saw as an instrument for conspiracy and counterrevolution.[128] In the next section we consider further the relationship between electrical technologies and politics.

7.3 TECHNOLOGY, POLITICS, AND GOVERNANCE

7.3.1 Radio and Politics

In late September 1938 Europe teetered on the brink of war. Germany, France, Britain, and Czechoslovakia had ordered mobilizations. In a desperate effort to forestall the catastrophe, the British Prime Minister Neville Chamberlain had flown to Germany to confer with Hitler on 15 September and again on 22 September. There followed a conference in Munich on 29 September, where Hitler, Chamberlain, Mussolini, and the French Premier Édouard Daladier settled the fate of Czechoslovakia, without permitting that country any part in the discussions. Chamberlain returned to England proclaiming "peace for our time."

In these tense days, people in dozens of countries followed the events by radio. Many of the principals, including Hitler and Chamberlain, used radio to address the world. Newscasters in Europe kept listeners informed around-the-clock. Shortwave links across the Atlantic allowed speeches and commentary from Europe to be carried live in the United States, and during these days the commentators H.V. Kaltenborn and Edward R. Murrow suddenly became famous. It is possible that radio, by bringing the world's attention to the crisis, helped avert war, at least for that moment. Anxious to support the peace process, the BBC would not permit broadcasts by the dissenter Winston Churchill, who said, "The idea that you can purchase safety by throwing a small state to the wolves is a fatal delusion."[129]

125 Fischer, p. 93.

126 Pool, p. 300.

127 Fischer, p. 24.

128 Pierce and Noll, p. 2.

129 Czitrom, p. 88; Gunther, pp. xi–xvi; and Manchester, pp. 217–221. Churchill is quoted in Gunther, p. xvi.

Many radio pioneers, including Marconi, had hoped the new medium would promote world peace. The international broadcast of the 1925 presidential address to the League of Nations supported this hope.[130] It is also true that broadcasts, heedless of national borders, probably increased understanding of foreign cultures, and, as we saw in Chapter 4, radio stimulated cooperation between governments. Yet by 1940 everyone recognized that radio had the potential for great political ill as well as good.

Germany at the beginning of the 1930s was a country ripe for demagoguery. Many Germans were still bitter over the harsh terms of the Versailles Treaty that ended the world war. The worldwide economic depression had hit Germany hard: unemployment reached 40% in 1930, and industrial production fell by almost half from 1929 to 1932.[131] Political parties of the center were weak, and political debate had become polarized, many people feeling that the only choice was between National Socialism on the far right and Communism on the far left.[132] National Socialist (Nazi) and Communist gangs battled on the streets.

Among all the politicians in Germany one stood out for his ability to persuade the people: Adolf Hitler. Some years earlier in *Mein Kampf* (a book Hitler composed while in prison following an attempted *coup d'etat* in 1923), he had emphasized that the force of the spoken word was much greater than that of the written word: "The broad masses of the people can be moved only by the power of speech."[133] John Gunther wrote, "[Oratory] is probably the chief external explanation of Hitler's rise. He talked himself to power."[134] William Shirer called Hitler "the most effective orator in Germany, with a magic power, after he took to radio, to sway millions by his voice."[135]

Radio indeed played a large role in Hitler's seizure of dictatorial power and in his continuing hold on the German people. The last free election in Germany in the 1930s was held on 5 March 1933. In the pre-election campaign, the Nazis made great use of the radio (which was government controlled) and allowed other parties almost no use of it.[136] Hitler created a new ministry "for popular enlightenment and propaganda" headed by Joseph Goebbels, which had oversight over the press, radio, the movie industry, the theater, and the music industry.[137] Goebbels made the radio his principal instrument, placing broadcasting stations under Nazi control and using the new medium himself to broadcast speeches, which reportedly combined clarity, humor, and stylistic brilliance.[138]

[130] Briggs 1974.

[131] Shirer, p. 136.

[132] Speer, p. 19.

[133] Quoted in Shirer, p. 25.

[134] Gunther, p. 15.

[135] Shirer, p. 35.

[136] Holborn, p. 723.

[137] Holborn, p. 738.

[138] Koch.

Eugen Hadamovsky, a Nazi theorist and author of "Radio as means of political leadership", was named head of German broadcasting. He said that his task was "to make of broadcasting a sharp and reliable weapon for the government" and that "all that happens in and through broadcasting today happens in order to create so broad a basis for National Socialism among the people that one day the entire nation will be drenched through and through with our philosophy."[139] Goebbels believed—and in William Shirer's view he was correct—that "the radio became by far the regime's most effective means of propaganda."[140]

With control of broadcasting, the Nazis wanted more people to own radios. In 1933 there began production of the People's Radio (Volksempfänger), a simple, inexpensive receiver. Already in August of that year, 100,000 had been sold. Beginning in 1938 an even less expensive model (Deutschen Kleinempfänger) was offered. Between the Nazi takeover and the outbreak of war the number of radio listeners in Germany tripled and the number of radios quadrupled. The Volksempfänger could receive only strong or nearby stations, and as early as September 1933 Germans were forbidden to modify the radio so that it could receive foreign stations.[141]

By order of Goebbels, the Nazi party organized listening groups for radio broadcasts. Radio was used to inform the people about and gain approval of government actions, as with, for example, the take-over of all trade-union offices on 1 May 1933.[142] Goebbels used radio to spread Nazi propaganda to other countries; in 1933 only one German shortwave station broadcast to areas outside Germany. Ten years later there were 130 such stations, broadcasting in 53 languages.[143] The Nazis used radio to help bring about the Anschluss (the German annexation of Austria in 1938) by broadcasting Nazi propaganda across the border.[144] Shirer, who lived in Germany in the 1930s, writes that he was constantly surprised by educated and intelligent people repeating some of the Nazis' outlandish assertions. He writes, "No one who has not lived for years in a totalitarian land can possibly conceive how difficult it is to escape the dread consequences of a regime's calculated and incessant propaganda."[145]

Probably the first government to make radio an instrument of propaganda was the Communist regime in Russia, which before the world war ended was broadcasting the contents of secret treaties to discredit the former regime and the remaining allies. The first Five Year Plan promised 12 million radios by the end of 1933, and already in 1930 Soviet foreign broadcasting took place in 50 different languages and dialects.[146] For example, in Arab countries throughout the interwar period the local Communists were supported by broadcasts from Russia.[147]

[139] Quoted in Briggs 1974.

[140] Shirer, p. 247.

[141] Braun, pp. 157–158, and Koch.

[142] Thompson.

[143] Koch.

[144] Shirer, pp. 279–280.

[145] Shirer, p. 248.

[146] Briggs 1974.

[147] Roberts, p. 753.

Within the Soviet Union, radio play had a much smaller role than in did in Germany. Hitler's ability to attract and hold the loyalty of millions through his personal appeal as a speaker made radio play a very important role in his regime. Stalin's position, by contrast, was primarily a result of his ability to inspire fear through ruthless control of bureaucracies, and radio played only a small role in achieving that.[148] The Communists, nevertheless, took advantage of the radio, as did the Nazis in Germany and the Fascists in Italy, to gain some degree of popular support, especially by justifying harsh actions as necessary in the battle with supposed enemies, external and internal.[149] It was, of course, not only in totalitarian countries that leaders made astute use of radio.

When George V died early in 1936, the prestige of the British monarchy was at its height. Cinema and radio had made him better known to his subjects than any previous king. Especially effective had been his annual Christmas broadcasts.[150] On March first, the new king, Edward VIII, spoke by radio to millions of listeners throughout the Empire. As Prince of Wales, he had long displayed informality, unconventionality, and sympathy for the less privileged, and in the first months of his reign he was enormously popular.[151]

A scandal, however, was brewing. The king was spending much time in the company of an American, Mrs. Wallace Simpson, who later that year filed for divorce from her second husband. Though the British public, because of media self-censorship, knew little of this, in the U.S. it was, in H.L. Mencken's words, "the greatest news story since the Resurrection." By the time the story finally broke in Britain in early December, the Prime Minister Stanley Baldwin had put Edward into the position of having to choose between the throne and Mrs. Simpson. Edward made that choice on December tenth, and the following day his farewell broadcast was heard by millions around the world, including millions in the U.S. John Gunther called it "a masterpiece to which a quarter-century of frustration gave perfect form."[152]

> *At long last I am able to say a few words of my own. … You know the reasons which have impelled me to renounce the throne, but I want you to understand that in making up my mind I did not forget the country or the empire which, as Prince of Wales and lately as King, I have for twenty-five years tried to serve. But you must believe me when I tell you that I have found it impossible to carry the heavy burden of responsibility and to discharge my duties as King as I would wish to do without the help and support of the woman I love. … This was a thing I had to judge entirely for myself. The other person most nearly concerned has tried up to last to persuade me to take a different course. … And now we all have a new King. I wish him and you, his people, happiness and prosperity with all my heart. God bless you all! God save the king!*[153]

148 Bullock, p. 362.

149 Black and Helmreich, p. 312.

150 Cannon and Griffiths, pp. 596–597.

151 Gunther, p. 243.

152 Allen 1939, pp. 198–199, and Gunther, pp. 244–251.

153 Quoted in Gunther, pp. 251–252.

The speech was well received, and phonograph records of it were sold in large numbers, though not in England. There the sale of such records was prohibited, as, in Gunther's words, "the ruling classes, trying desperately to "build up" the Duke of York, did everything possible to bury Edward and his memory at once."[154]

In the U.S. the radio had been important in politics at least as early as the broadcast of Calvin Coolidge's opening address to Congress in 1923. But it was Franklin Roosevelt who turned it into a powerful political instrument. Daniel Boorstin suggests that FDR's infirmity may have been an advantage; earlier public figures had delivered radio addresses from a standing position, while FDR "sat relaxed in his parlor and spoke to citizens individually in their parlors." [155] Though his inauguration and other speeches were also broadcast, it was his so-called "fireside chats" that were most effective.

When Roosevelt assumed office on 4 March 1933, the nation's banking system was breaking down. Two days later he declared a four-day national banking holiday, and on 9 March, Congress approved legislation to meet the emergency. On Sunday evening 12 March, FDR addressed the nation in his first "fireside chat": "My friends, I want to talk for a few minutes with the people of the United States about banking. … I want to tell you what has been done in the last few days, why it was done, and what the next steps are going to be."[156] The address was carried coast-to-coast by the radio networks. He made government actions understandable, gained support for his programs, instilled hope in his listeners, and gained their confidence that the situation would soon improve (a belief that was important if Roosevelt's plans to reopen the banks could occur without further mass withdrawals). Throughout his presidency he continued to reach the people through "fireside chats", always using simple language, concrete examples, and everyday analogies, always speaking quietly, confidently, and uncondescendingly. And though he might be reaching 60 or 70 million people, he seemed to be communicating with each of them individually.[157] Frances Perkins, FDR's Secretary of Labor, described these broadcasts:

> *His voice and his facial expression as he spoke were those of an intimate friend. … his mind was focused [clearly] on the people listening at the other end. As he talked his head would nod and his hands would move in simple, natural, comfortable gestures. His face would smile and light up as though he were actually sitting on the front porch or in the parlor with them.*
>
> *I have sat in those parlors and on those porches myself during some of the speeches, and I have seen men and women gathered around the radio, even those who didn't like him or were opposed to him politically, listening with a pleasant, happy feeling of association and friendship. The exchange between them and him through the medium of radio was very real. I have seen tears come to their eyes as he told of some tragic episode, of the sufferings of the persecuted people in Europe, of the poverty during unemployment, of the sufferings of the homeless, of the sufferings of people whose sons had been killed in the war, and they were tears of sincerity and recognition and sympathy.*

154 Gunther, p. 252.

155 Boorstin, p. 475.

156 Buhite and Levy, pp. 11–12.

157 Buhite and Levy, pp. xvii–xx, and Lewis 1939, pp. 86–89.

> *I have also seen them laugh. When he told how Fala, his little dog, had been kicked around, he spoke with naturalness and simplicity. He was so himself in his relation to the dog, based on the average man's experience of the place of a pet in the home, that the laughter of those gathered around radios of the country was a natural, sincere, and affectionate reaching out to this man. …*[158]

When told of Roosevelt's death, a soldier commented, "America will seem a strange, empty place without his voice talking to the people whenever great events occur."[159]

Another U.S. politician who used radio to great effect was Huey Long, a Louisiana lawyer with a talent for spell-binding oratory. In the early 1930s he gained an enthusiastic following as champion of the underdog and enemy of corporations and the rich. According to Daniel Boorstin, "When he christened himself 'the Kingfish' (after the chief of the lodge in the *Amos 'n' Andy* radio series), he proclaimed himself a product of the radio age. In Louisiana his uninhibited radio personality was driven home to listeners on late-night programs that sometimes lasted four hours."[160] He established control of his state, and then, with Presidential aspirations, he moved onto the national stage. As U.S. Senator he proposed the Long Plan for the Redistribution of Wealth, also known as the Share Our Wealth Plan. It would have heavily taxed all fortunes over one million dollars in order to provide old-age pensions, free education through college, and a guaranteed annual income. He reached the entire country by purchasing time on the NBC radio network, where he used the telephone to augment his audience:

> *Hello friends, this is Huey Long speaking. And I have some important things to tell you. Before I begin I want you to do me a favor. I am going to talk along for four or five minutes, just to keep things going. While I'm doing it I want you to go to the telephone and call up five of your friends, and tell them Huey is on the air.*

Listeners set up Share Our Wealth clubs across the country. He wrote a book called *My First Days in the White House*, his national popularity grew rapidly, and New Deal Democrats became alarmed. Long was assassinated by a lone gunman in September 1935.[161]

Father Coughlin, the Radio Priest, also became a strong political force. According to Wallace Stegner, his distinction was "a voice of such mellow richness, such manly, heart-warming, confidential intimacy, such emotional and ingratiating charm, that anyone tuning past it almost automatically returned to hear it again." He also knew what would please many people, blaming the economic crash on "money-changers", urging expansion of the money supply, warning of Communist and socialist subversion, and denouncing President Hoover and Prohibition. The number of listeners grew rapidly, but so did the number of critics, and in 1933, CBS declined to renew his contract. With donations from the faithful, he bought his own air time and created his own network of stations.

[158] Quoted in Boorstin, p. 475.

[159] Quoted in Buhite and Levy, p. xx.

[160] Boorstin, p. 476.

[161] Boorstin, pp. 476–477, and Carter 1949. Long is quoted in Boorstin, p. 477.

In 1934, Coughlin began denouncing the New Deal and organized labor (recommending that government settle labor disputes by fiat) and praising Huey Long and Benito Mussolini. He argued for "nationalization of banking and currency and of national resources" and for government guarantee of "a living annual wage". In 1934, he had some 45 million listeners and received more mail than anyone in the country, including the President. His program became more popular than *Amos "n" Andy*, and *Fortune* magazine called him "just about the biggest thing that ever happened to radio."[162] He created the National Union for Social Justice, which backed "Liberty Bill" Lemke as a third-party candidate in the 1936 Presidential campaign. But by then Coughlin had alienated many of his listeners by attacking the unions, calling Roosevelt a "great betrayer and liar", becoming increasingly anti-Semitic, and suggesting the use of bullets against "any upstart dictator." His candidate received fewer than a million votes.[163]

During World War II radio became more important than ever. Churchill's speeches were heard around the world, and many of his words—and the *sound* of them—became imprinted in the minds of millions of people: "not to flag or fail", "we shall fight on the beaches, we shall fight on the landing grounds, we shall fight in the fields and in the streets, we shall fight in the hills; we shall never surrender."[164] These words were important to Allied victory. Patriotic songs had long played a role in motivating people to fight or otherwise contribute to a war. Radio made such songs more effective than ever. Kate Smith's 1939 recording of "God Bless America", for example, became a national institution.[165] All of the belligerents recognized that radio could help with the tasks of mobilizing public support for the war, winning sympathy in non-belligerent nations, and undermining the morale of enemy soldiers.

7.3.2 Cinema and Politics

Another medium—besides radio and television—made possible by electrical technology was motion pictures, and they too were turned to political ends.

In Germany in the period before the First World War, the Navy League (Flottenverein) carried on nationwide propaganda (arguing for building up the German navy) by lectures and cinematograph shows. The Nazis made extensive use of film for propaganda. We have already mentioned Leni Riefenstahl, who made two documentaries about the 1936 Olympics. Her earlier *Triumph of the Will* on the 1934 Nuremberg Nazi Party Congress was itself a triumph, both as cinematography and as propaganda. This film secured her position as the leading German filmmaker, as Albert Speer, Hitler's architect, recounted:

[162] Quoted in Manchester, p. 131.

[163] Lewis 1939, p. 152, and Stegner.

[164] Gelernter, p. 18.

[165] Millard, p. 186.

> *The Nazis were by tradition antifeminist and could hardly brook this self-assured woman, the more so since she knew how to bend this man's world to her purposes. Intrigues were launched and slanderous stories carried to Hess, in order to have her ousted. But after the first Party Rally fim, which convinced even the doubters of her skill as a director, these attacks ceased.*[166]

Many films promoted by Goebbels ministry took the direct approach; the anti-Semitic "Jud Süss" and the anti-British "Ohm Krüger" are examples. But Goebbels found that cinema, like radio programming, was more effective if propaganda was combined with light entertainment, and this became the usual style of film propaganda.[167]

After the Communists came to power in Russia, Lenin encouraged the development of a domestic film industry. Like the theater, literature, and the press, it was to be under the control of the state. The Moscow State School of Cinematography was established in 1919, and there were soon schools in other parts of the country. Films were produced with specific objectives, as to show the tyranny of the Czarist regime or the Societ economic development of Ukraine, and sometimes for specific audiences. Technically and artistically, Soviet film, with such directors as Sergei Eisenstein, Vsevolod Pudovkin, and Alexander Dovzhenko, soon reached a high level.[168] A historian of film wrote in 1930, "The Soviet cinema is immensely powerful. Its films carry social and political contents expressed so emotionally and with such a degree of technical perfection that the content may be accepted in the temporary admiration of the method."[169]

The Commissariat of Education, which had jurisdiction over filmmaking, sought to use cinema to increase support for the Communist regime at home and to gain adherents of Communism abroad. Not all films had an overt Communist message; "art films" were produced, perhaps with the intent of winning admiration and demand for Soviet films in general. Many films won worldwide acclaim, including Eisenstein's *Battleship Potemkin* and Pudovkin's *Storm Over Asia*. The Soviet Union was exceptional in the extent of its production of educational films. Covering scientific, geographical, military, medical, and ethnographic subjects, these films aimed at raising the educational level of the people. Films were also frequently made for use in technical instruction of engineers, technicians, and soldiers.[170]

Mussolini's Italy and Franco's Spain were other countries where film was turned to propaganda. Not only authoritarian regimes but anyone in the position to make films could use cinema to influence people's attitudes. Sometimes a particular viewpoint, because it happened to be shared by many filmmakers, gained widespread acceptance. For example, the British attitude toward laborers, and miners in particular, was much influenced by film. Such films as *The Stars Look Down* (1939), which showed how greed put miners' lives at risk, helped to make nationalization

[166] Speer, p. 61.

[167] Koch.

[168] Rotha, pp. 217–223.

[169] Rotha, p. 218.

[170] Rotha, pp. 221–251.

of industry a popular cause and no doubt contributed to the victory of the Labour Party in 1945.[171]

In the U.S., New Dealers used film to promote the National Recovery Administration; the main feature at a movie theater would be preceded by, in the words of Frederick Lewis Allen, "a short picture, accompanied by a voice thrilling with patriotism, telling how America was marching on to prosperity under the slogan 'We do our part.'" And in the California gubernatorial election of 1934, the Hollywood studios helped defeat Upton Sinclair by distributing motion pictures showing the influx of destitute people to California they said Sinclair's programs would attract.[172]

7.3.3 Outdoor Lighting and Public-Address Systems

The annual Nuremberg rally was the high point of Nazi party activity. In 1933 Albert Speer, Hitler's architect (who during the war became Minister of Armaments and War Production), designed spectacular effects for the evening rally. Besides abundant use of flags and banners illuminated by spotlights, Speer used a new searchlight to spectacular effect. He writes,

> *I had occasionally seen our new anti-aircraft searchlights blazing miles into the sky. I asked Hitler to let me have a hundred and thirty of these. Goering [head of the Luftwaffe] made a fuss at first, since these hundred and thirty searchlights represented the greater part of the strategic reserve. But Hitler won him over: "If we use them in such large numbers for a thing like this, other countries will think we're swimming in searchlights."*
>
> *The actual effect far surpassed anything I had imagined. The hundred and thirty sharply defined beams, placed around the field at intervals of forty feet, were visible to a height of twenty to twenty-five thousand feet, after which they merged into a general glow. The feeling was of a vast room, with the beams serving as mighty pillars of infinitely high outer walls. Now and then a cloud moved through this wreath of lights, bringing an element of surrealistic surprise to the mirage. I imagine that this "cathedral of light" was the first luminescent architecture of this type, and for me it remains not only my most beautiful architectural concept but, after its fashion, the only one which has survived the passage of time. "The effect, which was both solemn and beautiful, was like being in a cathedral of ice," British Ambassador Henderson wrote.*[173]

It was not radio or cinema that brought followers of National Socialism to the highest pitch of enthusiasm, but rather political rallies. The Nazi calendar was marked by public festivals that brought people together in large numbers.[174] Much earlier Goebbels had began the careful development of techniques of mass

[171] Samuel.

[172] Allen 1939, p. 153.

[173] Speer, pp. 58–59.

[174] Koch.

meetings—loudspeakers, lighting, banners, marching, music, uniforms, and other pageantry—and this did much to bring Hitler to power.[175] The Nazi were quick to use any new technology for special effects at mass meetings, as they did with the Trautonium, an electronic musical instrument designed by the electrical engineer Friedrich Trautwein.

A spectacular new type of lighting came into prominence in the interwar period. In 1904 Perley G. Nutting of the U.S. Bureau of Standards had exhibited, at the Louisiana Purchase Exposition in St. Louis, an illuminating tube that generated light by an electrical discharge through neon gas. The Frenchman Georges Claude, recognizing its commercial possibilities, devised an appropriate voltage transformer and regulator and demonstrated a neon sign (consisting of two 38-foot tubes) at the Grand Palais in Paris in 1910. Neon alone glowed red, but by using other gases one could obtain other colors. The first neon advertising sign was sold in 1912, and a year later three-and-a-half-foot high letters spelled CINZANO against the Paris sky. In 1915 Claude received a patent for the advance that made tube lighting much more practical—an electrode with high resistance to the corrosion caused by gases within the tube.[176]

A Los Angeles car dealer who visited Paris in 1923 helped bring neon signs to the U.S., and Claude began selling licenses for his patent throughout the world. Neon lighting became especially popular in the U.S. At the Chicago Century of Progress Exposition (1933–1934) more than 75,000 feet of gaseous tube lighting, in many colors, were used; for example, 55-foot cascades of blue and green neon lighting adorned the Electrical Building. Entrances to cinemas were often decorated in neon.[177] By the mid-1930s Times Square in New York and Piccadilly Circus in London were dazzling displays of neon. In the late 1930s, Mussolini used neon to celebrate the new Italian empire.

Incandescent lights had, of course, long been used for advertising and spectacular effects. As early as 1900 there was a huge illuminated advertising sign in New York City; placed on the Flatiron Building, the sign measured 50 by 80 feet and contained 1457 lamps.[178] Incandescent lights, too, were improved. They made possible night-time baseball; in 1935 a major-league baseball game was played under lights at Crosley Field, Cincinnati.[179] In the Soviet Union, incandescent lights were effectively at the 1935 May Day celebration.

In the early 1930s, two other types of discharge lamp became common: the high-pressure mercury-vapor lamps and the low-pressure sodium-vapor lamps. Both of these were especially suitable for street lighting. Incandescent lamps had replaced both gas lamps and arc lamps for street lighting, but they were nevertheless quite inefficient in converting electrical energy into light. Hence, many engineers sought to develop more efficient types, and discharge lamps (in which electric current flows

[175] Gunther, p. 68.

[176] Bijker, p. 213, Heyn, p. 75, and Stern, pp. 19–23.

[177] Stern, pp. 24–27, and Underhill, p. iv.

[178] Stern, pp. 16–18.

[179] Gorowitz III, p. 42

from one electrode through a gas or a metal vapor to another electrode) received much attention. The mercury-vapor lamp gave a bluish light, whereas the sodium-vapor lamp gave a monochromatic, orange light. The latter was more efficient and was adopted in large numbers in Germany and the Netherlands. In other countries, including the U.S., England, and France, mercury-vapor lamps were preferred. Indeed, the dislike of the poor color-rendering of the sodium lamp was so great in the U.S. that its use for street lighting was outlawed in some states.[180]

Just before World War II there began to appear still another type of discharge lighting—fluorescent lighting. By the turn of the century researchers knew that discharge lamps often emitted ultraviolet light and that a property of certain minerals called fluorescence (re-emission of light at lower frequencies) could convert the ultraviolet light to visible light. Many attempts to develop a practical lamp—placing fluorescent materials in reflectors behind the discharge tube, in a coating inside the tube, in a coating outside the tube, or within the glass itself—came to naught. Discovery of fluorescent materials from which one could obtain "white light" (that is, light having a distribution of frequencies similar to sunlight) and improvements in lamp design finally brought success in the mid-1930s to researchers in France (Georges Claude's company), in England (at GEC), and in the U.S. (at GE). GEC and GE began commercial production in 1938, and fluorescent lighting was featured at the 1939 New York World's Fair.[181]

For the Nazi rallies something that was more important than lighting was a public-address system. Electronic amplification greatly increased the number of people an orator could reach, and toward the end of World War I, public-address systems began to be used.[182] (Even before electronic amplification there were a few public-address systems; in these systems the sole source of amplification was the microphone, where sound waves controlled a strong direct current by varying the resistance of a carbon button.) A system with electronic amplifiers and more than a hundred loudspeakers was used in 1919 in New York City for a Liberty Loan drive, and the following year the Republican and Democratic national conventions used public-address systems.[183] Western Electric began selling standardized systems in 1922, and they became increasingly common, especially after the development in the late 1920s of high-power speakers (notably the moving-coil speaker invented by E.C. Wente in 1926).[184]

Large, well-designed public-address systems permitted Hitler and other Nazi orators to address crowds that numbered hundreds of thousands, occasionally more than a million (as at the celebration on 1 May 1934 at Berlin's Tempelhofer Aerodrome or for speeches on 28 September 1937 of Hitler and Mussolini on Berlin's Maifeld).[185] At the annual Munich commemorations of the aborted putsch of 1923, Goebbels

[180] Clayton, pp. 80–84.

[181] Bijker, pp. 217–220, and Clayton, p. 77.

[182] Knox.

[183] Fagen, p. 293, and Knox.

[184] Fagen, pp. 182–190, 295.

[185] Kraus, p. 43, Koch, and Shirer, p. 301.

placed loudspeakers at street corners throughout the city so more people could hear the ceremonies.[186] When Hitler spoke to 120,000 in Berlin's Grunewald Stadium on 27 July 1932 an additional 100,000 outside heard him from loudspeakers.[187]

In the interwar period, public-address systems began to be commonplace, most often experienced in train stations and at sporting events. Also becoming almost commonplace were sound trucks (on which loudspeakers projected messages recorded on gramophone disks). The Nazis made use of them in the 1932 elections, as did Huey Long in Louisiana at about the same time.[188] During World War II, the Russians used sound trucks in the effort to persuade German soldiers to turn against Hitler.[189]

7.3.4 Governments and Information Processing

We have already seen the value of information dispersing technology to governments. Techniques for information gathering and information processing also played important roles. Small microphones aided Nazi information-gathering. Shirer, who lived in Germany in the 1930s, writes, "No one—if he were not foolish—said or did anything that might be interpreted as "anti-Nazi" without first taking precautions that it was not being recorded by hidden S.D. [Sicherheitsdienst] microphones or overheard by an S.D. agent."[190]

Much information gathering employed wireless communications, a disadvantage of which was that eavesdropping was much easier than with wire communications. This fact made codes, known since antiquity, of great importance in World War I (as discussed in Chapter 1) and afterwards. In the 1920s and 1930s, governments, companies, and a few individuals sought ways to make one's own communications secure from eavesdropping (principally by encoding messages) and to gain information from the communications by others (principally by intercepting and decoding messages).

In 1915 Edward Hebern used two electric typewriters to make an enciphering machine. The first typewriter produced the plaintext; its 26 keys were connected electrically in a random fashion to the keys of the second typewriter, which produced the ciphertext.[191] The ease of changing electrical connections was exploited in other, more sophisticated encoding machines. Enigma, a cipher machine patented in the Netherlands in 1919, was developed by the German military. In the Enigma electrical connections were continually changed by the motion of a set of four or five rotors, so that the pattern of letter substitutions was effectively nonrepeating.[192] In 1934,

[186] Koch.
[187] Shirer, p. 166.
[188] Carter 1949, and Shirer, p. 158.
[189] Solzhenitsyn, p. 10.
[190] Shirer, p. 273.
[191] Kahn, p. 415.
[192] Kidwell, pp. 50–51.

the Japanese government purchased an Enigma machine and used it as a starting point for designing their own machine for diplomatic coding.[193] The story of code and code-breaking machines is continued in Chapter 9.

Covered thus far have been electromechanical information-processing machines, such as totalisators (for pari-mutuel betting), Strowger switches (for telephone switching), and punched-card machines. Chapter 5 discussed how punched-card machines made possible the administration of the Social Security program, enacted as part of Franklin Roosevelt's New Deal. Now it's important to mention the use of punched-card machines in Nazi Germany. The National Socialist program called for greater control of the economy, and to do this effectively, more information about the population was sought, notably through national censuses in 1933 and 1939. Both times Hollerith machines played a large part and permitted completion of data processing within a year. The first census asked respondents about religion; the second asked respondents also to report if any grandparents were Jewish (hence enabling the Nazis to identify people of Jewish or partly Jewish descent who were not practising the Jewish religion). It is possible the compiled data were used to guide the planning of deportation of Jews. It is certain that beginning in 1944, Hollerith machines were used to organize the movement and exploitation of concentration-camp labor.[194]

The German affiliate of IBM, Dehomag, prospered in the 1930s, as did the German affiliate of Remington Rand, Powers Ltd. Numerous governmental and party agencies used Hollerith machines, including the central bank, the postal system, the national railroad system, all branches of the military, the armaments ministry, many city governments, the Nazi party treasury, and the central SS personnel office.[195]

7.3.5 Society and Communications

Communications technologies have played large roles in twentieth century politics. A principal feature of many totalitarian countries, including Nazi Germany and Soviet Russia, was complete control over mass communications.[196] Alan Bullock has written, "Thanks to modern technology Hitler and Stalin were able, as no political leaders had been before them, to make their public images omnipresent. …"[197] Indeed, they were able to control, in large measure, the information reaching the people. Immediately after coming to power, Lenin ended freedom of the press and entrusted management of the news to the Bolshevik newspaper *Pravda* and the newspaper of the Soviets *Izvestia*.[198]

[193] Hexlet, p. 176.

[194] Luebke and Milton, and Petzold, pp. 143–146.

[195] Luebke and Milton.

[196] Bullock, p. 400.

[197] Bullock, p. 372.

[198] Johnson, pp. 64–65.

In more democratic countries, too, political leaders made use of the mass media, as they allowed a single person—president, prime minister, radio commentator, or anyone with access to the media—to exert a much greater influence on public opinion than was possible earlier. Yet leaders in democratic countries were often constrained by the media, as radio broadcasts and newspapers—informed by wire services and telegraphed and telephoned reports—put political events quickly before the public eye. In countries with uncensored media, not only political leaders, but also the rich, big business, or the church could be constrained by public opinion. For example, in the U.S. just after the turn of the century, Ida Tarbell, Upton Sinclair, and other "muckrakers" used print media to arouse public opinion against certain practices of big business. On the international plane Hitler was conscious of public opinion; he made a practice of announcing foreign-policy decisions that he knew would provoke negative reaction abroad on Saturday afternoon so that the reaction would be less sharp.[199]

Even in democratic countries there were some restrictions on the information and opinions carried by the media. It is argued, for example, that the corporate sponsorship of most radio broadcasting in the U.S. restricted the range of political debate in the interwar years, as programming had to conform to definite political and cultural standards.[200] In 1926 the radio commentator H.V. Kaltenborn wrote, "… the radio has been extremely timid about permitting the broadcasting of anything that contravenes the established order."[201] In the U.S. political advertising attempted to mold public opinion in the same way that Hitler's broadcasts did. For example, in the 1936 Presidential campaign, the Republicans set aside more than a million dollars for radio advertising to promote Alf Landon, whose publicity should be handled, according to one advisor, "on the same basis as the handling of any other article that wants to be merchandized to the public."[202]

Person-to-person communication, by mail, telegraph, or telephone, seems less amenable to political control. Indeed, as mentioned above, both Hitler and Stalin hindered the development of the telephone system for political reasons. Yet these forms of communications were often put to effective use by dictators. One of the reasons Mussolini's "action squads" of the early 1920s gained ascendancy over socialist street-gangs is that they were better organized, using the telephone to coordinate their actions.[203] On the evening of 9 November 1938 there were throughout Germany "spontaneous demonstrations" against the assassination of a German official in Paris by a Jewish refugee. The demonstrations, which led to the violence of Kristallnacht (so called from the amount of glass broken), were in fact ordered by Goebbels, who issued teletyped orders to offices of the state police and the security service.[204]

199 Gunther, p. 13.
200 Czitrom, p. 79.
201 Quoted in Czitrom, p. 81.
202 Robert Choate quoted in Manchester, p. 172.
203 Johnson, p. 98.
204 Shirer, p. 430.

The telephone could be an effective instrument of control. When Congress was in session, Franklin Roosevelt reportedly spent a quarter of his time on the telephone, usually arranging support for his legislation.[205] Alan Bullock has written, "One of [Stalin's] habits was to telephone heads of government departments or party offices late at night and ply them with questions, a possibility that kept many of them anxiously at their desks until the small hours."[206] In Germany, Hitler gained a presence on telephone lines generally as "Heil Hitler" replaced the conventional "hello".[207]

On the international level, the First World War had underlined the value of good long-distance communications. Even before the war, the French worked to reduce their dependence on British telecommunications.[208] Mussolini, wanting an Italian-owned international communications company, helped establish the company Italcable in 1922. It laid cable from Anzio to Malaga, Spain, and thence to Horta in the Azores, where messages were sent over Western Union cables. On 16 March 1925, President Coolidge and the king of Italy exchanged messages over the line.[209] Germany in the 1920s vigorously developed its telephone network so that the German system—and not the French—would function as the center of the Continental telephone system.[210]

Any communications technology can have unifying and separating effects, reinforcing existing social bonds and differences or creating new bonds or differences. In the discussion in Chapter 6 of the consumer culture we saw unifying tendencies. Obvious examples of the opposite are Roosevelt's attacks on businessmen, Hitler's tirades against the Jews, and Stalin's demonization of "kulaks" for opposing collectivization of agriculture.

Radio created bonds between people, even between people in different countries, by giving them shared experiences in the form of news, music, reports of sporting events, or radio drama. Particular broadcasts became famous, such as the report of the crash of the zeppelin *Hindenburg* in 1937 or FDR's speech to Congress following the attack on Pearl Harbor ("a day that will live in infamy"). David Gelernter writes of Fiorello La Guardia, New York City's mayor in the 1930s, "When a strike stopped delivery of the city's newspapers, he took to the airwaves to read

[205] Manchester, p. 98.

[206] Bullock, p. 374. Robert Service (in Dear, p. 1055) writes that in World War II Stalin typically "continued to toil into the small hours of the night. This had become natural for his body clock, but he imposed his habits on everyone else: his colleagues had to be ready to receive a call from him at any time of night. … He frequently reinforced any decisions with telephone calls to impress urgency on his subordinates." Aleksandr Solzhenitsyn (in *The First Circle*, p. 1) writes "There was only one person, behind a dozen fortress walls, who could not sleep at night, and he had taught all: official Moscow to keep vigil with him until three or four in the morning."

[207] Shirer, p. 8. According to Speer (quoted in Keegan 1987, p. 303) "… Hitler always showed a distinct dislike for conducting important arguments on the telephone." Speer attributed this in part to the fact that Hitler "expected his aura and his persuasivenes to operate better in a face-to-face discussion with an individual."

[208] Headrick, *Tentacles*, pp. 130–137.

[209] Oslin, p. 291.

[210] Braun, pp. 151–152.

the Sunday comics over WNYC, the city-owned radio station. Two generations later, New Yorkers of that era still vividly remember him doing it."[211] The reports from the Munich crisis in 1938 and Edward R. Murrow's broadcasts from London during World War II were long remembered by millions. Radio sometimes impressed on the memories of millions of people particular words, such as Edward VIII's "I have found it impossible to carry the heavy burden of responsibility and to discharge my duties as King as I would wish to do without the help and support of the woman I love" or Franklin Roosevelt's "let me assert my firm belief that the only thing we have to fear is fear itself. …" Radio thus brought ordinary people closer to leaders of state and to the celebrated events of the day and added to the words and ideas shared by the general public.

[211] Gelernter, p. 3.

Chapter 8

Electrical Engineering in an Age of Science

8.1 AN AGE OF SCIENCE

8.1.1 1932, The Year in Science

There was no shortage of news events in 1932. Headlines often concerned the severe economic recession that had begun in 1929. In the United States, where industry operated at less than half its 1929 level, Franklin Roosevelt ousted the Presidential incumbent Herbert Hoover. In Spain a rebellion against the Republic began; in Portugal Alberto Salazar began what would be a 36 year period as ruler; and in Germany Paul von Hindenburg outpolled Adolf Hitler in the presidential election. The Soviet government began its second five year plan in 1932, and that year the Japanese army completed its conquest of Manchuria, setting up a puppet emperor in the newly independent state of Manchukuo. Sensational stories included the suicide of the Swedish "Match King", Ivar Kreuger, as his financial empire began to collapse, and the kidnapping of the child of Charles Lindbergh and Anne Morrow Lindbergh. Amelia Earhart became the first woman to fly solo across the Atlantic, and the Olympic Games were held in Los Angeles.

The year of 1932 was special, however, in how often science made its way into the headlines. Perhaps most spectacular was the announcement on 15 June 1932 by John Cockcroft and Ernest Walton at Cambridge University that they had split lithium atoms by bombarding them with protons. To do so, they had built a voltage multiplier, drawing on equipment and techniques that came from the power industry, specifically Metropolitan Vickers where Cockcroft had worked, and then used the enormous electrostatic potential (700,000 electron volts) to accelerate protons. This machine, known since as the Cockcroft-Walton, was the first particle accelerator and the first machine able to transmute elements, and this experiment was the first result in accelerator physics.[1] Moreover, Cockcroft and Walton were able to use this

[1] Pais, pp. 405–406.

Dawn of the Electronic Age: Electrical Technologies in the Shaping of the Modern World, 1914 to 1945, by Frederik Nebeker

splitting of lithium nuclei into helium nuclei to confirm Einstein's equation relating energy and mass, $E = mc^2$. Another device for creating an enormous electrostatic potential, the Van de Graaff generator, invented by Robert Van de Graaff at Princeton University in 1929, was also first used to accelerate ions in 1932.

Another spectacular result of 1932 was the discovery of the first antiparticle. In 1928, Paul Dirac had proposed that all particles occur in pairs and that the antiparticles of known particles comprise antimatter, and in 1932, Carl D. Anderson succeeded in demonstrating the existence of the antiparticle of the electron, the positron, by studying the cloud-chamber paths of energetic cosmic-ray particles.[2] It was also in 1932 that Eugene Wigner introduced time reversal in quantum mechanics: the idea that certain physical laws are not changed when the direction of time is reversed.[3]

A third spectacular physics result of 1932 was the discovery of the neutron. The existence, in the nucleus of an atom, of a neutral particle (conceived as a proton-electron composite by Ernest Rutherford) had been hypothesized for several years. In 1932, James Chadwick at Cambridge University showed that, unless conservation of energy and momentum were violated, neutral particles were produced in a reaction between alpha particles (helium nuclei) and beryllium nuclei.[4]

Attracting less attention at the time was the beginning of what now is called radio astronomy. It was in 1932 that Bell Labs researcher Karl Jansky first published results of his investigation into sources of atmospheric static; he distinguished three types of static: crashes from local thunderstorms, a steadier and weaker static from the combined effect of distant storms, and a weak hiss of unknown origin, which, in a paper published the following year, he argued came from outside the solar system.[5] The 1932 Nobel Prize in Chemistry was awarded to the GE researcher Irving Langmuir. (See Figure 8.1.) Born 31 January 1881 in Brooklyn, Langmuir studied both at Columbia University and at Göttingen University, where he earned his Ph.D. under Walther Nernst. From 1909 until his retirement in 1950 he worked at the research laboratories of GE. Earlier chapters mention his work on improving incandescent bulbs and electron tubes. His approach was always to understand the underlying phenomena, and it was for his work on the chemistry of surfaces, especially his studies of gas adsorption, that he received the Nobel Prize. His investigations in plasma physics in the 1920s led to improved gaseous electron tubes, such as the thryatron. He also worked on the design of miniature high-frequency vacuum tubes and contributed importantly to arc welding techniques.[6]

Other notable events of 1932 were Edwin Land's invention of Polaroid glass, a synthetic light polarizer, and Bedell's invention of the deaf speaker, a receiver held

[2] Invented by the Scottish physicist Charles T.R. Wilson in the 1890s, the cloud chamber shows the trail of ionized particles left by the passage of an energetic particle through a supersaturated medium. Anderson and Robert Millikan built a cloud chamber in 1930 to study cosmic rays.

[3] Pais, pp. 526–527.

[4] Pais, pp. 398–399.

[5] Hey, pp. 4–6.

[6] Brittain 1995, and Gorowitz, p. III.33.

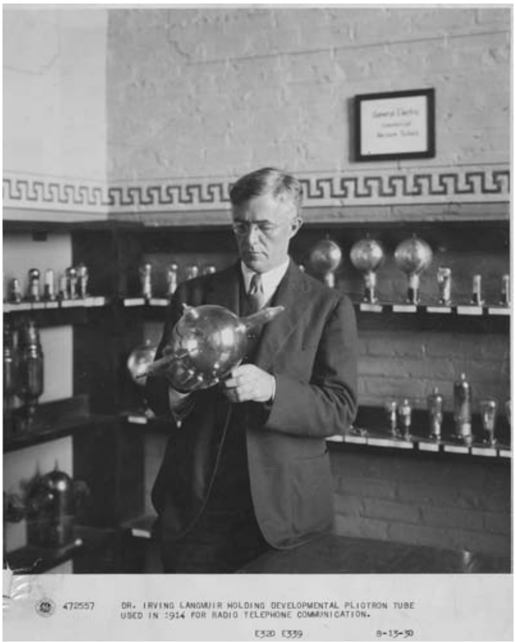


Figure 8.1. Irving Langmuir holding a radio tube (photo courtesy of the Schenectady Museum & Suits-Bueche Planetarium).

against the teeth or cheekbones that sends sound directly to the inner ear, bypassing the defective middle ear, which allowed many people to hear for the first time. The Belgian physicist Auguste Piccard became the first human to enter the stratosphere when he ascended 16,200 meters (10 miles) in an airtight chamber carried by a helium balloon. O. Haxthausen invented what he called “subcutaneous photography”, a photographic image is produced by the infrared radiation of the body; it was not much used, though infrared aerial photography came to be used in World War II to detect camouflaged factories and military vehicles. The mathematician Derrick Lehmer completed an electromechanical digital computing machine; called the “mathematical sieve”, it searched for prime numbers, signaling a prime by turning on an automobile headlight.

In 1932, GE began marketing electric dishwashers, and the plastic Bakelite was becoming common. The French superliner “Normandie”, the largest commercial vessel in the world, was launched in 1932; it was driven by four of the most powerful electric motors ever built.[7] Jimmy Doolittle set an airplane speed record of 292 mph.

In 1932, Technocracy burst onto the public scene. For years a New Yorker by the name of Howard Scott had argued—with whoever would listen—that technological progress offered a basis for unparalleled prosperity, but in order for this potential to be realized decision-making needed to be taken out of the hands of politicians and placed in those of scientific and technical experts (technocrats).

[7] Gorowitz, p. III.35.

The high esteem of scientists and engineers and frustration with the continuing Depression no doubt contributed to the popularity of technocracy. Suddenly, in Frederick Lewis Allen's words, "the thing was everywhere: in the newspapers, in the magazines, in sermons, in radio actors' gags, in street-corner conversation."[8] Thorstein Veblen and other social commentators regarded engineers as appropriate leaders of society, and engineers had, indeed, proven themselves to be able managers of business.[9]

At the same time, there was widespread critique of technology, and many blamed the unemployment on new production technologies. And one of the most lasting expressions of technological disenchantment appeared in 1932; Aldous Huxley's *Brave New World* portrayed a future world in which technology assures everyone bodily comfort, but in which there is little human creativity or even individuality.

8.1.2 Science Shaped by Technology

In the first decades of the century, science enjoyed a prominent place in popular culture. The reformulation of classical physics, with quantum theory (as Niels Bohr's quantum model of the hydrogen atom), relativity theory (especially Einstein's special theory of relativity), and subatomic physics (the discovery of subatomic particles and the elucidation of the structure of the atom), received much attention. The 1919 solar eclipse expedition (to northern Brazil and to an island off the west coast of Africa) to measure the bending of the light of the sun (precisely as predicted by Einstein's theory of general relativity, published in 1916) was front-page news. People wondered about the newly discovered phenomena of radioactivity, x-rays, and superconductivity (the complete disappearance of electrical resistance in certain substances at extremely low temperatures).

Observatories and planetariums were sources of local and national pride. In the 1920s, Edwin Hubble, using the new 100 inch reflector telescope at Mount Wilson near Los Angeles, demonstrated that millions of light-years outside the local Milky Way galaxy were other galaxies, or "island universes" as they were called, and that the more distant a galaxy, the faster it was moving away from the Milky Way (suggesting an expanding universe). In 1930, the Lowell Observatory in Arizona identified the planet Pluto in photographs. One of the most popular ways of communicating science to the layman became the optical projection planetarium, which shows the motions of stars, planets, and other objects in a realistic and accurate way. Invented in Germany and built by the Carl Zeiss Optical Works, the first planetarium projector was installed in the Deutsches Museum in Munich in 1923. Many other cities built planetariums, and they helped make astronomy a popular science.[10] (The projector

[8] Allen 1939, pp. 71–73; the quotation is from p. 71.

[9] Carlson 1988. Carlson notes [p. 537], "During the first half of the 20th century, nearly one-half of all the engineers trained at the Massachusetts Institute of Technology (MIT) went into business or managerial careers. …"

[10] Gingerich, pp. 271–272.

was a complex electromechanical device, which may be considered an analog computer for the motions of the heavenly bodies.)[11]

Air travel, the prospect of space flight, radio, and new synthetic materials (such as Bakelite, synthetic rubber, Plexiglas, and, in 1939, nylon) fascinated people. The Hall of Science was a major attraction at the Century of Progress Exhibition in Chicago in 1933, and science was featured at the 1939 New York fair, too. There was also, as pointed out in Chapter 2, the post-Great War "recognition of the national essentiality of science", to use Andrew W. Mellon's phrase of 1919.[12]

In popular discourse the term "science" denoted technology as well as science. Both scientists and engineers accepted this conflation of two concepts—a pursuit of knowledge conflated with the improvement of techniques for achieving practical objectives. The scientists, then, gained prestige from the obvious benefits of new technologies, the engineers from the high status accorded the term "science".[13] The broad denotation of science was appropriate, many would have argued, because technology was applied science. This view may be objected to because technologies have their own developmental paths, often little influenced by the research that scientists do, and because it makes technology derivative of science, when, in fact, science itself is highly indebted to technology. In the following is a section brief discussion of that indebtedness, giving special attention to the importance of electrical technologies.

First, more prosperous economies are able to devote more resources to science, and new technologies have driven the economic growth of the twentieth century. (In the first decades of the century, electrical power, electric traction, radio, and electrical appliances were among the fastest growing sectors of the economy.) Second, electrical technologies, because they were perceived as applied science, increased the general motivation to do science. (Electric lighting, electric power, x-rays, and radio were widely admired and were perceived as applied science.)[14] Third, the funding of specific scientific research was often justified by hoped-for application of the knowledge sought. Fourth, industrial R&D, aimed at technological advance, has often yielded scientific understanding of the underlying phenomena, as in Irving Langmuir's studies of gas adsorption in electron tubes.

Beyond such issues of societal support of science, there are more direct contributions of technology to science. Technologies have often revealed new phenomena or features of the world. Consider, for example, the discovery of the ionosphere. It was difficult to explain how Marconi's wireless transmissions could cross the Atlantic, since radio waves, like light and other forms of electromagnetic waves, travel in straight lines. In 1902, Arthur Kennelly in the U.S. and, independently,

[11] Campbell-Kelly and Aspray, p. 60.

[12] Mellon.

[13] The conflation of science and technology is seen in a statement Bertrand Russell made in 1923: "It is science, ultimately, that makes our age different … from the ages that have gone before. And science is capable of bringing mankind into a far happier condition than any that he has known in the past."

[14] Science has profited greatly from the belief that technology is applied science. This belief has gained much support from electrical technologies, such as electric power and radio. With many other technologies, the automobile for example, there is a smaller indebtedness to science.

Oliver Heaviside in England suggested that there was an electrically conducting layer (later given the name "ionosphere") high in the atmosphere which reflected radio waves back toward the earth. Beginning in the mid-1920s, several scientists, notably Edward Appleton, used radio to investigate the ionosphere, discovering that the ionosphere consisted of several layers and exhibited diurnal variations. Cosmic rays, discovered by Victor Hess in 1912, were detected, visualized, and measured by devices that respond to ionization (as Geiger counter or cloud chamber). The use of electroacoustic transducers of the sort developed for sonar in World War I led in 1934 to the discovery of sonoluminescence (the conversion of sound into light).[15] The intense radio emission from sunspots was discovered during World War II because it caused interference with anti-aircraft radars in southern England.[16]

Technologies have opened new windows on the world. The ability to generate and detect x-rays led to x-ray photography, x-ray crystallography (the determination of the structure of a crystal from the way it diffracts x-rays), and x-ray spectroscopy (the study of the particular frequencies emitted or absorbed by an element or compound). More generally, new parts of the electromagnetic spectrum (the entire range of frequencies of electromagnetic radiation, from radio waves to gamma rays) were opened up, as in infrared photography or radio astronomy. (In 1937, Grote Reber, radio engineer and amateur astronomer, built a 31 foot parabolic antenna and made the first radio maps of the sky, and not long after World War II radio astronomy became an important branch of astronomy.)

Harold Edgerton in 1931 devised a new photographic technique using high-intensity stroboscopic lighting. Several of his photos, such as one showing the crown-shaped splash of a drop of milk, became famous. This technique made visible the invisible.[17] Sensitive seismographs revealed structures within the earth, such as the mantle-crust boundary, the mantle-core boundary, and the inner-core outer-core boundary.[18] The phenomena of the upper atmosphere were elucidated, beginning in the 1930s, by the measurements of temperature, humidity, and pressure taken by balloon-borne instruments and radioed back to the ground. Sound waves were used to measure ocean depths—acoustic fathometry dates from the late 1920s—and detect underwater features such as icebergs, reefs, or shipwrecks.

It is true that some of the greatest achievements of twentieth century science have been theoretical—notably quantum theory and relativity theory—but even here technology has played a vital role, as such advances are often prompted by better measurements (of greater range or precision) or, after the elaboration of the theory, confirmed by new measurement (as the demonstration by Clinton Davisson and Lester Germer of the wave nature of the electron—a tenet of quantum mechanics). Indeed, much of science depends upon measuring instruments (such as the electronic

[15] Putterman.

[16] Klaus, p. 126.

[17] At the other end of the time scale, time-lapse photography made visible certain motions that were so slow as to be imperceptible by unaided sight.

[18] The mantle-crust boundary is called the Mohorovicic Discontinuity after Andrija Mohorovicic who discovered it in studying an earthquake in 1909; the mantle-core boundary was discovered by Beno Gutenberg in 1913; and the inner-core–outer-core boundary was discovered by Inge Lehmann.

photometer), imaging devices (such as the electron microscope), and means of laboratory manipulation (such as particle accelerators), and technology has continually improved these instruments. The next section of this chapter reviews progress in each of these areas of instrumentation. The section that follows considers the increasing use by scientists of calculating aids. We consider now some less visible, but nevertheless extremely important, ways electrical technologies have contributed to scientific enterprise.

8.1.3 Facilities for Research

There are some striking trends in twentieth century science. (1) There is more laboratory investigation, as contrasted with purely theoretical research and field research. According to a historian of biology, "At the center of the story of the life sciences' rise to prominence in the twentieth century is the biological laboratory. Early in the century the laboratory replaced the field as the center of research activity. It became the premier site for the development of new and specifically quantitative techniques for analyzing life processes."[19] This quotation identifies a second trend. (2) There is more quantitative information, and this has depended upon new measuring instruments. Three other trends likewise depend upon new technologies. (3) There are more images, and this has depended upon new techniques of visualization. (4) There is more experimentation, as contrasted with observation, and this has depended upon new means of manipulation. (5) There is more calculation, and this has depended upon new calculating aids. Each of these trends is associated with certain instrumentalities. The last four trends and the technologies related to them are the subject of the next two parts of this chapter. Here we consider the first trend and the role of electrical technologies in providing facilities for research.

Figure 8.2 shows a laboratory early in the century. This is the laboratory of the French biologist Yves Delage, who carried out experimental studies of marine embryology. There are few instruments of any sort, and the importance of natural light in this laboratory is apparent.

Electric lighting made a great difference by extending working hours and making uniform illumination possible at a optimal level. Electric heating was valuable for space heating, but much more valuable for localized heating as in ovens, incubators, sterilizers, dryers, and evaporators. Ventilation and air conditioning, with humidity control, could be very important in some types of work. Electrostatic dust removal was sometimes employed. Refrigeration was often vital in biological research.

Experimenters often used electrical signaling (as with a light, bell, or buzzer) and remote and automatic control (switches, solenoid valves, and thermostats, for example). Electric motors could be used in many ways, as in pumps, fans, stirrers, agitators, and pulverizers. They were used too in shop machinery, both for power-driven tools and in lifting devices. Electric welding and soldering was often important.

[19] Borell, p. xiii.

Figure 8.2. The laboratory of Yves Delage at the Roscoff Biological Station in France early in the century (photo by Paul Hareck, courtesy AIP Emilio Segre Visual Archives).

These tasks may seem like the housekeeping, rather than the essence, of laboratory science, but they were nevertheless extremely important. Of course, the measuring instruments, imaging devices, means of manipulation, and calculating aids, all of which we deal with below, were even more important. The cumulative effect was striking. Figure 8.3 shows some equipment used for biological field work in the late 1930s.

8.2 MEASURING AND IMAGING INSTRUMENTS

8.2.1 Measuring Instruments

Most of science and engineering depend crucially upon instruments of measurement. Chapter 4 cited Kelvin's dictum—"… when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind. …"—and discussed the great importance of quantification in radio engineering. In this, radio engineering was typical: again and again, in the development of scientific and engineering fields, the ability to quantify and measure has proved of enormous value.

In addition to this trend to quantify, the history of science and engineering has been characterized by a trend to measure with greater and greater precision. In 1931

Figure 8.3. Recording equipment used by Julian Huxley and Ludwig Koch used in a 1938 study of animal language (photo courtesy AIP Emilio Segre Visual Archives).

the physicist F.K. Richtmeyer said: "Why should one wish to make measurements with ever increasing precision? Because the whole history of physics proves that a new discovery is quite likely to be found lurking in the next decimal place."[20] For example, the discrepancy, between predicted and observed values, in the motion of Mercury that Einstein sought to explain in his theory of general relativity, was 43 seconds of arc per century.[21]

Quantification and precise measurement have proved crucial not only in scientific investigation and engineering design, but also in industrial production, as measuring devices are integral to many types of process control. Chapter 5 discussed the rapid increase in industrial R&D and in automatic control of machinery during the interwar years. In the same period, precision instrumentation came to be generally recognized as essential technology for successful warfare and therefore to receive continuing government support.[22] In 1949 an observer of U.S. industry wrote that a typical factory used eight to ten instruments, where one had sufficed a decade earlier.[23]

[20] Quoted in B.N. Taylor, "Constants, fundamental", in Rita G. Lerner and George L. Trigg, eds. *Encyclopedia of Physics* (New York: VCH Publishers, 1991), pp. 181–190.

[21] Pais 1982, pp. 22, 253–254. A second of arc is one sixtieth of a minute of arc, which is one sixtieth of a degree of arc.

[22] M.E.W. Williams, pp. 178–179.

[23] Vogel, p. 67.

The rapid proliferation of instruments in science, engineering, and industry was made possible by the emergence of an instruments industry. From the seventeenth century to the late nineteenth century, most optical and measuring instruments were either built by the user or came from very small firms. In the early decades of the twentieth century, with the rise of industrial research and the heavy use of instruments in manufacturing processes, specialized instrument companies flourished and the production of instruments became a sizable industry.[24] A historian of the U.S. instrument industry concluded that, though important work has been done in universities and in large government and industrial laboratories, "twentieth century innovations in the design and application of complete instruments have been mainly the work of mobile scientists and small new companies."[25] Some of the small companies in the 1930s were Baird Associates (especially spectroscopes), Beckman, Consolidated Electrodynamics Company (especially mass spectrometers), General Radio (which pioneered in providing instruments for radio engineering), Jarrell-Ash (especially spectroscopes), Perkin-Elmer, Leeds & Northrup (electrical measuring instruments, automatic recording and controlling devices), and Applied Research Laboratories (optical emission spectrographs). Large companies, however, were the producers of instruments whose commercialization required large R&D efforts. Thus RCA, Philips, and General Electric were leaders in the market for electron microscopes.[26]

The instruments industry came to occupy a central position in science, engineering, and industry, vital to each of these areas and often bringing advances in one area to another.[27] The technology transfer could be from one specific application to another—a flow meter or strain gauge, for example, developed for one purpose could often be applied immediately elsewhere—or from realm to another. In addition, the instrument industry promoted the geographic transfer of technology. For example, the Weston Electrical Instrument Company, and many of the companies named above, sold instruments worldwide.[28]

Many instruments fit the following general description: a transducer (in this context usually called a sensor) converts the physical quantity of interest into an electric current, and the current, through the magnetic field it generates, rotates a magnetic needle mounted in front of a scale. In this or other ways, almost any physical quantity—velocity, acceleration, light, sound, pressure, temperature, electric field, magnetic field—can readily be measured.

Electrical engineering was the reason for development of many instruments that later found wide application. There were electrostatic instruments to indicate the presence of an electric charge (electroscopes) or measure its intensity (electrometers). There were ammeters (sometimes called galvanometers) and voltmeters, often consisting essentially of a coil of wire placed in a magnetic field. (In "fixed-coil instruments" current in the wire causes a compass needle to rotate; in "moving-coil instruments", current in the wire causes the coil to rotate; some instruments ("hot

[24] Shimshoni.

[25] Shimshoni, p. 65.

[26] Shimshoni.

[27] M.E.W. Williams, p. 1.

[28] M.E.W. Williams, p. 159.

wire instruments") exploit the expansion of a wire heated by current passing through it.) William Thomson, later Lord Kelvin, devised the highly sensitive "mirror galvanometer" to detect signals through the 1858 Atlantic cable. There were magnetometers for measuring the strength of a magnetic field. These devices were later employed in many different contexts.

Instruments to measure non-electrical quantities could draw on these techniques once a transducer had converted the quantity of interest to an electrical or magnetic quantity. There were thermometers, pressure sensors, strain gauges, hydrometers, spectrographs, calorimeters, dynamometers (for measuring forces or torques), ergometers (for measuring mechanical power), extensometers, pyrometers, and katharometers (for determining the composition of a gas mixture by measuring thermal conductivity). Engineers continually added to the quantities that could be measured electrically. In 1934, Arnold Beckman developed a pH meter, using electronic means to measure accurately the acidity or alkalinity of a solution, and in 1941 he developed a spectrophotometer for use in determining the chemical composition of a sample based on the wavelengths of light reflected.

A given type of measurement, as of temperature, may be taken by a variety of instruments, specialized for particular applications. Special types of manometer are the barometer and the sphygmomanometer (for measuring blood pressure). There was a great variety in electrical measurement of temperature, which might be based on a thermocouple (a difference of temperature generating a voltage) or on a resistance thermometer (resistance changing with temperature). For example, the bathythermograph, invented by Athelstan Spilhaus in 1937, allowed convenient measurement of temperature at different depths in the ocean (the instrument was not only important for oceanography, but also for the design of underwater acoustic systems, since it allowed one to calculate a sound-speed—depth profile).[29]

Means of recording data automatically became widely used. One of the oldest types was the kymograph; typically, an electric motor turned a paper-covered drum on which a pen traced a graph recording the reading of some instrument over time. The Leeds & Northrup's Micromax Recorder, introduced in 1931, soon became one of the most widely used recording devices in industry.[30]

With electronics came enormous advances in the measurement of electromagnetic variables. The vacuum-tube voltmeter, for example, was greatly superior to earlier voltmeters: it could measure without drawing appreciable current from the circuit being tested; it was extremely sensitive; and it could make measurements at high frequencies.[31] Vacuum-tube ammeters were especially valuable for the measurement of small currents, vacuum-tube ohmmeters for the measurement of large resistances.[32] Electronics permitted better wattmeters, time and speed meters, and frequency meters.[33]

[29] Burdic, p. 10.

[30] Vogel, p. 102.

[31] Reich 1939, p. 555.

[32] Reich 1939, pp. 575–576, 583.

[33] Reich 1939, pp. 582, 585–592.

Why was the electron tube so useful in measuring devices? It is extremely effective as an amplifier, and many signals have insufficient power to run a pen-and-drum apparatus. The electron tube can be both exquisitely sensitive (registering the weakest of inputs) and have negligible effect on the circuit under test (because of high input impedance). It can respond extremely rapidly, so can work for a wide range of frequencies. Acting as a rectifier, it can convert hard-to-measure high-frequency voltages to easy-to-measure direct currents.[34] And it can generate high-frequency signals. The availability of such a general-purpose device led to a much greater interest in electrical measurement.[35]

An example of an electronic instrument is the "ultra-micrometer" invented in 1920 by R. Whiddington. Length, traditionally measured by mechanical devices, was determined electronically in Whiddington's device because variation in length caused variation in capacitance, which in turn caused variation in frequency of oscillation of a electronic circuit.[36] The electron tube also gave great impetus to studies of speech through such instruments as the audiometer for measuring human hearing and devices to measure pitch and energy content of speech waves.[37]

The vacuum-tube voltmeter was one of two extremely effective and versatile instruments, which soon became ubiquitous in laboratories and workshops around the world. The other was the oscilloscope. The minuscule inertia of the electron beam enables an oscilloscope to respond rapidly and accurately to even very weak signals. At Bell Labs in the 1920s, the oscilloscope was used in radiowave propagation.[38] In many engineering contexts it is important to know a signal's harmonic content (that is, what frequencies are present and in what amplitudes), and the oscilloscope made such harmonic analysis possible.[39]

With many measuring devices there was movement from mechanical means to electrical or electromechanical means and then to electronic means. (We see the same trend in the history of computing devices.) For example, mercury thermometers were replaced by thermocouple devices, which later incorporated electronics. Means of displaying response were first mechanical and electromechanical (strip charts) and later electronic (oscilloscopes).[40] Time measurement shows the same trend. In the early 1930s, the National Physical Laboratory used an electromechanical device, called a vibration clock, for accurate time timekeeping. An electronic amplifier kept an invar bar in longitudinal oscillation at its natural frequency. Time

[34] Sinclair.

[35] Sydenham, p. 389.

[36] Sydenham, p. 446.

[37] Fagen, p. 928.

[38] Fagen, p. 918.

[39] For harmonic analysis the oscilloscope was not as accurate or convenient as devices that made the measurements directly. The practical value of the measurement and the increasing repertoire of electronic techniques stimulated the development of a variety of such devices in the interwar years [Reich 1939, pp. 618–627].

[40] Other examples of this trend may be found in range finding (which employed optics and mechanics up to World War II, then radar and later lasers) and seismometry (where electromechanical seismographs replaced mechanical ones and were later replaced by electronic ones).

was marked by the AC output of the amplifier, which was in exact synchronism with the bar. The quartz-crystal controlled oscillator superseded this method.[41] Similarly, in the early 1930s the primary frequency standard at NPL was an electronically maintained tuning fork, which was superseded by a quartz oscillator.[42]

One of the most important analytic tools of the twentieth century has been electromagnetic spectroscopy. Visual spectroscopy (which takes its name from "spectrum", meaning the array of component colors of sunlight as revealed by a prism), developed in the nineteenth century, can identify substances by the particular frequencies of light absorbed or emitted. (For example, sodium, when heated, emits light at 589 nm.) Electrical technology expanded the range of this technique by providing sources of electromagnetic waves with frequencies far below and far above those of visible light, thus making possible microwave, infrared, ultraviolet, and x-ray spectroscopy. For example, infrared absorption by gases and liquids became an active subject of research in the early twentieth century, and the development of x-ray spectroscopy by Karl Siegbahn earned him the 1924 Nobel Prize for physics.[43] High-precision radio-frequency spectroscopy began in 1937 with I.I. Rabi's work at Columbia University. Probably the first to do microwave spectroscopy were Claud E. Cleeton and Neil H. Williams of the University of Michigan; in 1933 they studied the absorption spectrum of ammonia gas using a magnetron that generated radiation of wavelength 1 to 3 cm.[44]

Electrical technology also contributed highly sensitive and discriminating detectors. The technical improvements—together with the design and manufacture of low-cost instruments—made spectroscopy a widely used technique.[45] In the 1930s, absorption and emission spectroscopes (using different portions of the electromagnetic spectrum) began to be used in various industries.[46] Alcoa, for example, in 1937 adopted optical emission spectroscopy company-wide for process and product control. The production demands of World War II hastened the adoption of optical emission spectrographs in industrial labs, and by war's end the technique was standard.[47] In the late 1930s, Norman Wright (Dow Chemical), R. Bolling Barnes (Princeton University), and others made clear to organic chemists the value of infrared spectroscopy.[48]

In 1919, Francis William Aston invented the mass spectrograph, a device that separates atoms having different masses. He used it to demonstrate that atoms could have the same atomic number but a different atomic mass (which is to say that there

[41] Pyatt, p. 104.

[42] Pyatt, p. 95.

[43] In 1906, the English physicist Charles Barkla showed that each chemical element emitted x-rays at particular frequencies; Karl Siegbahn exploited this property to develop a powerful analytic tool.

[44] Brittain 1985.

[45] Shimshoni.

[46] Shimshoni.

[47] Angelotti.

[48] Wilks.

may be several isotopes of the same element). Likening the dispersion of a beam of light in the optical device known as the spectrograph to the dispersion of a beam of ions in his machine, Aston called it a mass spectrograph. He worked to make his machine more accurate, and a machine he built in 1927 was accurate enough to measure the disappearance of mass (according to Einstein's formula $E = mc^2$) in certain nuclear reactions.

The range of materials studied by mass spectroscopy expanded steadily: petroleum, synthetic chemicals, pharmaceuticals, and metals, alloys, and other solids.[49] In the interwar period industrial spectroscopy (as for analyzing metals and alloys) became an important business for some instrument makers, such as Adam Hilger in Britain, Zeiss in Germany, and Bausch & Lomb in the United States. Bausch & Lomb was first to introduce, in the early 1930s, an almost fully automatic spectroscope.[50]

In the late 1920s, Hans Geiger and Walter Müller developed a practical device for counting energetic particles, such as those emitted by radioactive materials. The sensitive part of the device was a gas-filled tube containing two electrodes; a particle passing through the tube ionized some of the gas molecules, allowing a pulse of current across the electrodes. Geiger-Müller counters, often called simply Geiger counters, became a standard tool in physics and chemistry laboratories. (Such a counter was used by James Chadwick in his 1932 demonstration of the existence of the neutron.)

In astronomy, the photocell (usually combined with electronic amplification) found numerous uses: measurement of the variation in the light of certain stars (notably pulsating stars such as the Cepheids), of the color of stars, and of the steadiness of stellar images (that is, of the twinkling of stars). Photocells were used with photographic telescopes both for automatic guiding (which was achieved by keeping a star image accurately fixed in the field of view) and for automatic control of exposure time. Perhaps the most impressive early achievement of photoelectric photometry was the detection of close companion bodies to bright stars, which were revealed by variations in luminosity when the companion bodies passed in front of the bright stars.[51] Photocells found, of course, applications in many other sciences, as in chemistry to measure the density of a suspension.

One way in which the world changed from 1914 to 1945 is that electrical measuring instruments became ubiquitous. They appeared in ships, airplanes, cars, and trucks, monitoring speed, engine temperature, the pressure of various fluids, and many other factors. In factories, instruments such as temperature sensors, pressure sensors, and flow gauges became common for monitoring and control. And in research laboratories in academia and industry, instruments were everywhere. The availability of standard instruments contributed to the prevalence, among scientists, of the conception of "hard data" (such as a phase-transition temperature or the chemical composition of a mineral or the frequency range of a cricket's chirp) and

[49] Shimshoni.

[50] M.E.W. Williams, p. 152.

[51] Stebbins.

to the commonality of data. This is to say that standard instruments helped achieve a delocalization and decontextualization of scientific results.

The most important factor in this proliferation of instrumentation was the availability of electronics. As Ernest Heyn expressed it, "Electronics is the common denominator of twentieth-century science … the keystone that supports an enormous array of other modern-day marvels … the huge pin on which much of our life today turns."[52]

8.2.2 Imaging Devices

One of the most prominent of twentieth century artifacts is the cathode-ray tube. As a television or computer screen it was everywhere. It was a part of imaging devices in transportation (radar and sonar), medicine (ultrasound, computerized tomography, and many others), and laboratories of all sorts (especially in the form of the oscilloscope). It got its start in 1897 when the German physicist Ferdinand Braun constructed the first cathode-ray tube in order to study the rapid variations of electrical currents.[53] (In Germany today the cathode-ray tube is still known as the Braunsche Röhre.)[54]

Oscilloscopes make visible a time-varying electrical state, usually in a graph with time as the horizontal coordinate and signal voltage as the vertical coordinate. This capability makes the instrument valuable wherever electrical processes are studied. But because nonelectrical variables can usually be converted to electrical signals by transducers (such as thermocouples or microphones), the oscilloscope has become a universal device for visualizing physical processes.

Its stucture is essentially the same as that of the television picture tube. (See Figure 8.4.) Electrons, emitted by the cathode, are accelerated and collimated by the anodes. The end of the tube is coated with fluorescent minerals, so that the electron beam causes a spot of light where it strikes. In a typical arrangement, the electrical signal is applied to the first set of plates, while a so-called sweep-circuit applied to the second set of plates moves the beam across the screen horizontally (returning to the left side of the screen when the right side is reached).

Until the late 1920s, researchers had to construct their own oscilloscopes, combining a cathode-ray tube with special-purpose circuitry. What may have been the first commercial oscilloscope was introduced by the H.C. Burt Company in 1927.[55] To Allen B. DuMont is credited technical advances (in 1931 a long-lived CRT, in 1933 a memory oscilloscope, and in 1935 circuitry that allowed three or more

[52] Heyn, p. 281 (ellipses in the original).

[53] It was also in 1897 that J.J. Thomson used a cathode-ray tube to measure the charge-to-mass ratio of the electron.

[54] Kurylo and Susskind, pp. 89–93. Braun's first oscilloscope produced only vertical deflection of the electron beam; by using a rotating mirror outside the tube Braun observed the oscillations in two dimensions. In 1899 Jonathan Zenneck added a means of horizontal deflection in order to achieve this on the oscilloscope screen.

[55] Dalton and Kreps.

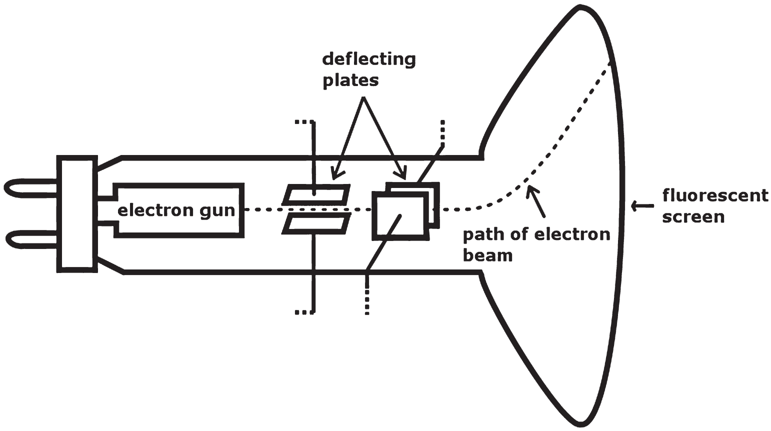


Figure 8.4. Schematic drawing of a cathode-ray oscilloscope.

independent signals to be displayed simultaneously) and successful marketing of the oscilloscope.[56] From the 1930s on, oscilloscopes were widely used in many types of laboratories, including biological laboratories.[57]

X-ray imaging, mentioned in Chapter 2, found wider and wider application. A different type of image, a diffraction pattern, was used to determine crystal structures. This study began in about 1912 by Max von Laue in Germany and was carried soon thereafter to a high level by Lawrence Bragg and his son William Henry Bragg in England (who earned the 1915 Nobel Prize for this work). It became a central tool of modern mineralogy and was later applied to the study of other materials, including metals and biological molecules.

In Germany in the early 1930s, Ernst Ruska and, independently, Reinhold Rüdenberg, invented the electron microscope. With electron beams, one could achieve higher resolution than was possible with light waves. The development of a commercial machine took place in large companies with the requisite engineering resources. Siemens and Halske, which hired Ruska for its development effort, began selling electron microscopes in 1939. Other companies that developed commercial machines were Philips, GE, and RCA.[58] In 1937, Erwin W. Müller built the first field-emission microscope, a type of electron microscope in which the image is formed by electrons drawn from the material by a strong electric field. The improved field-emission microscopes of the 1950s provided images of individual atoms.

In the late 1920s, the Western Electric engineer F.F. Lucas, collaborating with the Zeiss company of Jena, Germany, developed an ultraviolet microscope, which had twice the resolving power of light microscopes.[59] Even with optical instruments, electrical technology was sometimes important; for example, the controls for the

[56] Shimshoni.

[57] Borell, p. 145.

[58] Borell, p. 49, Rüdenberg and Rüdenberg, and Shimshoni.

[59] Fagen, p. 962.

200-inch Mount Palomar telescope were designed by Edward J. Poitras, an expert in automatic control.[60] In biological studies, the motion picture camera was often useful, also in conjunction with the microscope (a technique called microcinematography).[61] Time-lapse photography makes extremely slow changes visible. It was pioneered by Margaret and Warren Lewis in 1915 in studies of living cells.

Thus techniques for imaging, like those for measuring, provided new means for most scientific investigation, permitted a much more effective mode of engineering design, and facilitated control of industrial processes.

8.2.3 Means of Manipulation

Besides measuring and imaging equipment, technology has supplied laboratories with new means of manipulating physical systems. There are the means of mechanical manipulation, such as pulverizing, shaking, mixing, and maintaining a flow of liquid or gas. Here electric motors usually provided the power. High-speed motors made possible a class of laboratory device of the highest importance: centrifuges. Because separation of materials is central to laboratory analysis, these found countless applications. In the early 1920s the ultracentrifuge was invented; while earlier centrifuges might have a speed of 6000 revolutions per minute, it had speeds up to 80,000 rpm. In World War II, a so-called human centrifuge was used to study how pilots reacted to extreme accelerations. The centrifuge could also be made into a measuring device: with transparent sample-cells, sedimentation rates could be measured.

There were the means of thermal manipulation, as in furnaces, evaporators, dryers, incubators, refrigerators, and freezers. Here the underlying techniques were more various: resistance heating, induction heating (as in diathermy), electric-arc furnaces, and various types of refrigeration.

Controllable light sources were central to many types of investigation, as in photochemistry (the study of the role of radiant energy in chemical reactions) and botany. Special types of lights were useful, as the mercury-vapor light for germicidal and fungicidal lamps or high-speed or stroboscopic flash for the study of rapid changes. There were new sources of radiant energy outside the optical band: radiowave, infrared, ultraviolet, and x-ray sources. A landmark in the history of genetics was the discovery by H.J. Muller in 1927 that x-rays may be used to induce hereditary changes.[62] And electrical technology also provided sources of sound. For example, the acoustic wave generators of the sort developed for sonar were used by chemists in the 1920s and 1930s to catalyze reactions taking place in an aqueous solution.[63]

Laboratory researchers began to use electric and magnetic fields in their investigations, not only in the direct way of studying the influence of such fields on physical or biological phenomena, but also as a means of achieving other types of

[60] Wildes and Lindgren, p. 184.

[61] Borell, p. 128.

[62] Muller.

[63] Putterman.

manipulation. An example of the former was the discovery of the Zeeman effect, which is the splitting of spectral lines when the emitting atoms are subjected to a magnetic field. An example of the latter is the use of magnetic fields to reach temperatures close to absolute zero. Another example of the latter was the development of electrophoresis, one of the most important of biology's analytic techniques. Introduced by Arne Tiselius in Sweden in 1937, it depends on different rates of migration of particles in an electric field.[64]

Scientists, especially physicists, began to employ high-intensity electric and magnetic fields. Robert Millikan, for example, used an electric field to levitate electrically charged droplets of oil and thus measure the charge of an electron. New devices—such as surge generators, oscillators, and signal generators—facilitated their work. Variable-frequency oscillators were used in wave analyzers, which reveal the component frequencies of a signal. Also, frequently there was automatic control of ambient conditions, as in bacteriological incubators, and of experimental intervention, as in automatic titration.

Ion and particle accelerators formed an important class of instruments. Louis Dunoyer in France in 1912 was the first to use molecular beams—a sharply collimated stream of molecules moving in high vacuum—to study atoms and molecules.[65] The beginning of this chapter mentioned the Cockcroft-Walton accelerator and the use of the Van de Graaff generator to accelerate ions. In the late 1930s, linear electron-accelerators were built at MIT and Stanford. Extremely influential were the cyclotrons (accelerators in which the particles followed roughly circular paths) built by Ernest O. Lawrence. His 1931 cyclotron had a diameter of 4.5 inches and accelerated protons to 80 kilovolts. The next year he completed an 11 inch cyclotron that accelerated protons to more than one million volts. (See Figure 8.5.) Earlier one studied nuclear physics using natural radioactivity, but this was expensive and awkward to use; moreover, the artificial sources of accelerated particles provided a range of energies. In building his cyclotrons Lawrence made use of old naval radio equipment.[66] By 1940, cyclotrons had been built at many labs throughout the world.

Many of the devices mentioned herein were electronic devices, as they either incorporated electron tubes or themselves created a flow of charged particles in vacuum or gas. The essence of electronic technology is that electrons moving through a vacuum or gas are controllable in ways not possible when they move in a conductor. Electron tubes encapsulate these regions of controllability; some instruments, such as mass spectrographs, required much larger regions of controllability. The scientific laboratory was transformed by the application of electronics, but it is well to recall that the useful tubes of Fleming, de Forest, and others derived ultimately from the work of physicists interested in the motion of electrons and ions in glass chambers.

[64] Borell, p. 63.

[65] Berthon. For example, in 1912 Dunoyer de Segonzac studied the fluorescence and absorption spectra of alkaline metals and in 1913 the electrical and optical properties of sodium vapor.

[66] Burke, p. 325.

Figure 8.5. Ernest O. Lawrence (photo from Lawrence Berkeley Laboratory, courtesy AIP Emilio Segre Visual Archives).

8.2.4 Medical Technology

By 1945, hospitals, like laboratories and factories, were full of instruments. This was not the case in 1900, when a person could receive treatment during several weeks in a hospital and not undergo any laboratory tests at all.[67] By 1925 in the U.S. clinical testing had become a major activity of hospitals, as blood tests, urinanalysis, and x-ray examinations had become routine and as clinical laboratories worked day and night.[68]

As covered in Chapter 2, diagnostic x-ray became widely used during the Great War.[69] In the late 1920s and early 1930s, Russell Reynolds developed cineradiography (moving x-ray images), with a commercial machine being produced in 1935.[70]

[67] Howell, p. 1.

[68] Howell, p. 3. Examination of urine has been part of medical practice for centuries, and in the second half of the nineteenth century, it became almost routine in U.S. hospitals. The nature of urinanalysis, however, changed fundamentally in the period from 1900 to 1925. Traditional uranalysis, performed mainly by visual examination of the urine, required almost no apparatus. By 1925, it was usual for urinanalysis to include measurements of specific gravity, sugar and urea and testing for solid constituents (isolated by use of a centrifuge) [Howell, pp. 69–102].

[69] The development of x-ray tubes for medical treatment benefited from the work to achieve high voltages for physics research [Norberg and Seidel, Tracking].

[70] It did not, however, become a widely used techniques for several decades.

As early as 1913, the German surgeon Albert Salomon showed that x-ray photography could be used to detect breast cancer, but mammography was not widely practiced until the 1930s and did not become a standard diagnostic tool until the late 1950s. As early as 1897, x-ray treatment of cancer was attempted; radiation therapy (almost exclusively for cancer) later became an important medical treatment. The danger of overexposure to x-rays was recognized early on; in 1925, an international meeting considered the issue of the safety of x-rays, and in 1928, standards for exposure to x-rays were set.[71]

It was in the interwar years that electronics began to be applied to the problem of hearing loss. The hearing aid, like phonograph recording and public-address systems, worked by converting sound to an electric current, amplifying the current, and reconverting it to sound.[72] In 1923, the Marconi Company in Britain began marketing a hearing aid, the "Otophone", which weighed 16 pounds. There followed somewhat smaller devices, which might be made more wearable by having the battery in one pocket, the amplifier in another, and just a small earpiece in the ear. Obviously, for those otherwise unable to participate in conversations, use a telephone, hear music, or see a movie, a hearing aid could improve the quality of life enormously. Another new electronic device of the interwar period was the audiometer (which measured human hearing), notably the Western Electric Model 2A, and there resulted, for the first time, demographic data on hearing loss.[73]

Electric motors and electrically-driven pumps found applications in medicine. For example, in 1927 in the U.S., Philip Drinker invented the iron lung (a chamber enclosing most of the patient's body that causes respiration by alternate compression and decompression) for the treatment of polio victims and others with paralyzed respiratory muscles.[74] Surgery on the heart was greatly facilitated by the introduction in 1936 of an artificial heart that pumps the blood while the heart is being operated upon. And electric dental-drills became widespread in the first years of the century; because they worked much faster than earlier drills, they subjected the patient to less pain.[75]

In medical diathermy—the generation of heat in tissues for medical purposes—some part of the body is exposed to high-frequency electromagnetic waves. (Like microwave cooking, it generates heat within a region rather than heating by conduction from the outside in.) In 1928, Harvey Cushing and W.T. Bowie introduced surgical diathermy, in which a probe, carrying high-frequency current, cauterizes blood vessels to prevent fluid loss. In the interwar years, medical diathermy often caused interference with radio transmissions; for example, a Bell Labs investigation found that a major source of radio interference in eastern New Jersey was a diathermy machine in a Cleveland hospital.[76]

[71] Cochrane's history of NBS.

[72] Another medical application of electronic amplification was the electric stethscope [Fagen, p. 290].

[73] Millman, p. 97.

[74] Borell, p. 256.

[75] Ring. Speeds of electric drills increased gradually, nearing 6000 rpm in the 1940s; in 1960s drills powered by compressed air (capable of 250,000 rpm) displaced electric drills.

[76] Arthur Keller, p. 20.

In the mid-1890s when Willem Einthoven of Leiden University began studying the electrical activity of the heart, he found existing instruments, notably the capillary electrometer, unsatisfactory. He therefore sought to construct an extremely sensitive galvanometer. There being at that time no electron-tube amplifier, he worked to make the d'Arsonval galvanometer more sensitive by reducing the mass of the coil of wire that moved in response to the feeble current detected. He eventually replaced it with a single strand of wire (hence his galvanometer is known as the string galvanometer), and still later with a fine quartz fiber coated with silver. Einthoven's 1903 publication describing the new tool, the electrocardiograph, attracted much attention and quickly led to commercial production in several countries. The results obtained with this extremely sensitive instrument established the measurement of heart potentials in clinical practice.[77] There were, of course, numerous improvements over time, such as the introduction in 1924 of a portable electrocardiograph designed by H.B. Marvin of GE.[78] A related development was the work in the 1920s of Hans Berger, a German psychiatrist, in recording the electrical activity of the brain, and gradually the electroencephalograph became an important research and diagnostic tool.[79]

In about 1930 in the U.S. Alfred Hyman built a cardiac stimulator or pacemaker that applied electric impulses to the heart to cause a regular heartbeat. The so-called Hymanotor weighed about 15 pounds. In 1933, the Baltimore electrical engineer William Kouwenhoven and physician O.R. Langworthy build a defibrillator (a device that administers an electric shock to stop ventricular fibrillation). Later an external version (which could be used without opening up the chest) was developed.

Related to medical technology was the rise of the crime laboratory, which became usual in large U.S. police departments in the 1920s. These laboratories contained tools for chemical analysis, such as infrared, visible, and ultraviolet spectrographs. With such tools, one could show, for example, that two bits of material were chemically identical. Some crime labs had electron microscopes and machines for making x-ray images or x-ray diffraction patterns. A new tool for police investigation (though the results were not usually accepted as evidence in court) was the polygraph or lie detector. The idea was to record electrically a number of physiological phenomena not subject to a great degree of voluntary control (as blood pressure, pulse, respiration, and electrodermal response) while asking the subject questions, with the hope that the recording would allow one to distinguish between true and false responses.[80]

[77] Burch and DePasquale, pp. 29–55, and Rowbottom, pp. 169–171.

[78] Gorowitz, p. III.4.

[79] Borell, p. 145.

[80] Even more important in the investigation of crime than these instruments were the new means of communications, such as two-way radio, teletype, and transmission of photographs and fingerprints by wire. Surveillance was made effective by placing hidden microphones and tapping telephone lines. And through radio broadcasting the police enlisted the aid of the public in the apprehension of criminals.

Electrical technology not only changed medical diagnosis and treatment, but also the way the human body was conceptualized. Consider R. Buckminster Fuller's 1938 definition of man:

> *A self-balancing, 28-jointed adapter-base biped; an electro-chemical reduction-plant, integral with segregated stowages of special energy extracts in storage batteries, for subsequent actuation of thousands of hydraulic and pneumatic pumps, with motors attached; 62,000 miles of capillaries; millions of warning signal, railroad and conveyor systems; crushers and cranes (of which the arms are magnificent 23-jointed affairs with self-surfacing and lubricating systems, and a universally distributed telephone system needing no service for 70 years if well managed); the whole, extraordinarily complex mechanism guided with exquisite precision from a turret in which are located telescopic and microscopic self-registering and recording range finders, a spectroscope,* et cetera*, the turret control being closely allied with an air conditioning intake-and-exhaust, and a main fuel intake.* [81]

8.3 CALCULATING MACHINES

8.3.1 Growth of Applied Mathematics

A rapid growth of applied mathematics characterizes the twentieth century. There are various contributing factors. In many branches of science and technology, theory moved from verbal and qualitative to mathematical and quantitative; for example, solar astronomy, meteorology, genetics, and telephone engineering. Related to this was the spectacular rise in the use of measuring instruments, swelling the data flood of twentieth century science. Mathematics became more useful through its own development, particularly in applications-oriented branches such as statistics and operations research. The instrumental and mathematical tools encouraged a quantitative approach to a wide variety of problems, such as the work on tactical and logistical problems in World War II that stimulated operations research.[82]

This last point is related to the emergence of systems engineering, which is the application of scientific methods to solve problems of large-scale systems. Traditionally, scientific methods had been applied "locally", especially to isolated systems in laboratories. In the first half of the twentieth century, scientific methods began to be applied "globally", as in the design of power and telephone systems, and the pattern was repeated in many areas of industrial research.[83] The systems engineering stimulated new types of applied mathematics, such as statistics, quality control, queueing theory, and information theory. The incandescent lamp and electron tube industries pioneered methods of quality control and helped create what became known as reliability engineering.[84]

[81] R. Buckminster Fuller, p. 18.

[82] Quantitative approaches to such problems were also occasionally taken in the First World War: Croarken [p. 20] tells of a World War I study of anti-aircraft gunnery that made use of desk calculators.

[83] Fagen, p. 1003.

[84] Okamura, pp. 73–75.

In many cases, this growth of applied mathematics depended upon calculating aids, many of which were electromechanical, electrical, or electronic. Abundant quantitative data and extensive calculations had long made astronomers and meteorologists interested in calculating aids, such as numerical tables and desk calculators.[85] Physicists frequently needed calculating aids; in the 1930s, Douglas Hartree, for example, used desk calculators to find, by numerical methods, approximate molecular wave functions as predicted by quantum mechanics.[86] The use of statistics in biology, psychology, economics, and many other areas depended upon desk calculators. As explained in Chapter 3, electric-power engineering stimulated the development of analog computers. And mathematical cryptanalysis was another field whose emergence was tied to calculating machines.[87] At the same time, of course, many areas were held back by computational difficulties.[88]

The crucial point is that in the first half of the twentieth century, there was a great demand for calculating aids from people in many branches of science and technology. (If computers had been miraculously provided to eighteenth or nineteenth century researchers, most of them would have had little use for them.) The demand drove the development of calculating aids, leading eventually to the computer revolution.

8.3.2 Digital Computers

Calculating aids, such as the abacus, the slide rule, and mathematical tables, were well established by the nineteenth century. Mechanical adding and multiplying machines, too, go back centuries, but it was not until late in the nineteenth century that a market for mechanical desk calculators was established. One of the first successful products was the Brunsviga, which was introduced in 1892 and widely used for the next half-century.[89] Another type of business machine, punched-card tabulating machines, were, as mentioned in Chapter 5, developed in the 1890s.

In England, from 1925 to 1936, Leslie John Comrie used both desk calculators and punched-card machines to expedite the work of the Nautical Almanac Office. Comrie's great insight was that scientific data might be processed in the same way that commercial data was processed by banks and insurance companies, using large numbers of people with modest mathematical skills to operate adding machines and tabulating equipment. This required, however, that the calculating task was appropriately organized.[90] Comrie may have been the first to use punched-card machines for elaborate scientific calculation; in 1928 he began a project to calculate future positions of the moon using a sorter, tabulator, and duplicating punch, with data and

[85] Nebeker 1995.

[86] Wilkes 1985, p. 107.

[87] Burke, p. 8.

[88] Bennett 1979, p. 146.

[89] Croarken, p. 13.

[90] Campbell-Kelly and Aspray, pp. 66–67.

intermediate results punched onto Hollerith cards (ultimately a half-million cards).[91] Seeing the wide applicability of his calculating techniques, he set up in 1937 a private Scientific Computing Service (SCS), with a staff of about 20, to do calculations for scientists. Some early tasks involved analysis of the ionosphere and the scattering of neutrons. The immediate financial success of SCS indicates the need for scientific calculation.[92]

In 1934, Wallace Eckert, influenced by Comrie's work, established the Thomas J. Watson Computing Bureau in New York—IBM supplied the machines—to use punched-card machines for scientific calculations, and in 1940, he published the influential book *Punched Card Methods in Scientific Computation*.[93] Punched-card machines were used also at the Columbia Statistical Bureau (set up in the late 1920s) for analyzing the results of educational tests and at Iowa State University in agricultural studies.

In the first half of the nineteenth century, Charles Babbage in England introduced more sophisticated types of mechanical calculators. In the 1820s, he designed what he called a Difference Engine, a mechanical device for computing mathematical tables. Babbage himself never completed a Difference Engine, but Georg and Edvard Scheutz, a Swedish printer and his son, did build a Difference Engine based on Babbage's design and exhibited it at the Paris Exposition of 1855. In the next half-century, it and a few similar machines were used in producing mathematical tables.[94]

One of the reasons Babbage never completed a Difference Engine is that he became interested in a much more ambitious machine, an Analytical Engine, that would be able to carry out any computation. This was a general-purpose mechanical digital computer whose operation would be controlled by a set of cards with specially punched patterns of holes (here Babbage was copying the control mechanism of the Jacquard automatic loom). Though he spent many years elaborating the design of his Analytical Engine, he was unable to obtain financial support for its construction.[95]

The Babbage machines were digital, with information stored in discrete rather than continuous form. Some other early digital computers deserve mention. In 1912 the Spanish inventor Leonardo Torres y Quevedo built a chess-playing device out of electromagnetic relays. The machine could play only one type of endgame, king and rook against king, but it always won and it assessed the legality of its opponent's moves.[96] In the early 1930s, the U.S. mathematician Derrick Lehmer built a "mathematical sieve" (built of motors, wheels, and belts) that examined 30,000 numbers per minute searching for primes.[97]

[91] Ceruzzi 1997.

[92] Croarken, pp. 23–32, 42–46.

[93] Ceruzzi 1997.

[94] Campbell-Kelly and Aspray, pp. 53–60.

[95] Campbell-Kelly and Aspray, pp. 53–60.

[96] Zemanek.

[97] Goldstine, p. 273.

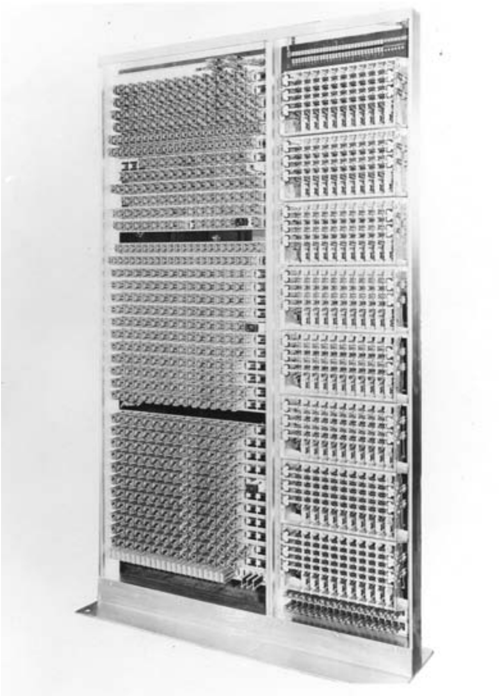


Figure 8.6. Stibitz's Complex Number Calculator (photo courtesy of AT&T Archives and History Center).

The underlying technology of Lehmer's machine was that of electromechanical desk calculators, whereas Torres y Quevedo's machine was based on electromagnetic relays, which were electrically controlled and involved little mechanical inertia. At Bell Labs such relays were used by George Stibitz to build "The Complex Number Calculator" (Figure 8.6). In the early decades of the century it became increasingly common to solve problems in electrical engineering through calculation, and such calculations frequently involved complex numbers (that is, numbers of the form $a + bi$ where a and b are ordinary real numbers and i is the so-called imaginary unit, often thought of as the square root of -1). Because such calculations could be extremely tedious, and though desk calculators helped, they were not designed to do operations on complex numbers. Hence, Stibitz built his relay-based calculator.[98]

The switching of telephone relays still involved mechanical inertia, which limited the rate. With electron tubes, however, there was virtually no mechanical inertia, so much faster rates of switching became possible. A pioneer in applying electronics to calculation was C.E. Wynn-Williams. In the early 1930s, he used banks of thyratron tubes, which have two stable states, to scale down rapid impulse rates (such as those coming from a Geiger counter) so that a mechanical relay would be triggered only every 10 or 100 counts.[99] In World War II, Wynn-Williams applied

[98] Williams, pp. 225–230.

[99] Reich 1939, pp. 458–461.

such techniques to automatic decryption, a subject treated in Chapter 9.[100] Another sort of electronic counter came into use at artillery proving-grounds. A so-called "counter chronograph" counted electric cycles, supplied by an oscillator at a known frequency. The count was started and stopped by electrical signals, which might come from the passage of a shell in front of two photocells (and, knowing the distance between the photocells, one could then calculate the speed of the shell).[101]

8.3.3 Analog Calculators

The essence of analog calculation is that one physical system serves as a model or analog of another. For example, the network analyzers built by the electricity producers constituted small-scale models of the power networks. Most analog computers were, like the network analyzers, specific to particular problems, but some were fairly general-purpose devices. The slide rule is an example: two quantities are represented by lengths on logarithmic scales, the lengths are added or subtracted physically, and the product or quotient is read off the appropriate scale.

The integration problem mentioned in Chapter 2 (calculating the cumulative effect of continuous series of small effects) occurred in a great many contexts and gave rise to a great variety of calculating aids. Power companies, for example, in order to charge customers for the total power consumed, used watthour-meters to sum the continuously varying consumption rate over the entire period of service. These meters were analog calculators of different types: in electrolytic devices the amount of some material decomposed or released or deposited was proportional to the electricity consumed; the much more usual motor watthour-meters registered this quantity in the total rotation produced.

One of the most sophisticated analog calculators of the prewar period were tide-prediction machines. Because most of the factors influencing tides (mainly the positions of the sun and the moon) are foreseeable, it is possible to calculate their times and heights. Doing such calculations by hand, however, is so laborious that up to the 1870s, tide tables were prepared for only a few of the world's ports. In 1872, William Thomson, later Lord Kelvin, built such a tide predictor of gears, rods, pulleys, and wires (see Figure 8.7). Many similar machines were built and served many years. One completed by the U.S. Coast and Geodetic Survey in about 1910 remained in constant use until the 1960s.[102]

What the tide predictor did was to sum a number of particular sinusoidal functions; that is, it calculated the complex curve resulting from the addition of a number of simple curves. In 1897, Albert Michelson and Samuel Stratton built a similar machine, called a harmonic synthesizer, that could be applied to various problems. In 1937, Thornton C. Fry and R.L. Dietzold devised a more complex harmonic synthesizer (called the isograph) for use in solving polynomial equations, and the

[100] Burke, p. 277.

[101] Simon, pp. 162–163.

[102] Campbell-Kelly and Aspray, pp. 60–61, and Williams 1985, p. 205.

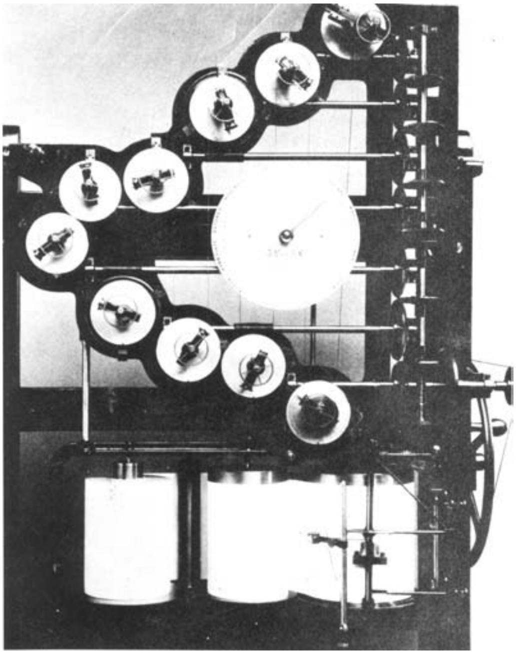


Figure 8.7. Kelvin's tide predictor (photo courtesy of IEEE).

same year H.C. Hart and Irven Travis built an electrical harmonic synthesizer for the same purpose (with values represented by voltages).[103]

The inverse problem was to find the component frequencies of a periodic curve, that is, the simple sinusoidal curves that together would form a given curve. That this could always be done was shown in the early nineteenth century by Jean Fourier: any periodic function **f** can be represented as a sum of sine and cosine functions having periods that are submultiples of the period of **f**. Finding the amplitudes of the sinusoidal components for a given function is called Fourier analysis or harmonic analysis. This is so useful an operation—regularly employed in most branches of science and engineering—that many people have devised mechanical means to do it. As with harmonic synthesizers, early machines were mechanical. James Thomson (brother of William Thomson, Lord Kelvin) invented one in 1876, and O. Mader made a much improved one in 1909. In 1939, H.C. Montgomery devised a harmonic analyzer that used photographic film and photocells (to quantify the light transmitted through superimposed strips of film).[104]

In the early 1930s, in Great Britain, scientists and engineers built quite a number of electromechanical analog computers to solve particular problems, such as the Mallock Machine to solve simultaneous linear equations and the Blackburn Network

[103] Stibitz.

[104] Stibitz.

Calculator to simulate power networks. Such machines, however, were one-of-a-kind devices with extremely limited applicability.[105]

One type of analog machine did have wide applicability and was duplicated: the differential analyzer that Vannevar Bush built at M.I.T. in 1930. As described in Chapter 3, interest in solving problems posed by electric-power networks was a principal motivation to build the machine. Versions of Bush's machine were constructed in several countries. In England, Douglas Hartree, working with Metropolitan-Vickers, completed one in 1935, which was then used at Manchester in various industrial research tasks, such as calculating the potential distribution in thermionic electron tubes.[106] Differential analyzers were built at two other British universities, at Cambridge and at Belfast (Queen's University).[107] The Rockefeller differential analyzer, completed in 1945, was one of the most sophisticated. It was faster and easier to use than earlier differential analyzers in part because it relied increasingly on electrical rather than on mechanical means. Information was fed to the machine on punched paper tape, which operated electrical switches, and instead of mechanical linkages, the Rockefeller differential analyzer used rotating capacitors to convert shaft rotations into electrical signals that controlled motors that turned other shafts.[108]

Most of the early digital computers, such as desk calculators and punched-card machines, were general-purpose devices, while most of the early analog calculators were special-purpose devices. These special-purpose devices, however, were on the whole much more impressive than the digital machines. Their success created interest in the field of automatic computing, and though many scientists and engineers continued through the 1940s to regard analog computing as a more promising technology than digital computing, the interest was eventually transferred to digital machines.[109]

The electronic measuring instruments described above began a revolution in data acquisition for the majority of scientists and engineers. During World War II, as Chapter 9 will show, electronics began to be applied to computing, leading after the war to a revolution in data processing.

8.4 THE PROFESSION OF ELECTRICAL ENGINEERING

8.4.1 The Image of the Electrical Engineer

For a great many people in the early twentieth century, Herbert Hoover was the model of the modern engineer. (See Figure 8.8.) Orphaned at the age of nine, Hoover

[105] Croarken, pp. 47–50.

[106] Croarken, pp. 50–53.

[107] Croarken, p. 58.

[108] Stibitz.

[109] Birkhoff.

Figure 8.8. Herbert Hoover with an early radio (photo courtesy of the Library of Congress, LC-USZ62-111716).

earned a Stanford degree in mining engineering and became a millionaire before the age of 40. Spectacularly successful in directing relief programs in Europe and the U.S. during and after World War I, he served as Secretary of Commerce under Presidents Warren Harding and Calvin Coolidge before becoming President himself in 1929. Until that point, at least, his career suggested to many that a technocratic approach to social problems was the right one.[110]

Hoover wrote of engineering:

> *It is a great profession. There is the fascination of watching a figment of the imagination emerge through the aid of science to a plan on paper. Then it moves to realization in stone or metal or energy. Then it brings jobs and homes to men. Then it elevates the standards of living and adds to the comforts of life. That is the engineer's high privilege.* [111]

Around the turn of the century American popular culture began to give considerable attention to the engineer. By one count, "… the engineer … appeared as the hero in over one hundred silent movies and in best-selling novels approaching five million copies in sales between 1897 and 1920."[112] The engineer was depicted as skilled, scientific, and effective. More than that, he loved what he did. (Engineers were almost always depicted as male.) He was both dreamer and achiever. He was passionate and imaginative, yet rational and prudent. There was fierce determination

[110] Jordan, p. 110.

[111] In Tichi, p. 97.

[112] Tichi, p. 98.

to succeed and exhilaration in attempting what others deemed impossible. One engineer-hero tried to explain the appeal of engineering as follows: "If you can, imagine some spirit seizing hold of you and making you see difficulties as joys—impossible tasks as only things to strike fire from genius."[113] Young readers found engineer role models in Sinclair Lewis's *Dodsworth* (1929) and in the Tom Swift novels (40 of which appeared in the years from 1910 to 1941).[114]

In the late nineteenth and early twentieth centuries, engineering was changing from an occupation that one learned on the job, rising gradually from less to more skilled work, to a profession that one entered through a course of study at an institution of higher education. The engineer attained a higher social stature, possessing science-based knowledge, practicing objectivity in decision making, and standing as the disinterested facilitator between management and labor.[115] Though there were some notable exceptions, such as Charles Steinmetz, most engineers fit the popular characterization of engineers as apolitical and socially conservative.[116] The favorable image of the engineer as skilled, scientific, and effective led by the 1930s to the relabeling of occupations: demolition engineer for wrecker, sanitary engineer for garbage man, printing engineer for printer, and so on.[117]

The establishment of the profession of electrical engineering occurred through many interrelated actions, including creating educational programs, founding professional societies, publishing journals, and setting technical standards.

8.4.2 Societies, Journals, and Standards

Most industrialized countries had professional organizations for electrical engineers before World War II, such as the British Institution of Electrical Engineers (founded in 1871) and the American Institute of Electrical Engineers (founded in 1884).[118] As described in Chapter 4, there was established in 1912 a society, the Institute of Radio Engineers, that aspired to be international. Its membership grew from 46 in 1912, to 3550 in 1927, and to almost 16,000 in 1946. (In 1927 about 16% of its members were from outside the U.S.)[119] In the interwar years, societies for radio engineering emerged in many countries. The British Institution of Radio Engineers was formed in Britain.[120] In France, just three years after the Armistice, Gustave Ferrié and others

[113] These words come from Warren Neale, hero of Zane Grey's *The U.P. Trail* (1918) [quoted in Tichi, p. 120].

[114] Swift.

[115] John M. Jordan, pp. 33–34.

[116] John M. Jordan, p. 36.

[117] H.L. Mencken, in *The American Language* (4th edition, 1936), lists 65 such engineer euphemisms [Tichi, pp. 116–117].

[118] See Rollo Appleyard, *The History of the Institution of Electrical Engineers, 1871–1931* (London: Institution of Electrical Engineers, 1939), and McMahon.

[119] Brittain 1977, p. 100.

[120] British Institution of Radio Engineers. *A Twentieth Century Professional Institution: The Story of the British Institution of Radio Engineers*. London: British Institution of Radio Engineers, 1960.

established the *Société des amis de la TSF*, which became the *Société des radioélectriciens*, and then the *Société française des électroniciens et des radioélectriciens* (SFER).[121]

As technologies matured and engineers became increasingly specialized, societies with narrower focus emerged. For example, in Britain in 1909 was formed the Association of Mining Electrical Engineers.[122] In the U.S. before World War I, there was an Illuminating Engineering Society, also a Society of Motion Picture Engineers. Closely related to electrical engineering was the American Acoustical Society, founded in 1929, with Harvey Fletcher of Bell Laboratories as its first president.[123] Resisting this trend was the fact that many types of electrical engineering shared theory and techniques. Leading engineers—Pupin, Kennelly, Elihu Thomson, Steinmetz, and many others—contributed both to electric-power engineering and to communications engineering, indeed using the same physics and mathematics in the two realms.[124] As radio engineering evolved into electronics and as electronics became pervasive in almost all types of electrical engineering, it made less sense for there to be a separate society for electronics. In both Great Britain and the U.S. the radio engineering societies mentioned above later merged with the older electrical engineering societies.

These professional societies held meetings and conferences where engineers could learn about the theories and techniques that others had developed. Even more important in the dissemination of new results were the journals that these societies published. For example, the *Proceedings of the Institute of Radio Engineers*, which began publication in 1913, made new findings known worldwide. Societies honored outstanding achievements through prizes and awards.

Societies in some cases helped to define a set of professional ethics. The American Institute of Electrical Engineers, for example, adopted a formal code of ethics in 1912, which provided guidelines for the engineer in dealing with employer or client (such as: "An engineer can not honorably accept compensation, financial or otherwise, from more than one interested party, without the consent of all parties") and stated obligations of an engineer to the general public and the engineering profession (such as: "It is desirable that first publication concerning inventions … should not be made through the public press …"). Whether, however, this code significantly affected the behavior of engineers or served mainly a ceremonial function is debated.[125]

Professional societies helped to create national engineering cultures. There were other elements, of course, such as standards and educational organizations, both considered below. Engineers frequently made efforts to educate the general public about their technologies—important to individual and government decision-making

[121] Libois, p. 51.

[122] A.V. Jones, p. 4.

[123] Fagen, p. 965.

[124] Coggeshall 1963.

[125] The code is reprinted in Brittain 1977, pp. 89–92. Layton (1971) argues that the code served mainly a ceremonial function.

and important in recruiting young people to the profession—through lectures and books. Outstanding examples are Michael Pupin's 1922 autobiography, which won a Pulitzer Prize, and Vannevar Bush's 1945 *Science: The Endless Frontier*, which greatly influenced national science policy in the postwar era.[126]

Science, industry, and commerce require standardized units of measure. For science to be a collective enterprise—for scientists to understand each other's results and to share data—there must be standardized units, and for science to achieve extreme accuracy (recall Richtmyer's remark, quoted above, that "discovery is quite likely to be found lurking in the next decimal place") there must be highly refined measurement procedures. In industry, quality of products and manufacturing techniques themselves often depend upon the fabrication of components to extremely low tolerances, which in turn depends upon extremely accurate measurement. And commerce is greatly facilitated by accurate and communicable measurements. Governments and professional societies have had the leading roles in the development of metrology—the science and technology of measurement—and in the acceptance of standardized units.

Pursuing an idea of Carl Friedrich Gauss, Wilhelm Weber showed in 1851 that one could define all electrical units in terms of the fundamental units of mechanics—length, mass, and time.[127] The British Association for the Advancement of Science later established such a system of "absolute" units, and it was a modified version of this system that gained international acceptance in the early 1880s.[128] The metric system had originated in France in 1791, and French scientists and engineers took a leading role in working toward worldwide standards. International conferences in Paris in 1870 and 1872 led to the establishment in 1875 of the Bureau International de Poids et Mesures in Sèvres, near Paris (where it remains to this day).[129] In addition, an 1881 congress specified "reproducible" units that could be created in a laboratory and that would closely approximate the absolute units. (The ohm, for example, was approximated by the resistance at 0 °C of a uniform column of mercury with mass 14.4521 g and length 106.3 cm.)

Governments began to set up national laboratories to maintain, improve, and apply systems of measurement. In 1887, Germany established the Physikalische-Technische Reichsanstalt in Charlottenburg (a suburb of Berlin) to use scientific

[126] Michael Pupin, *From Immigrant to Inventor* (New York: Charles Scribner's Sons, 1922), and Vannevar Bush, *Science: The Endless Frontier* (Washington, DC: U.S. Government Printing Office, 1945).

[127] The other quantities of mechanics are defined in terms of the fundamental units: acceleration in terms of length and time, force in terms of mass and acceleration, work in terms of force and length, and so on.

[128] Weber contrasted "absolute measurement" with "relative measurement". One performs the latter by comparison with an arbitrary quantity of the same kind (as electrical resistance in terms of the resistance of a meter of No. 16 copper wire), the former by relating the quantity to fundamental units of another kind (as relating the ohm to the mechanical units of length and time). A set of absolute units forms a single, coherent system, "avoiding useless coefficients in passing from one type of measurement to another." [Bordeau p. 280.]

[129] Pyatt, pp. 14–15.

methods in meeting the measurement and standardization needs of industry and commerce. Great Britain and the U.S. followed suit: Great Britain set up its National Physical Laboratory in Teddington (near London) in 1900, and the U.S. its National Bureau of Standards in Washington, DC in 1901.[130]

The needs of the new electrical industry provided great impetus for the establishment of the national laboratories. In Great Britain the need for electrical standards was a principal motivation for founding the National Physical Laboratory.[131] And in the U.S., according to a 1904 report on the U.S. National Bureau of Standards, "It was largely to meet their needs [those of the electrical manufacturers and instrument-makers] that the bureau was organized. …"[132]

There was frequent interaction between national laboratories. In 1910, for example, those of Great Britain, France, Germany, and the U.S. collaborated in a series of measurements in Washington, DC to assign values to standard resistors and standard cells. Such agreements underlay the worldwide use of a single set of units.

The national laboratories maintain reference devices, such as the Weston voltaic cell, used as a standard in measuring voltage. Soon after its establishment the National Physical Laboratory (NPL) began receiving large numbers of instruments for testing, as manufacturers prized the label "NPL Approved". Already in 1905 such work, which the companies paid for, accounted for 20% of all work at NPL, which then employed 65 people.[133] Technological advance brought with it metrological challenges. The use of higher voltages for power transmission prompted the NPL to construct a special building, which opened in 1927, where standards and measurement techniques related to high-voltage transmission could be developed.[134] Wireless communications posed numerous challenges, and in 1933 NPL expanded the Wireless Division of the Electricity Department to a separate Radio Department.[135]

There is a need for standards in research, in production methods, and in the final products. For example, standardization of motion-picture technology was vital to the rapid growth of the film industry. There needed to be agreement on film size, frame size, scheme of sprocket holes, speed of the film motion, manner of recording sound, and so on. Agreement came about partly through the dominance of particular companies (such as Western Electric with sound movies) and partly through the standardization efforts of the Society of Motion Picture Engineers (formed in 1916).[136] The increasing importance of standards led in the 1930s to the recognition of a new specialty of standards engineering.[137]

[130] Cochrane, p. 39. In 1988 the National Bureau of Standards became the National Institute of Standards and Technology.

[131] Pyatt, pp. 12–20.

[132] Quoted in Cochrane, p. 103.

[133] M.E.W. Williams, p. 49.

[134] Pyatt, pp. 95–96

[135] Pyatt, p. 97.

[136] Raibourn.

[137] Ryerson, p. 1324.

8.4.3 Education

Part of the process of making engineering into a profession was establishing educational programs, a great many of which came into being in the period from 1880 to 1930. In the U.S., the number of students awarded engineering degrees of all types increased from about 230 in 1880, to more than 11,000 in 1930.[138]

In the U.S. from the late nineteenth century on, there was a trend in engineering education away from shop work and hands-on experience and toward the study of science and mathematics.[139] At the same time, there were efforts in many places to ensure that the education that universities were providing was suited to the work of engineers in industry. Among the leaders in establishing ties between industry and EE education were Dugald Jackson at MIT and Frederick Terman at Stanford.[140] At MIT, for example, there was a collaborative educational program with GE beginning in the 1920s.

The early decades of the century saw many debates over the content of EE education. These reflected different views of the role of the engineer in business: a highly trained technician, a designer possessing scientific knowledge and mathematical skills, a supervisor of shop or factory, or a corporate executive.[141] There came to be a clearer differentiation between technicians and engineers, with the crucial difference being that the latter makes regular use of mathematics.[142] A technician's skills could be learned on the job, while an engineer's skills almost required formal education. It came to be expected that engineers would understand phenomena in mathematical terms, use mathematical calculations, and often conceptualize problems as mathematical models. Algebra, graphical techniques, and calculus became everyday tools.

As the work of engineers became increasingly abstract, education moved somewhat away from hands-on practice, with more time given to analytical and theoretical grounding.[143] In some areas, such as radio engineering, an undergraduate education gave hardly enough time to learn the relevant mathematics and physics, and in the U.S. beginning about 1930 there was rapid growth in graduate EE programs.[144] Another change at about the same time was that technical writing became a part of engineering education in many U.S. universities. While English may have been required earlier as part of the humanistic education of the engineer, at this time there was a clear demand in the workplace for engineers who could convey technological ideas clearly and concisely. Hence there appeared courses specifically designed for

[138] Carlson 1988. In the same period the number of practicing engineers increased from 7000 to 226,000.

[139] Carlson 1988.

[140] Carlson 1988.

[141] Carlson 1988.

[142] Adams, p. 43.

[143] Wallich.

[144] Nebeker 1994, pp. 7–9.

presentation of the technical material, and these were seen as part of the utilitarian training of the engineer.[145]

8.4.4 Engineering Science

"Natural science"—or simply "science" in its usual meaning—may be defined as the investigation of the natural world, "engineering science" as the investigation of devices fashioned by humans. Both involve introduction of concepts, discovery of regularities, and formulation of theories. Though engineering science draws heavily on physics and chemistry, it has a life of its own, with concepts, laws, and theories applicable only to engineered objects. Radio engineers, for example, introduced concepts like amplification factor and transconductance for tubes, or sensitivity, selectivity, and fidelity for receivers; they measured such parameters, found regularities, and devised theories to account for the behavior of tubes and receivers. Though engineers of the interwar period more often used the phrase "applied science" to denote such work, "engineering science" seems preferable in suggesting the autonomy of the activity. Another phrase common in that era was "engineering research"; here, too, "engineering science" seems preferable, suggesting more clearly that knowledge is the main product.[146]

The picture remained, however, confused. Electrodynamics and some other branches of physics were much more concerned with the behavior of artificial systems than of naturally-occurring phenomena. Many of the people doing engineering research were trained as physicists, not engineers. Moreover, people thought of scientists as producing knowledge, engineers as using existing knowledge to make useful devices. As Vannevar Bush at MIT pointed out in 1935, a new conception of the engineer was called for, with engineers taking up "the research spirit of the scientist."[147]

In the nineteenth century, much of the design of electrical devices and systems proceeded largely by trial and error. This process was improved by the introduction of measurement techniques. We cited earlier Kelvin's dictum, that an essential step in understanding a system is to devise ways to measure the relevant variables. The value of measurement as a heuristic was attested by Arthur Keller, inventor of stereophonic recording. He wrote: "In solving problems, one important method is to measure some of the factors related to the problem. Often the results of measurements lead to entirely new directions and inventions."[148] Hendrik van der Bijl, one of the most important developers of electron tubes in the second decade of the century, wrote in 1919: "It is hardly possible to meet the requirements of efficiency and satisfactory operation of the device without an explicit mathematical formulation of its operation."[149]

[145] Kynell.

[146] Kline 1995.

[147] Quoted in Kline 1995, p. 214.

[148] Keller, p. 105.

[149] Van der Bijl.

Through analysis of a system on the basis of physics or the introduction of a quantitative theory, new areas were added to engineering science. One of the oldest was transmission line theory. Later came electrical circuit theory. Its main objective was to be able to design highly accurate circuits built with mass-produced components, which have quite variable characteristics (the variability of a component such as a resistor or capacitor frequently exceeds one part in a hundred, yet circuits in many applications must be much more accurate).[150] There emerged a theory of electrical filters.[151] In the 1930s a coherent subject of control systems emerged.[152]

Engineering science allows designs to be conceived and evaluated before they are built. This possibility of systematic design to meet preselected criteria is an important goal of engineering. By the time of World War II, generators and motors could be designed on paper to achieve a specified performance, and when built, these machines usually performed as expected. Design of electronic devices, however, was more often "cut-and-try", in part because of variability in performance of components, caused by modest standards of quality control in their manufacture. Hence at that time heavy-current engineering was seen as more scientific than light-current engineering.[153]

As engineering design became more mathematical and scientific, the solution to problems in one area were more readily applied to problems in other areas; information theory, control theory, systems engineering—these conceptual tools became quite independent of any type of hardware, applying equally well to mechanical, electromechanical, and electronic systems.[154] "Partly because so much of modern science and engineering knowledge is applicable to many industries, and partly because progress in one branch of science or engineering has been more or less matched by progress in some other branches, the results indeed suggest that mankind today possesses, and for some time has possessed, a *multi-purpose knowledge base*. We are, and evidently for some time have been, able to extend the technological frontier perceptibly at virtually all points."[155]

By mid-century, there was an intellectual excitement in engineering science that was lacking in many of the older sciences. The situation may be compared to that of geography and science in the nineteenth century. As the European explorers and adventurers of the fifteenth and sixteenth centuries ranged farther and farther from home, they discovered more and more strange lands. In the nineteenth century, though, the globe was fairly well mapped. Many sciences, by contrast, were beginning to reveal new realms, and scientists had the enthusiasm of explorers. By the mid twentieth century, many areas of science were fairly well mapped out—mechanics, optics, the chemical elements, and human anatomy for example—yet the forays

[150] Dewilde and Helton.

[151] Nebeker 1998.

[152] Bennett, p. 3.

[153] John M. Bennett 1996.

[154] Mindell 1995b.

[155] Schmookler, p. 210.

of the engineers seemed quite unbounded. There was a feeling that just as increasing the understanding of the natural world—the things that existed before humans—was a noble objective, so was increasing the understanding of possible worlds—all things that might be constructed or done—a noble objective. Adding to the excitement of the latter endeavor was that feeling of unboundedness: while natural science deals with the materials and processes that occur naturally, the realm of what might exist is unbounded and that each technical advance frees human creativity even more.

Chapter 9

World War II and Electrical Technology

9.1 THE WORLD WAR RESUMED

9.1.1 Renewal of War

On the evening of 31 August 1939, nine Germans, dressed in uniforms of the Polish army, stormed the German radio station at Gleiwitz near the border. Those listening to the station heard gunshots followed by an appeal, in Polish, for Poles to attack Germany. This staged action, arranged by the Gestapo and chosen because—through broadcasting—it could be witnessed by a great many people, served Hitler as a pretext for his invasion of Poland the next morning.[1]

That invasion is usually regarded as the beginning of World War II, but it may be seen instead as the flaring up of the global war that had begun in 1914 and smoldered since the armistice of 1918. In the decade following the armistice, there was civil war in Russia, war between Greece and Turkey, war between Poland and Russia, fighting in Korea to achieve independence from Japan, and fighting in Ireland to achieve independence from England. In the 1930s, there was the Spanish civil war, Italy's invasion of Ethiopia, and full-scale war between Japan and China.

Though the Great War was meant "to make the world safe for democracy", in the two decades that followed, that form of government seemed on the retreat. In Russia, democracy lasted only nine months until the Bolsheviks came to power late in 1917, and the dictatorship Lenin established became even more powerful under his successor, Joseph Stalin. Italy's fragile democracy succumbed in 1922 when Benito Mussolini took power. In Japan the military gained control of the government at the beginning of the 1930s. Germany's Weimar Republic lasted only until 1933, when Hitler, quite legally, assumed charge of the country. In Spain, Nationalists led by Francisco Franco began their successful fight against the republic in 1936.

[1] Dear, p. 488.

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These dictatorships frequently reinforced each other. Both Hitler and Mussolini supplied substantial military assistance to Franco. The Soviet Union helped Weimar and Nazi Germany rearm secretly (in violation of the Versailles Treaty) and in turn derived military know-how from the Germans.[2]

German technology, especially military technology, made its way to Japan, too. As one of the Allied powers of the Great War, Japan took, as reparations, German aircraft, submarines, radio transmitters and receivers, and much other equipment, which then served as starting points for Japanese development. Later, Japanese engineers traveled to Germany, where they visited factories and purchased advanced equipment, and many German engineers were invited to work for Japanese firms. There were also joint ventures between German and Japanese companies (as between Siemens and Furukawa), licensing of German patents, and study of German technical publications. Finally, the growing political alliance between Germany and Japan, marked by the 1936 Anti-Comintern Pact and the 1940 Tripartite Pact, further facilitated technology transfer.[3]

In the 1930s, three of these dictatorships—the German, the Italian, and the Japanese—posed the chief threats to the existing world order. Japanese military aggression in Manchuria in 1931 led to the establishment the following year of the puppet state of Manchukuo, and in 1937 Japan began waging war on a large scale and soon controlled much of China, including most of its cities. Italian forces invaded Ethiopia in 1936 and occupied Albania in 1939. Hitler militarized the Rhineland (contrary to the Versailles Treaty) in 1936, and two years later Germany annexed Austria and part of Czechoslovakia. These moves evoked protests, but no military action, from the League of Nations and many countries individually.

In the democracies of Great Britain, France, and the U.S., there had been a general disinclination to spend money for military preparedness. The terrible human losses suffered by Great Britain and France in the Great War had weakened the resolve of these countries to stand up to Hitler.[4] Churchill called the years following the first world war "that period of exhaustion which has been described as Peace".[5] There was a widespread pacifist movement, and it was especially strong in Great Britain. In the U.S., an isolationist mood prevailed. And the Great Depression heightened these trends.

German remilitarization and other events of the late 1930s, however, finally changed attitudes in Great Britain and France enough that these countries, but not the U.S., began preparing for war. The Great War had made clear that battles tended to be won by the side with the most tanks, artillery, planes, and material supplies of other sorts. Preparation for war, therefore, meant first and foremost mobilizing the economy.

[2] Dear, p. 1230. The two militaries shared an air base at Lipetsk and a tank school at Kazan.

[3] Pauer, and Braun, pp. 247–254.

[4] Hobsbawm, p. 152.

[5] *Gathering Storm*, p. 37.

9.1.2 Mobilizing for War

The experience of the First World War and the increased intervention of governments in economic affairs during the Depression helped make mobilization in World War II, in almost every country, more successful than in World War I. In the late 1930s, Germany, Italy, and Japan were already mobilizing for war.[6] Great Britain and France belatedly followed suit. Much slower to mobilize were the Soviet Union and the U.S.

The Soviet Union, having signed a nonaggression pact with Germany in August 1939 and one with Japan in April 1941, did not expect full involvement in the war. The picture changed, of course, with the German invasion of 22 June 1941. Within months, Germany had taken the main industrial regions of the Soviet economy. Forty percent of the population, ⅔ of iron, steel, and coal production, 60% of armaments production, and 42% of the electric generating capacity fell into German hands.[7] Yet by relocating factories further east—in the period from July to December 1941 some 1500 factories were moved—and by building new ones, the Soviets restored production. Indeed, by the end of 1942 they were producing more weapons than the Germans, and the gap widened thereafter.[8]

The U.S., though strong industrially—in 1941 it produced more steel, aluminum, oil, and motor vehicles than all the other major countries combined—was quite unprepared for war. In 1940, just 2% of its national product went for defence, whereas in Germany before war broke out the military claimed one quarter of the national product.[9] The U.S. mobilization that began even before the attack on Pearl Harbor is remarkable both for the rapid redirection of economic activity and for the overall economic growth. By late summer 1942, U.S. armaments production surpassed that of Great Britain, and by 1944, it was six times as great.[10] By war's end, the U.S. had manufactured almost ⅔ of all Allied military equipment, such as aircraft, artillery, tanks, and trucks.[11] The economy as a whole grew at an annual rate of about 10%, the fastest ever before or since, and industrial production nearly doubled.[12]

Electrical technologies played a large role in the mobilization for war. Most important was electric power. At the time of the First World War, U.S. industry was in large measure electrified, but the amount of electric power per worker increased substantially in the subsequent decades, from 1.25 horsepower per worker in 1918 to more than 5 horsepower in 1945. This led to greater effectiveness, and industrial productivity in World War II was almost two-and-a-half times that in

[6] In Japan the 1938 National Mobilization Law gave the government much greater powers over the economy [Morris-Suzuki, p. 147].

[7] Dear, p. 1212.

[8] Overy, pp. 180–183.

[9] Overy, pp. 190, 199.

[10] Milward, p. 172.

[11] Overy, p. 192.

[12] Hobsbawm, p. 48. Federal spending increased from $9 billion in 1940, to $95 billion in 1944. The war greatly speeded the industrialization of the West Coast.

World War I.[13] To keep all the factories and shipyards operating, the U.S. electric industry increased by 50% the amount of power generated from 1937 to 1945, and though there were wartime shortages of many materials, there was almost always enough electric power.[14]

Providing power to new factories was greatly speeded by the wartime innovation of “unit substations”. Previously the power system for each new factory was custom designed. Now standardized units—metal-enclosed and factory-built sets of transformers and switchgear—were manufactured in quantity so that new power systems could be quickly assembled.[15]

One of the most important electrical technologies of the war was arc welding, which increasingly replaced riveting as it saved metal, manpower, and time. In shipbuilding, one welder could do the work of a four-man riveting crew, and it cut by one-quarter or more the time required to build a ship.[16] Henry Kaiser used this and other methods to reduce the time needed to build a standard cargo vessel (called the Liberty Ship) from 1.4 million man-hours and 355 days in 1941, to 500,000 man-hours and 41 days in 1943.[17] The spectacular results achieved by Kaiser finally induced British shipyards in 1943 to adopt welding on a large scale.[18]

Welded construction was one of the advantages of the tanks Erwin Rommel led against the British in North Africa. A shell striking a British tank could sent the rivet heads flying inside the tank, causing injury or death. After the U.S. entered the war, engineers developed a new type of arc welding suitable for building tanks, and the “General Sherman” tanks thus constructed stood up well in combat.[19]

With welding, drilling, milling, and other construction techniques, automatic control could increase productivity. Automatic welding was a principal reason the Soviets were able to increase tank production as rapidly as they did.[20]

Automatic test of assembly-line products also increased productivity.[21] For example, the U.S. Army discovered that some of its grenades exploded prematurely. The cause, it turned out, was that some fuses received too little powder during manufacture. GE built a machine to check the fuses automatically. The fuses moved on a belt past an x-ray beam that caused a certain level of fluorescence on a screen when the powder charge was satisfactory. When the level of fluorescence changed, indicating a defective fuse, a photocell triggered an alarm and caused a dab of paint to be placed on the fuse.[22]

[13] Miller, p. 138.

[14] Miller, p. 138.

[15] Miller, pp. 143–144.

[16] Miller, pp. 148–150. In the U.S. four-fifths of the merchant ships built during the war were welded.

[17] Overy, p. 194.

[18] Millward, p. 191.

[19] Miller, p. 141.

[20] Overy, p. 186. The widespread adoption of welding prompted the suggestion that Rosie the Riveter should instead have been Wanda the Welder [Overy, p. 197].

[21] Editors, p. 44.

[22] Miller, pp. 167–168.

Labor shortages increased the interest in automation, and government support of R&D often bore fruit in manufacturing efficiency. Governments in many countries compelled manufacturers to share know-how, so technical knowledge spread much more rapidly than it had in peacetime.[23] Also, governments promoted standardization in manufacturing. For example, when the U.S. entered the war, there were some 2300 different electron tubes in army and navy equipment; at the end of the war there were only 224 military tube types. There was also standardization of other components, such as capacitors, resistors, insulators, and switches.[24]

For these and other reasons there were great gains in productivity during the war. In the U.S., overall worker productivity rose 21% from 1940 to 1945, with much greater gains in certain areas, such as shipbuilding, where productivity tripled.[25] In Germany, labor productivity in the war industries increased 60% from 1939 to 1944,[26] while in the Soviet war industries, which began at a lower level, the output per worker doubled or tripled during the war.[27]

A vital part of wartime mobilization was coordinating the actions of the armed services, the civilian government, industry, and commerce, which greatly increased the demand for all types of communications. The existing common-carrier systems—telegraph, telephone, and mail—bore the heaviest burdens. In the U.S., war brought a great increase in long-distance calls; the number of AT&T long-distance circuit-miles increased from 3.8 million at the end of 1939, to 9.7 million at the end of 1945. The development in the 1930s of broadband carrier telephony (described in Chapter 7) was perfectly timed to permit this great increase in long-distance traffic with relatively little increase in physical plant.[28]

The war brought also a much greater use of radio-links for telegraph and teletype communications, as radio-links could be set up more rapidly (essential in combat zones), could span great distances, and could supplement wire-links, such as the Atlantic cables, when traffic increased enormously. The fading often encountered with long-distance radio, though it could usually be tolerated for voice communications, caused serious problems for the digital messages of telegraph and teletype. Engineers countered with several techniques. One was frequency diversity, the sending of each message on two channels located in different parts of the spectrum; it was unlikely that fading would obliterate both channels simultaneously. Another was the use of frequency-shift keying, with two different tones designating mark and space, rather than the usual on-off keying; on a transmission path with

[23] Millward, p. 173.

[24] Editors, p. 44.

[25] Dear, p. 1181.

[26] Dear p. 1283.

[27] Overy, p. 186. In the Soviet Union in the period from 1941 through 1943, the manhours required to manufacture a 152-mm howitzer fell from 4500 to 2400, and to manufacture the Ilyushin 4 aircraft from 20,000 to 12,500 [Millward, p. 186].

[28] Fagen 1978, pp. 232–234. The highly efficient use of copper by broadband carrier telephony was also crucial, as that the demand for that metal far exceeded supply.

rapidly varying loss, this method produced much less ambiguity between mark and space than did the earlier method.[29]

Effective wartime mobilization depends upon more than production techniques and point-to-point communications. It depends also—as the Great War had shown—upon psychological factors, such as willingness of soldiers to risk death and the willingness of the population as a whole to bear food shortages, longer working hours, and bombing. Governments, therefore, sought ways to influence attitudes, and here too electrical technologies played a large role.

9.1.3 Propaganda

In many belligerent countries, people were reminded of the war every day by the government-imposed blackouts of cities and towns. The blackouts recalled life 50 years earlier, before electric lighting became common, and when the danger of air raids was past, the resumption of outdoor night-lighting was greeted enthusiastically. For example, in London after victory over Germany, when the powerful lights outside Buckingham palace were turned on, there were, in the word of one reporter, "cheers and ohs from children who had never seen anything of that kind in their short, blacked-out lives." [30]

Electrical technologies shaped, in addition, the aural landscapes of wartime. Cities in many countries experienced the "prolonged banshee howlings" of air-raid sirens.[31] When Germany was defeated, the British government "decided against sounding the sirens in a triumphant 'all clear' for fear that the noise would revive too many painful memories."[32] People everywhere listened to the radio to follow events, and one historian has written that World War II "was quintessentially the war of the radio news bulletins. …"[33] And during the war public-address systems came into widespread use. A great many of them—in factories, offices, shops, and public buildings—were used principally for playing recorded music.[34] An American reporter in London during the war commented on the incessant music in the air-raid shelters and added "This public music is a wartime phenomenon; the railway stations, too, have acquired the habit of playing … records to speed the departing trains."[35]

[29] Fagen 1978, pp. 246–247.

[30] *New Yorker Book of War Pieces*, p. 475.

[31] The phrase comes from *New Yorker Book of War Pieces*, pp. 62–63, 69. Siren-technology advanced during the war. For example, Bell Laboratories developed a 40-kilowatt acoustic siren, one of which, it was reported, could produce 90 dB sound over most of lower Manhattan [Millman, p. 103].

[32] *New Yorker Book of War Pieces*, p. 474.

[33] Hobsbawm, p. 24. Even before the war a survey conducted in the U.S. found that ⅔ of the population preferred radio news to newspapers and magazines (Harvey Green, p. 196). In 1939 people learned about the events surrounding the outbreak of war through radio, not, as they had in 1914, through newspapers [Bessel 1996].

[34] Millard, pp. 3–4. It was during the war that it became common to play music in factories and offices.

[35] Behrman, p. 430.

As these examples show, governments employed electrical technologies to influence people, and the First World War had shown how important psychological factors were in wartime, both in the fighting and on the home front.

During World War II, as earlier, Germany led the way in governmental use of the media. Hitler continued to employ radio to build support for the Nazi regime. For each military campaign, he personally chose a musical fanfare that was played preceding the reporting of victories,[36] and radio served to build up the image of certain generals, such as Erwin Rommel, who became national heroes.[37] Listening to a foreign broadcast was prohibited (regarded as treason and punishable by death), though many did so nevertheless.[38]

While a great many Germans believed the Nazi propaganda, many did not. C.F. von Siemens, head of the Siemens companies, must have spoken for many engineers when he wrote in 1941 that: "Those who were once proud that their work was devoted to the task of serving progress and humanity, can now only be sad that the results of their work merely serve the evil of destruction."[39] Many engineers must have adopted dilatory tactics, as did Herman Schwann when ordered to investigate materials for antiradar coatings.[40] It is likely that if the German people had had greater access to non-Nazi sources of information, they would much earlier have recognized the inevitability of defeat.

Germany used radio also to influence non-Germans. As a rule, as soon as the German army conquered a country, it would take control of radio and press.[41] Radio also helped in the conquest of France. In late 1939 and early 1940, broadcasts from Germany helped undermine French morale—also under attack from the French Communist party, which argued against any defense of French capitalism—and thus contributed to the French military collapse in June 1940.[42] Nazi propaganda minister Joseph Goebbels exploited the stance of the French Communist party by running a station (Radio Humanité) that claimed to be the voice of that party and that encouraged opposition to the French military effort.[43] In May and June 1940, as German armies moved into France, mobile radio stations, with French Nazi sympathizers as announcers, followed the front line and helped destroy French morale.[44] Resentment of Great Britain was stimulated with the slogan, "England means to fight this war to the last Frenchman." [45] Germany also directed broadcasts toward Britain, where

[36] Speer, p. 180.

[37] Dear, p. 489. The Americans and British took Nazi propaganda seriously, hence took over all radio stations and newspapers as they occupied Germany [Eyck].

[38] Schwann interview by Nebeker.

[39] Siemens, p. 260.

[40] Nebeker 1994, pp. 34–35.

[41] Dear, p. 1086. For example, when the Germans took control of Rome after the Italian capitulation, they began by cutting certain telephone wires and seizing radio stations [*The New Yorker Book of War Pieces*, p. 541].

[42] Dear, p. 1085.

[43] Soley, p. 15.

[44] Sorlin.

[45] Soley, p. 13.

the name “Lord Haw-Haw” came to be applied to all male announcers (some of whom were pro-Nazi British emigrés) of these broadcasts.[46] Later in the war, broadcasts were directed toward U.S. soldiers; one of the announcers was the American Mildred Gillars, known as Axis Sally.

German radio gained listeners through its use of magnetic tape recording, which, as described in Chapter 6, was developed in Germany in the 1930s. Recorded music from Allied stations came either from commercial records or transcription disks. The magnetic recording that the German stations used allowed a much longer playing time and a wider frequency range, and these advantages were apparent to listeners.[47] Hence many people outside of German-controlled Europe elected to listen to German stations.

The Nazis considered cinema their most effective means of controlling German culture.[48] Particularly noteworthy among the propaganda films was *Sieg im Westen*, a cinematographically outstanding portrayal of the 1940 triumphs over Netherlands, Belgium, and France.[49] During the war German cinema turned somewhat away from direct and indirect propaganda and toward escapist entertainment, because, as Goebbels said, “to keep [the] people happy … is of strategic importance too.”[50]

In Italy, Mussolini, like most other leaders, used radio to address the people directly. Cinema, too, served the regime. The *Direzione generale per la Cinematographia*, set up in 1934, exerted considerable control over the making and exhibiting of movies. It excluded almost all major films produced outside Italy, though its efforts to develop a Fascist cinema achieved little, in part because of the unwillingness of the public to attend movies with explicit political messages.[51] The Fascists did use cinema to great effect at the time of the Abyssinian invasion: extensive newsreel coverage and full-length docu-dramas helped raise the regime’s popularity to its high point.[52]

In Japan, radio broadcasting had always been an instrument of government policy. Radio proved so useful in creating support for the war with China that in 1939, the government began a nationwide drive to encourage radio ownership, and as a result the number of license holders increased from 4.2 million in 1938, to 5.7 million in 1940.[53] However, ownership of shortwave receivers—which could receive broadcasts from much of the world—was strictly forbidden.[54]

[46] Soley, p. 20.

[47] Mullin. The Allies did develop magnetic wire recording, and one of its applications was recording radio transmissions [Dear, p. 1040].

[48] Dear, p. 479.

[49] Dear, p. 1086.

[50] Dear, p. 479.

[51] Ellwood.

[52] Ellwood.

[53] Daniels.

[54] Ryo.

Shortly after the attack on Pearl Harbor a government official broadcast the following:

> *Now is the time for all people to rise for the nation. The government and people must be united. One hundred million Japanese must join hands and help each other to go forward. The government will inform the people over the radio of where our nation will go and how they should behave. All the people of Japan please gather round the radio.*[55]

Hours of broadcasting were increased, and almost all programming was aimed directly at supporting the war effort, justifying government policies, exhorting workers to increase productivity, urging people to raise vegetables, and so on. Interest in radio increased, and in 1943, 7.3 million families had licenses. In mid-1944, as reports from the fronts became grimmer and as living conditions at home deteriorated, the government, paralleling the change taking place in German radio, adopted a new strategy: to raise morale through entertainment, which traditionally had been a small part of Japanese broadcasting.[56]

Following the two atomic bombs in August 1945, the Cabinet decided to surrender, but feared that patriotic military or civilian groups would continue armed resistance or even attempt to take over the government. The Cabinet believed that only a direct message from the Emperor could maintain national unity, and on 15 August, Emperor Hirohito told the nation that Japan had decided "to effect a settlement of the present situation"; words such as "surrender" and "defeat" were avoided for fear of provoking opposition to the government decision.[57] Because the media had continued to give the impression that the Japanese military was usually victorious, the people were, in the words of one Japanese, "struck dumb with surprise, bewildered and aghast" at the Emperor's announcement of termination of the war.[58]

Japan used radio in an attempt to gain sympathizers outside Japan for its Greater East Asia Co-Prosperity Sphere, with some success among native populations, and—undoubtedly with less success—to undermine morale in Australia and among U.S. soldiers and sailors in the Pacific. In 1943, the Japan Broadcasting Corporation was making shortwave broadcasts in 24 languages using three 50-kilowatt transmitters.[59]

Many female announcers were called Tokyo Rose. A typical broadcast included the following: "Hello you fighting orphans in the Pacific! How's tricks?" "How'd you like to be back in Los Angeles tonight, dancing at Coconut Grove with your best girl? How would you like to be parked with her in Griffith Park listening to the radio. How'd you like to go to the corner drug store tonight, and get an ice cream soda? I wonder who your wives and girl friends are out with tonight."[60]

[55] In Daniels, p. 298. The speaker was Miyamoto Yoshino of the Cabinet Information Bureau.

[56] Daniels. In the last year-and-a-half of the war, Japanese radio was important, too, in warning civilians of air raids.

[57] Daniels.

[58] Ryo, p. 323.

[59] Ryo.

[60] From a 1943 broadcast, quoted in Ryo, pp. 325–327.

Emulating the Nazi exploitation of cinema, the Japanese government took control of the film industry in 1939. Feature films, full-length and short documentaries, and newsreels were popular and quite effective as propaganda.[61]

In the Soviet Union radio assumed a new importance on the morning of 22 June 1941, the day the Germans launched Barbarossa. Soviet radio broadcast the following:

> *In its time a patriotic war was our people's answer to Napoleon's invasion of Russian, and Napoleon suffered a defeat, he found his end here. The same destiny awaits the conceited Hitler who has made a new attempt to invade our country. The Red Army, the whole Soviet people will fight a new victorious patriotic war for their Motherland, for their dignity, for their freedom. Ours is a just cause. The enemy will be crushed. We shall win.* [62]

Radio led the way in rallying the country in what became known as the Great Patriotic War. Stalin used radio to speak directly to the people. On 3 July 1941 he urged resistance to the German invasion, calling for a "scorched earth" policy. Largely setting aside Bolshevik rhetoric, he sought to appeal not only to supporters of his regime but to all citizens, calling them "brothers and sisters".

Cultural expression became freer in radio broadcasts, and news reports became more believable than they were before the war. Stalin believed that knowledge of German atrocities in occupied territory would further Soviet unity.[63] A new radio program furthered the aim of unifying the country: announcers read the letters of listeners, who told about themselves, exchanged addresses, and asked for help in tracing lost family and friends.[64] Most radios could receive only the official broadcast, and tunable receivers were confiscated.[65] Incessant propaganda, including stories of German atrocities, created an ethos of struggle and commitment to the war.[66]

The Soviet Union sought to influence people in other countries both openly, as through Moscow Radio, which proclaimed Communist policy to the world, and covertly.[67] The Soviets began illegal, clandestine broadcasting for political purposes—often from stations that misrepresented their sponsorship and purpose—in the 1930s with clandestine stations that broadcast Communist propaganda in Czechoslovakia, Hungary, Germany, and Italy.[68] There was also the Voix Chrétienne, a radio station for occupied France that hid the fact that it was Communist and run

[61] Daniels.

[62] In Drobashenko, p. 107. With the German invasion, Soviet propagandists had in some cases to make complete reversals in message. For example, up to that time anti-British films were being made and exhibited [Drobashenko].

[63] Dear, pp. 1050–1057.

[64] Drobashenko.

[65] Dear, p. 1084.

[66] Overy, pp. 188–189.

[67] Dear, p. 1085.

[68] Soley, p. 8.

from Moscow.[69] Cinema supported "the Great Patriotic War" though some 500 newsreels, 120 documentaries, and 100 full-length films. The vandalism of German troops, life in besieged Leningrad, the defense of Sevastopol, and the victory at Stalingrad were all brought home in image and sound to citizens everywhere, and these reports carried much greater credibility than what might be read in newspapers or heard over the radio.[70]

In France, because propaganda was usually associated with totalitarian regimes, the governments of the interwar years avoided the term and, for the most part, the practice. With the coming of war, however, the government exerted much greater control over the media. Movies, for example, were censored, and propaganda films were made for showing both in France and outside.[71]

After the defeat of France, a paper shortage caused a drastic reduction in newspaper and magazine publishing, which in turn caused a striking increase in radio listening, so that before the end of the war a great majority of the French were regular radio listeners. Radio had the additional attraction of giving access to information sources from other countries. Indeed, there is evidence that the BBC and the Swiss station of Sottens had larger audiences than did any French station.[72] It was principally through radio that news of Charles de Gaulle and other Frenchmen carrying on the fight abroad reached the nation.[73]

The British Broadcasting Corporation (BBC) worked to sustain the morale of the British and their allies, to win over neutrals, and to subvert the morale of those in enemy countries. By the end of 1943, the BBC was broadcasting in 45 languages, and stations throughout the British Empire carried many of the programs.[74] Through radio, Churchill's speeches reached hundreds of millions around the world: "I have nothing to offer you but blood, toil, tears and sweat" (12 May 1940, just after becoming Prime Minister), "We shall fight on the beaches, we shall fight on the landing grounds, we shall fight in the fields and in the streets, we shall never surrender …" (4 June 1940, just after the evacuation of British troops from Dunkirk), "Let us so bear ourselves that, if the British Empire and Commonwealth last for a thousand years, men will still say, 'This was their finest hour!'" (17 June 1940, at the beginning of the fight to prevent a German invasion).

The BBC gained credibility worldwide through its policy of presenting largely factual news reports, even when the news was unfavorable to Great Britain. Many people could pick up broadcasts from Switzerland or other neutral countries, thus gaining some indication of manipulation of the news in other broadcasts.[75]

[69] Dear, p. 1085.

[70] Drobashenko.

[71] Pithon.

[72] Sorlin.

[73] De Gaulle's first radio speech from London proclaimed "France has lost a battle but not the war" [*The New Yorker Book of War Pieces*, p. 333]. "On the night that the Germans entered Paris, Queen Elizabeth broadcast [in French] to the women of France …" [*The New Yorker Book of War Pieces*, p. 31].

[74] Dear, p. 116.

[75] Dear, p. 1085.

Interviews after the war showed that the BBC had earned even the trust of many Germans.[76]

To undermine morale in the German army and navy, the propaganda branch of the British Special Operations Executive (SOE) operated two shortwave stations, which pretended to come from Germans who were both anti-Hitler and anti-British.[77] The British made much use of clandestine stations that purported to be located in Axis countries; the Department of Propaganda in Enemy Countries established eighteen or so clandestine stations before March 1942.[78]

Subversive warfare in enemy-occupied territories, notably promoted by the British SOE, depended upon encrypted communications sent and received by compact shortwave-transceivers. Groups of secret agents typically included a wireless operator.[79] Umberto Eco, who as a boy in northern Italy had some involvement with the Resistance, wrote "Sticking close to the radio, I spent my nights—the windows closed, the blackout making the small space around the set a lone luminous halo—listening to the messages sent by the Voice of London to the partisans."[80] As the British advanced through France and Belgium, they used powerful amplifiers and loudspeakers, placed near the front, to talk to the German soldiers. Such activity speeded up surrenders in some cases.[81]

The British Ministry of Information also was deeply involved in film-making, helping to produce almost 1900 films and approving others that were shown in the cinemas, which all together attracted 20 to 30 million people weekly.[82]

In the U.S., the Office of War Information directed the propaganda effort, providing information about the war and government policies to the media. As earlier, Franklin Roosevelt made effective use of radio, which carried his proclamation on 29 December 1940 that the U.S. will be the "arsenal of democracy" and his address to a joint session of Congress after the attack on Pearl Harbor (referring to the preceding day as "a day that will live in infamy"). The Armed Forces Radio Service helped maintain the morale of soldiers and sailors through stations around the world—more than 800 of them by war's end.[83]

GE operated four powerful shortwave transmitters: WGEA and WGEO, located near Schenectady and broadcasting to Europe and South America, and KGEI and KGEX, located on the West Coast and broadcasting to Asia and South America.

[76] Eyck.

[77] Dear, p. 1085.

[78] Soley, pp. 23–30.

[79] Dear, pp. 1018–1022. M.R.D. Foot writes [Dear, p. 1021] "… it was through their wireless-operators, readily enough detected by direction-finding, that most of such groups as came to grief were caught. The best wireless operators, like the best agents, kept on the move as much as they could and evaded arrest altogether."

[80] Eco, p. 12. Eco writes also "In my country today there are people who are wondering if the Resistance had a real military impact on the course of the war. For my generation this question is irrelevant: we immediately understood the moral and psychological meaning of the Resistance. For us it was a point of pride to know that we Europeans did not wait passively for liberation."

[81] Eyck.

[82] Dear, p. 1158.

[83] Lewis, p. 280.

These stations had thousands of listeners in dozens of countries. WGEA and WGEO broadcast regularly in 11 languages. After conquering much of East and Southeast Asia, Japan sent hundreds of thousands of shortwave receivers to China, the Philippines, Indochina, Malaya, and Burma so that the natives would listen to Radio Tokyo (and welcome a Japanese-dominated Greater East Asia Co-Prosperity Sphere). But many of the receivers were used instead to listen to the GE stations KGEI and KGEX.[84]

In the last year of the war, the Psychological Warfare Branch of the U.S. 12th Army operated a radio station in Luxembourg that claimed to be located in Germany and to be run by Germans critical of Hitler. Called Radio 1212, it provided accurate reports from the western and eastern fronts, information generally not available from Third Reich stations. It gained a great many listeners in Germany and achieved some success in stimulating resistance to the Nazi leadership.[85]

In the U.S., movie theaters built a broad consensus behind the war effort through full-length films, newsreels, and government promotional films. At a time when the country's population was 130 million, average weekly attendance reached 100 million. The Office of War Information monitored the output of Hollywood and tried to induce the studios to help achieve war aims, such as improving the popular image of the Soviet Union (as in *Mission to Moscow*), portraying Nazis—but not all Germans—as evil, and encouraging labor-management accord.[86] Film was also effective in prosecution of the Nazi war criminals at Nuremberg just after the war.

9.2 ELECTRICAL TECHNOLOGY IN BATTLE

9.2.1 On Land

The brilliant writer A.J. Liebling, in one of his many war reports for *New Yorker* magazine, described communications on the battlefield:

> *Divarty, the familiar term for divisional artillery headquarters, is under ordinary conditions an ideal place to follow the progress of a battle … because Divarty controls the small spotter planes. … They report not only on targets and the effect of the division's artillery fire but on all enemy troop and vehicle movements they observe. … When ground observation is available, Divarty has the best of that, too, for the artillery has its observers at points of vantage up in the lines with advanced elements of the infantry. These observers have telephone lines to their battalions, and the battalions in turn have direct lines to Divarty. The infantry is served by a parallel but separate telephone network. Communications between the infantry and the artillery go through a division switchboard. The infantry and artillery of a division live like a sensible married couple—in the same house but in separate beds. … The headquarters battery of Divarty has no guns, it merely has a switchboard, a set of maps, and a lot of telephone wires. Divarty is a small, itinerant brain trust that moves*

[84] Miller, p. 130.

[85] Soley, pp. 138–146.

[86] Dear, pp. 542–543.

quickly with the front-line troops and calls down upon distant Germans the thunder of the division's battalions of artillery.[87]

During World War II, the communication between military units that made possible coordinated action came from telegraph, teletype, telephone, and radio. Telegraph was still a usual means for one-way communication, as in sending informational messages or orders. It also had the important advantages over telephony of providing a record of the transmission and of readily permitting encryption of messages. The teletype shared these advantages and was usually favored over the telegraph because it was faster and its operators did not require so much training.[88] The telephone, offering easy-to-use two-way communication, found constant use in almost all contexts. Its importance is indicated by the fact that U.S. Lend Lease provided the Soviets with 380,000 field telephones and almost a million miles of telephone cable.[89] Telephone lines were used also for facsimile transmission, as of aerial reconnaissance photographs.[90]

As in the First World War, however, the fragility, under battlefield conditions, of telegraph and telephone wires led to extensive development of radio.[91] A great variety of systems, from handheld sets to massive semi-permanent installations, were built, each designed for particular operating conditions.

Portable radio—which needed to be light in weight, small in volume, rugged, and reliable, and to have voice capability—was vital for maintaining the communications of mobile units. It served also to extend the senses of a unit, as scouts—whether on foot or in a jeep, boat, or airplane—used it for immediate on-the-spot reports. During World War I, as we saw, aircraft and tanks began to be equipped with radiotelephones, and by the late 1930s many other vehicles too, such as landing craft, trucks, and jeeps, contained two-way radio.[92]

In the British army, tank-brigade exercises in the 1930s established that radiotelephony was the best means of coordination and control. Tanks were equipped with two transmitters (one for regimental and squadron communications, the other for inter-tank communications) as well as an intercom system (for the tank commander to speak to his crew).[93] A principal factor in the British defeat of the Italian army in North Africa in the winter of 1940–41 was the British use of radiotelephony for control of tank operations.[94]

[87] A.J. Liebling, "Letter from France," *New Yorker*, 12 August 1944; reprinted in *The New Yorker Book of War Pieces*. New York: Schocken Books, 1988 (originally published by Reynal & Hitchcock (New York), 1947), pp. 358–361 (quotation from pp. 360–361).

[88] Fagen 1978, pp. 240–241.

[89] Overy, p. 214. U.S. Lend Lease provided the Soviets with 35,000 radio stations also.

[90] Fagen 1978, p. 285.

[91] In occupied Europe, resistance fighters frequently chose sabotage of the telephone system as a way of striking at their German occupiers, and this telephone sabotage forced the Germans to make greater use of radio [Dear, p. 1089].

[92] Fagen 1978, p. 239.

[93] Hartcup 1970, pp. 182–185.

[94] Hartcup 1970, p. 185.

Figure 9.1. General Guderian's command vehicle, with radio and cipher machine (photo courtesy of the Imperial War Museum, London, MH 29100).

The Germans, too, made effective use of mobile radio. Heinz Guderian, who had commanded a radio unit in World War I, became a tank specialist in the interwar years. He urged the development of a tank radio to be used in the Blitzkrieg warfare he championed.[95] (See Figure 9.1.) In the first years of fighting between the Soviet Union and Germany, the principal failing of Soviet armor was the lack of two-way radio, a deficiency that finally began to be removed in 1943.[96]

U.S. forces were well equipped with mobile radio. In 1941, GE engineers designed the SCR-506 medium-range army radio for use in tanks, trucks, amphibious vehicles, and jeeps.[97] For the U.S. Marine Corps, GE built the TBX radio. Able to go through water and still function, it played a vital role in marine amphibious assaults at Guadalcanal, Bougainville, Saipan, Okinawa, and elsewhere.[98] New to this war were handheld two-way radios, notably the SCR-536 "handie-talkie" (later

[95] Dear, p. 923. Blitzkrieg, according to Kenneth Macksey, "combined air power, tanks, and subversive warfare actuated by dynamic command and control through radio and rapidly laid line communications" [in Dear, p. 140]. Its objective was to make up for the German military's inferiority in numbers with new technologies and speed of action [Braun, p. 197].

[96] Overy, p. 212.

[97] Miller, pp. 124–126.

[98] Miller, p. 127.

called "walkie-talkie"). Developed by Motorola, the handie-talkie proved extremely valuable on the battlefield, providing, for example, much better communication between spotters and artillery.[99]

Both the British and the Americans developed portable radio-telephones (called the S-phone and Joan respectively) that could be used in enemy territory with little chance of detection. These worked by directing the radio waves at an upward angle, so that the transmissions could be received in an aircraft at a considerable distance, but not by a ground station unless it was within a mile of the transmitter.[100]

Two notable areas of technical advance in radio during the war were the adoption of frequency modulation and the move to higher transmission frequencies. As described in Chapter 7, Edwin Howard Armstrong championed FM radio in the late 1930s. When the war came, he waived his patent rights for the duration and urged the military to use FM radio for short-range communications. Successful trials led to its adoption for tank and jeep radios and for handie-talkies, and the navy also adopted FM.[101]

Before the war most radio communications were at frequencies below 30 MHz, mainly in the medium frequency band (300 kHz to 3 MHz, which included the broadcast band) and the high frequency band (3 to 30 MHz). Very high frequency or VHF (30 to 300 MHz) had two important advantages: heavy use of lower frequencies meant that there was often interference at these frequencies, and VHF was less susceptible to intercept by the enemy (since transmissions were usually limited to line-of-sight).[102] Thus, U.S. submarines in the Pacific, when working in groups, communicated by VHF voice radio, which could not be picked up by Japanese listening or direction-finding stations much beyond the horizon.[103] And in the last years of the war, the British navy used VHF almost without restriction (six channels for intership communication and four channels for communication between ships and airplanes).[104]

Even microwave frequencies, higher than VHF, were used during the war for communications. The British, for example, used microwave transmitters and parabolic antennas to generate narrow radio beams. Such microwave links were important in maintaining communications across the English Channel when a severe storm not long after the Normandy invasion damaged the undersea telephone cable.[105]

In addition to communications, many other types of electrical technologies were important on the battlefield. Sound-ranging equipment, to locate enemy guns, was much better than in World War I; for example, the set designed by Bell Labs (the GR-6) used magnetic recording to determine precisely the differences in

99 Dear, p. 925.

100 Dear, pp. 1039–1040.

101 Lewis, pp. 283–284.

102 Dear, pp. 926–927.

103 Hezlet, p. 234.

104 Hezlet, p. 248.

105 Hartcup 1970, p. 188.

arrival time of the gun's report at different microphone locations.[106] Magnetic recording was important in other contexts. Large numbers of Dictaphone-like wire-recorders were used by observers in the field.[107] In what was called Project Heater, wire recorders were used, along with powerful amplifiers and loudspeakers, to project the sounds of military activity in order to mislead the enemy. One participant recalls:

> *The sound scenarios were carefully scheduled. For example, we would create the sound of a column of tanks moving along a level road, down a hill, across a wooden bridge, onto cobblestone streets and into defilade positions. … Of course, the deceptive radio network coordinated the phony unit's movement in parallel with the sound and visual effects.*[108]

Another application of magnetics was the mine detector. During the war, anti-tank and anti-personnel landmines were laid in the millions, and they frequently played a large part in the fighting.[109] a means of detecting the mines was vital. Various devices built before the war—such as ones to find mineral deposits or coins in the ground or to detect metal objects hidden in the mattresses of convicts—might be applied to the task. With such devices, a nearby metal object disturbed the balance of an electronic circuit and generated an audible tone.

An improved detector, the SCR-625, was designed for the U.S. Army by Harold Wheeler at Hazeltine Corporation. Earlier devices contained a transmitting coil and a receiving coil. Balancing the circuit was so delicate an operation that temperature changes, as from exposure to sunlight, upset the balance. Wheeler replaced the double coil with three coplanar concentric coils, the opposing inner and outer coils being the transmitter and the intermediate coil the receiver. With this design, the balance between the coils became insensitive to temperature change.[110] (See Figure 9.2.) Later in the war this and other mine detectors were less effective because of the use of non-metallic mines.[111]

Electric power was important at the front, provided by a variety of generators, from ones small enough to fit in a jeep (for arc welding in the field) to 600-kW

[106] Dear, p. 61, and Millman, p. 103. A special-purpose sliderule permitted the calculations for the GR-6 to be done rapidly [Millman, p. 103].

[107] Miller, p. 128. The Armour Research Foundation build about 2000 Model 50 wire recorders for the military during the war; GE built about 6000 of the Model 51, a copy of the Model 50 [Daniel, Mee, and Clark, p. 42]. A spool of ultrafine steel wire, 15,000 feet long, could hold 66 minutes of recording on one spool of steel wire (15,000 feet long) [Miller, p. 128].

[108] Edwin H. Miller, in *Legacies*, p. 63. A sea-going version, called Water Heater (also because it looked like a water heater), was mounted in a torpedo casing; the unit was sent to a beach where a landing was not being made, a loudspeaker was raised, and the sounds of an amphibious landing were broadcast [Fagen 1978, p. 227].

[109] In the fighting in France in 1944, the Germans laid more than one million land mines [Hartcup 1970, p. 194].

[110] Frederik Nebeker, "Harold Alden Wheeler: a lifetime of applied electronics," *Proceedings of the IEEE*, vol. 80 (1992), pp. 1223–1236.

[111] Simon, p. 188. Another problem was that some soil naturally contained much iron [Coll, Keith, and Rosenthal, p. 477].

Figure 9.2. A mine detector (SCR 625) used by the U.S. Army to clear lanes through the minefields in Normandy following the D-Day invasion (photo courtesy of IEEE).

trailer-mounted power stations.[112] There were also railcar power plants that could follow an army, and the powerful generators on electrically-driven ships were on several occasions used to provide power for a port or city that was otherwise without electric power.[113] In addition, four barges built as floating power stations (30,000 kW each) saw service in the U.S., Europe, and the Pacific.[114]

Searchlights were one of the uses of electric power. GE manufactured in large numbers a 60-inch searchlight of 800 million candlepower (providing enough light at 12 miles to read a newspaper), and these searchlights were vital to anti-aircraft defense until radar-directed guns (discussed in Chapter 10) became available.[115] Both the British and the Germans used radar-directed searchlights that locked onto enemy aircraft, and the Allies placed searchlights on aircraft, notably the Leigh Light, which

[112] Miller, pp. 90–91, 102–103.

[113] Miller, pp. 95–98. The Russian advance westward was greatly aided by 63 railcar power plants (each of ten cars) built by General Electric [Miller, pp. 101–102].

[114] Miller, pp. 98–100.

[115] Miller, pp. 115–116.

proved of great value in antisubmarine warfare.[116] At the Siemens Electric Lamp company in England, John Aldington developed a mercury arc that made searchlights more powerful and more maneuverable than the existing carbon-arc lights. Other wartime projects at that company concerned gunsight lamps, signaling lamps, special lamps for illuminating instrument panels in airplanes, headlamps for tanks able to withstand severe mechanical shocks, and xenon flash tubes for aerial photography.[117]

Electrical technology made huge contributions to the medical care of soldiers and sailors in unglamorous ways, such as lighting, ventilation, air conditioning, and refrigeration. In addition, there were x-ray machines, electrocardiographs, diathermy machines, sterilizing lamps, and the diagnostic instruments mentioned in Chapter 8. In the U.S. during the war, 12 million x-ray exams were made at induction centers—this had not been done in World War I—and these revealed 120,000 chest conditions serious enough for deferment (most of them tuberculosis and most previously unsuspected). For military use, GE built portable x-ray units, each capable of fluoroscopy, diagnosis, and therapy.[118]

All branches of the military demanded meteorological information, since military operations are usually much affected by weather conditions. The Germans built 21 land-based automatic weather stations for placement in sparsely inhabited regions, such as Greenland or islands in the Barents Sea north of Norway. The WFL-26 (*Wetterfunkgerät-Land 26*) consisted of instruments and transmitting equipment (a 150-watt shortwave transmitter, an antenna, and batteries) packaged in 10 cylinders, each one meter high and 1.5 meters in diameter. Every three hours the station produced coded signals for the observed values of temperature, air pressure, humidity, wind speed, and wind direction and transmitted them, in a highly condensed form, to German stations in northern Europe.[119]

Both the Axis and the Allies developed infrared night-vision systems during the war. The Germans used such a system so that tanks could be driven in the dark,[120] and some U.S. soldiers used the “sniperscope”, a combination of an infrared flashlight and an infrared-sensitive telescopic sight, which had an effective range of 75 meters.[121] Both Germany and Great Britain developed infrared detection systems for use by fighter aircraft at night; the Germans successfully used such a system (*Kiel Gerät*) in combat, but they, like the British, opted for airborne radar instead (in part because the infrared system could not determine the range of the target).[122] U.S.

[116] Dear, p. 995. The Leigh light was important because the airborne radar used in the middle years of the war was good enough to detect surfaced submarines at night, but not to guide the attack on the submarine [Hartcup 1970, p. 56].

[117] Brian Bowers and Lenore Symons, “J.N. Aldington and electric lighting,” *Engineering Science and Education Journal*, vol. 4, no. 6 (December 1995), pp. S4–S10.

[118] Miller, p. 132.

[119] Hadley, pp. 163–164.

[120] Simon, p. 187.

[121] Thiesmeyer, p. 268. The Germans built a detector of infrared light so that soldiers could know when they were under infrared observation by the enemy [Simon, p. 174].

[122] J.V. Jones, p. 280.

ground forces sometimes used infrared light to mark their positions; it was then easy for an aviator, equipped with an infrared-sensitive scope, to determine the location of friendly forces.[123]

9.2.2 At Sea

Already in the First World War, as shown in Chapter 2, electrical technologies played vital roles in warships: lighting, motive power (for fans, pumps, elevators, winches, and many other devices), communications (intraship, ship-to-ship, and ship-to-shore), navigation, steering and stabilization, and fire control. In the Second World War, the roles were even larger.

Electrical equipment accounted for ten percent of a warship's cost.[124] Besides wiring and electrical fittings (such as switches, fuses, circuit breakers, and relays), there were electric motors and electric lights throughout a ship. A battleship might have 20,000 light bulbs in use. GE developed shock resistant bulbs, which came to be widely used on warships, and, for running lights, two-filament bulbs, in which the second filament automatically came into service when the first burnt out.[125] Electrical instruments and control devices were everywhere; a warship might contain 2000 or more.[126]

As mentioned in Chapter 2, some warships were equipped with turboelectric drives (steam turbines that drove electric generators that powered electric motors directly connected to the propellers), but in the interwar years improvements in reduction gearing made direct-drive turbine propulsion, which eliminated the electrical middleman, the most efficient for large ships.[127] Nevertheless, turboelectric drives remained widely used, in part because there was not enough gear-making capacity for all ships to have direct drive. Before the war ended, GE had built turboelectric drives for 244 destroyer escorts (boats slightly smaller than destroyers) and for 378 tankers.[128] For smaller boats, such as tugboats, salvage vessels, and mine sweepers, diesel-electric drives were common.[129] And, as in the First World War, submarines used diesel-electric drives when on the surface and ran off batteries when submerged.

At the outbreak of war both the British and the U.S. navies had high-frequency radio networks allowing long-range communication with all ships, but coverage was poor in certain geographic areas and the networks were further developed.[130] At the

[123] Thiesmeyer, p. 268.

[124] Miller, p. 2.

[125] Miller, pp. 30–31.

[126] Miller, p. 7.

[127] McBride.

[128] Miller, pp. 5, 20. Turboelectric drives continued to be used in some large warships, including the battleships California, New Mexico, and West Virginia and the aircraft carriers Saratoga and Lexington [Miller p. 38].

[129] Miller, p. 25.

[130] Hezlet, pp. 180–181.

outbreak of war the Admiralty had 17 land stations around the globe for communicating with warships; in 1945 it had 65 such stations, as well as 20 stations for intercepting enemy messages.[131] Low- and medium-frequency radio was normally used for short-range communications, as within a fleet or with nearby shore stations.[132]

At the beginning of the war navies ordinarily used radio telegraphy or teletype rather than radio telephony, but by the end of the war the latter was common.[133] When the war began, a British battleship was typically equipped with eight transmitters and nine receivers; by the end of the war there were 16 transmitters and 23 receivers.[134] In the large ships of the U.S. Navy, the number of transmitters increased from three or four in 1939, to 20 or 30 in 1945, the number being limited mainly by the difficulty of finding space for additional antennas.[135] A German U-boat typically contained several radio receivers, several transmitters, a radar set, several radar detectors, a hydrophone, and an Enigma coding machine.[136]

Ships began to be equipped with combat information centers (CICs), as the volume of information available—especially from various radar sets, but also from sonar, direction-finding, radio communication, and visual sighting—increased. Here the dispositions and movements of enemy and friendly vessels and aircraft could be plotted. The CIC became the nerve center of the ship. Information from the CICs of a group of ships was relayed to the CIC of the command vessel so that the fleet could be effectively controlled as a whole.[137] In the words of a student of naval strategy, "By the end of 1943, the battle fleet had become an integrated set of air and surface platforms that depended on a complete range of electronic equipment."[138] This resulted not only from the wide variety of communications devices, but also, as described in this and the next chapter, from many types of radar, sonar, electronic means of navigation, electronic identification (IFF), and electronics in various control systems.

Playing a large part in naval strategy were mines: during the war the belligerents laid half a million of them, and more ships were lost to mines than to any other weapon.[139] Their effectiveness depended in large measure on electrical technology.

[131] Dear, pp. 925–926.

[132] Hezlet, pp. 180–181.

[133] Dear, p. 926. For communication with carrier aircraft, 2-way radio telephony was used even before the war [Hezlet, p. 217]. At the beginning of the war the U.S. Navy did not use intership telephones, using instead Morse code for radio communications [Kraus, p. 115].

[134] Dear, p. 926.

[135] Miller, p. 128. The addition of substantial weight high on masts—one type of direction-finding antenna, for example, weighed a hundred kilograms—might make ships top-heavy and may have caused some ships to turn over in high seas [Kraus, p. 123].

[136] K. Williams, p. 24.

[137] Thiesmeyer, p. 258. In 1943 and 1944 scientists from the U.S. Office of Field Service studied how CICs actually work, using a battery of dictaphone machines to record communications taking place during battle practice and later analyzing transcripts of these messages to see how effectively information moved [Thiesmeyer, pp. 259–261].

[138] Lautenschläger, p. 38.

[139] Hartcup 1970, p. 49.

Contact mines, the most common type in the Second World War as in the first, were tethered below the water surface so as not to be visible, but high enough that a ship would not pass over them. Mine-sweeping traditionally consisted of severing the tether (with a cable extending between two boats or between a boat and a small underwater craft called a paravane) and, when the mine surfaced, destroying it by gunfire. Magnetic mines, introduced by the British and Germans at the end of World War I, were triggered by the magnetic field of a ship, so could be placed on the bottom. This simplified mine-laying—even aircraft could sow mines—and made mine-sweeping difficult.

In the first six months of the war, German mines, especially the new magnetic mines, were highly effective, sinking 120 merchant vessels and 17 naval craft.[140] In November 1939, however, the British recovered a magnetic mine intact and determined how it functioned. The two main defenses against magnetic mines were to detonate them harmlessly and to demagnetize ships.

Trailing a magnet along the seabed was not practical, as a rough seabed could cause a magnet to be lost. A floating cable had the advantage that it produced no vertical magnetic field in the seabed directly below it, so the cable would not be destroyed by the mines it detonated. A mine-sweeping procedure developed by the British and widely used was called the Double-L Sweep. It required two ships, one trailing a short cable, the other a long cable. Current flowed from the end of one cable to the end of the other. (The system worked only in salt water.) To achieve sufficient field strengths enormous current was required, but the power requirements were greatly reduced by passing short pulses of currents (which required, however, precise synchronization of pulses in the two ships).[141] In February 1940 the Double-L Sweep destroyed its first mine in the Thames Estuary.[142]

Because mines could be surreptitiously placed by airplane or submarine, and because mines could be made to detonate only after several ships had passed or to become active only after a period of time had passed, minesweeping was a huge and never-ending job.[143] Already by the summer of 1940 the British minesweeping force had grown to 700 vessels, with flotillas of sweepers at each

[140] N. Miller, p. 37.

[141] Since detonation was sensitive to the polarity of the field, it was necessary to reverse the current continually, and when several ships swept in parallel, it was necessary that their magnetic fields reinforced; this, too, required synchronization.

[142] Hartcup 1970, pp. 43–44. In his autobiography, the electrical engineer Percy Dunsheath tells of his contribution to this anti-mine technique. The principal difficulty was making an electrical cable that would float. Dunsheath, who was a director of Henley Tyre and Rubber Company, which manufactured tennis balls, had the idea of placing copper wires along a string of cylindrical tennis balls. Within a few months 13 million of these strange tennis balls were manufactured and used for mine-sweeping cable. Dunsheath was also a director of Henley Cable Company, and his expertise in underwater electrical cable was turned to advantage in project PLUTO (Pipe Line Under The Ocean), which after the Allied invasion of Normandy carried 4000 tons of gasoline a day across the English Channel [Dunsheath, pp. 120–124].

[143] The Germans incorporated into mines both clocks, which would keep a mine disarmed until some period had elapsed, and electromagnetic switches, which would count the triggering impulses and cause detonation only when that count reached a preset number [Crowther, pp. 173–174].

major harbor.[144] It was also a hazardous job. For example, when the German forces in the Netherlands surrendered in May 1945, one of the terms of the armistice was that they sweep their own mines from Dutch waterways. But in trying to carry out this task, the entire German minesweeping flotilla in the Netherlands was destroyed, and the task had to be completed by the Royal Navy.[145]

When the mines could not be swept, a ship could protect itself with degaussing equipment (consisting of a high-current low-voltage generator and carefully placed wires around the hull), which could nullify the ship's magnetic field.[146] Almost all Allied ships that traveled in dangerous waters were thus protected.[147] Another procedure (called "wiping") neutralized the magnetic fields of ships by subjecting them for a short time to a powerful magnetic field in the direction opposite to that of the ship's magnetic field. These measures were quite effective, and neither German nor Japanese mines caused much damage in the many Allied seaborne invasions.[148]

Mine warfare was a battle of technological wit, each move eliciting one or more countermoves. After the British developed the magnetic sweep, the Germans in the summer of 1940 introduced acoustic mines, triggered by the sound of a propeller.[149] The British responded quickly with an acoustic sweep.[150] The Germans countered with a mine that required both magnetic and acoustic influence for triggering, but the British soon developed appropriate sweeps for this too.[151] The Germans then developed a pressure mine (called Oyster), which was triggered by the pressure wave of a passing ship, and used them with considerable effect in 1944. These were extremely difficult to sweep, as only a ship would trigger them.[152] After obtaining an intact mine and investigating the mechanism, however, the Allies found that if ships stayed below certain speeds (dependent on the size of the ship), the mines would not be triggered. Though the speed limitations slowed shipping somewhat, the mines otherwise had little effect on the Allies.[153]

[144] Roskill, p. 89.

[145] Maher, p. 178.

[146] The task was to generate a magnetic field opposite to that produced by the ship so that the resultant field would be too weak to trigger the mine. John Kraus, who worked for the Naval Ordnance Laboratory (NOL), writes, "… the magnitude of the problem was gigantic. It was necessary to design coils, specify the number of turns and exact locations where they should be installed on hundreds of ships and determine how many amperes of current would be needed in each coil for all possible headings [since the orientation of the ship with respect to the earth's magnetic field affected the ship's magnetic field]" [Kraus, p. 109]. Also working for NOL at the time was John Bardeen (known today as co-inventor of the transistor and winner of two Nobel Prizes) and, as a consultant, Albert Einstein [Kraus, p. 114].

[147] Miller, p. 54. The heavy wires of degaussing coils used so much copper that this became the country's number one use of the metal, and copper became so valuable that, for a time, the government minted steel, rather than copper pennies [Kraus, pp. 114–115].

[148] Miller, p. 53.

[149] Hezlet, p. 193.

[150] Dear, p. 753.

[151] Hartcup 1970, p. 47.

[152] Hezlet, p. 262.

[153] Crowther, pp. 176–178.

Torpedoes, too, became more dependent upon electrical technologies. An important advance of this war was the electric torpedo, which was trackless. With earlier torpedoes, an attacked ship could see the torpedoes coming and take evasive action; also, anti-submarine vessels could use the tracks to locate the submarine.[154] Both the Germans and the Allies equipped torpedoes with magnetic detonators, which made them more lethal: it might take two or three torpedoes exploding on contact to sink a ship, but a single torpedo exploded under the ship could achieve the same result.[155] Both sides, however, had great difficulties with their torpedoes, both with the magnetic firing mechanism and with the depth control system.[156] Later in the war, torpedoes were fitted with duplex pistols—a contact pistol that fired if the torpedo hit the target ship, and a magnetic pistol that fired if the torpedo passed under the ship.[157]

In 1943 the Germans incorporated a more sophisticated control system in their *Zaunkönig* torpedoes, which homed onto the noise of a propeller. These damaged and sank many ships and made torpedo attack on smaller ships, such as escort vessels, possible.[158] The Allies, however, quickly designed and deployed a towed noise-maker that attracted the torpedoes, and began using an acoustic homing torpedo (called the Mark 24 Mine) themselves.[159]

9.2.3 In the Air

The tank and the airplane, when introduced in World War I, carried out only relatively minor roles in existing tactics and strategies, but they assumed a determinative role in the tactics and strategies of World War II. Similarly, jet aircraft and rockets, introduced with only minor effect in World War II, came to have enormous military significance in the postwar world.[160] This section considers the part played by electrical technologies in the air combat of World War II.

A pilot relied on many instruments to monitor the engines and the flight of the plane. There were selsyn systems that showed the fuel level and the movements made by landing flaps and landing gear. (A selsyn is a generator-motor system that reproduces remotely some instrument indication or valve setting.) There were four

[154] Hezlet, p. 187.

[155] Edwyn Gray, pp. 230–231.

[156] Of the German torpedoes, Hezlet [p. 214] writes, "… the magnetic firing mechanism for torpedo warheads … was a disastrous failure. If it had been effective in the Norwegian campaign the German U-boats would have inflicted losses on the Royal Navy as serious as the Luftwaffe was later able to do off Crete." Of the U.S torpedoes, Murphy [pp. 60–62] writes, "But the magnetic field generated by a metallic hull varies with the latitude. Close to the equator the field spreads out, which is why torpedoes would often detonate 50 feet or more from a ship. Later in the war, commanders were permitted to disconnect the magnetic trigger, so that only contact would set off the mine. It was not until after the war that the Navy built at reliable magnetic exploder."

[157] N. Miller, p. 121.

[158] Monsarrat, p. 396, and Hezlet, p. 235.

[159] Thiesmeyer, p. 116, and Hezlet, p. 236.

[160] Braun, p. 194.

types of gyros: horizon indicator, direction indicator, horizontal control, and directional control. With autopilot, a gyro system detected deviations from the intended flight, amplified the weak signals, and activated elevators, ailerons, or rudder to remove the deviation.

A pilot made use of a variety of communications systems. For local commanders to call for air strikes against specific targets there needed to be ground-to-air communication, and the coordination of groups of airplanes required air-to-air communications. Blitzkrieg operations, for example, involved coordination of dive bombers and tanks.[161] Bombing aircraft contained intercoms that connected pilots, navigator, bombardier, and gunners (and had to function under the noisiest of conditions). The rapidly increasing use of high-frequency wavebands prompted the British to develop very high frequency (VHF) radio for use by aircraft. A VHF set ready at the outbreak of war (the TR 1133) had a ground range of 140 miles and allowed one aircraft to communicate with another at a distance of 100 miles.[162]

Control centers for air operations came to resemble the shipborne combat information centers described above. Consider the control room of No. 11 Group of Fighter Command at Uxbridge, England in September 1940:

> *Phone lines linked controllers to the various airfields, which communicated with individual planes by high-frequency radio. A special red hotline went directly to Fighter Command headquarters at Bentley Priory. Plotters hovered around the situation map …. A vast electric tableau, glowing in a bewildering array of colored lights and numbers, spanned the wall opposite the viewing cabin like a movie curtain. On this totalizator, or tote board, controllers could see at a glance the pertinent operational details—latest weather, height of the balloon barrage layer guarding key cities, and, most especially, fighter status.*[163]

These systems might be subject to countermeasures. For example, in August 1943 the British fitted some bombers with a transmitter (codenamed Tinsel) that jammed the radio transmissions between German fighters and control stations; the Germans countered with transmitters that used several frequencies.[164]

Such instrumentation and control systems, together with communications, surveillance, and navigational equipment, changed, in the course of the war, the appearance of the cockpit, which became, in the words of one writer, "a maze of electronic instruments".[165] (The next chapter describes various types of radar and various means of electronic navigation that became common during the war.)

[161] Overy, p. 212. Not all pilots were happy about the communication link provided by radio; the British radar expert R.V. Jones [p. 408] tells of an RAF pilot who made sure that his radio did not work so that he could not be instructed from the ground.

[162] Hartcup 1970, pp. 110–111. Almost every U.S. bomber carried the 75-watt radio SCR-287 (with long-range transmitter for either voice or key operation); 70,000 were manufactured during the war [Miller p. 124].

[163] Buderi, p. 95.

[164] Dear, p. 1109, and R.V. Jones, p. 295. Using a powerful transmitter, the British sometimes counterfeited the voice of the German flight controller, on one occasion successfully ordering all German nightfighters to land because of the danger of fog [R.V. Jones, p. 387].

[165] Ryerson, p. 1322.

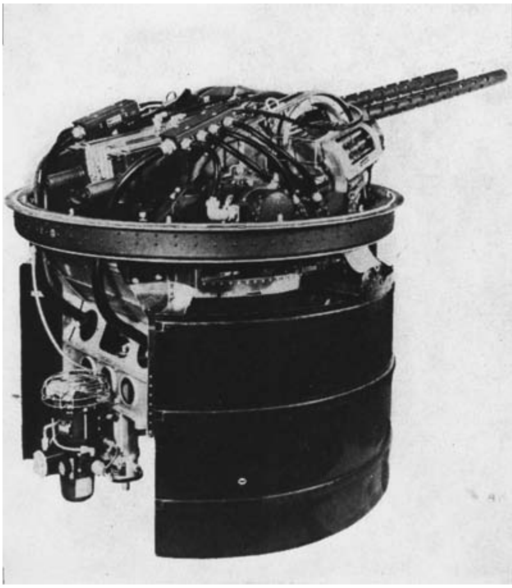

Figure 9.3. A B-29 gun turret (photo courtesy of the Schenectady Museum & Suits-Bueche Planetarium).

Electric heating turned out to be important to aviation. Bomber crews were regularly subjected to temperatures below −30 °F.[166] GE, which manufactured electric blankets before the war, designed for the military a lightweight, electrically-heated flying suit; by war's end GE had made 400,000.[167] GE also produced 220,000 electrically-heated goggles, and electric heating also was used to prevent the malfunction of oxygen masks, bombsights, autopilots, and other equipment.[168]

The increased use of electrical technologies in aircraft is seen in the B-29 Superfortress, designed and built during the war. A great many tasks that had been done mechanically or hydraulically in earlier planes were done electrically. Each Superfortress had 170 electric motors, 26 motor-generator sets, and 15,000 feet of wiring. Motors changed the elevation of a gun and turned its turret; opened and closed ventilators, hatches, and bomb doors; operated brakes on landing wheels; changed the pitch of propellers; raised and lowered landing flaps and landing gear; and ran fuel pumps.[169]

In the B-29, five turrets were remotely controlled from sighting stations in the nose, tail, and along the sides of the fuselage. (See Figure 9.3.) (As the turrets were unmanned, they could hold much more ammunition.) A gunner aimed a sight at a target; an analog computer corrected for speed, wind drift, parallax, and other factors; and the gun was directed appropriately. The gunner merely sighted on the

[166] Dear, p. 727.

[167] Miller, pp. 75–77.

[168] Miller, pp. 80–81.

[169] Miller, pp. 67–68.

target and fired; the control mechanism insured that the paths of the projectile and the target would cross.[170]

Toward the end of the war a change in airplane power-systems recapitulated electrical history. A large 6-engine bomber, the B-36, was being designed for extremely-long-range missions. The miles of wiring for its 120 kilowatt system would have weighed too much if they carried 30-volt DC, as did the B-29 electrical system. GE engineers, whose grandparents were the right age to have had some involvement in the first AC transmission systems, helped design a 120-volt AC system that used much thinner wire and therefore weighed much less.[171]

9.3 CONTROL SYSTEMS AND COMPUTERS

9.3.1 Guided Missiles

Weapon designers followed two paths to self-guided weapons. One approach was to expand the uses of an airplane by replacing the human pilot by an automatic pilot. The other was to make a rocket or torpedo more effective by adding a guidance system. The two most famous guided missiles of the war, the German V-1 and V-2, exemplify these two approaches.

A pilotless bomber aircraft is an idea going back to the First World War (as mentioned in Chapter 2). Improved control systems, as seen in the automatic pilots of the early 1930s (described in Chapter 5), seemed to make the idea more practical. The British developed a prototype as early as 1927, but shortly thereafter discontinued the project for financial reasons.[172] In Germany the idea fared no better until June 1942 when Field Marshall Milch, Chief of the Air Staff, decided to make the production of such weapons a top priority, and just two years later the V-1 flying bombs were operational.[173]

Called Vengeance Weapon 1 (Vergeltungswaffen 1), it was a pilotless jet plane (not a rocket since it used air for combustion) guided by a automatic pilot incorporating a gyroscope, a magnetic compass, and an altimeter.[174] In 80 days in mid-1944, the Germans launched about 7500 V-1s against London (see Figure 9.4). All together, about 10,000 were sent toward Britain, causing some 24,000 casualties and destroying or damaging 1,100,000 houses, 149 schools, 111 churches, and 98 hospitals.[175]

Damage would have been much greater if a high-tech defense had not been ready just in time; as Chapter 10 will explain, the V-1 was defeated by the M-9

[170] Miller, pp. 73–74.

[171] Miller, pp. 75–77.

[172] Hartcup 1970, pp. 246–247.

[173] Hartcup 1970, pp. 247–248.

[174] The V-1 was not radio controlled, though some V-1s were equipped with a radio transmitter that turned on just before the bomb exploded so that the Germans could determine (by taking compass bearings on the signal) where the bomb hit, permitting corrected settings on other V-1s having the same target [Taylor, pp. 231–232].

[175] Baldwin, p. 260.

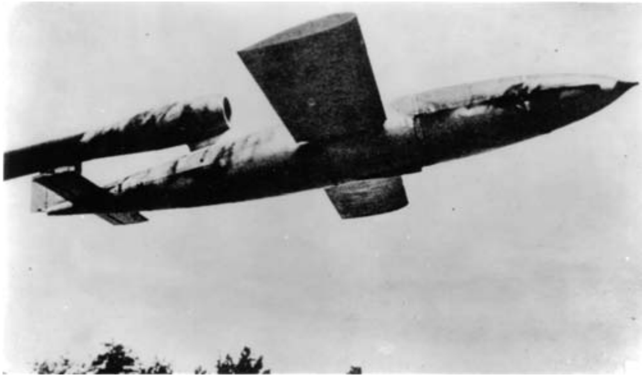

Figure 9.4. A German V-1 pilotless plane (photo courtesy of the Imperial War Museum, London, CL 3433).

anti-aircraft system (comprising radar, automatically controlled guns, and proximity fuze). Seen clearly here is the race of technological war. According to General Eisenhower, "if the German had succeeded in perfecting and using these new weapons six months earlier than he did, our invasion of Europe would have proven exceedingly difficult, perhaps impossible."[176] Here also is an early glimpse of the robotic battlefield, as two fully automatic devices contended: the V-1 rocket and the M-9 anti-aircraft system.[177]

In September 1944 came the first use of a still more advanced guided missile. Called A-4 by the Germans and V-2 by the Allies, it was rocket-propelled, rather than jet-propelled, and had much greater speed and range than the V-1. Indeed, its top speed of 3500 mph greatly exceeded the speed of any manned aircraft and made it immune to any air defense then available.[178] Werner von Braun, who after the war contributed greatly to the U.S. rocket program, was principal designer. The development of the V-2 and related anti-aircraft rockets was one of the war's largest projects; at its height it employed 2200 scientists, engineers, and technicians, and by one estimate, ⅓ of all of Germany's scientists at one time or another worked on the rocket project.[179]

The rocket contained an automatic pilot for stabilizing its flight and for correcting any deviation from the set trajectory.[180] To measure range and speed of the rocket, the Germans invented a method involving the retransmission, from the rocket, of a continuous-wave signal from a ground station. This method served also to control the rocket, shutting off the engine when the speed reached a predetermined value.[181] Because the Allies might defeat this system by jamming, the Germans developed

176 Quoted in Baldwin, p. 267.

177 Mindell 1995c.

178 Baldwin, p. 273, and Sanders.

179 Simon, pp. 33, 130.

180 Siemens, p. 273.

181 Simon, pp. 168–169.

several types of onboard mechanisms for calculating speed; one was a fairly simple electromechanical gyroscopic device, others were more complicated electronic devices.[182]

Crucial to the development of the V-2 was a sophisticated system of telemetry, and in this area, German achievements exceeded those of the Allies. Sensors placed in the rocket produced information such as temperature, gas pressure in the burning chamber, air pressure inside and outside the rocket, steering rudder angle, and mechanical strain. The information was sent to ground using standard multi-channel radiotelegraph techniques; a 13-channel system was adopted.[183]

From 8 September 1944 to 27 March 1945, more than 1000 V-2s landed on England, half of them hitting London where they killed some 2700 people. The Germans also fired some 900 V-2s against the port of Antwerp in the last three months of 1944.[184] Despite its technological sophistication, the V-2 had little impact on the war.[185] (However, as the ancestor to the intercontinental missiles of the 1960s, the V-2 did have an enormous impact on the postwar world.)[186]

A remarkable variety of guided weapons were developed by both sides in the war. In 1921, both the British and the U.S. navies developed radio-controlled target ships, whose speed and direction could be controlled remotely,[187] and in World War II the Germans used a radio-guided explosive boat (*Linse*) against Allied ships, reportedly sinking twelve ships during Operation Overlord.[188] The U.S. used remote control to guide a unmanned B-17 bomber filled with explosives to the German submarine pen at Helgoland.[189] The U.S.-built Mark 24 Mine (a deliberately misleading name) was an air-dropped torpedo that homed acoustically on submarines; it destroyed about a dozen submarines during the war. The Germans built an acoustic-homing torpedo (Zaunkönig), especially for use against convoy escorts, and began using it in September 1943; the Allies managed to neutralize the weapon by a noise-making decoy that attracted the torpedo.[190]

[182] Simon, pp. 170–171. In the electromechanical device, a gyroscope was mounted in such a way that its precession rate was proportional to acceleration, which meant that the total angle turned was proportional to velocity; when the gyroscope axis reached a predetermined position it closed a switch, shutting off the engine.

[183] Simon, pp. 132, 171–172. One of the channels was a calibration channel. By electronic switching, each channel was sampled 500 times per second for 1/7500 second. In the ground station, the data were recorded on oscillographs.

[184] Dear, pp. 1252–1253.

[185] It has been estimated that the V-2 cost more lives in its production (which relied on half-starved slave laborers) than it claimed in battle (Neufeld p. 264).

[186] Overy, p. 224.

[187] Hezlet, pp. 159, 301.

[188] Dear, p. 344.

[189] Thiesmeyer, p. 287.

[190] Dear p. 516, Hartcup 1970, pp. 49–50, and Millman, p. 103. A towed noisemaker (Foxer) was developed first, but it interfered with a ship's sonar and could not be towed faster than 15 knots. It was therefore superseded by an expendable decoy (Pelican) that was launched from the ship when it was believed to be under attack.

Both the Germans and the Allies developed air-dropped guided weapons—the Henschel Hs293 glider-bomb, the Fritz-X guided bomb, and the Azon guided bomb—that were steered from an airplane by radioed control signals.[191] Both of the German weapons were used with some success in 1943 and 1944, though the Allies built jammers that reduced their effectiveness.[192] The U.S. Azon bomb was quite effective against linear targets (since left–right control was much better than range control), such as a viaduct in the Brenner Pass (between Austria and Italy) and Japanese railroad bridges in Burma.[193]

In 1943 in Germany, Herbert Wanger invented and built an air-to-air missile, and toward the end of the war German planes began using the highly effective 55 mm air-to-air missile.[194] The Germans produced also the "Wasserfall" ground-to-air missile (for which an infrared homing device was developed) and the X-4 air-to-air wire-guided missile.[195]

Another reason to make a pilotless aircraft was for use in target practice. Early in the 1930s, the Royal Navy developed for this purpose the radio-controlled Queen Bee (a designation that today seems a misnomer as such aircraft came to be known as drones). Toward the end of the decade, the U.S. Navy had its own drones. Controlled remotely, they could be made to turn or climb or dive, and so provided much more realistic target practice than the towed sleeves used earlier. Indeed, the inadequacy of anti-aircraft fire thus revealed stimulated an increased effort to develop automatic fire control.[196]

The possibilities of television were not ignored. In 1941, RCA developed a small TV camera, transmitter, and power supply (weighing only 70 pounds), and before the end of the war, the U.S. built several weapons consisting of an unmanned, explosive-filled airplane that was guided remotely through the television images of the target it transmitted back to the controller, but such weapons saw little use.[197]

9.3.2 Control Systems

Guided missiles were only one of many areas of development of control systems during the war. The next chapter describes some of the sophisticated systems built to direct anti-aircraft fire and to release bombs on target. Control of frequencies and amplification in communications, process control in factories, governors in power stations, and various control systems in aircraft and ships were also objects of intense effort. New types of automatic control appeared in many contexts during the war.

[191] Dear, p. 516. A special-purpose digital computer, designed by Konrad Zuse (see below), was used to adjust the control surfaces of each Hs 293 prior to use (see Williams 1985 p. 224).

[192] Hezlet, pp. 261–262.

[193] Thiesmeyer, pp. 281–286. The U.S. did develop a glide bomb (called Razon) with control over range as well as azimuth.

[194] Sanders.

[195] R.V. Jones, p. 464, and Simon, p. 11.

[196] Howeth, pp. 479–484, and A.H. Taylor, pp. 217–218.

[197] Dear, p. 516, and Howeth, pp. 479–493.

For example, to improve the accuracy of attacks on submerged U-boats the British developed a depth-charge pattern control system, with the throwers controlled electrically from a central clock (in order to achieve a precisely defined pattern having spread in both lateral dimensions and in depth).[198] Many control systems involved servomechanisms.

A servomechanism is a power amplifier. But it is more than that; it incorporates feedback in that it senses the actual value of the controlled parameter and adjusts the input to the actuator so as to reduce the difference between desired and actual value.[199] In its simplest form, a servo converts the operator's moving of an indicator into much more powerful forces that act correspondingly on the system being controlled. It is a servo that converts the slight force exerted by the helmsman on the wheel to the large force turning a rudder and changing the course of the ship.

The design of a servo may be fairly simple: a power amplifier and a feedback mechanism that detects deviation between the desired motion and the resulting motion and applies a correcting force. A simple design, however, may well cause unacceptable lags and overshoots. The first occurs because the correcting force is too late or slow in acting, the second because the correcting force is too powerful (sometimes causing "runaway" behavior as successive over-corrections increase in magnitude). Then one may need a power amplifier with anticipation, which is to say, automatic means of reducing lags and overshoots by taking into account not just the desired state (as indicated, say, by an operator), but also the difference at any time between the desired state and the actual state. Thus, when the system is far from the desired state, the employment of the actuators may be heightened, or when the state is approaching the desired state, the actuators may be turned off or even reversed. By foreseeing the effects of crude control, one may attain finer control.

Servomechanisms were developed for many different applications. Servos were used in industry in regulating flows, controlling machinery, and positioning heavy masses. In airplanes, they moved control surfaces and landing gear, and in ships they moved rudders and turrets. Some highly sophisticated servos were developed for ship stabilization. There were gyroscopic stabilization methods, developed especially by Elmer Sperry, and active fin systems (which adjusted orientation of fins extending from the hull of the ship so as to reduce roll). In the late 1930s, Nicolas Minorsky studied, for the U.S. Navy, active anti-roll tanks, which countered the roll of a ship by pumping water from a tank on one side of the ship to the other. He improved upon existing systems by making the control mechanism of the pump sensitive not only to the roll acceleration, but also to its first and second derivatives (that is, its rate of change and the rate of change of this rate of change).[200]

Some of the most advanced work on servos in the interwar years was done by Harold Hazen at MIT. He developed a variety of servos, such as torque amplifiers and curve followers, for electromechanical calculating machines such as the

[198] Crowther, p. 162.

[199] The earliest citation for "servo mechanism" in the Oxford English Dictionary (2. edition) dates from 1926, though "servo motor" (from the French "servo-moteur") was used as early as 1889.

[200] Bennett 1993, pp. 15–18.

differential analyser. In 1934, Hazen published two papers that are landmarks in the history of control engineering: one on the theory of servomechanisms and one on the design of a high-performance servomechanism. Hazen brought the tradition of academic engineering research to the problem of servomechanism design.[201] MIT remained at the forefront of servo design, and in 1940 the MIT Servomechanisms Laboratory was established, which grew during the war to a staff of 100. Among the systems developed there were gun drives, radar-antenna drives, and control systems to stabilize the flight of the navy's Pelican and Bat guided missiles.[202]

The war brought together engineers who had worked on control systems in quite different contexts. There were electrical, electronic, mechanical, hydraulic, and pneumatic control devices. Among all the engineers who had studied power amplification and feedback, it was perhaps the telephone engineers who had achieved the greatest success. Telephone service between San Francisco and London, which worked well at this time, involved an overall amplification factor of 10^{256} (equivalent to applying 10-fold amplification 256 times).[203] It was, as we saw in Chapter 7, telephone engineers exploited negative feedback in extremely effective ways, and telephone engineers, such as Harold Black and Henrik Bode, were the principal contributors to the mathematical theory of feedback amplifiers. Such studies, intensified during the war, gave enormous returns in the years following the war in the numerical control of machine tools, in process control, in regulation of power systems, in the new field of cybernetics, and in many other disciplines.[204] Until World War II, engineers in many areas dealt with problems raised by the goal of automatic control, but subject boundaries held firm and no shared control-systems language existed. A historian of control has written "It was during the World War II, with the need for servomechanisms to operate at higher speeds and with much greater precision than previously though possible, that engineers and mathematicians came together to create the control engineer."[205]

9.3.3 Computers

Analog computers of many sorts played a part in the war. The network analyzers described in Chapter 3 continued their work in providing electric power. The differential analyzers described in Chapter 8 were pressed into direct military service, especially to prepare firing and bombing tables.[206] Also in Germany, electromechanical integrators were built for use in preparing ballistic tables.[207] When the Germans

[201] Bennett 1993, pp. 97–114. The two papers were "Theory of servomechanisms" (*Journal of the Franklin Institute*, vol. 218 (1934), pp. 279–331) and "Design and test of a high performance servomechanism" (*Journal of the Franklin Institute*, vol. 218 (1934), pp. 543–580).

[202] Noble, p. 106, and Wildes and Lindgren, p. 227.

[203] MacColl, p. xiii.

[204] Wildes and Lindgren, pp. 210–212.

[205] Bennett 1993, p. 3.

[206] Wildes and Lindgren, p. 229.

[207] Simon, p. 135.

occupied Norway in 1940 and it appeared that one of the most advanced differential analyzers in the world, at Oslo University, might be used for the German war effort, the Norwegian builder of the machine, Svein Rosseland, surreptitiously removed certain precision parts to render it inoperable.[208] Highly sophisticated analog computers were designed for fire control and bombing; these are considered in the next chapter. For the development of the V-2 rocket Helmut Hoelzer built a flight simulator that was an analog electronic computer. As impressive as these machines were, however, hindsight accords greater importance to digital machines developed during the war.

Before considering certain specialized computers that were precursors of the postwar electronic digital computers, we should mention the information-processing devices familiar in the business world of the interwar years—typewriters, adding and calculating machines, and punched-card tabulators—which were, indeed, much more important at the time. Such machines were vital in the routine of procurement, manufacturing, inventory, accounting, and fulfilling of contracts carried out by thousands of businesses and government agencies. Put simply, the wartime mobilization of military and economic forces would not have been possible without them.[209]

Interesting for its adumbration of the role of computers in the postwar world is a listing of a few of the tasks performed by punched-card equipment: to control inventories, to manage transportation routing, to make payments automatically, to oversee compliance with the rules of the Wage Labor Board, to locate people on the National Roster of Scientific and Specialized Personnel, to forecast the demands for materials, and to track the millions of armed-forces inductees.[210] These machines also were used for much more sophisticated calculations in the manner demonstrated by L.J. Comrie and Wallace Eckert before the war (as described in Chapter 8), wartime applications included designing aircraft, forecasting the weather, and designing the atomic bomb.[211]

The war stimulated a significant improvement in the equipment for this type of calculation. For the Army's Ballistic Research Laboratory at Aberdeen, IBM built a punched-card machine that could perform a short sequence of operations (up to six, or with human intervention up to 12) on each card (such as multiply the first two numbers on the card, add to the product the third number, and punch the result at the right of the card). The operations to be carried out were set by the appropriate placement of patchcords in plugboards on the side of the machine (see Figure 9.5). IBM made five of these Aberdeen Relay Calculators (later called Pluggable Sequence Relay Calculators) before the end of 1945. Since they were programmable (by setting patchcords) they may be regarded as a link between standard punched-card machines and the stored-program computer.[212]

[208] Holst.

[209] Cortada 1993, pp. 189–190.

[210] Cortada 1993, p. 201.

[211] Nebeker 1995, pp. 115–118, and Ceruzzi 1997.

[212] Ceruzzi 1997.

Figure 9.5. The Aberdeen Relay Calculator, later called the Pluggable Sequence Relay Calculator (photo courtesy of the IBM Corporate Archives).

A much more thorough-going adaptation of accounting machinery to automatic calculation was carried out during the war by Howard Aiken at Harvard University. As a graduate student in physics in the 1930s Aiken had felt the need of a calculating machine because of the enormous labor required to solve certain nonlinear differential equations. In 1937 he obtained engineering and financial support from IBM for designing and building an electromechanical computer, the Harvard-IBM Automatic Sequence Controlled Calculator, usually known as the Harvard Mark I. It contained 132 mechanical registers (of the sort used in IBM tabulating machines), each able to store 23 decimal digits and a sign (plus or minus). Seventy-two of these registers were also accumulators (so that the number in one register could be added to that in another without involvement of an arithmetic unit), the remainder being so-called constant registers. (See Figure 9.6.) The Mark I was completed in 1944 and immediately set to doing calculations for the navy.[213] Though an electromechanical machine, it holds an important place in computer history as the first large-scale fully-automatic general-purpose digital computer.[214]

As described in Chapter 8, George Stibitz and others at Bell Labs built digital computers based on the electromagnetic relay for use in communications engineering. When the U.S. entered the war, Stibitz became involved in the effort to design an automatic device to direct anti-aircraft fire. Though the fire-control computer itself was an electrical analog computer (described in the next chapter), two relay-based digital computers designed by Stibitz were used in its development. The first, called the Relay Interpolator, simulated the motions of a target plane. The other, called the Ballistic Computer, simulated the flight of the anti-aircraft shell. Both of these relay-based computers functioned well and remained in use by the military for

[213] Williams 1985, pp. 240–247. One of Aiken's assistants was Lieutenant Grace M. Hopper, who became famous after the war for her work in developing the first compilers and the computer langauge COBOL.

[214] Wilkes 1985, p. 107.

Figure 9.6. The Harvard Mark I (photo courtesy of the IBM Corporate Archives).

15 years after the war.[215] In 1944, Bell Labs contracted with the government to build two copies of a much larger and more complex relay-computer, the so-called Model V, intended principally for calculations of firing tables, but these machines were not completed until 1946 and 1947.[216]

One of the great pioneers of digital computing was the German engineer Konrad Zuse. During the war he designed and built several relay-based computers. The so-called Z2 had a mechanical memory unit, while the Z3, completed in late 1941, used relays—some 2600 in all—for the memory, the arithmetic unit, and the control circuits. It is regarded as the first fully operational computer with automatic control of its operations—the control sequence coming from a punched tape.[217] Zuse also built a special-purpose relay-based computer that helped in determining the aerodynamic design of the Henschel glider-bomb (mentioned above).[218]

There were many other electromechanical computers. A number of code-breaking machines are described in the next section. The Chain Home radar stations used an electromechanical computer to determine the height of a detected object from its range and the signal-strengths from antennas at two different heights.[219]

Digital calculation, unlike analog calculation, permitted data storage and transmission without any loss of information (since the system could be designed so that any corruption of the signal, as by thermal noise, would not be likely to cause one digital signal to be mistaken for another) and permitted any level of accuracy. These

[215] Williams 1985, pp. 231–235.

[216] Williams 1985, p. 235.

[217] Williams 1985, pp. 218–222.

[218] Williams 1985, p. 224.

[219] Hanbury Brown.

advantages, however, came at a high price in speed (compared, at least, to some analog machines, such as the network analyzers that in effect solved complicated sets of differential equations as soon as the problem was set up).

Electronics was a realm of engineering offering speed. Chapter 8 explained how C.E. Wynn-Williams achieved electronic counting in the early 1930s using banks of thyratron tubes (which have two stable states that can be changed by an electrical impulse) in his radiation counter. In the U.S. during the war, Warren Weaver, head of the mathematical and scientific instrument section of National Defense Research Committee, turned to electronics for solutions to three needs: automatic control of anti-aircraft fire, high-speed counters for ballistic tests, and instruments to monitor atomic processes.[220] In mid-1942, however, Weaver decided against continuing the development of digital electronics for fire control. Such an effort, he believed, would be too costly given that the greater speed and precision of digital electronics were not required in this application (in the next chapter some of the analog fire-control computers are described).[221] In the two other applications—high-speed counters and monitoring instruments—digital electronics did prove useful.

Quite a number of people, in different parts of the world and in different contexts, sought to carry out digital calculations electronically. One of the first was Helmut Schreyer, a coworker of Konrad Zuse, who, in about 1939, suggested that electron tubes might substitute for the relays in one of Zuse's computers. Schreyer used a "glow tube" (Glimmlampe) that had two well-defined states (conducting and non-conducting). This tube could act as a relay because a signal could change the state of the tube. As proof of principle, in late 1942 or early 1943, Schreyer completed a small computer, containing about 150 tubes, that converted decimal numbers to binary numbers. Shortly thereafter, however, other war work, including radar, claimed his attention, and this early start in electronic computing went no further.[222]

In the U.S. in 1937, John Atanasoff at Iowa State College conceived of an electronic calculator to solve simultaneous linear equations. Over the next several years he and his graduate student Clifford Berry designed and built a computer that used vacuum tubes for the calculation circuits, a rotating drum of capacitors for memory, and punched cards for input and output. The computer (now called the Atanasoff-Berry Computer or ABC) became operational in 1942, but because of difficulty with the input-output system it could not solve sets of more than five equations (though it had been designed to solve sets of up to 29 equations). The project ended at that point as Atanasoff and Berry took up war work. The ABC, which may be the first special-purpose electronic digital computer, did not become well known, but it had influence on the further development of ocmputing through John Mauchly, co-designer of the first general-purpose electronic digital computer (the ENIAC, described below). In 1941, Mauchly visited Atanasoff, who explained

220 Burke, p. 85.

221 Burke, pp. 207–208.

222 Ceruzzi 1981.

and demonstrated the ABC, and it appears that Mauchly derived some important ideas from it.[223]

The war did see a fully functional electronic digital computer. This was the Colossus, a special-purpose computer built by the British for breaking German codes. It is described in the next section. This section describes the development of what became the first general-purpose digital electronic computer, the ENIAC (Electronic Numerical Integrator and Computer).

The military need that elicited ENIAC was the calculation of ballistic tables. These were numerical tables to be used by artillerymen, telling how the range of a particular gun depended upon the type of shell fired, the charge of propellant, the angle of elevation, and, in some cases, the meteorological conditions. New guns, new shells, and new propellants required new tables, and the calculation of a table involved solving a complicated set of differential equations. Hence, this was a major task, one carried out for the U.S. Army mainly at the Ballistic Research Laboratory of the Aberdeen Proving Ground in Maryland.[224]

When the U.S. entered the war, the Moore School of Electrical Engineering at the University of Pennsylvania undertook to build an electronic computing machine for the Ballistic Research Laboratory. The principal designers were J. Presper Eckert, an electrical engineer at the Moore School, and John Mauchly, a physicist who had become interested in calculating devices from his efforts to apply statistical methods to meteorological data. Eckert and Mauchly designed the machine to computer ballistic tables, but recognized that it could be applied to very wide range of problems.[225]

ENIAC contained 20 electronic accumulators, each of which could store a 10-digit decimal number. Each digit of the 10-digit number was stored by a so-called decade counter, containing 22 electron tubes. Logic circuits were also electronic. The sequence of operations was set by the placement of patchcords in plugboards. There was also a read-only memory of about 300 numbers, which were entered by turning switches. An IBM card readers and and IBM card punch provided input and output. All together there were 18,000 tubes, 70,000 resistors, 10,000 capacitors, 1500 relays, and 6000 manual switches. This equipment consumed 140 kW of power and filled a room 20 by 40 feet.[226]

Work on the ENIAC began in 1943 and proceeded rapidly, but the war ended before the machine was fully operational. In December 1945, it solved a problem for the hydrogen-bomb project, and in February 1946 it was formally dedicated. The computer was extremely influential in the subsequent growth of electronic computing. Many of those involved in building the ENIAC came to play major roles in the larger story: John Mauchly, Presper Eckert, John von Neumann, Herman Goldstine, and Arthur Burks are a few of them. The expertise developed in the project was

[223] Macintosh, and Burks 1981.

[224] Williams, p. 272.

[225] Burks 1981.

[226] Burks 1981.

widely shared through publications, site visits, and a course on electronic computing offered by the Moore School in the summer of 1946.[227]

One of the people who took that course was Maurice Wilkes, a British physicist who had worked on radar during the war. He also read a 1945 publication by John von Neumann, *Draft of a Report on the EDVAC*, which first publicly enunciated the concept of a stored-program computer. Wilkes went on to design and build the first full-scale, operational, stored-program computer (the EDSAC) at Cambridge University in 1949.[228]

The appeal of electronics was obvious: operations could be extremely fast because they involved no mechanical motion. Engineers, though, knew that using electron tubes for digital calculation would be difficult for two reasons. First, tubes had been developed as analog devices, handling continuously varying signals as in an amplifier or modulator. Maurice Wilkes has written:

> *It is easy enough for an engineer to explain … how vacuum tubes could be used to make digital circuits; to do it in practice was another matter. … The engineer's task is to take more or less refractory analogue devices and persuade them to behave in a digital manner. Learning how to do this with vacuum tubes was the first task to which the various groups had to address themselves. They arrived at surprisingly different solutions. …*[229]

The second difficulty was the unreliability of vacuum tubes. Devices like radios containing a small number of tubes could be quite reliable, but digital calculation would require very large numbers. There was some experience in using large banks of tubes—as in the Rockefeller Differential Analyzer, which contained 2000 tubes—and this experience made engineers wary. In 1942, MIT terminated a program to build an electronic calculator. MIT's Samuel Caldwell explained, "… although it was possible to build such a machine and possible to make it work, we did not consider it practical. The reliability of electronic equipment required great improvement before it could be used with confidence for computational purposes. …"[230]

Overcoming these difficulties, engineers made electronic digital computing a reality. In so doing, they began opening up a new realm of engineering that would transform the world in the second half of the twentieth century. The central feature of the new engineering was speed. Colossus and ENIAC crossed what has been called "the Newton-Maxwell Gap", the vast difference in computing speed between mechanical devices, whose behavior is governed by Newton's laws of motion, and electronic devices, whose behavior is governed by Maxwell's laws of electromagnetism;[231] for example, to multiply two decimal numbers the ENIAC took .003 seconds, the Harvard Mark I six seconds, which means that an hour's multiplications

227 Burks 1981.

228 Pugh and Aspray.

229 Wilkes 1985, pp. 160–161.

230 Quoted in Wildes and Lindgren, p. 231.

231 Ceruzzi 1997.

on the ENIAC would require three months of continuous operation, day and night, on the Mark I.[232]

9.4 THE BATTLE OF THE ATLANTIC, CODEBREAKING, AND SONAR

9.4.1 The Battle of the Atlantic

"The Battle of the Atlantic", Winston Churchill wrote, "was the dominating factor all throughout the war. Never for one moment could we forget that everything happening elsewhere, on land, at sea, or in the air, depended ultimately on its outcome. …"[233]

German submarines had come close to strangling Great Britain in the Great War, and they were to do so again in the next world war. Strangely, however, when that conflict broke out neither Germany nor Britain had expended large resources on improving submarines or anti-submarine techniques.[234] At the very end of the war—too late to make a difference—the Germans introduced a new class of submarine that was almost invulnerable to Allied countermeasures, and most of the Allied anti-submarine techniques were developed during the war itself.

The Great Britain depended upon the arrival by sea of 40 million tons of cargo annually, including all her oil, most raw materials for her industries, and ⅔ of her food.[235] At the outbreak of war, though well aware of this vulnerability, the Admiralty believed its anti-submarine capability adequate and was more worried about German surface raiders.[236] The U-boats, however, soon proved to be the major threat, and the fall of France in June 1940 gave Germany new bases from which submarines could more readily intercept Allied shipping. In early 1941, ship sinkings increased—the 126,000 tons lost in January grew to 249,000 tons in April—and in this period supplies reached Britain at only 90% of the rate Churchill believed necessary to keep the population healthy, the factories running, and the armed forces equipped.[237] If Germany were to win this Battle of the Atlantic, Great Britain might be forced from the war and the Soviet Union would be seriously weakened.

Karl Dönitz, directing the U-boat campaign, made skillful use of radio to coordinate operations. Up-to-the-minute information about Allied shipping was collected at headquarters and used in deploying the U-boats. And when a submarine sighted a convoy, it would radio the location to headquarters and maintain contact at a

[232] Ceruzzi 1997.

[233] In Kahn 1991, p. ix.

[234] N. Miller, p. 29. The Versailles Treaty prohibited Germany from possessing U-boats, and this prohibition no doubt influenced the British choices about military research and development.

[235] N. Miller, p. 23.

[236] Hezlet, pp. 179–180.

[237] Kahn 1991, pp. 5–6. The flow of goods reaching Britain in the spring of 1941 was half the rate of 1939 [K. Williams, pp. 7–8].

distance, and headquarters would direct other submarines to join with the first for a combined attack on the convoy. Dönitz wrote, "… I could myself quite easily direct the *whole* tactical operation against a convoy from my headquarters ashore."[238] Dönitz knew that this use of radio entailed two risks: the enemy, by direction-finding, might momentarily locate a U-boat, and the enemy might be able to read the messages transmitted. The first risk, when reduced by countermeasures, he judged of small import; the second risk he discounted because he had absolute confidence in his system of encryption.[239] At least in the long term, he was mistaken on both counts.

As in the First World War, direction-finding equipment—sometimes called "huff-duff" for HF/DF (High Frequency/Direction Finding)—found widespread use. On land, the Germans used direction-finding to locate clandestine transmitters.[240] The Japanese used it to track U.S. warships across the Pacific.[241] It was the Allies, however, who advanced the technology fastest and best exploited its military possibilities.

The Admiralty maintained 69 direction-finding stations,[242] and direction-finding was the its principal source of information about U-boat locations.[243] Two technical advances made this possible. The first was the development of a high-frequency direction-finder.[244] In World War I only long-wavelength (low frequency) transmissions could be DF'd, so Dönitz was not much worried about the shortwave radios used by the U-boats.[245] The second was the replacement of the earlier aural method for taking a bearing with the automatic display of the direction of a signal on a cathode-ray tube.[246] This capability, combined with automatic scanning of the horizon, meant that a bearing could be taken almost instantaneous, thus foiling the German countermeasure of short-signal coding, which was to use tape recorders to compress a message so that it could be sent in a 1-second burst.[247]

Another important advance was made in the U.S., though it derived from France. Earlier HF/DF equipment was so large and heavy that it could not be placed on convoy-escort vessels. Henri Busignies, a French engineer at ITT in Paris, designed a compact HF/DF device that took bearings automatically and almost

[238] In K. Williams, p. 9.

[239] Kahn 1991, p. 48.

[240] Dear, p. 569.

[241] Dear, p. 626.

[242] Dear, pp. 925–926.

[243] Hezlet, p. 202. Tracking of U-boats was aided by recognizing particular radio operators (by what was called radio fingerprinting, recognizing a radio operator's distinctive sending habits in sending Morse code) and particular transmitters (using a device called TINA that recorded and displayed characteristics of a radio transmission) [Kahn 1991, p. 215].

[244] Taylor, pp. 237–238.

[245] K. Williams, p. 10.

[246] Kahn 1991, pp. 215–216.

[247] Walsh. The German burst transmitter (*Kurier*), which began to be installed on U-boats in August 1944, used magnetic tape to send 7 letters in 452 milliseconds [K. Williams, pp. 53–54].

Figure 9.7. Henri Busignies with direction-finding equipment (photo courtesy of IEEE).

instantaneously.[248] (See Figure 9.7.) Sosthenes Behn, president of ITT, brought it to the attention of the U.S. military at the beginning of 1941. But it was not until the British scored tactical successes with their HF/DF in early 1942 that the U.S. Navy decided to develop and deploy HF/DF, which was ready in mid 1943.[249]

Busignies, born near Paris on 29 December 1905, worked almost his entire career for ITT; he began work for the Paris subsidiary (Laboratoire Téléphonique) in 1928 and retired as ITT chief scientist emeritus in 1975. One of his first inventions, made while he was still a student, was a radio compass (a device that indicates the direction from which a radio transmission arrives). When Charles Lindbergh landed in Paris in 1927 after his famous solo flight across the Atlantic, his compass had been malfunctioning; it was Busignies who corrected the problem. At ITT he worked to improve the radio compass, and in 1936 one of his radio compasses successfully guided a plane from Paris to Réunion (the French island-colony east of Madagascar). He escaped from France just ahead of the Nazis, taking his direction finder to the U.S.

[248] K. Williams, p. 87.

[249] K. Williams, p. xvii.

An important role for HF/DF was the following: when a U-boat spotted a convoy, its contact signal was DF'd and an escort or aircraft then forced the U-boat to dive, the convoy took an evasive turn, and contact was lost.[250] HF/DF, indeed, became as important as radar in antisubmarine vessels, and, as a sign of this, the HF/DF antenna usually claimed the best site—at the top of the tallest mast.[251] So effective was Allied use of direction-finding in the Pacific that a Japanese ship radioing for air protection was, in doing so, more likely to attract air attack than air protection.[252] (Japan's lack of many of the antisubmarine measures used by the Allies allowed U.S. submarines, together with airplanes, to destroy merchant shipping and thus, by mid-1945, strangle that island nation, just as Dönitz had hoped to strangle Great Britain.)[253]

Though it was made compact enough for escort vessels, direction-finding equipment remained impractical for aircraft.[254] The war did witness, however, an innovative airborne device that served the same purpose. Called the Magnetic Anomaly Detector (or the Magnetic Airborne Detector) and first deployed in 1944, it allowed Allied airplanes to detect a submerged submarine by accurately measuring the earth's magnetic field, which the metal mass of a submarine would distort slightly.[255] Despite great efforts, its range could not be increased much beyond 600 feet, so it was useful only in certain situations, as in monitoring sensitive areas or when it was already known that a submarine was in a particular location. It was used with some success in American coastal waters and in the Straits of Gibraltar.[256]

Some other antisubmarine measures bear mention. Electrical cable laid across a harbor entrance or narrow body of water and connected to a highly sensitive magnetic fluxmeter could reveal the passage of any ship containing any appreciable amount of iron, and this technique was especially valuable in guarding against submarines.[257] In 1943, the U.S. Navy began using Fido, an air-dropped torpedo that homed in on its target acoustically.[258] The U.S. Naval Research Laboratory developed a sono-radio buoy: a small buoy with a microphone suspended beneath it that could relay the sound of a submarine's propellers to search aircraft or ships by means of a radio transmitter in the buoy. Such buoys, often dropped by aircraft in areas suspected of harboring enemy submarines, were widely used in the war.[259]

[250] K. Williams, pp. xiii–xiv.

[251] Hartcup 1970, pp. 69–70.

[252] Overy, p. 229.

[253] Louis Brown.

[254] K. Williams, p. xvii.

[255] Dear p. 42, and Hackmann, pp. 287–288.

[256] Hartcup 1970, p. 70. Hezlet writes [p. 251], "A 'retro-bomb' was devised to work with the Magnetic Airborne Detector so as project the bomb to the rear and counter the forward motion of the airplane."

[257] Miller, p. 55.

[258] Dear, p. 43.

[259] A.H. Taylor, p. 216. More than 160,000 were manufactured during the war. These sonobuoys bore omnidirectional hydrophones; a more advanced sonobuoy bore a directional hydrophone; some 7000 of them were manufactured during the war. [Hackmann, p. 289.]

9.4.2 Codebreaking

In almost every aspect of national defense, communication was vital. The enemy, too, could profit by gaining access to the information conveyed. Thus arose two major enterprises of twentieth-century warfare: intercepting and interpreting enemy communications (intelligence) and preventing the other side from doing the same (secrecy).

As we saw in Chapter 1, decryption of enemy messages played a large role in the First World War. In the 1920s, military leaders gradually learned (sometimes from the published memoirs of participants) how frequently the enemy had read their secret communications, and so redoubled their efforts to devise secure means of communications. Some obvious measures were use of wire communications whenever possible, restriction of radio traffic (even maintenance of radio silence as by the Japanese fleet that attacked Pearl Harbor), and frequent changes of cipher keys or even cipher systems. In World War II, Great Britain valued communications intelligence so highly that it assigned 30,000 people to the work.[260] In almost all countries during the war, agents of the government regularly eavesdropped on telephone calls and surreptitiously read telegrams. Often enemy agents managed to do the same; hence, many people felt the need to encrypt messages.

The German navy, like the army and air force, used versions of a commercial cipher device, the Enigma. This machine resembled a typewriter. (See Figure 9.8.) When the operator pressed a key, current followed a tortuous path through three or four rotors and illuminated a letter on a glass panel. In the enciphered message, this letter substituted for the one on the key. On each face of a rotor was a set of electrical contacts, one for each letter of the alphabet. Short wires passed through the rotor, each connecting a contact on one face to a different contact on the other face. So for a given placement of the rotors, a letter on the keyboard was electrically connected with one on the glass panel, and the machine effected a simple substitution cipher, as, for example, **f** replacing **a**, **w** replacing **b**, and so on.

Using knowledge of the frequencies of occurrence of different letters, a cryptanalyst can solve a substitution cipher in minutes. Enigma, however, changed the substitution alphabet constantly: with each keystroke the rightmost rotor moved one position. When the first rotor made a complete revolution, the second rotor moved one position, where it stayed until the first rotor had made another revolution. When, after 26 revolutions of the first rotor, the second rotor had moved through all of its positions, the third rotor advanced one position. Thus Enigma had 17,576 (or $26 \times 26 \times 26$) substitution alphabets (or 456,976, if there were four rotors), each of which was used before the sequence repeated. There were further complications. The rotors were removable and additional rotors were supplied with each machine. Thus one could change the set of rotors used, the order of a given set, and the starting position of each rotor. Also, some machines had a plugboard with 26 sockets for placing still another alphabet substitution on top of the rotor substitutions.

[260] Kahn 1967, p. ix. The staff of the U.S. Army's cryptanalytic center in Washington, DC, grew to 7000 before the end of the war [Dear, p. 1171].

Figure 9.8. The Enigma machine (photo courtesy of the Imperial War Museum, London, MH 27178).

In the 1930s, as German and Soviet military power grew, Poland became increasingly anxious. Its codebreakers, who were already having much greater success than those from other countries, redoubled their efforts to read German and Soviet codes. To help in reading German Enigma messages, Polish cryptanalysts designed and built an electromechanical device called the bombe. Looking something like six interconnected Enigma machines running simultaneously, the bombe automated and greatly speeded the task of trying different rotor orders and settings. As a result, solutions of Enigma messages came faster than ever. In 1939, Poland began sharing its codebreaking knowledge and techniques with Britain and France, so that when Poland fell in September of that year its codebreaking capability was not lost to the Allies.[261]

The center of British cryptanalysis was the Government Code and Cypher School (the name was meant to mislead) at Bletchley Park, 50 miles northwest of London, where more than 1000 people worked to read German messages.[262] There Alan Turing and others improved on the Polish techniques and built much larger and more complicated bombes.[263] In May 1940, the British began reading the

[261] Kahn 1991, pp. 49–91.

[262] Kahn 1991, pp. 4–5.

[263] Kahn 1991, pp. 90–103.

Luftwaffe Enigma messages regularly and rapidly, but naval Enigma communications proved refractory.[264] By July 1941, Bletchley Park cryptanalysts had built eight bombes and had been helped by captured documents, and solution times for U-boat messages fell from days to hours.[265] This enabled the Allies to locate and sink U-boats and to route convoys around wolf packs.

In February 1942, however, U-boats began using new Enigma machines with a fourth rotor, and Bletchley Park lost its ability to decrypt the messages.[266] The consequences for the Battle of the Atlantic were apparent: in the last half of 1941, when Enigma decrypts were used to divert convoys, U-boats sighted only one in 10 convoys; in the last half of 1942, with only direction-finding information available, U-boats sighted one in three convoys and quadrupled their toll on Allied shipping.[267] Bombes were needed more than ever. By August 1942 the British cryptanalysts had 30 bombes in operation, seven months later 60 bombes, and by the end of the war 200 bombes.[268] The largest assemblage of bombes, however, was on the other side of the Atlantic.

In 1940, as part of a scientific and technical exchange, Britain and the United States began sharing codebreaking techniques. After the German navy began using the four-rotor Enigma, a much larger bombe (equivalent to six three-rotor bombes) was designed and manufactured in large numbers by National Cash Register Company in Dayton, Ohio. With the help of these machines, from August 1943 until the end of the war, naval Enigma messages were read regularly and rapidly.[269]

The Germans sometimes used a more complex encrypting machine than Enigma. Called the Geheimschreiber, it used as many as 10 rotors, while Enigma machines used three or four, sometimes five, rotors. At Bletchley Park, a series of electronic digital computers were built to decrypt such messages.[270] Most important was the Colossus. A special-purpose electronic digital computer, Colossus contained 2500 electron tubes. It became fully operational in the spring of 1944, and by the end of the war, 10 of these machines were in use at Bletchley Park.

ULTRA, cover-name for the solution of the Enigma intercepts, aided the Allies because antisubmarine forces could be directed to their prey instead of having to search a large area for them and because convoys could be steered around wolf packs. In the periods when U-boat codes were being read, shipping losses were only $\frac{1}{6}$ that of periods when the codes were not solved.[271] The historian of cryptology David Kahn has concluded that without ULTRA, the supplying of the Soviet Union would have been seriously hampered and the invasions of Sicily and Normandy would have been delayed. He writes:

[264] Kahn 1991, p. 114.

[265] Kahn 1991, pp. 183–184. After mid-August 1941, most messages were solved within 36 hours.

[266] Kahn 1991, pp. 210, 214.

[267] Kahn 1991, pp. 216–217

[268] Kahn 1991, p. 231.

[269] Kahn 1991, pp. 235–242.

[270] Dear, p. 432.

[271] Kahn 1991, p. 277.

> *By bringing peace closer, ULTRA shortened the time that fathers were separated from their children, husbands from wives. And it spared an untold number of people—men in the cargo ships and their escorts; men at the fighting fronts; men, women, and children under the bombs in the cities of the home fronts. That was ULTRA's greatest gift: it saved lives. Not only British and American lives, but German lives as well.*[272]

The Axis powers, too, were effective codebreakers. In 1942, some 5000 people worked for the Kriegsmarine's intelligence service (the B-Dienst), and in December of that year it was reading 80% of the Allied naval messages it intercepted, including the Convoy Cypher and the British Merchant Navy Code, which revealed the routes of convoys and of independent merchant ships. Dönitz relied heavily on these decrypts in planning his U-boat operations.[273] In the first months of the war the pocket battleships Deutschland and Admiral Graf Spee eluded British and French hunting groups, in part because B-Dienst was reading British naval codes.[274] From 18 December 1941, to 29 June 1942, when the security breech was corrected, Italian military intelligence intercepted and decrypted the daily situation reports of the U.S. Eighth Army.[275] Some of the machine ciphers used by the Allies, however, were never broken by Axis cryptanalysts, notably the British Typex and the U.S. Electrical Cypher Machine (or SIGABA).[276]

Japan's most secret diplomatic messages were encrypted with the Purple cipher machine, which was similar in conception to the Enigma, but used stepping switches (of the type developed for dial telephones) instead of rotors. The guess (by the U.S. Navy cryptanalyst Harry L. Clark) that the Japanese machine used stepping switches rather than rotors eventually led to the first decryption in September 1940. As with the Enigma, the Allies built a machine of the same sort (bombes) for decrypting.[277] They also used punched-card tabulating machines; the Navy cryptanalytic center in Hawaii, for example, consumed three million IBM cards a month at the height of its activity in 1942.[278]

"ULTRA" is used also to designate the solution of Japanese encrypted messages. According to one historian, "ULTRA was a secret weapon of enormous importance. Without it, the war against Japan would have been far more perilous and difficult than it was." [279] ULTRA contributed vitally to the rebuff of the Japanese assault in

[272] Kahn 1991, pp. 278–282, quotation from page 282. Kahn writes [p. 278], "So, taken in isolation, it may be concluded that ULTRA saved the world two years of war, billions of dollars, and millions of lives. But events do not occur in isolation. … If Germany had continued fighting into the summer of 1945, the first nuclear bomb would probably have exploded not over Hiroshima but over Berlin. And the war would have ended then, no matter what the codebreakers had done, or had not."

[273] Dear, p. 116, and Kahn, p. 212.

[274] N. Miller, p. 44.

[275] Dear, pp. 597–598.

[276] Dear, p. 1128.

[277] Dear, pp. 707–708.

[278] Dear, p. 1172.

[279] Waldo Heinrichs in Dear, p. 1171. Hezlet [p. 217] writes that the Battle of Midway "would never have been possible without the breaking of the Japanese codes, and this stands as the supreme achievement of cryptography in both world wars."

May 1942 on New Guinea and the Solomon Islands and to the Japanese defeat at Midway in June. After Japan's Water Transport Code was broken, U.S. sinkings of merchant ships rose dramatically and by the end of 1944, most of Japan's merchant fleet had been destroyed.[280]

The need for message security gave a great boost to the teletypewriter. The messages thus sent could, of course, be enciphered by an Enigma-type machine or any other means prior to typing the letters on the keyboard, but what made the teletype extremely efficient was automatic online encipherment and decipherment. The operator typed the plaintext, each character being converted, as usual, into a five-bit signal. Before transmission, however, the signal passed through an attached cipher station that added some other five-bit signal to the first one, the signal that was added changing with each character. At the receiving teletype, a cipher station performed the inverse operation and the plaintext was printed out.[281]

This method, which the U.S. Army and Navy began using soon after Pearl Harbor, made the enciphering teletype as easy to use and as fast as an ordinary teletype.[282] In various sizes—large units for permanent land stations, compact units for ships, and still smaller mobile units for use on battlegrounds—and designed for either wired or wireless transmission, teletypewriters found extensive use and formed a global communications network.[283] The density of this network is suggested by the fact that more than 16,000 of the most common teletypewriter (TG-7) were delivered to the U.S. military in that year alone. This network provided General Eisenhower in North Africa had a direct and secure communication line with General MacArthur in Australia.[284] The teletype capacity at OP-20-G, the cryptanalysis agency of the U.S. Navy, was one million words a day.[285]

As soon as telephone systems included radio links, there was a need for voice scramblers, devices that disarrange the signal so as to make it unintelligible to eavesdroppers. One was part of the first radio link in the AT&T system, established in 1920 between Catalina Island and mainland California. Before World War II, AT&T was using the A-3 scrambler, which divided the voice-frequency band into five subbands, inverted each of them, permuted the subbands, and changed the permutation every 20 seconds. Though such scramblers achieved their purpose of preventing casual eavesdropping, they could be overcome through a determined effort. Indeed, by the fall of 1941, German engineers had broken the A-3 and were

[280] Dear, pp. 1172–1173.

[281] Because the signals were added bit-by-bit, modulo 2 (that is, $0 + 0 = 0$, $0 + 1 = 1$, $1 + 0 = 1$, and $1 + 1 = 0$), the operation was its own inverse, so the same circuitry worked for decipherment. For the highest level of security the signals added came from a nonrepeating sequence used only once.

[282] Fagen 1978, pp. 244–246. The message could be punched onto a paper tape and sent automatically, at the rate of 100 words-per-minute [Dear, p. 925].

[283] Fagen 1978, pp. 251–263.

[284] Fagen 1978, pp. 278–283. Just after V-E Day the Army demonstrated the span and speed of this network by sending from the Pentagon a message around the world; its reception began on a second teletypewriter in the Pentagon just one second later.

[285] Burke, p. 249.

descrambling transatlantic conversations between U.S. and British officials, including ones between Roosevelt and Churchill.[286]

To make radio links more secure, a team at Bell Labs headed by Paul Blye designed an entirely new scrambler, called X-system by Bell Labs, SIGSALY by the Army. It was not only a great practical success during and after the war, but also a milestone engineering foray into the latter-twentieth-century realm of digital communications.

SIGSALY conveyed speech through 12 channels. There were two channels for pitch, and 10 channels representing 10 frequency bands. Each frequency band was sampled 50 times per second, and the amplitude of each sample was approximated by one of six amplitude levels (10 decibels apart). A set of discrete values thus replaced the analog voice signal. One could then add a random "key" to these values at the transmitting end, which would render the transmitted values random, and then subtract the key at the receiving end, exactly recovering the original values.[287]

This system required a quantizer, or, in modern terms, an analog-to-digital converter. Required, too, was a means of exactly synchronizing the addition (at the transmitter) and subtraction (at the receiver) of the key; this was achieved using a quartz crystal, whose oscillation frequency was extremely stable (within one part in ten million). The key itself was generated from the thermal noise of mercury-vapor rectifier tubes and recorded on a high-quality phonograph record, one copy of which was at the transmitter and one at the receiver. The 12 channels were spaced uniformly across the 3000-hertz telephone band (thus constituting one of the first instances of spread-spectrum transmission, if that is defined as transmission over a wider frequency band than that of the information signal).[288]

The first terminals were installed in 1943, the first overseas test call taking place on 29 June. Bell Labs made a dozen SIGSALY terminals before the end of the war, and they were placed in the United States, Hawaii, Guam, Australia, Algeria, England, and, after the entry of Allied troops, in France and Germany. They functioned faultlessly.[289]

[286] Kahn 1984. Kahn writes [p. 72]: "This weakness perhaps contributed to the Japanese success at Pearl Harbor, for Army Chief of Staff General George C. Marshall refused to use the A-3 scrambler … on the morning of Sunday, Dec. 7, 1941. He had wanted to tell the commander in Hawaii that the Japanese were going to submit a note breaking off negotiations at 1 p.m., Washington time, which was 7:30 a.m. in Hawaii. But he feared that the Japanese might have solved the scrambler, in which they had already expressed some interest, and might use the intercept to suggest that the Roosevelt administration had forced Japan's hand, thereby sending the country to war divided. So he sent his warning by radiotelegraph in code—and it arrived after the attack was over." Kahn also points out [p. 78] that the Roosevelt-Churchill conversation, overheard on 29 July 1943, suggested to the Germans that the Allies were in contact with the new government in Italy (after Mussolini's ouster), so probably hastened the transfer of large numbers of German troops to Italy.

[287] Fagen 1978, pp. 298–309. The addition of the key produced an essentially random sequence because both signal and key were senary digits (that is, from the set of digits 0, 1, 2, 3, 4, 5) and the addition was modulo six (so that any value exceeding five was reduced to a senary digit by subtracting 6).

[288] Fagen 1978, pp. 298–309.

[289] Kahn 1984.

The pulse code modulation used in this system (whereby a waveform was transmitted as a sequence of digits rather than as a continuously varying signal) has become standard in telephony, notably in optical-fiber transmission, and in musical reproduction with compact disks. SIGSALY may have been its first use. The wartime work on SIGSALY and other voice scramblers is notable, too, for the people who contributed. Besides Harry Nyquist, Alan Turing (computer pioneer), Claude Shannon, and Hedy Lamarr (the Hollywood actress who shared a patent on spread-spectrum secrecy system), the novelist Aleksandr Solzhenisyn took part. During the war, Stalin ordered the development of a secure radiotelephone, a project carried out partly by jailed scientists. One of them was Solzhenitsyn, then a physicist and mathematician, who later described such a project in his novel *The First Circle*.[290]

World War II saw many other types of signals intelligence besides codebreaking. Agents of many countries made use of telephone taps and other listening devices.[291] Direction finding was discussed above. As in World War I, there was also traffic analysis; even without the ability to decrypt U.S. messages, the Japanese usually obtained, by traffic analysis, advance knowledge of enemy offensives.[292] A technique called "radio fingerprinting" enabled the British to identify individual Japanese radiomen solely by their manner of operating a telegraph key (and thus to track ships without needing to decrypt any messages). The received signals were displayed on a cathode ray tube and then recorded with a high-speed movie camera. A film library was thus compiled and the sending style of individual operators could be recognized.[293]

Again and again during the war, military intelligence proved of value. With the help of Bletchley Park's ability to read the Italian naval codes, the British navy sank or captured 10 Italian subs in the first month of Italian participation of the war.[294] In the summer of 1940 the British learned from decrypted intercepts that the Germans had no immediate plans to invade Britain.[295] The German Balkan campaign was much aided by signals intelligence, and German decrypts in 1942 provided detailed dispositions and plans for British units in North Africa, which contributed to Rommel's successes that year.[296] Codebreaking by the Allies probably shortened the war by one or two years, but codebreaking by the Germans lengthened the war

[290] Kahn 1984. The war saw another type of secret communication: in German-occupied countries, broadcasters and journalists sometimes evaded censorship by *doubles entendres* that would be understood by their compatriots but not by the German censors [Dear, p. 1086].

[291] "Source K" was probably the most famous telephone tap. It was placed in January 1942 by Robert Keller, a French telephone engineer, on a line between Paris and Hitler's headquarters in East Prussia. For some months he gave valuable information thus gained to Vichy intelligence agents, who passed it on to the British. In December, Keller and several accomplices were arrested and sent to forced-labor camps when their tap on a second long-distance line was discovered by the Germans [Dear, pp. 1023–1024].

[292] Dear, p. 1005.

[293] Dear, p. 927.

[294] N. Miller, p. 112.

[295] N. Miller, pp. 94–95.

[296] Dear, p. 1006.

substantially. As in many other types of technological arms-race, advances by the two sides tended to cancel out, yet failure to match the enemy was costly. The great codebreaking successes have perhaps unjustifiably overshadowed the countless instances when secure communication was achieved and the many occasions when major military operations, whose organization required large amounts of communications, took the enemy by surprise.

9.4.3 Sonar

Chapter 2 discussed how, in the First World War, the principal means of detecting submerged submarines was a passive device, the hydrophone, but that near the end of the war engineers tested an active device, echo-ranging (later known in Britain as asdic and in the U.S. as sonar).[297] When the war ended, so did the intense effort to develop anti-submarine techniques. Britain, however, did continue to devote some resources to the quest. In the mid-1920s, the Admiralty put sonar systems into use, and in 1927 it decided to abandon hydrophones and use only sonar for submarine detection (though the sonar set could be used passively).[298] The only other country to develop sonar in the interwar period was the U.S., though at a much slower pace than the British.[299]

Generating the acoustic waves for a sonar set was oscillator, usually about 18 inches in diameter and 6 inches thick, made of layers of quartz and steel. It emitted a supersonic tone, which, when reflected back, was picked up by the oscillator and made audible to the operator by a heterodyne valve receiver.[300] The choice of frequency involved a trade-off; higher frequency gave a narrower beam, hence a more accurate bearing for the source of an echo, but lower frequency gave greater range, since the acoustic absorption coefficient of water is roughly proportional to the square of the frequency.

Most World-War-II sonar had a range of only 1000 meters or so, which limited its usefulness in searching for submarines. The range was great enough, however, that escort vessels could usually detect any submerged submarine approaching a convoy.[301] For surveillance, a sonar set could be used passively (simply as a hydrophone), which gave much greater range.[302] Indeed, because of the range of hydrophones, U-boats regularly used them to locate convoys.[303]

Another limitation of sonar was that it was not effective in detecting surfaced submarines. As a result, U-boats often remained surfaced when approaching convoys

[297] In 1943 the Royal Navy adopted the name "sonar" in place of "asdic" [Dear p. 62].

[298] Hezlet, pp. 165–167.

[299] Hezlet, pp. 167–168.

[300] Hezlet, p. 165. Recall that a heterodyne receiver combines an incoming signal with a self-generated signal to produce "beat frequencies", that is, frequencies equal to the difference of an incoming frequency and the self-generated frequency.

[301] Hezlet, p. 188.

[302] Devereux.

[303] Hackmann, pp. 233–234.

at night, relying on their small silhouettes to avoid detection.[304] In late 1940, British destroyers began to be equipped with radar that allowed detection of surfaced submarines at night.[305]

Sonar stimulated the introduction of ahead-thrown weapons. The standard means of attacking a submarine was by dropping a pattern of depth charges, set to explode at varying depths, off the stern of the vessel when it was believed to be above the submarine. Because sonar sets were unable, until late in the war, to "look" downwards, sonar contact was necessarily lost before the attack. Moreover, as the vessel moved away from the suspected location of the submarine, the explosions of the depth charges prevented renewed sonar contact. The British and Americans developed weapons, the British "Hedgehog" being the most famous, that fired a pattern of projectiles ahead of the ship, and the projectiles were designed to explode only on contact so that sonar contact was not lost.[306]

During the war the Allies added a second oscillator (the "Q attachment") to sonar sets in order to project sound directly downward and thus retain contact when above U-boats.[307] Another improvement was the ability to measure the depth of the target, and with the British "Squid" weapon, introduced in 1943, the depth-pistols of the projectiles were set automatically by the sonar set.[308] The addition of automatic gain control to sonar sets substantially improved their performance (as otherwise the large variations in strength of signals made it difficult for operators to identify significant echoes).[309]

Sonar technology illustrates well the trend toward automatic control and information-processing. With early sonar, the operator determined both range and bearing, the former by measuring with a stopwatch the interval between pulse and echo, the latter by changing the direction of the sound transmitter and noting response. During the war, sonar sets, such as the British Type 144, performed automatically these and other functions, such as calculation of the correct bearing for an ahead-thrown weapon and the course required for a conventional depth-charge attack.[310]

Germany had 57 U-boats at the outbreak of war. In the first seven months they sank a battleship, an aircraft carrier, two destroyers, and 222 merchant ships. In this same period, when 13 new U-boats were completed, 18 were sunk, 11 of them having been detected by sonar.[311] In the first two years of the war, 104 U-boats were sunk, and sonar was at least partly responsible for 68 of these sinkings. And for the

[304] Hezlet, p. 199.

[305] Hezlet, p. 200. These radar sets could detect a surfaced U-boat two or three miles away [Kahn 1991, p. 3], but the adoption later in the war of radar with shorter frequencies and higher power increased the range substantially.

[306] Hackmann, pp. 303–307.

[307] Hezlet, p. 229.

[308] Hackmann, p. 308. The increased lethality of antisubmarine weapons is reported by Hackmann [p. 310]: "A single depth charge attack had roughly a 6 per cent chance of sinking a U-boat, a Hedgehog pattern roughly 20 per cent, and a Squid pattern roughly 50 per cent."

[309] Hackmann, pp. 268–269.

[310] Hackmann, pp. 271–272.

[311] Hezlet, pp. 187–188.

war as a whole, sonar was involved in more than half of the 246 U-boat sinkings, hence the conclusion of some historians that without it Germany would have won the Battle of the Atlantic.[312]

Wartime sonar R&D made a significant contribution to the technology of sound recording. The British wished to use recordings of underwater noises to train sonar operators, but existing recording methods were inadequate to the task. As we saw in Chapter 6, electrical recording and playback had improved the phonograph in the 1920s: while the acoustic phonograph had a range of 200 to 3000 Hertz, the electric phonograph reproduced sounds from 130 to 4200 Hertz. Improved microphones and the moving-coil disc cutter extended it further at the upper end (to 8000 Hertz); but this was still well below the upper limit of human hearing (20,000 Hertz). During the war Arthur Haddy led an effort that improved the moving-coil cutter, the recording surface itself, and the procedures for making copies. The result was a range from 80 to 15,000 Hertz. This system, named Full Frequency Range Recording, was introduced commercially in 1945 and led the way to the high-fidelity movement of the postwar years.[313]

Sonar was more than an antisubmarine technique. It was used for detect mines and underwater obstacles (such as those intended to impede landing craft), and in this capacity sonar was valuable in the Normandy landings.[314] It was used by submarines to locate other vessels. It was used for guarding the entrances of harbors. And it was used for sounding (that is, determining depth of the water) and mapping the sea floor.

Victory over the U-boats depended upon many technologies, especially HF/DF, codebreaking, sonar, and radar. It was the combination of techniques that turned the hunters into the hunted. Enigma decrypts might direct airplanes to refueling points, when the U-boats were particularly vulnerable, and with radar, HF/DF, and sonar escort, vessels might locate and pursue U-boats that approached a convoy. HF/DF had rather limited applicability, and sonar suffered from two notable shortcomings. First, it was ineffective in detecting submarines on the surface, and surface attack at night was a mode of operation favored by U-boat commanders.[315] Second, the short range of sonar meant that, on the whole, it was effective only in providing local protection and in counterattacking once detection had been made by other means. It was radar—in both aircraft and ships—that most often provided the means of initial detection.[316]

The next chapter tells the story of the development of this new technology and the role that radar, especially high-frequency (centimetric) radar, had in winning the Battle of the Atlantic. Nicholas Monsarrat, who served in convoy escort during the

[312] Hezlet, pp. 213, 264.

[313] Millard, pp. 198–199.

[314] Hackmann, p. 275.

[315] N. Miller, p. 32.

[316] Hezlet writes [p. 264], “Most of the 290 U-boats destroyed by aircraft were initially detected by radar, which was unquestionably the most important reason for the defeat of the U-boats in the Atlantic.”

[317] Monsarrat, p. 214.

war, called radar “the most formidable invention in sea warfare”.[317] In the novel *The Cruel Sea*, he described the equipping of a small escort ship with radar:

> *Radar was the one thing they needed, the one weapon that the Atlantic war had long demanded: a means of making contact at night or in thick weather with whatever lay in waiting near by. … It was going to be a help and a comfort—that they all realized; and beyond this, perhaps it would, as a weapon, even start to equalize the Atlantic score, meeting the cunning and secret attack with a delicate revealing finger, the best that science could do for man.*[318]

[318] Monsarrat, p. 215.

Chapter 10

Radar, the Weapon That Decided the War

10.1 THE BATTLE OF BRITAIN

10.1.1 Operation Sea Lion

With the military collapse of France shortly after the German invasion on 10 May 1940, Hitler expected Britain to make peace. On 27 and 28 May the British Cabinet debated the issue, and Neville Chamberlain (former Prime Minister) and Lord Halifax (Foreign Secretary) were in favor of seeking peace terms. But a majority of the cabinet supported the new Prime Minister, Winston Churchill, in his resolve not to seek terms, and in July, Hitler decided to proceed with an invasion of England. The operation, codenamed Sea Lion (*Seelöwe*), required control of the skies (especially for ferrying troops across the English Channel), and Hermann Göring, head of the Luftwaffe, promised to achieve it. As it turned out, he failed and Sea Lion was canceled. Göring's failure resulted from a new technological capability that the threat posed by air power had elicited.

The threat of air power was a subject of discourse, and a source of anxiety, in the 1920s and 1930s. In 1921, the Italian general Giulio Douhet published *The Command of the Air*, in which he argued that in the next war, aircraft could quickly defeat the enemy by destruction of cities.[1] One of those who studied Douhet's writings was Göring, and the new style of warfare, called Blitzkrieg, which was extremely effective against Poland in 1939 and France in 1940, depended heavily upon air power.[2] Others who believed that air power would dominate future wars were the U.S. general Billy Mitchell, who demonstrated in the early 1920s that bombers could sink warships, and Lord Trenchard, first marshall of the Royal Air Force.[3] In the

[1] Overy 1996.

[2] Burns 1995/1996.

[3] Burns 1995/1996.

Dawn of the Electronic Age: Electrical Technologies in the Shaping of the Modern World, 1914 to 1945, by Frederik Nebeker

1930s, people in many countries feared the airplane for its ability to rain destruction onto cities (as demonstrated in the Spanish civil war), and in Great Britain most people knew the words of Stanley Baldwin, spoken in 1932 over the radio, that "the bomber will always get through".

When the Nazis took power in Germany many British scientists and engineers began to worry about national defence, particularly the threat of air power. The Air Ministry formed a Committee for the Scientific Study of Air Defence, headed by Henry Tizard, which met for the first time in January 1935. That same month, one of the committee members contacted Robert Watson-Watt of the National Physical Laboratory, who immediately began investigation of the possibility of using electromagnetic waves to detect aircraft.[4] Before the end of 1935, Watson-Watt demonstrated what would later be called continuous-wave radar and pulse radar.[5]

Early investigators of radio found that large objects, such as buildings, ships, and mountains, blocked radio waves, and there were some efforts to exploit this phenomenon as a means of monitoring the entrance to a harbor. Another phenomenon, however, proved immensely more exploitable: large objects reflected radio waves back to the sender. Here was a new way of seeing, an active sensing (as was sonar) rather than passive (as were human vision and hearing).[6] In 1904, Christian Hülsmeyer demonstrated what he called a "Hertzian-wave projecting and receiving apparatus adapted to indicate … the presence of a metallic body, such as a ship … in the line of projection of such waves". Successful demonstrations that year in Cologne and Rotterdam failed to interest either the German navy or international shipping companies. Despite wide publicity, Hülsmeyer found no buyers for his device and turned to other things.[7] In 1925 Breit and Tuve, as related in Chapter 8, measured the height of the ionosphere by sending up pulses of radio waves and measuring the time until the echo was received. Besides in such ionospheric studies, reflected radio waves were used to determine distance in geodetic surveying and altimetry.

Such reflections could be used to build up an image by scanning a narrow beam of radio waves and registering the strength of the echo for each direction. (As with television and fax, a two-dimensional image was constructed from a one-dimensional data stream.) Scanning a beam and detecting echoes reveals the direction of an object. Its distance is determined in a simpler way than the triangulation typically used by optical devices: measure the elapsed time between transmission of a pulse and reception of the echo, and multiply this quantity by the speed of the known waves to get the round-trip distance.

[4] Hanbury Brown, and Swords, pp. 174–175. Watson-Watt had begun thinking about radio location during the Great War when, as an employee of the Meteorological Office, he sought means of locating thunderstorms by the atmospherics generated; this work led him to the use of rotating antennas and, later, cathode ray tubes [Hanbury Brown].

[5] Skolnik.

[6] Several forms of passive detection of airplanes—sound, infrared, and radio—were developed, but proved of very limited usefulness [Getting 1962].

[7] J.E.D. Williams, pp. 202–203.

The time intervals involved are extremely short. Since a radiowave pulse (like light or any other form of electromagnetic radiation) travels through air at a rate of about 300,000 km/sec, an object 1.5 kilometers away will reflect a pulse back to the sender in 1/100,000 sec (the pulse and its echo traveling a total of three kilometers). Since the pulse itself may last this long, it was necessary to take the onset of the pulse and the onset of its echo as the events that start and stop the timing circuit. The cathode-ray tube made possible the visual presentation of such signals. In the first radars, when a pulse was transmitted, a bright spot began moving steadily left-to-right across the face of the tube and was deflected upward when an echo was received.[8]

The power of an electromagnetic wave from a point source decreases as the square of the distance, so a radar signal, which is the part of the wave reflected back to the sender, decreases as the fourth power of the distance. (Hence, doubling the distance decreases the power by a factor of 16.) It was only the enormous amplifying power of the electron tube that made radar possible, to make both powerful transmitters and sensitive receivers. (Radar receivers could detect signals with as little power as $\frac{1}{10}$ picowatt, which is $\frac{1}{10}$ of a millionth of a millionth of a watt.)[9]

As soon as Watson-Watt showed the feasibility of this method of warning of air attack, work began on a chain of radar stations (known as the Chain Home), and the system began operation in 1937.[10] At the outbreak of war, some 25 stations, two of them in Scotland, were in service. (See Figure 10.1.) At the end of the war, some 50 Chain Home stations covered almost all approaches to Great Britain.[11]

A Chain Home transmitter radiated about 350 kW at about 25 MHz, which corresponds to a wavelength of 12 meters. The long wavelength necessitated large antennas, and separate transmitting and receiving antennas were used. (See Figure 10.2.) A cathode ray tube showed echoes received along a timebase. The effective range was 100 to 200 kilometers, depending upon the size and height of the aircraft.[12]

After weeks of bombing of English Channel shipping and English ports, the Luftwaffe launched its campaign for control of the skies on 12 August 1940 with raids on landing fields and radar stations. From bases on the continent, the Luftwaffe threatened Great Britain with almost 1600 bombers and 1100 fighter escorts.[13] Great Britain, with only 900 fighters, could not defend the country by continuous patrolling of the skies, and so pioneered in what became known as "fighter direction", made possible by radar and an excellent communications network.[14]

[8] Buderi, pp. 56–57. The technique had been developed for studies of the ionosphere.

[9] Schneider.

[10] The prospect of radar caused the abandonment of work on another system for early warning: sound reflectors (some of them 200 feet across) and sensitive microphones, which could detect aircraft at 20 or so miles (hence give several minutes' warning) [Hanbury Brown].

[11] Hanbury Brown.

[12] Hanbury Brown.

[13] Dear, p. 159.

[14] Taylor, p. 224.

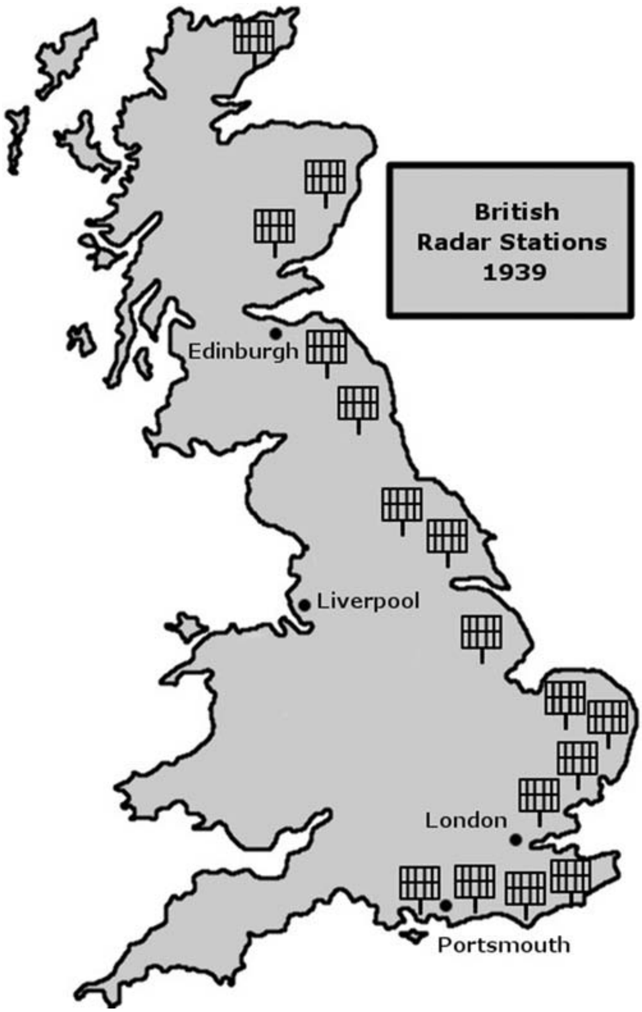

Figure 10.1. Depiction of the radar stations of the Chain Home system.

The objective was to send up fighter aircraft when and where they were needed, and only then and there. Radar early-warning made this feasible. Control centers received reports from Chain Home stations, supplemented by sightings and information from radio receivers and sound detectors. The control centers evaluated the information, plotted the positions of enemy aircraft, and directed both fighter aircraft and antiaircraft guns on the ground. After the fighters were sent up, they could be further directed by radio telephony.[15] By one estimate, the radar early-warning system effectively multiplied the fighter defence by a factor of four.[16]

[15] Taylor, p. 224.

[16] Hanbury Brown.

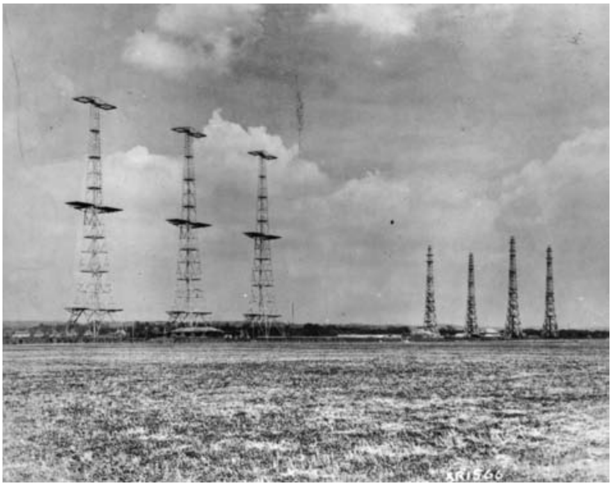

Figure 10.2. 110-meter towers supported the transmitting array of a Chain Home station, and 73-meter towers supported the receiving antennas (photo courtesy of the Imperial War Museum, London, CH 15173).

British air defense succeeded. From July through October, the Royal Air Force (RAF) maintained a better than 3-to-2 loss ratio. On a single day (called 'Battle of Britain Day') some 60 German aircraft were downed, and two days later Sea Lion was indefinitely postponed.[17] Air-defense radar became operational just in time to save the country, and it did so only because a few individuals, who had seen the value of technological factors in the Great War, set the development process in motion in 1935.[18] This again demonst rates the shift, already begun in World War I, from weapons wielded by individuals to weapon systems involving many men and much machinery.

On 24 August 1940, German pilots strayed from their intended course and dropped bombs on London. Churchill responded by ordering raids on Berlin. Hitler then resolved, "We will raze their cities to the ground." Thus began what the British called the Blitz, following immediately on the heels of the Battle of Britain. Instead of destruction of the RAF, the Luftwaffe aimed at damaging the cities. There was almost continuous bombing until May 1941. At this time almost every English city and town was ringed with antiaircraft guns and searchlights.

Great Britain was the first country to be subjected to a sustained air offensive. (Edward R. Murrow's broadcasts from London during the Blitz increased U.S. admiration for the British.) Radar, which had been decisive in fending off the planned invasion, aided greatly in limiting the damage German bombers could inflict on the cities. During the Blitz, the British had success with a gun-laying radar, the

[17] Dear, p. 163.

[18] Dear, p. 984.

GL Mark II, both to direct antiaircraft fire and to direct searchlights (illuminating the bombers which could then be attacked by fighter aircraft).[19]

Because of heavy losses in daylight raids, in the autumn of 1940 the Luftwaffe turned almost exclusively to night bombing. Daytime interception, though dependent on radar for detection of enemy aircraft, relied on visual sighting by the pilot of the intercepting aircraft. Since this method would rarely work at night, Bowen led an effort to develop a radar set to be carried in the interceptor. In June 1939 an airborne radar set operating at 1.5-meter wavelength was tested. In November 1940, an improved system, the AI Mark III system, was used in the first kill by a radar-directed night fighter. By May 1941, the AI Mark IV was in use.[20] In that month alone the Luftwaffe lost about 100 bombers to the radar-equipped night fighters and another 30 to ground antiaircraft fire, and as a result, it called off the night offensive.[21] And in the spring of 1942 centimetric radar (discussed below) became available for interceptor radar.[22]

10.1.2 Technical Developments

In the mid-1930s research groups in at least eight countries—France, Germany, Italy, Japan, Netherlands, the Soviet Union, Great Britain, and the U.S.—independently developed radar.[23] In most cases the objective was warning against air attack, but only in Great Britain was radar an important element of national defense prior to the outbreak of war.[24] This resulted in part from the considerable fear of German air power, mentioned above, and in part from the precocity of British electronics, as seen most clearly with television. In 1936, Great Britain began regular broadcasting with an all-electronic system, and the experience with higher-frequency circuits, high-power transmitting tubes, and cathode-ray tubes contributed to the development of radar systems.[25] (This is an example of a military benefit from a civilian technology.) The great British superiority, however, was not in technics but in the operational use of radar, a point appreciated by Churchill, who wrote that the Germans would have been surprised, not at the British radar equipment but at the way the British had "woven radar into [the] general air defense system."[26]

A legacy of the First World War was, as shown in Chapter 2, continuing military R&D. In the U.S. the two principal military research establishments of the interwar period were the Naval Research Laboratory (NRL) in Washington, DC and the Army Signal Corps Laboratory at Fort Monmouth, NJ. It was at these two labs that the first operational radars in the U.S. were built, NRL demonstrating an early-warning

19 Louis Brown.

20 Louis Brown.

21 Hanbury Brown.

22 Hartcup 1970, pp. 111–113.

23 Dear, p. 918.

24 Louis Brown.

25 Fox.

26 Churchill, *Gathering Storm*, p. 156.

radar in 1936 and the Fort Monmouth lab demonstrating a searchlight-directing radar in 1937. The navy tested an early-warning radar at sea in early 1939 and began taking delivery of production models (of what became known as the CXAM) in May 1940. The army began taking delivery of a searchlight-directing radar (the SCR-268) in 1940 and early-warning radars (the SCR-270 and SCR-271) in 1941.[27]

The name 'radar' came from the U.S. In Great Britain in the first years of the war, the technique was called radio direction finding or RDF; in Australia it was called radiolocation. But in November 1940 Samuel M. Tucker and F.R. Furth of the U.S. Navy proposed the acronym RADAR (for RAdio Detection And Ranging), and this term was adopted by the British in July 1943.[28]

A great boost to the U.S. effort came in the late summer of 1940 with the arrival of a British technical mission, commonly referred to as the Tizard mission, after its leader Sir Henry Tizard. The British shared information about technologies potentially of great consequence for the war: jet aircraft, submarine detection devices, gun directors, and much information about radar. The U.S. had the world's largest radio manufacturing business, and the British hoped to enlist these resources to develop radar.[29] Several areas in particular seemed to call for additional resources: centimetric radar for night-fighters (the highest priority), a long-range navigation system for guiding bombers, and an antiaircraft gun director.[30] E.G. "Taffy" Bowen (a member of the mission who remained in the U.S. to assist in radar development) summarized the significance of the Tizard mission as follows: "It convinced the US Chiefs of Staff that radar was a supremely important weapon of war, one which was already playing a vital part in military operations in Europe"; it "introduce[d] the resonant magnetron to the USA"; it "led to the establishment of the Radiation Laboratory at MIT"; and it "introduced airborne radar to the United States." Bowen argued also that the Tizard mission "established a rapport between the USA and Britain …" that found lasting expression in the British Commonwealth Scientific Office in Washington and the NDRC (later OSRD) Office in London.[31]

In France, the Companie Générale de Télégraphie sans Fil developed a magnetron of advanced design and used it in a pulse-radar iceberg detector installed on the liner *Normandie* in 1935.[32] The French air force developed a continuous-wave radar for long-range warning, and in 1939, with British help, the French began development of a high-power pulse system.[33]

In Germany the outstanding German pioneer of radar was Rudolf Kühnhold of the navy's communications research institute (Nachrichtenmittel-Versuchsabteilung der Marine). In the mid-1930s this institute produced a continuous-wave radar that could detect a ship as far away as two kilometers.[34] Kühnhold founded a company

[27] Van Keuren 1994.

[28] Buderi, p. 56.

[29] Clark, p. 251.

[30] Buderi, p. 43.

[31] Bowen, pp. 193–195.

[32] Brittain 1985.

[33] Hezlet, p. 171.

[34] Kümmritz.

(GEMA) to developed pulse radars, and Telefunken conducted its own program to develop radio location.[35] In 1938 a radar, Seetakt (operating at 365 MHz and with a range of 15 to 20 kilometers), was installed on the pocket battleship Graf Spee,[36] and that same year an early-warning radar, Freya (operating at 125 MHz), began to be used and production began of a gunlaying radar, Würzburg (operating at 560 MHz).[37] Expecting the war to be short, German military leaders stopped all radar research that seemed unlikely to result in a usable product within a year, and many radar researchers were drafted into the army.[38] In 1942 it became clear to German leaders that radar played vital roles in many types of warfare and that most German radars were technically inferior to Allied radars. As a result, some 15,000 engineers and technicians were brought back from the front to work on radar development.[39]

In Japan in 1939, Yoji Ito, working for the navy, designed and built a split-anode magnetron with 10-centimeter wavelength, and before the end of the war the Japanese were using 10-cm radar.[40] These were, however, of low power (2 kW), and in general the Japanese radars—land-based, shipboard, and airborne—were not as successful as those of Great Britain or the U.S.[41]

One of the most significant changes in radar technology over its first decade was the movement to higher frequencies. Chain Home operated at 25 MHz, and early U.S. Navy radars operated at 200 MHz; before the end of the war there were systems operating at 10,000 MHz. Since frequency and wavelength are inversely related (their product equals the speed of light), one may express this change as the movement to shorter wavelengths, with Chain Home using 12-meter waves and some systems at the end of the war using 3-centimeter waves.

The move to higher frequencies had in fact begun in radio communications decades before the war. It was hampered by the fact that in order to function effectively, nearly every component of transmitters and receivers needed to be modified. Especially difficult was generating high frequency waves with sufficient power. Different insulation was required. High-frequency currents travel in the outer surface of a conductor (the so-called "skin effect"), which led to new conductor design (first conductors made up of a large number of fine strands, then hollow conductors).[42] Receiver noise increased at higher frequencies.[43]

35 Kern.

36 Kümmritz.

37 Skolnik.

38 Skolnik.

39 Kern. Kern explains that under the Nazis the training of electrical engineers suffered—from 1932 to 1939, the number of graduations declined by half—and that the outbreak of war further reduced engineering ranks.

40 Okamura, p. 56.

41 Dear, p. 919, and Hezlet, p. 234.

42 A.H. Taylor, p. 167.

43 Absorption of radio waves by the atmosphere —moisture for frequencies above 10,000 MHz and atmospheric gases for frequencies above 30,000 Hz—imposed an upper bound on useful frequencies in many applications.

Moving to higher frequencies promised to help in extending the range of early radars, which was quite limited. The shorter wavelengths were easier to focus into narrow beams, so that a distant object would reflect more energy back. Also, early airborne radar (such as the 200-MHz radar) was limited in range to the height of the aircraft, because the unwanted ground return from the necessarily broad antenna pattern masked any target at a greater distance; with higher frequency, one could obtain a narrow transmission-beam.[44]

Even more importantly, higher frequencies gave greater resolution. Directing antiaircraft and long-range naval guns entirely by radar required centimetric radar, as longer-wave radar did not provide accurate enough angular measurements (of azimuth and elevation).[45] Another application of radar made possible by the shorter wavelengths was the display of the topography below an aircraft, as by the H2S airborne radar.

The most important technical breakthrough in the move to higher frequency radar was the invention of the cavity magnetron. In 1916, GE researcher Albert W. Hull invented the magnetron diode: an externally applied magnetic field controlled the electron flow from cathode to plate. (GE sought a magnetically controlled tube because of the vulnerability of its patent position on grid-controlled tubes.)[46] In a later design, the anode was a hollow metal tube (rather than a filament as in the usual radio tubes), the cathode a cylinder within the anode, and an applied magnetic field controlled the flow of electrons from cathode to anode.

In the 1920s several people—notably the Czech physicist August Zacek and the Japanese researchers Hidetsugu Yagi and Kinjiro Okabe—discovered that the magnetron could be used to generate high-frequency oscillations. But it was difficult to obtain sufficient power from such magnetrons, so early radar systems used radiation of longer wavelength that could be generated by vacuum tubes.[47]

Among the efforts stimulated by the threat of German bombers was the microwave research group formed in 1939 by Mark Oliphant at the University of Birmingham; a part of this team, Randall and Boot sought to find a more powerful source of microwave energy.[48] They changed the design by placing openings or cavities in the anode. As electrons leave the cathode, the applied magnetic field makes them move around the cathode (circling rapidly but only slowly approaching the anode). When air is blown across the top of a tube, a sound wave is built up inside at the resonant frequency of the tube. Similarly here, the motion of the electrons across the cavity openings causes an electromagnetic wave to build up inside at the resonant frequency of the cavity.

For the development of the cavity magnetron, Randall and Boot used the Manchester differential analyzer, which was a version of Vannevar Bush's machine. It may have been an advantage that Randall and Boot were physicists not very

[44] Dear, p. 199.

[45] Hezlet, p. 241.

[46] Brittain 1985.

[47] Brittain 1985.

[48] Brittain 1985.

familiar with electron-tube design, so, as Ivan Getting expressed it, "were completely uninhibited by the then current state-of-the-art in the design and construction of oscillator tubes. They placed the resonant circuit inside of the vacuum envelope, instead of outside."[49] It was engineers, however, ones from the British GE laboratory at Wembley, who gave vital assistance in turning the Randall and Boot magnetron into a practical device. It worked for the first time on 21 February 1940, and in May 1940 it was tested in a radar set that was able to detect a submarine periscope at a distance of seven miles.[50]

Unknown to Randall and Boot, investigators in other countries—notably Shigeru Nakajima and Yoji Ito in Japan, and N.F. Alekseev and D.E. Malyarov in the Soviet Union—had already produced experimental cavity-magnetrons. However, the efforts elsewhere, in contrast to Randall and Boot's work, did not lead to practical systems of much success.[51]

In September 1940 the Tizard mission showed the magnetron to U.S. scientists and engineers. Lee DuBridge, who, a month later, became director of the newly established MIT Radiation Laboratory, wrote after the war:

> *I shall never forget the thrill that came to some of us at the Radiation Laboratories at M.I.T. in the fall of 1940 when we first tested a replica of the British magnetron … and we saw it produce many kilowatts of pulses power at a wave length of 10 centimeters—a frequency of 3000 megacycles. Very seldom in the history of technology does a single device produce improvement by a factor of nearly a million, but the magnetron raised the usable power from milliwatts to kilowatts in a single stroke.*[52]

When the Germans obtained a cavity magnetron from a downed British plane in Frebruary 1943, they, too, were amazed. They immediately made copies, and this magnetron appeared in a number of German radars before the end of the war.[53]

Effective centimetric radar depended on the cavity magnetron in the transmitter.[54] It depended, too, on another electronic marvel: the klystron in the receiver. The receiver took advantage of heterodyning (combining the received signal with a locally generated signal) to improve sensitivity, but finding a suitable local oscillator at microwave frequencies was not easy. In 1937, Russell Varian invented the klystron as a means of generating high-frequency radio waves; in the next few years Russell Varian, his brother Sigurd Varian, William Hansen, and others developed the klystron

[49] Getting 1989, p. 103.

[50] Brittain 1985.

[51] Dear, p. 199, and Nakagawa, pp. 20–21.

[52] DuBridge 1953, p. 781. A. Hoyt Taylor also, in his autobiography, recorded the surprise U.S. engineers felt (p. 209): "… we could hardly believe that these little tubes could so so much."

[53] Kern.

[54] Centimetric radar, which used frequencies in the microwave range, has, properly enough, in light of the postwar development, captured much of the attention given to wartime radar. It should, however, be recognized that the vast majority of wartime radars operated at lower frequencies: virtually all German and Japanese radars and most Allied radars (even the British MKII airborne radar, ten thousand of which were built, operated at 200-MHz).

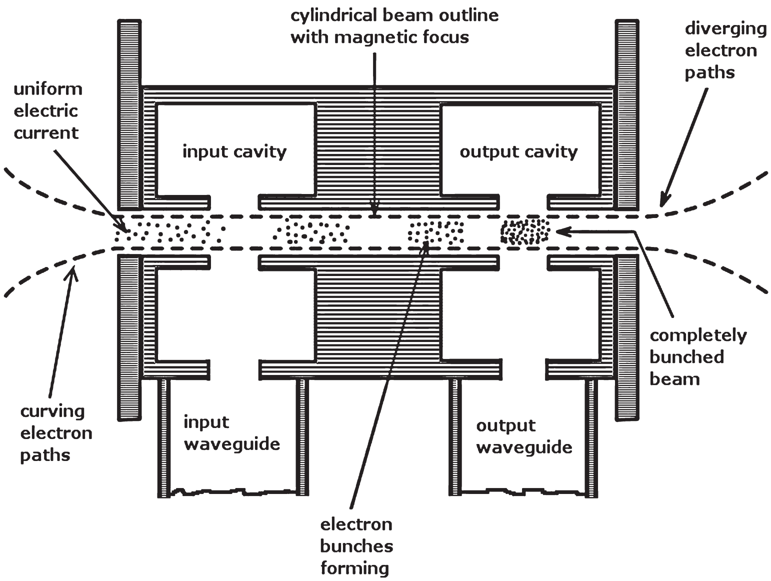

Figure 10.3. Schematic depiction of the klystron.

as a circuit component, showing that it could do most of the things conventional electron tubes could do, but in microwave frequencies rather than radio frequencies or lower.[55]

A klystron does not control the electron flow by attracting or repelling electrons with an interposed grid (as in the triode), but rather by causing bunching in the flow, speeding up slow electrons and slowing down fast electrons. The influence can be exerted by an electromagnetic wave, the input signal. The bunches generate an output signal that is an amplification of the input signal. (See Figure 10.3.) A cathode-ray tube influences the beam laterally (in a direction perpendicular to the electron motion), while a klystron influences the beam longitudinally (in the direction of the electron motion or the exactly opposite direction).

With feedback added, the klystron can function as an oscillator. Unknown to the Varians, velocity modulation (used in the klystron) had been discovered in 1933 by A. Arsenjewa-Heil and Oscar Heil in Europe.[56]

Radar became much more useful with the wartime development of the plan position indicator (PPI), the type of radar screen familiar from movies. Radar was already using the cathode ray tube, which had been, in the 1920s and 1930s, the object of much work for oscilloscopes and television. Figure 10.4 shows the Chain Home radar display. The large blips at the left come from the outgoing pulse. Two

[55] Ginzton 1975.

[56] Ginzton 1975. Both the klystron and the magnetron use resonant cavities in the vacuum tube to generate particular frequencies at high power. Indeed, knowledge of the klystron gave Boot and Randall the idea of introducing the resonant-cavity idea into the magnetron [Wildes and Lindgren p. 195].

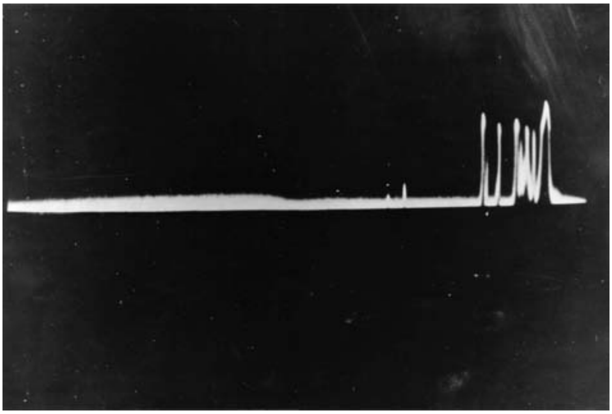

Figure 10.4. Chain Home radar display (photo courtesy of the Imperial War Museum, London, E(MOS) 1446).

small blips left of center are echoes from aircraft at distances of about 50 and 55 miles respectively.

Much more effective was a way of depicting the radar information as from an overhead view. It displayed all detected objects as on a map with the radar set at the center. On a cathode ray tube, a rotating radial line (indicating the current direction of the radar antenna) shows by a spot any reflecting object that lies in that direction. The distance of the spot from the center of the screen indicates the range. It was necessary to develop tubes on which the image would persist for several seconds. In both Great Britain and the U.S., so-called "duplex" screens were developed for this purpose. There were two layers of phosphors, the inner layer serving to activate the outer layer, in which the light emission decayed much more slowly.[57]

Great Britain had developed PPI by the time of the Battle of Britain.[58] It made it easy to calculate relative positions, courses, and speeds.[59] The British airborne radar Mark IV, equipped with PPI, proved effective, as by May 1941 102 night bombers were downed through its use.[60]

There were, of course, many other technical advances that were vital to effective radar systems. One of the earliest was duplexing, using a single antenna to serve as both transmitter and receiver. The U.S. Naval Research Laboratory developed a duplexer in 1936, several years before this was accomplished in other countries.[61] At the time of the Tizard mission, duplexing was one area in which the U.S. was ahead of the British.[62] Another new technology was the use of waveguides to conduct

57 Guerlac, p. 269.

58 Wildes and Lindgren, p. 194.

59 Hezlet, p. 245. The PPI gave no indication of the height of the aircraft, but the British built a separate display that could give the height of any aircraft as its spot on the PPI was illuminated [Hartcup 1970, p. 121].

60 Louis Brown.

61 Skolnik.

62 A.H. Taylor, p. 209.

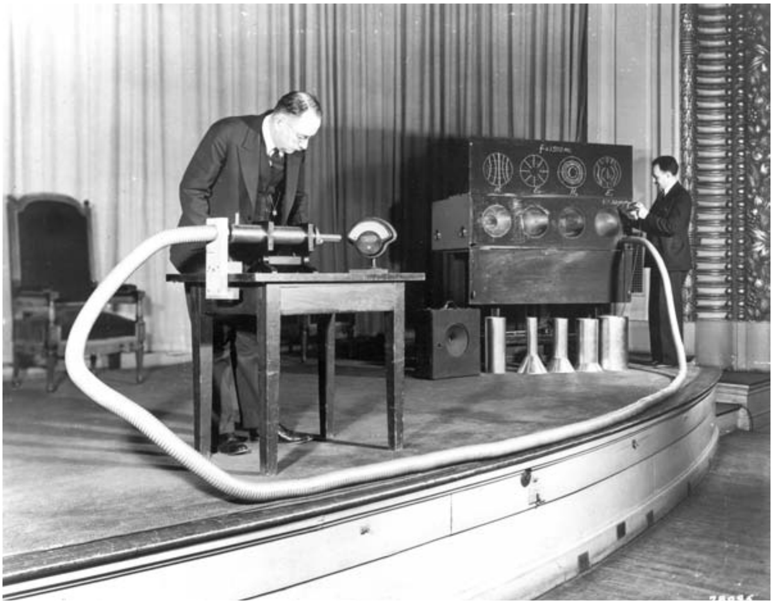

Figure 10.5. George Southworth's 1938 demonstration for the Institute of Radio Engineers (photo courtesy of AT&T Archives and History Center).

electromagnetic waves from one point to another. (See Figure 10.5.) In radar, waveguides were used to convey the microwaves from the magnetron to the antenna coaxial cables. One might mention also the Moving Target Indicator, developed at Rad Lab, which, when attached to radar sets, caused the display of moving objects only (eliminating, that is, the echoes received from stationary objects).[63]

10.1.3 Variety of Radars

The objective of the prewar development of radar was, in most cases, to obtain a means of early warning of air attack. The instrumentality invented—"seeing" with radio waves—was so basic a way of obtaining information that it soon found dozens of other uses.

Ground-based radar of the Chain Home type not only gave early warning of air attack, but also permitted centralized direction of anti-aircraft defense.[64] The British

[63] There were, in addition, many advances in non-electrical technologies that might be mentioned. For example, according to Robert Watson-Watt [quoted in Alexander, p. 1531], "The availability of polythene transformed the design, production, installation and amaintenance problems of air-borne radar from the almost insoluble to the comfortably manageable. A whole range of aerial and feeder designs otherwise unattainable was made possible; a whole crop of intolerable air maintenance problems was removed."

[64] The Germans, too, used radar in this way: a ground station tracked both bombers and fighters continuously and issued commands by radio [Dear, p. 643].

supplemented the original Chain Home with the higher frequency Chain Home Low (300 MHz) and Chain Home Extra Low (3 GHz) in order better to detect low-flying aircraft.[65] Radar was soon used in directing antiaircraft searchlights (Search Light Control radar) and in directing antiaircraft guns.[66] At one point the Germans had some 4000 Wurzburg-type radars used in directing some 16,000 heavy guns.[67] Radar was also used in guiding planes during landing (called ground-controlled approach radar).

In the land battles of the Pacific theater Japanese mortars caused high casualties; the Americans modified a SCR-584 radar so that it tracked a mortar shell and calculated its firing point.[68] Another type of portable radar developed for the U.S. Army was for locating mines. Military meteorologists used radar: thunderstorms were visible on radar screens and radar could be used for tracking pilot balloons (to determine wind speeds at various heights).[69] The U.S. National Bureau of Standards developed a lightweight transponder (pulse repeater) that was carried by a weather balloon for measurement, using a ground- or ship-based radar, of wind speed and direction. Thousands were built for the navy during the war.[70] (See Figure 10.6.)

In 1936 a group at Bawdsey Research Station headed by E.G. Bowen began work on airborne radar. This was an ambitious undertaking, as at that time a radar unit filled a small house, weighed several tons, consumed many kilowatts of power, and used huge antennas, yet in 1937 an airborne set was ready for testing and in August 1939, Air Interception (AI) radar began to be delivered to the Royal Air Force. This was the AI Mark IV, operating on a wavelength of 1.5 meters, which performed well against German night attacks.[71] The move to higher frequencies benefited airborne radar in particular, as it became possible to get a narrow beamwidth from a small antenna.

The first airborne radar for detecting ships and submarines (the Air-to-Surface-Vessel or ASV radar) was delivered to the Royal Air Force in March 1940. This was the ASV Mark II, operating on a wavelength of 1.5 meters, which became widely used and proved especially valuable in antisubmarine work.[72] Italy and Germany

[65] Dear, p. 921.

[66] Some antiaircraft radar was used for range information only, as, for example, the SCR-547, called "Mickey" because of the two parabolic antennas, one for sending, one for receiving. With early radars, optical tracking gave more accurate angular readings, and optical tracking was made possible for the Search Light Control radar, which illuminated the targets. [Mindell 1995c.]

[67] Miller, p. 110. This concentration of antiaircraft guns and radars made Allied bombing missions extremely perilous for the crews, a point made in Joseph Heller's novel *Catch-22*.

[68] Thiesmeyer, pp. 244–245.

[69] Dear, p. 741. Since thunderstorms generated radio waves, they were also located by radio direction-finding.

[70] Snyder and Bragaw, pp. 323–327. A passive system—using reflectors rather than transponders—was also developed and manufactured in large quantities [Snyder and Bragaw, pp. 326–327].

[71] Hanbury Brown, and Dear, p. 921.

[72] Hanbury Brown. Initially the aircraft posed little direct threat to U-boats, but the ASV radar was valuable in guiding the aircraft to the convoys they were to help protect (since locating a convoy through cloud and fog was otherwise hardly possible) and in detecting surfaced U-boats (whose locations could then be reported to convoy escorts) [Devereux].

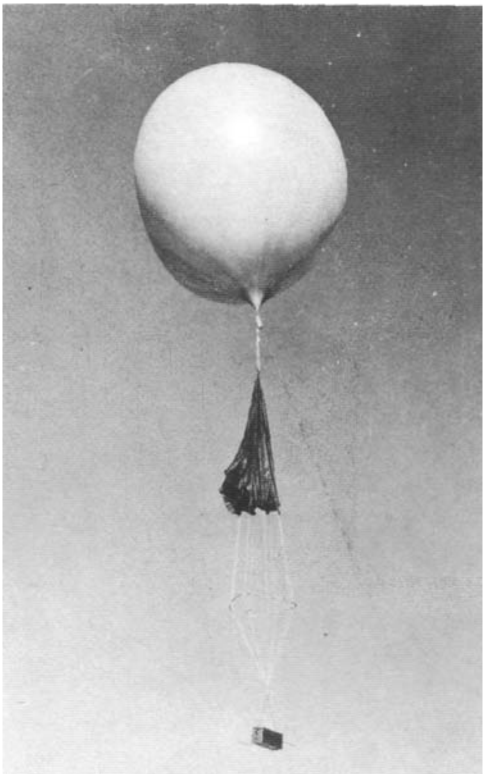

Figure 10.6. Weather balloon, provided with a parachute so that when the balloon bursts the 3-pound repeater will descend slowly (photo courtesy of NIST Boulder Labs).

sought to supply the Afrika Korps by means of night convoys across the Mediterranean, but British planes through the use of radar sank large numbers of the ships thus employed; lack of supply was a principal reason for the defeat of the Afrika Korps.[73]

The ASB radar (which operated at 515 MHz) was the most widely used airborne radar: from 1942 through 1944, some 26,000 sets were produced. It was used for detection of ships and surfaced submarines, for bombing, and for airborne intercept.[74] The SCR-720 was an S-band (3.3 GHz) radar used in nightfighter aircraft, with a range of four nautical miles for fighters and twice that for bombers; the first units were delivered in the spring of 1943, and before D-day, several thousand had been produced.[75]

Radar was also used as an altimeter, and some planes were equipped with tail-warning radar (where the presence of another aircraft was the important information, direction and distance being of secondary importance). Radar came to be extremely important in navigation and in bombing, and these topics are considered in detail in

[73] Louis Brown.

[74] Skolnik.

[75] Skolnik.

later sections. This section reviews the importance of airborne radar in the fight against submarines.

The Battle of the Atlantic was going badly for the Allies in early 1943. Shipping losses totaled 400,000 tons in March. That was the month that the decimetric ASV Mark II radar began to be used. It transmitted a narrow beam to each side so that surfaced submarines within 25 miles could be detected.[76] The Mark II also came with PPI; earlier ASV radar gave only range and left-right indications.[77] The blimps or airships that flew over convoys to provide protection against submarines were also equipped with radar.[78] Escort vessels, too, were equipped with radar.[79]

As shown in Chapter 9, codebreaking and other factors made large contributions to the defeat of the U-boat, but perhaps decimetric radar was the most important single factor.[80] In August 1943, six months after the introduction of the Mark II, Allied shipping losses were down to 40,000 tons, and the submarines no longer posed a mortal threat.[81] This dramatic effect and its strategic importance have prompted some observers to judge the introduction of the decimetric ASV radar as the most important single event of the entire war.[82] Admiral Doenitz said:

> *… the enemy has deprived the U-boat of its essential feature—namely the element of surprise—by means of radar. With these methods … he has conquered the U-boat menace. … It was not superior strategy or tactics which gave him success in the U-boat war, but superiority in scientific research.*[83]

At the outbreak of war there were just a few radar sets at sea, by May 1941 almost every large ship of the British Home Fleet was fitted with radar, and by the end of 1943 it was essential equipment in warships of all sizes.[84] Shipboard uses of radar multiplied: sea-search radar, air warning radar, ranging radar, navigational radar, and fire-control radar. Radar was important, too, in directing carrier-based aircraft (see Figure 10.7), and radar was deployed in the aircraft themselves, especially for detection of submarines and low-flying aircraft.

British radar superiority played an important part in several victories against the Italian navy, including the Battle of Matapan in March 1941 that put an end to

[76] Hezlet, pp. 199–200.

[77] Hartcup 1970, pp. 55, 60.

[78] Dear, p. 138.

[79] Dear, p. 922.

[80] Hezlet writes (p. 231), "Without doubt the most important reason [for the outcome of the Battle of the Atlantic] was the spread of efficient airborne radar." He also points out (p. 233) that many of the other important factors depended upon electronics: the centimetric radars on escort vessels, improved sonars, use of high-frequency direction-finders on escort vessels, and great improvements in convoy communications.

[81] Hartcup 1970, p. 59.

[82] Crowther and Whiddington, p. 71, and Hartcup 1970, p. 59.

[83] Quoted in J.E.D. Williams, p. 214. When Dönitz made this statement he was unaware of the large role that Enigma decryptions played in the Battle of the Atlantic [R.V. Jones, p. 322].

[84] Hezlet, pp. 184, 205, 246. Hezlet writes (p. 184), "The total number of sets at sea in the British, American and German Navies was seven. …"

Figure 10.7. Air plot room showing radarmen directing combat air patrols (photo courtesy of the Imperial War Museum, London, A 21602).

fleet actions by Italy.[85] It was with radar-directed fire that the *Bismarck* sank the British battleship Hood in May 1941.[86] British sea-search radar was vital in bringing about the final confrontation with the *Bismarck*.[87]

In the first years of the war in the Pacific, when the Japanese had a powerful air force, the CXAM early-warning radar on U.S. capital ships was extremely important.[88] In the naval battle of Guadalcanal, the U.S. ships, but not the Japanese, had radar, and it was probably radar that tipped the scales in favor of the Americans.[89] In November 1943 a major naval engagement in the Pacific (the Battle of Empress Augusta Bay) was fought at night entirely on the basis of radar information, as there were no visual sightings by either side and torpedoes and guns were directed by radar.[90] The Battle of Surigao Strait in October 1944 is another example of a major naval engagement fought almost entirely by radar; the superiority of the U.S. Navy's radar—both search and fire-control—played a large part in the U.S. victory.[91]

[85] Louis Brown.

[86] Louis Brown.

[87] Hezlet writes (p. 208), "If the British had not possessed radar there is no doubt that the *Bismarck* would have broken out on to the trade-routes without being brought to action."

[88] Louis Brown.

[89] Hezlet, pp. 223–225.

[90] Hezlet, p. 240.

[91] Hezlet, pp. 257–259.

Shorter-wavelength radar showed the fall of shot (the splashes of the rounds missing the target), so that complete blind fire was possible.[92]

Radar allowed Allied aircraft to lay sea-mines accurately from a much greater, and therefore much safer, height.[93] U.S. submarines effectively used search radar (notably the centimetric SJ radar) to locate enemy ships.[94] In 1944, U.S. submarines sank half of the Japanese merchant fleet, which caused severe shortages of materials in Japan; most of these attacks were made at night using SJ radar, and many of the daytime sinkings were also indebted to SJ radar.[95]

Many uses of radar elicited countermeasures. For example, the Germans learned the frequency of the Mark II and placed warning devices in their submarines.[96] The Japanese learned the frequency of the aircraft warning radar used by U.S. submarines and placed receivers on their airplanes, which were then able to home on the signals.[97] These are two examples of the multitude of wartime countermeasures, a subject so large that it deserves its own section.

10.2 RADAR COUNTERMEASURES

10.2.1 Detecting, Jamming, and Changing Frequency

In technological warfare, as discussed in Chapters 1 and 2, almost every move elicits a countermove. Radar, because of its importance, produced move-countermove chains of many links. Before discussing these individually, we consider several general points. First, military intelligence was always a part of warfare, but in World War II what was called "scientific intelligence" (information about the technological capabilities of the enemy) was vital, since it was necessary to understand how the enemy was achieving some result in order to devise a countermeasure. Second, the development in each country of radar and radar countermeasures occurred with continual interactions.[98] Third, since detailed knowledge of a method frequently made it easy to devise a countermeasure, there was usually extreme need for secrecy. Fourth, since the use of a countermeasure might reveal enough to the enemy for it

[92] Hezlet, p. 259.

[93] Dear, p. 753.

[94] Hezlet, p. 233.

[95] Hezlet, p. 253. U.S. submarines began using the centimetric SJ radar in June 1942, the X-band ST in 1944; the latter was operable when the submarine was submerged, the antenna (which was just six inches by two inches) located just below the periscope lens [Devereux].

[96] Dear, pp. 922–923. The Allies countered with the ASV Mark III, which did not trigger the warning devices.

[97] A.H. Taylor, p. 214.

[98] Guerlac, p. 299. In the U.S., most radar development took place at the Radiation Laboratory at MIT, while most countermeasures development took place at the Radio Research Laboratory at Harvard. It was decided to keep the two efforts largely separate, partly for security reasons, partly because Rad Lab was concerned with microwave radar, while most countermeasurers were directed against longer-wavelength radars. [Guerlac, pp. 299–300]

to be copied (and then used against one's own radars), there was always caution and frequently delay in putting countermeasures into use.[99]

One characteristic of radar immediately suggests itself as exploitable: radar advertises its presence by sending out electromagnetic waves. Indeed, radar detectors became a principal countermeasure. A radar detector was a receiver that could rapidly scan the frequencies that enemy radar might be using and register its direction, strength, and other characteristics. Work on rapid scanning receivers (not for enemy radar, but for enemy radio transmissions) began at the Naval Research Laboratory as early as 1929.[100] By the end of 1941, the Naval Research Laboratory had made great progress in designing wideband receivers to detect enemy transmissions and determine their frequencies.[101] The British, too, developed radar detectors, such as the so-called "Boozer" installed in RAF planes beginning in the spring of 1943 that told pilots when German radar was directed toward them.[102]

As soon as Admiral Dönitz realized—in the summer of 1942—that the enemy was using radar to locate U-boats, he had radar detectors (the FuMB search receiver) placed on U-boats, which to some extent restored the surface mobility of U-boats, since U-boats could submerge before an enemy aircraft reached them.[103] The adoption, however, of the centimetric ASV Mark III, beginning in December 1942, turned the tide, as this radar was not detectable with the FuMB.[104] Nine months later, U-boats began to be equipped with the new *Hagenuk* search receiver, which was effective with centimetric radar.[105]

A great many Allied bombers were lost because the Germans learned to detect the H2S radar (with a device called Naxos) and thus to track the airplanes.[106] German fighters were equipped to detect enemy radar, a fact known to the Allies. But many RAF fliers believed that their IFF (Interrogate Friend or Foe) device (explained below) jammed German radar, when in fact it made the British planes more detectable. Not until 1944 did the RAF order its fliers to turn off IFF over enemy territory;[107] it was decryptions of Enigma messages that finally convinced the RAF that the Germans were taking advantage of the British IFF.[108]

The Japanese, too, made use of radar detectors. For example, at the naval Battle of Kolombangara in 1943, a Japanese force detected a U.S. force from a distance of

[99] Among the British the stongest opposition to the use of radar countermeasures came from Robert Watson-Watt. R.V. Jones proposes (p. 290) that Watson-Watt "had developed a 'bridge on the River Kwai' attitude toward radar, and it hurt him emotionally to think of radar being neutralized, even German radar."

[100] Taylor, p. 226.

[101] Guerlac, p. 299.

[102] R.V. Jones, p. 290.

[103] Hezlet, pp. 230–231, and Kahn 1991, p. 261.

[104] Hezlet, p. 231.

[105] Hezlet, p. 236.

[106] R.V. Jones, p. 392.

[107] J.E.D. Williams, p. 214.

[108] J.E.D. Williams, p. 221.

about 100 miles using a radar search receiver. Within 50 miles this receiver could accurately track the U.S. ships using radar.[109]

Another characteristic of radar also suggests itself as exploitable: since radar depends upon receiving a weak echo, the presence of strong electromagnetic waves might drown out the desired signal. So-called jamming could be used against surveillance radar, fire-control radar, and other types of radar, including the the electronic navigation systems described below. The Germans may have been first to use radar-jamming, which they directed against the British Chain Home radars beginning in September 1940.[110]

Jamming allowed the German battleships *Scharnhorst* and *Gneisenau* to navigate the English Channel without detection in February 1942.[111] The Germans achieved this in a clever way so that the British radar operators did not realize they faced jamming. The jamming signals sent at dawn were made to resemble atmospheric interference, then the period of jamming was slowly extended from day to day so that the British operators became accustomed to this early morning phenomenon.[112] This is an example of so-called "confusion jamming", jamming that the enemy does not recognize as jamming.[113]

The German air-defense employed several types of radar, including Freya, Mammut, and Wassermann, and Würzburg. In answer, RAF bombers began using a jamming transmitter, called Mandrel, in December 1942. The Germans modified the radars so they could operate on different frequencies—at the time an exceptional engineering achievement—and several times extended the range of frequencies (reaching, at the end of the war, from 475 to 585 MHz).[114] The Germans modified airborne radar too (such as the Lichtenstein SN2) so that it could change frequencies.[115] The RAF countered by increasing the power and the frequency range of Mandrel.[116]

The U.S. Army Air Force developed the jamming device called Carpet. When first used in a raid on Bremen in October 1943, it reduced losses by more than half.[117] A German scientist reported:

> *The dispensing of "Döppel" [also called chaff, described below] in conjunction with the simultaneous application of electronic jamming produces such catastrophic results that the attack is by preference tracked with optical means and therefore our defense is practically blind. The awful destruction of our cities which the enemy oftentimes*

[109] Hezlet, p. 239.

[110] Dear, p. 331.

[111] Miller, pp. 109–110.

[112] Walsh. R.V. Jones reports (pp. 233–234) that at least one British radar man recognized what the Germans were doing, but was unable to convince others of what was going on.

[113] Guerlac, p. 299.

[114] Dear, p. 332, and Hartcup 1970, p. 147.

[115] Kümmritz.

[116] Dear, p. 332.

[117] Miller, p. 111.

> *carries out with negligible losses is an eloquent proof of the effectiveness of these jamming means used by the enemy.*[118]

According to one estimate, jamming saved the RAF on the order of 1000 bombers and their crews and saved the U.S. Air Force some 600 bombers and their crews.[119] By late 1944, the Allies were effectively jamming almost all forms of German radar, with a result of much lower losses.[120]

Jamming was used also against the German radio-controlled rocket-bomb, the Henschel 293 (Hs-293), which was guided from the bomber that had released it. It scored two early hits, but the jamming system rendered it ineffective.[121] In December 1944 when, in the Battle of the Bulge, the Germans captured thousands of artillery rounds containing the proximity fuse (described below), the U.S. needed to develop quickly a jammer that would work against its own proximity fuse.[122]

The British developed an arsenal of jamming devices, some to jam radar-controlled guns, some to jam air-interception radar, some to jam radio-telephone transmissions, and so on. The Germans turned these to their advantage by homing on the jamming transmissions, which contributed to the heavy losses of British bombers in the spring of 1944.[123] Jamming was very effective against Japanese anti-aircraft fire-control radar, so although Japanese cities were heavily defended by AA guns, the U.S. B29s bombing Japan suffered an average loss of just 0.8 percent.[124]

10.2.2 Chaff, Coating, and Active Deception

World War II's most famous anti-radar technique was the dropping from aircraft of large numbers of strips of foil or metal-covered paper, which created radar echoes. Called Window in Great Britain, Chaff in the U.S., Düppel in Germany, and Gimanshi in Japan, the technique saw widespread use. Both the British and the Germans developed this countermeasure early in the war, but refrained from using it so as not to reveal it to the enemy. After more than a year the British learned, from a conversation overheard in occupied Denmark, that the Germans knew of the technique, so not long afterwards introduced it, reasoning that its use would harm the Germans more than themselves.[125]

Window was first used in a raid on Hamburg in July 1943. It reduced losses dramatically, and these bombing raids significantly reduced the war production coming from that city.[126] On 2 December 1943, the Luftwaffe used Düppel with

[118] Quoted in Miller, p. 112.

[119] Dear, p. 334.

[120] R.V. Jones, pp. 468–469.

[121] Lyon, and Walsh.

[122] Lyon.

[123] Hartcup 1970, p. 148.

[124] Dear, p. 334.

[125] R.V. Jones, pp. 291–299.

[126] Dear, p. 523, and Miller, p. 111.

great success in its raid on the Italian port of Bari.[127] Window was used not only to provide an electronic smokescreen, but also to suggest falsely the presence of a large number of aircraft. For example, at the time of the first British attack on Peenemünde, as a diversion eight planes dropped large amounts of Window over Berlin, attracting some 200 nightfighters.[128]

Window proved quite effective and became an integral part of bombing operations; at the end of the war, 20 million tons of Window had been dropped over Europe.[129] By the end of the war almost every U.S. heavy bomber was using both Window and Carpet.[130] These Allied countermeasures reportedly reduced the effectiveness of German radar fire-control to $\frac{1}{5}$ of its previous level, and optical fire-control became usual against Allied aircraft.[131]

The Germans countered chaff in several ways. One was the addition of an audio output to the radar, so that the operator could hear the propeller modulation of the radar echoes (and thus distinguish target from chaff).[132] Another was to develop radar systems of different frequencies or systems that could change frequencies.[133] For example, the low frequency radar SN-2, which operated at 90 MHz, was unaffected by chaff. It did, however, prove vulnerable to long lengths of foil, a countermeasure the Allies introduced (and called Rope) in the summer of 1944.[134] These were called electronic counter-countermeasures (ECCMs). By one count the Germans used 13 different ECCM devices during the war and had 18 additional ECCM devices under development.[135]

The use of radar in the Battle of the Atlantic also shows the move–countermove of technological warfare. In the summer of 1943, Admiral Dönitz conceded, “The method of radio location which the Allies have introduced has conquered the U-boat menace.”[136] In 1944 the Germans began to equip U-boats with a snorkel, a retractable air intake, which allowed the boat to travel submerged while still running the diesel engines and recharging the batteries. The Allied move to centimetric radar (as the three-centimeter ASV Mark VII) made these snorkels detectable. The Germans countered by placing antiradar covering on the snorkels.[137] To divert attention from

[127] Dear, p. 113.

[128] R.V. Jones, p. 347.

[129] Hartcup 1970, p. 156.

[130] Miller, p. 111.

[131] Walsh.

[132] Dear, p. 332.

[133] Kümmritz.

[134] Dear, p. 332.

[135] Johnston.

[136] Quoted in Guerlac, p. 723.

[137] Hezlet, pp. 249, 251, and Nebeker, p. 34. A reflecting surface can be made into an absorbing surface by coating it with a quarter-wave layer, that is, a partly transparent layer whose thickness is one-quarter the wavelength of the electromagnetic radiation passing through it. (Thus, the waves passing through the layer, reflecting off the surface, and passing again through the layer are shifted by one-half wavelength so as to cancel with the waves reflected from the layer initially.) By placing several layers on a surface, it can be made invisible to radar operating at several wavelengths.

centimetric radar and decryption of Enigma messages, the British made the Germans believe that they were locating U-boats by infrared detectors. The Germans then developed an ingenious way of painting U-boats, so that they were camouflaged in both visual frequencies and infrared frequencies (thus producing a countermeasure to a pretended measure).[138]

Self-deception was possible. On 26 July 1943, U.S. warships misidentified radar images as coming from a Japanese convoy, when they were in fact coming from some distant mountains. In what became known as the "Battle of the Pips", the U.S. ships fired a thousand shells and reported flares, lights, and torpedo trails from the (quite imaginary) enemy.[139]

"Chicken" was a means of deceiving enemy radar operators. A radar reflector, made largely of chicken wire, was towed behind a small ship, giving it the radar appearance of a large ship.[140] Like Window, Chicken was a passive measure; more effective were several schemes of active deception.

"Moonshine" was a transponder that sent back amplified and extended echoes. Thus, a single plane could resemble, on enemy radar, a large formation of planes. The British began using Moonshine in August 1942. On August 17, for example, a small number of Moonshine-equipped planes diverted nearly 150 German fighters from a major bomber assault.[141]

On D-Day the Allies launched two deceptive operations ("Taxable" and "Glimmer"), involving both aircraft and boats, at the eastern end of the English Channel. They hoped to convince the Germans that two assault convoys were approaching the French coast there, so that fewer troops would be transferred to the western end of the channel. (See Figure 10.8.) The Allies used three devices to simulate ships on German radar screens: "Window" aluminum strips dropped from aircraft; "Filbert" balloons containing a reflecting device; and "Moonshine" equipment that responded to an enemy radar pulse by amplifying it and transmitting it back.[142] The Allies used also boats and planes with radar jamming equipment, though their objective was not to jam enemy radars completely (which would then not have detected the simulated convoy), but to appear to be trying to do so. On D-Day two "electronic armadas", simulating large fleets, advanced at about 15 kilometers per hour toward the French coast. Near the coast a smoke-screen was laid down and the amplified sounds of landing craft (coming from wire-recorders) were projected toward the shore. There are conflicting opinions on whether these ingenious deceptive operations, an early example of virtual reality, had any significant effect. The slowness of the Germans to recognize that the Normandy landings were the main invasion force probably owed something to these efforts.[143]

[138] R.V. Jones, p. 321.

[139] Dear, p. 115.

[140] Taylor, p. 234.

[141] R.V. Jones, pp. 290–291.

[142] The idea of Moonshine was to detect the enemy radar-transmission and to send back stronger echoes to suggest a whole formation of aircraft [R.V. Jones, pp. 243–244].

[143] Cruickshank, pp. 199–200, Dear, p. 333, and R.V. Jones, pp. 411–412.

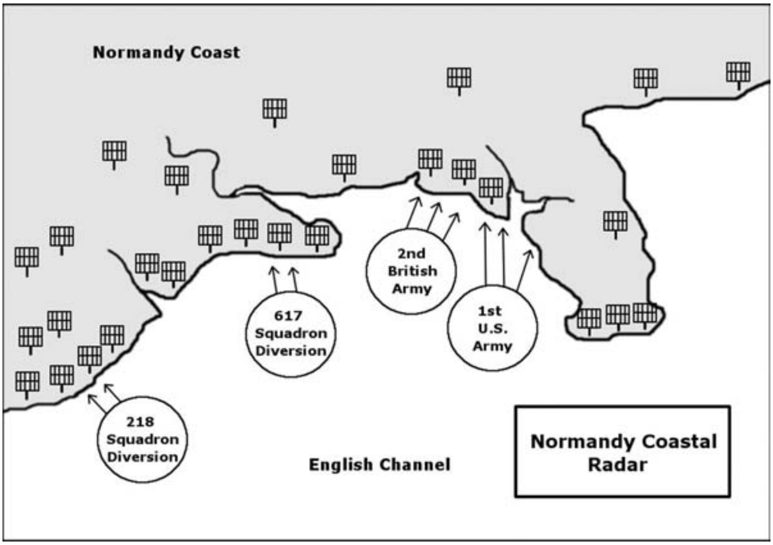

Figure 10.8. Map showing the deployment of German radar in Normandy in June 1944.

Countermeasures are, of course, as old as warfare. In the fifth century B.C., Sophocles wrote "If the plotter lurks with swift intent, let the counterplot be ready just as speedily." In the sevententh century Thomas Hobbes remarked, "Force and fraud in war are the two cardinal virtues."[144] With the dominance of electronic means of information gathering and communication, it became easier, in many situations, to deceive the enemy, and high-technology measures offered, in many situations, more opportunity for countermeasures. Thus electronic warfare accelerated the age-old endeavor to deceive and outsmart the enemy.

10.3 THE PROXIMITY FUSE

10.3.1 A New Weapon

One of the most decisive weapons of World War II was the proximity fuse. Secret at the time, it has remained little known, yet it was remarkable in several respects. First, it was a great advance on earlier technology. Indeed, even today the concept sounds like science fiction: a miniature radar set in each piece of ammunition that causes detonation at the ideal distance from the target. Second, it moved rapidly from conception, to experimental device, to mass-produced weapon, all in the course of the war, and at war's end, 22 million had been made. Third, it proved extremely effective in combat and, because it was used only by the Allies, substantially shortened the war. This new device was spawned by the threat of airplanes, just as radar itself had been.

[144] Quoted in R.V. Jones, p. 215.

At the beginning of the war, anti-aircraft gunners typically fired thousands of rounds for every plane brought down, and ships were therefore quite vulnerable to air attack.[145] At that time a standard antiaircraft shell was detonated by a time fuse, which was set just before firing. Since time-to-target was difficult to predict, one idea, investigated in the late 1930s in Great Britain, Germany, and the U.S., was to make a fuse that automatically detonated when near the target.[146] Electronics seemed the only feasible means of achieving this, yet an electronic device (together with its power supply) was generally much too large to fit into an artillery shell, and, even more problematic, existing electron tubes were far too fragile to withstand the explosive discharge from the gun and the rapid spinning of the projectile in flight.

Bell Labs, however, succeeded in designing a special phototube that could be placed in the nose of a surface-to-air projectile. When the projectile entered the shadow of the target aircraft, the change in light level set off the explosive charge. Though such a device has obvious operational shortcomings (requiring direct sun, passage of the shell in the shadow of the target, and absence of clouds whose shadows would trigger the fuse), it was often far more effective than timed-fuse shells, and its use reportedly reduced the number of German daylight bombing raids over England.[147]

Much more effective and a much greater technological achievement was the proximity fuse. Its development began in August 1940 when the newly established National Defense Research Committee funded a project headed by Merle Tuve at the Carnegie Institution in Washington, DC. The British, who had developed a photoelectric fuse and made considerable progress toward a fuse that used radio waves to detect the target, shared their knowledge, which greatly speeded the U.S. program in its initial stages.[148] Fifteen months later, Tuve's group had designed a tiny radar unit that could fit into a shell five inches in diameter. It transmitted radio waves, detected reflections of those waves, and detonated the shell when the reflections reached a certain strength. It was powered by a battery and used five tiny vacuum tubes, each an extremely rugged tube about an inch long, which were suspended so as to shield them from mechanical shock.[149]

Its operation was fairly simple. The firing of the shell activates the battery, which provides three different voltages. An oscillator tube, with the cap and casing of the shell serving as antenna, sends out continuous radio waves. If the waves are reflected back to the shell, they modulate the plate voltage of the oscillator tube (since the relative motion of shell and target causes the reflected wave to have a slightly

[145] Baldwin writes (p. 25) "It was estimated that it took about twenty-four hundred rounds of five-inch time-fuzed ammunition to bring down a single plane." On 10 December 1941 the Japanese demonstrated the vulnerability of capital ships to air attack by sinking *Prince of Wales* and *Repulse*.

[146] Klingaman, pp. 3–4.

[147] Smits, p. 146. The British developed a similar device, in which Churchill took a personal interest; see Baldwin, pp. 31–37.

[148] Baldwin, p. 47. The development of such fuses was one of the subjects discussed by the Tizard Mission, and the basic circuit design for the proximity fuse came from the British [Baldwin, pp. 63, 65].

[149] Klingaman, pp. 5–6.

different frequency), producing a beat frequency in the audio range. (So the radar receiver uses the same antenna and tube as the transmitter.) The audio-frequency signal then passes through a three-tube amplifier. If both the frequency and the intensity of the audio signal are within prescribed limits, it triggers a thyratron tube (acting as a switch), which releases a surge of electricity to detonate the shell.[150]

Some miniature tubes had been manufactured for hearing aids, but these were neither reliable enough nor rugged enough.[151] When fired, the shell experienced an acceleration of some 20,000 G (that is, 20,000 times the acceleration of gravity), and in flight the shell spun at a rate as high as 475 revolutions per second.[152] In certain guns, so-called "side slap" (shock to the exiting shell from the side of the gun barrel) could reach almost 400,000 G.[153] Breakage of the glass envelope of the tube was, not surprisingly, a serious problem. Less obvious was the need for strengthened filaments; in some early tests when the glass envelopes survived firing, each tube was found to contain what looked like a tiny wad of tinfoil, which was all that remained of the filaments. Though they had to be structurally strong, the filaments also had to be tiny. Some were too fine to be seen with the naked eye and had to be welded into the tubes under microscopes.[154] Another serious problem was "microphonics", mechanical vibration of the filaments causing variations in the electrical output.[155] Also required was that the fuse function over a wide range of temperatures, from well below freezing to 40 or 50 degrees Celsius. Yet an accelerated development program, drawing on the expertise of a number of U.S. tube manufacturers, did succeed in designing sufficiently small and sufficiently rugged tubes.

There were other major challenges. The batteries, too, had to be tiny and rugged. First a dry-cell battery was developed. It functioned well, but it proved to have a shelf life that could be as short as three or four months in the tropical conditions of the South Pacific. A wet-cell battery, with a much longer shelf life, was therefore developed.[156] Since the barrel of the gun might trigger the shell, the fuse needed safety devices to delay the activation of the fuse and thus prevent premature triggering for the first half-second or so after the shell was fired.[157]

After extensive testing of the fuse, the navy decided to transform the experimental device into a reliable weapon that might be mass-produced. Tuve became director of a new organization, the Applied Physics Laboratory at Johns Hopkins University, set up for that purpose in March 1942.[158] A milestone was reached in

[150] Baldwin, pp. 20–21.

[151] Ryerson.

[152] Klingaman, p. 5.

[153] Baldwin, p. 170.

[154] Baldwin, p. 113.

[155] Baldwin, p. 107.

[156] Baldwin, pp. 119–122. In the wet-cell battery, a glass ampule (which broke when the shell was fired) held the electrolyte; the equipment used to make the ampules were ones that earlier made Christmas-tree lights; hence this put an end to the manufacture of Christmas-tree lights for the remainder of the war [Baldwin, pp. 121–122].

[157] Baldwin, pp. 127–131.

[158] Klingaman, pp. 6–8.

August 1942, at a trial of the fuse, only four rounds were needed to bring down three drone aircraft. This was so far beyond anything previously possible in anti-aircraft fire that observers were astounded. George F. Hussey, Jr., director of production of the U.S. Navy's Bureau of Ordnance, recalls, "I left that meeting with my eyes almost sticking out of my head!"[159] The navy then ordered full-scale production.[160]

The proximity fuse was an extremely complex device, which, when used, encountered conditions near its operating limits. In addition, the fuse had to be manufactured in huge numbers—monthly production reached two million in mid-1945. An effective program of quality control was therefore essential. There was constant laboratory testing of components and test firings of completed fuses. Because of the volume of production, statistical methods had to be developed so that the characteristics of large lots could be adequately gauged from relatively small samples.[161] At the end of the war, the U.S. had produced 22 million fuses of 30 different types, and ⅓ of the country's electronic industry—87 companies using 110 different plants—was engaged in making them.[162] Of the ruggedized miniature tubes, 140 million were manufactured.[163] The U.S. spent about $1 billion on the proximity fuse, half of what it spent on the Manhattan Project.[164]

10.3.2 The New Weapon in Combat

Usually called the VT (for variable time) fuse, the proximity fuse was first fired in combat in January 1943, when it brought down a Japanese bomber. By the end of 1943, 9100 VT-fused shells had been fired in combat. When used with the best radar fire-control (discussed below), VT-fused shells were three times as effective as time-fused shells.[165] According to the chief of staff of the U.S. Navy Fast Carrier Task Forces, "those fuses knocked down enemy planes by the dozens. Had it not been for those fuses, our ship losses and casualties in the Fast Carriers in the last half of the war would have been enormously larger than they were."[166] For example, on 19 June 1944, Admiral Jisaburo Ozawa sent hundreds of planes against a U.S. fleet in the Philippine Sea, and, thanks in large part to the proximity fuse, 373 of them were shot down.[167] In 1945 the proximity fuse was used effectively against the Kamikaze bombers. Assessing its significance in the Pacific, James Forrestal, Secretary of the

[159] In Baldwin, p. xix.

[160] Klingaman, p. 12.

[161] Baldwin, pp. 163–166, 220.

[162] Baldwin, pp. xx-xxi, 210–214.

[163] Baldwin, p. 111.

[164] Noble, p. 7.

[165] Hezlet, pp. 256–257. Pointing out that the ratio of three to one came from a study of action in 1943, Baldwin writes [p. 245], "Improvements in VT fuzes and fire control methods after 1943 increased this advantage ratio to six to one."

[166] Admiral Arleigh Burke as quoted in Baldwin, p. 237.

[167] Baldwin, pp. 244–245.

Navy, said “The proximity fuse has helped blaze the trail to Japan. Without the protection this ingenious device has given the surface ships of the Fleet, our westward push could not have been so swift and the cost in men and ships would have been immeasurably greater.”[168]

As with all new weapons, there was reluctance to use it for fear the enemy would learn about it and copy it, or at least develop countermeasures. (If the enemy knew how the shells worked, they could explode them prematurely by emitting the appropriate signal.) Because the Allies had so much more to lose if anti-aircraft fire became much more effective, General “Hap” Arnold, commander of the U.S. Army Air Forces, opposed all use of the proximity fuse.[169] The first uses authorized in the European theater were only over water (where recovery of unexploded rounds was unlikely), and when the navy first used in the fuse in the Mediterranean, the ships sent out a radio signal to mask the signals coming from the shells.[170]

The V-1 attacks on England, which began in June 1944, led to heavy use of the fuse. Though balloon barrages (large numbers of helium-filled balloons holding up steel cables) shielded the cities and fighter aircraft defended the approaches to England, these defenses could do little against the V-1s. The best hope for defense was anti-aircraft artillery.[171] Radar-controlled guns (described below) and VT-fused shells made this defense extremely effective.[172] With advance knowledge of the V-1 from military intelligence, the Applied Physics Laboratory had designed a VT-fuse specifically for the V-1. These fuses were manufactured in time for the assault in the summer of 1944, and they proved five times as effective as time fuses.[173] On the last day that the Germans sent a large number of V-1s against England, early-warning radar detected 104, but only four reached London (anti-aircraft fire downing 68 of them, others being stopped by aircraft fire and balloon barrages).[174]

On 24 September 1944 the British, under Field Marshall Montgomery, captured Antwerp before the Germans were able to destroy the port facilities. In order to deny the Allies this important port—it was soon supplying all six Allied field armies—the Germans launched a massive V-1 attack. The V-1 was not an accurate weapon, but of 4900 launched, almost half, 2400, were on target. Yet air defense, principally anti-aircraft fire, managed to destroy all but 200 of them, and the port continued to function.

The proximity fuse made still another vital contribution to the victory in Europe. It was well-known that when firing artillery against ground targets air bursts were usually more effective than contact bursts. This, however, was very difficult to achieve with time fuses as variations in trajectory and burst times meant that some shells exploded too early and some too late. In 1944, a smaller proximity fuse for

[168] Quoted in Baldwin, p. 249.

[169] Baldwin, pp. 261–262.

[170] Klingaman, pp. 12–14.

[171] Miller, p. 114.

[172] Miller, p. 2.

[173] Baldwin, pp. 260–261.

[174] Baldwin, p. 266.

use especially in army artillery was developed. The fuses detected radiowave reflections from the ground and detonated the shells at a height so that the explosion would have maximum effect.[175]

On 16 December 1944, the Germans launched a massive counteroffensive through the Ardennes that became known as the Battle of the Bulge. Until then the army had refrained from using the fuse, but the great German advances convinced Allied leaders that it was time to do so.[176] According to Ralph Baldwin (an APL physicist who later wrote a history of the proximity fuse),

> *The use of antipersonnel VT fuzes in field artillery weapons during and after the Battle of the Bulge must be considered the greatest tactical advent of a new weapon in the history of warfare. All the advantages claimed for the fuzes were immediately confirmed, as thousands of rounds of heavy shells were poured on road junctions, bridges, and highways over which troops were advancing. For the first time in the history of warfare, the artillery was able to obtain devastating air bursts over targets as much as fifteen miles distant, both day and night.*[177]

After the battle a U.S. staff officer wrote "PW [prisoner-of-war] reports are unanimous in characterizing our artillery fire as the most demoralizing and destructive ever encountered."[178] According to another report, "To a man, [captured German officers] thought the terrible beating they had taken was due to some new, unbelievably efficient method we had discovered to train our artillery-men."[179] General George S. Patton said: "The funny fuze won the Battle of the Bulge for us."[180] And General Ben Lear, head of U.S. Army ground forces, called the fuse "the most important innovation in artillery ammunition since the introduction of high-explosive shells."[181]

The Allies developed a proximity fuse for use in bombs, and proximity-fused bombs were used effectively both in Europe and in the Pacific.[182] The Germans worked on several types of proximity fuse (including one that detected infrared radiation), but none reached the stage of a standardized service item.[183] The Japanese did develop a proximity fuse for use in bombs, and its effectiveness was shown when a single bomb dropped above a U.S. airfield in Saipan destroyed or damaged scores of bombers. Before the end of the war, the Japanese manufactured 12,000 of these fuses and fitted many of them to bombs stored on Kyushu for use when the Americans invaded the home islands.[184]

175 Klingaman, pp. 16–17.

176 Baldwin, p. 277.

177 Baldwin, p. 280.

178 Quoted in Baldwin, p. 280.

179 Quoted in Baldwin, p. 288.

180 Quoted in Baldwin, p. 279.

181 Quoted in Klingaman, p. 18. Hartcup [1970, p. 180] writes, "But post-war investigation showed that the claims made for the proximity fuse in halting the German advance were 'grossly exaggerated.'"

182 Baldwin, p. 247.

183 Baldwin, p. 300, and Sanders.

184 Baldwin, p. 64.

Except for this type of proximity fuse, the Allies had a virtual monopoly on the new weapon. This fact, together with the weapon's effectiveness, made it decisive in many situations. Admiral Lewis L. Strauss of the U.S. Navy wrote "While no one invention won the war, the proximity fuse must be listed among the very small group of developments, such as radar, upon which victory largely depended."[185]

10.4 THE RADAR-COMPUTER COMBINATION

10.4.1 Fire Control

The offensive threat posed by airplanes became widely appreciated in the 1930s. Experts realized that the higher speeds and greater altitudes of new aircraft made traditional gunnery methods, which had never enjoyed much success, quite obsolete. It was this "antiaircraft problem" that Vannevar Bush called attention to even before the outbreak of war.[186] When war came it soon confirmed the urgency of the problem: in the Battle of Britain in the summer and fall of 1940, an average of 18,500 antiaircraft shells were fired for each German plane brought down.[187] Bush and other NDRC leaders initiated efforts to solve the problem by coupling three of the most advanced technologies of the time: radar, computers, and automatic control systems.[188]

Consider the difficulty of shooting down an airplane. First, one must observe the plane's direction and distance. This radar could achieve, giving measurements of azimuth, elevation, and range continually. Second, one must extrapolate its motion over the time required for an antiaircraft shell to reach the plane, perhaps 10 or 20 seconds. This, it was hoped, computers could achieve. Third, the gun must be aimed, the fuse set (so that the shell would explode at the appropriate time after firing), and the gun fired, all extremely rapidly. This, it was hoped, control systems could achieve.[189]

The calculational problem was not straightforward. To calculate the appropriate azimuth and elevation of the gun, one must know the exact time of flight, since the shell and target must arrive at a position simultaneously. But to calculate the time of flight, one must know the azimuth and elevation, since, in general, the distance of the target changes constantly. Though explicit solution of a set of equations might sometimes be possible, the method of successive approximations provided a more general—and more easily implemented—solution. Assume a particular time-of-flight and calculate the azimuth and elevation of the airplane after that time has

[185] Quoted in Baldwin, p. 5.

[186] Mindell 1995c.

[187] Burns 1995/1996.

[188] Burke, pp. 204–205.

[189] The problem is one of leading the target, a skill that hunters, with bow-and-arrow or rifle, can acquire. The speeds and distances of aircraft, however, took the problem beyond what human reactions and calculations are capable of. [Mindell 1995a.]

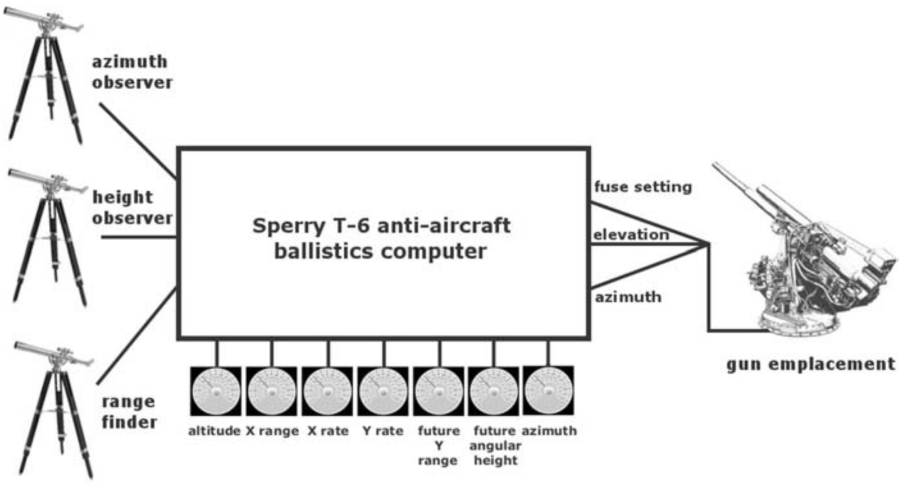

Figure 10.9. Schematic depiction of the T-6 anti-aircraft system.

elapsed, then calculate the actual time-of-flight for that direction, take the improved estimate of time-of-flight and calculate azimuth and elevation, and so on. If this process converges (that is to say, the differences between successive values of time-of-flight, azimuth, and elevation approach zero) and if it can be carried out rapidly enough, then it can be used to control the gun.

In 1930, the Sperry Gyroscope Company, which had built fire-control equipment in the Great War, designed an antiaircraft gun director that the army adopted. Known to Sperry as the T-6 Director (and to the army as the M-2), it was a man-machine system that took into account not only the changing position of the aircraft, but also winds, air density, and the gravitational force exerted on the shell. The system incorporated electromechanical analog calculators, automatic data transmission, and a dozen or more human operators. (See Figure 10.9.) By design, the tasks performed by the operators were simple, typically adjusting a parameter by means of a hand crank to keep it in accord with a desired value shown on a dial.[190] It is not then surprising that most of the operators could be replaced, in later gun directors, by servomechanisms. This replacement, however, required technical advances, as human operators acted as data filters, not responding to low-level noise and recognizing erroneous or corrupted data, and were less prone to "hunting" or other stability problems encountered with servomechanisms.[191]

The difficulty of large-scale production of mechanical and electromechanical calculating devices—parts had to be machined and fitted to high accuracy—stimu-

[190] Two reasons for making the tasks simple were the difficulty of performing complex operations in the stress of battle and the difficulty—experienced acutely in the Great War—of rapidly acquiring large numbers of highly-trained personnel in a national emergency [Mindell 1995a].

[191] Mindell 1995a.

lated work—stimulated work on electrical analog-computers.[192] In 1940 a group of Bell Labs engineers examined electrical means of performing the mathematical operations needed to solve fire-control equations—adding, subtracting, multiplying, dividing, differentiating, integrating, and retrieving tabulated data—and produced a manuscript called "Electrical Mathematics".[193] A basic component was the custom-shaped potentiometer, which could provide an electromechanical analog of mathematical functions such as sine or logarithm or tabulated functions. (Typically a servomechanism provided the input by turning the potentiometer through a particular angle, and the resulting potentiometer voltage was the output.)

Bell Labs people—making great use of their experience with feedback systems and electrical filters—designed a gun director, the T-10, that was similar in function to an earlier Sperry director, but which performed most calculations electrically rather than mechanically. The T-10 performed about as well as the Sperry director, and since it was much more easily manufactured, the U.S. Army adopted it in February 1942 as the M-9 Director. It was fully automatic except for the use of human trackers who operated telescopes. Before the end of the war, 1500 M-9s and its derivatives were manufactured,[194] and it was effective at the Anzio beachhead, against the buzz bomb, and at Saipan, Iwo Jima, and Okinawa.[195] The M-9 is a good example of the trend in military technology away from individual instruments wielded by humans and toward integrated systems in the operation of which humans played a smaller and smaller role.

The trend continued with the M-9 when it was combined with radar, so that the tracking was done entirely automatically. This occurred in April 1942, when the SCR-584 fire control radar, designed at Rad Lab, went into production. It tracked an aircraft to $\frac{1}{20}$ of a degree out to 18 miles. It became the most successful ground radar of the war, and 1700 were manufactured. Bell Labs and Rad Lab worked together in the design of the M-9 and the SCR-584 so that they could form an integrated system.[196] This indeed happened, and the M-9/SCR-584 combination, especially when supplemented with the proximity fuse, was extremely effective. In protecting the Allied beachhead at Anzio in February 1944, more than 100 German aircraft were shot down in one month.[197] The most impressive performance of the M-9/SCR-584 was against the German V-1s (a robot defense against a robot weapon); in the period from 17 July to 31 August 1944, the automatic AA system, deployed along the British coast, shot down 1286 V-1s headed toward London.[198]

[192] Mindell 1995c. Sperry gun directors contained a great many parts—the successor to the T-6 that the army was using when the U.S. entered the war contained 11,000 parts—and many of them had to be made extremely accurately. Notable in this regard were the so-called ballistic cams, which stored, in their three-dimensional form, the information of a traditional firing table. [Mindell 199a.]

[193] Mindell 1995b.

[194] Getting, p. 115, and Mindell 1995b.

[195] Fagen 1978, p. xi.

[196] Mindell 1995b.

[197] Mindell 1995b. The introduction of the SCR-584 was timely, as the Germans had found effective electronic countermeasures to its predecessor, the SCR-268 [Skolnik].

[198] Mindell 1995b. This was 34% of the total launched during that period.

Long-range gunnery thus continued its tradition of stimulating technological advance. By the time of the First World War, it had, as shown in Chapter 2, elicited sophisticated analog computers to aim the guns. The addition of radar to naval fire control in World War II was a great step forward. For example, in November 1942 the *U.S.S. South Dakota* and the *U.S.S. Washington* sank three cruisers and a battleship from a distance of eight miles using radar-assisted fire control.[199] Against aircraft, automatic control of searchlights helped.[200] This was relatively easy because the light should point in the same direction as the target at that moment; illumination of enemy planes was, though, of much more help to fighter aircraft than to ground antiaircraft batteries.

It was the combination of radar and computers that provided an answer to the fire-control problem. The British Director-General of Artillery, Edward Clarke, wrote that radar "provided the means of locating and tracking aircraft accurately, instantaneously and continuously in all circumstances. …"[201] Computers and automatic control systems made it possible to use that information effectively. In 1940 some 18,500 antiaircraft shells were fired on average for each German plane brought down by British batteries; against the V-1 in the late summer of 1944 some batteries fired on average just 40 shells per plane brought down.[202]

The fire control problem brought together engineers and scientists with different experiences. This stimulated new thinking about feedback control, as the frequency-domain approach (plotting amplitude and phase relations between input and output signals) rather than the traditional time-domain approach (modeling the system with linear differential equations).[203] The difficulties in using radar input from the SCR-584 with the M-9 gun director stimulated efforts to use Nyquist's frequency-response methods in designing automatic control.[204] The fire-control problem helped about a merger of two fields: the theory of electromechanical servomechanisms and the theory of electronic feedback amplifiers.[205]

The fire-control problem stimulated computing also, not only for the gun director itself, but also for testing fire-control systems. George Stibitz at Bell Labs designed three different relay computers for this purpose and two of them remained in service for more than a decade after the war.[206] Analog computers were used to study the performance of servomechanisms: an electrical network was

[199] Miller, p. 1.

[200] Dear, p. 62.

[201] Quoted in Hartcup 1970, p. 170.

[202] Burns, p. 179.

[203] Bennett 1993, p. viii.

[204] Mindell 1995b.

[205] Mindell 1995c.

[206] Mindell 1995c. Mindell writes [p. 96]: "While Stibitz's relay computers have been called milestones in computer history, their relationship to machine control has not been explored: programming machine movements by digital program tapes anticipated the development of numerically controlled machine tools. In 1941, in fact, [NDRC] Division 7 member Duncan Stewart asked Stibitz about the possibility of using his Tape Dynamic Tester to perform automatic milling for commercial applications, and the device was used to mill cams for later testers. …"

built with appropriate inductances, capacitances, and resistances in order to model the servo motor and its driven load. In this work Westinghouse engineers drew on their experience modeling the performance of electrical networks, as described in Chapter 3.[207]

10.4.2 Bombing Systems

The first vehicle-borne computers may have been the fire-control computers described in Chapter 2. Chapter 5 provided the example of the Sperry autopilot. Bombing gave another reason to develop a vehicle-borne computer.

When, as was often the case in the First World War, bombs were released at very low altitudes, it was not difficult to hit a specific target. In World War II, however, antiaircraft fire compelled bombers to fly at great heights. Then, as with naval gunnery earlier, the much greater range necessitated some type of calculating aid if the target were to be hit.

Bombing systems and antiaircraft directors performed inverse tasks: both needed to take into account airplane motion, wind, and ballistics, the one to strike a stationary ground target, the other to strike a moving airborne target.[208] It is not surprising, then, that the analog calculators devised to perform the two tasks were similar.

The relatedness of the calculational tasks, as it turned out, worked to the disadvantage of the bomber. For most bombing systems the airplane had to maintain straight flight as it approached the release point (in order for the bombing system to be able to perform the calculation of release point), and this behavior made antiaircraft fire-control effective because it assumed straight flight (because of the calculational difficulties of doing otherwise).[209] Later in the war both bombing systems and antiaircraft gun-directors could handle more complicated motion of the airplane.

One of the most celebrated devices of the second world war was the Norden bombsight. This was an electromechanical analog computer that took values of aircraft speed, altitude, and distance to the target (entered manually from optical or radar images) and calculated when to release the bomb. Electrical servomechanisms, controlled by electrically-driven gyroscopes, precisely maintained verticality and a given azimuth.[210] During the approach the bombadier, who tracked the target either through a telescope or on a radar screen, indicated the desired direction of flight by remote control of an indicator on the pilot's instrument panel or steered the airplane himself from the bombsight. The bomb was automatically released when the calculated drop-point was reached.

The Norden bombsight became standard in U.S. bombers, but another World War II bombsight was to have greater significance in the long term, the Sperry S-1 bombsight. The S-1 was an advance over earlier Sperry bombsights. The azimuth

[207] Herwald.

[208] Mindell 1995a.

[209] Mindell 1995a.

[210] Kayton and Searle.

gyro, for example, no longer acted directly (which necessarily involved a physical linkage and significant friction), but served simply as a sensor, generating electrical signals that controlled a servomechanism that compensated for the plane's azimuthal movements. Also, the gyros were induction powered rather than supplied with current through carbon brushes (which wore out and generated carbon dust).[211]

Most significant, however, was the stimulus the S-1 gave to developing a much more precise control of the direction of motion of the airplane (both course and attitude), its altitude, and its orientation. Neither a human pilot nor the commercially available autopilots (such as the Sperry A-3) could deliver the degree of control desirable for precision bombing.[212] For the new bombsight, a young engineer at Sperry, Carl Frische, developed the first all-electronic autopilot, the Sperry A-5. High-speed induction gyros acted as sensors, and the control of the servomechanisms maintaining the plane's motion and orientation depended not only on the displacement-error signal, but also on the first and second time derivatives of that signal. The result was a control system that avoided searching (the behavior, caused by over-correction, seen in many control systems), but responded rapidly. During the bombing run, the pilot turned control of the plane over to the bombardier, who controlled the bombsight, which in turn controlled the autopilot. The S-1/A-1 combination was simple to operate and performed excellently.[213]

The Norden and other optical bombsights worked well only under certain conditions: daylight, clear weather, and little danger from antiaircraft fire (in order to permit a straight run at constant speed to the release point). To achieve accurate bombing under other conditions, new technologies were brought into play. German bombers used the X-Gerät (an electronic navigational system described in the following section), which contained a mechanical computer that took aircraft speed, altitude, and distance from target and indicated release point.[214] What made the greatest difference, however, was the development of radar bombing-systems.

Navigational radar, mentioned above, allowed airplanes to reach their targets, but higher resolution radar was needed if it were to be used for accurate bombing. The move to shorter wavelengths helped, and by 1944 the Allies had developed high-resolution bombing radars, such as the Eagle AN/APQ-7.[215] These were then combined with more sophisticated analog computers. (See Figure 10.10.) One system developed at Bell Labs during the war did not require level flight as the plane approached the target and permitted "offset bombing" (where the target was different from the ground site used for tracking, since not all targets showed up well on radar).[216]

[211] Searle.

[212] Searle.

[213] Searle. In this article, Searle explains how the Norden bombsight and the Honeywell C-1 autopilot came to be the standard equipment in U.S. airplanes in the last year-and-a-half of the war; both of these devices incorporated features of the Sperry S-1 and A-1.

[214] R.V. Jones, p. 140.

[215] Skolnik.

[216] Nebeker, pp. 68–73.

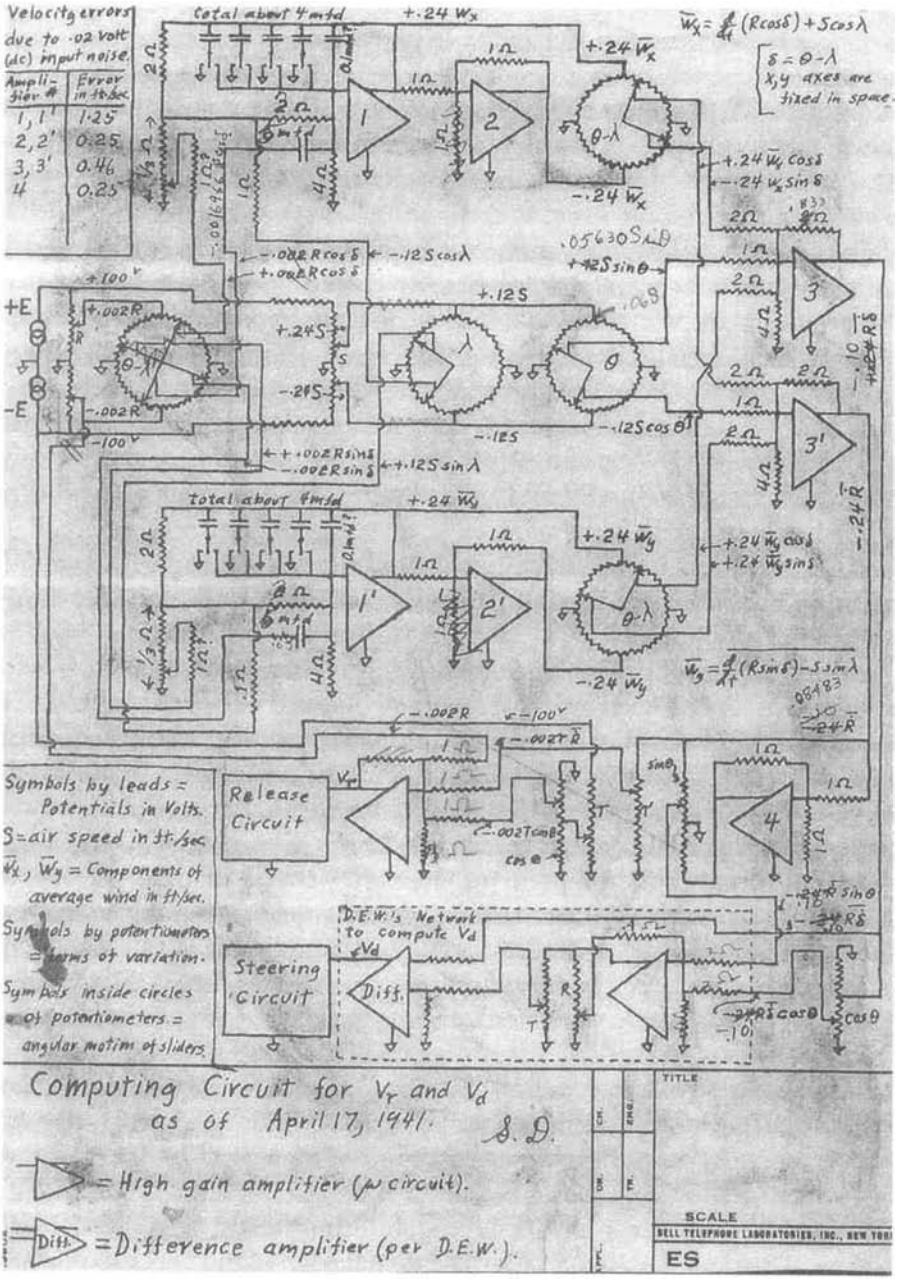

Figure 10.10. Computing circuit for two of the variables used in a radar bombing system developed at Bell Labs (photo courtesy of AT&T Archives and History Center).

10.5 ELECTRONIC NAVIGATION

10.5.1 Navigational Systems for Strategic Bombing

Intended to diminish an enemy's capacity for war by destroying industries and transportation and demoralizing the population, strategic bombing played a major role in World War II. The Germans, unable to invade Great Britain, hoped bombing would induce the British to abandon the war. The British, for their part, adopted strategic bombing as a means both of retaliation and of continuing the war in a period when they had no army able to challenge the Wehrmacht. After the U.S. entered the war, it mounted massive bombing campaigns against both Germany and Japan with the objective of compelling their surrender.

Strategic bombing required long-range and accurate navigation, which pre-existing techniques could not provide. Compounding the problem was the decision made early in the war by both Germany and Britain—having experienced heavy losses in daylight attacks—to conduct only night-time bombing. In response to these difficulties were developed a variety of techniques known then as "radio navigation" and today as "electronic navigation" that became standard in both airplanes and ships before the end of the war.

In Hitler's Germany the Luftwaffe, headed by Hermann Göring, received abundant resources, and Germany was clearly ahead of other nations in many areas of aeronautical technology. Navigation was one of these areas. Shortly before the war, the Luftwaffe developed a system called Knickebein. A directional aerial radiated a so-called Lorenz beam (see Figure 10.11), which was actually two slightly overlapping beams. A radio receiver on the aircraft produced a steady note when the plane was in the lane of overlap, which had an angular width of just $\frac{3}{10}$ of a degree. To direct bombers to a target, two transmitters, located far apart, were used: each transmitter produced a lane directed toward the target, the plane flew along one lane and knew it was at the target when it entered the other lane. As used over Great Britain the system had an accuracy of about one kilometer, until it was made almost useless by RAF jamming.[217]

The Luftwaffe developed a more accurate system, called X-Gerät, which used four beams, and with this system the bombs could be released automatically.[218] The reported beam width of the X-Gerät of 8 to 10 seconds of arc imply that at 200 miles the beam was only 20 yards wide.[219] The fleet of 509 bombers sent to bomb Coventry

[217] Dear, pp. 328–329. R.V. Jones (pp. 127–129) explains how Knickebein was jammed. The British used "meaconing" (use of a masking beacon) to good effect: a British station picked up the Knickebein, Lorenz, or Ruffian (a navigational system using two narrow beams at 70 MHz) signals and retransmitted them from a so-called "masking beacon", which then interfered with and could be mistaken for the original beacon. On several occasions German planes were completely misdirected as a result (the Knickebein countermeasure was called Aspirin, that for Ruffian [i.e., the X-Gerät] was called Bromide) [Walsh].

[218] Dear, p. 329.

[219] R.V. Jones, p. 135. The X-Gerät was so accurate that in its use it was important to regard the earth as an oblate spheroid (flattened toward the poles) rather than as a sphere [R.V. Jones, p. 142].

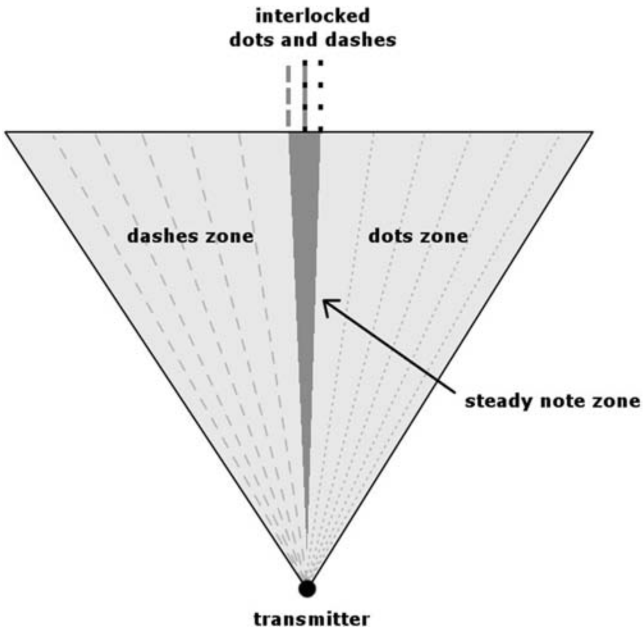

Figure 10.11. Schematic depiction of the Lorenz beam.

on 14 November 1940 were accurately guided by the X-Gerät beam system. The British jamming equipment was ineffective because improperly set, with the result that "Twelve armaments factories and much of the city centre, including the 14th-century cathedral, were destroyed. …"[220] Before long, however, the British were effectively jamming the transmissions, and they also often succeeded in decrypting the messages to the X-Gerät transmitting stations, so could foretell the exact place and time of attack.[221] When the Germans switched to another system (Y-Gerät), the British quickly learned to jam its transmissions, too.[222]

By February 1941, the British had won the "Battle of the Beams", as Knickebein, X-beam, and Y-beam were all defeated. Many bombs landed far from their targets, and many German planes were lost because the interception techniques took advantage of the beams.[223] When the Germans resumed the bombing of Great Britain in April 1942 (with the so-called Baedeker raids), they modified the X-beam (by adding a modulation frequency above the limit of human hearing) so that British jamming would be ineffective. It worked well only in the initial raids (when 50% of bombs

[220] Dear, p. 275.

[221] R.V. Jones, p. 139. Because the Germans began transmitting the beams (as for Ruffian) hours before the mission, the British could follow the beams and thus determine the target [Walsh].

[222] Dear, p. 329. The British "masking" of X-Gerät signals led, on one occasion, to a German flyer landing in England, believing himself to be over France [R.V. Jones, p. 146].

[223] R.V. Jones, p. 179.

fell on target), but was quickly defeated by improved jamming (and the next month only 13% of bombs fell on target).[224]

Great Britain and the U.S., though far behind Germany in the development of such systems early in the war, made rapid progress. At the outset British bombers had only traditional techniques of navigation—astronomical navigation and dead reckoning[225]—and, because of the blackout of German cities and towns, received few clues from the ground. A study revealed that only 22% of planes dropped their bombs within five miles of the assigned target. To improve this performance, the British developed and deployed a radar-based navigational system called Gee.[226]

Gee made use of a master transmitter **M** and several distantly-located slave transmitters, say **S** and **T**. The master transmitter, which contained a crystal-controlled oscillator, sent out pulses at a precise rate, and these triggered transmissions from the slaves. Inside the airplane was an apparatus containing a receiver, an adjustable crystal-controlled oscillator, and a cathode-ray display. The navigator used the pulses from **M** to calibrate the time base (a horizontal line with a regularly-spaced series of small peaks) shown on the display. The pulses received from **M**, **S**, and **T** were also shown, and their positions along the time base allowed the navigator to calculate the location of the airplane. As in the method of locating artillery by sound ranging, described in Chapter 2, position was fixed on a map by the intersection of two hyperbolas.[227] (Many other electronic systems developed during the war incorporated quartz crystals for frequency stabilization, and the demand for such crystals increased greatly; when the U.S. entered the war the national production was only some 75,000 annually, yet by war's end, U.S. companies had delivered some 35 million crystals.)[228]

Gee transmitters had a range of about 450 miles, and stations were initially set up to cover the Ruhr region, where much of Germany's industry was located. The results of the first full-scale use of the system—on the night of 8 March 1942—were impressive: 35% of bombs fell within five miles of the assigned target. Within months, however, the Germans were jamming the Gee transmissions. Great Britain responded by making the transmissions on multiple frequencies and by attacking the jamming stations. During the Normandy invasion, Gee gave excellent service.[229] Gee performed well also in guiding planes back to bases in Great Britain.[230]

[224] R.V. Jones, pp. 251–252.

[225] Astronomical navigation uses sightings of celestial objects to determine position and direction. Dead reckoning is the calculation of present position on the basis of knowledge of the starting position and of distances and directions traveled.

[226] J.E.D. Williams, p. 230, and Dear p. 179. The system was first designated "G", from "grid", and then "Gee" [Hartcup 190, p. 128].

[227] J.E.D. Williams, pp. 230–231. The time interval between the pulses from **M** and **S** implies that the airplane's position lies somewhere on a particular hyperbola; the interval between the pulses from **M** and **T** implies the position lies also on another hyperbola.

[228] Affrunti, p. 66.

[229] J.E.D. Williams, pp. 231–232.

[230] Taylor, p. 236.

In 1943 the RAF began using a navigational system based on radar. Called Oboe (because of the sound of the pulses it emitted), it directed a bomber to a target by precise radar measurement of the distance of the plane from two ground stations.[231] Radar could measure range much more accurately than bearing, and Oboe took advantage of this. The ground stations not only determined the distances, but also, knowing the height and speed of the aircraft, calculated the time of release of the bombs. Oboe was the most accurate of the bombing systems.[232] In a trial of the system in Britain, aircraft flying at 6000 feet dropped bombs an average of just 45 yards from the target point.[233] The British began using Oboe in late December 1942, attacking localized targets such as Wehrmacht headquarters in Belgium and a Hamburg power station, which was put out of operation.[234]

Though it was only a few months until the Germans were jamming Oboe, the system was so successful that its operating principles were copied in other blind-bombing systems: by the British in an improved version of GEE (denominated GEE-H), by the Americans in the Shoran system, and by the Germans in the Egon system.[235] So accurate were such systems that on several occasions they revealed discrepancies in the geodetic grid; for one rather extreme example, the use of Shoran in Italy revealed that the map position of Corsica was in error by almost 1000 yards.[236]

10.5.2 Radio and Radar Applied to Navigation

In the twentieth century the airplane replaced the ship as the main reason for improving navigational skill. Strategic bombing, as we have just seen, gave rise to new systems. Here, and in many other cases, electronics provided the means, and shortly after the war Robert Watson-Watt declared, "Radio systems are now primary, and the celestial arts secondary, parts of navigation."[237]

Chapter 5 explained that radio beacons were established in the 1930s so that aircraft could obtain their bearing using radio direction-finding. In the 1930s, the British developed a high-frequency direction-finding system as a means of tracking their own aircraft: ground control followed the course of each plane, which transmitted a signal periodically, by determining its bearings from two or more direction-finding stations; the plane's position could be reported to the pilot by radio telephone.[238]

[231] Dear, p. 330.

[232] R.V. Jones, p. 276. Oboe determined position by measuring times of transit, while Gee determined position by measuring differences in time of transit; Oboe could therefore be much more accurate [Hartcup 1970, p. 131].

[233] Hartcup 1970, p. 136.

[234] Hartcup 1970, p. 140.

[235] Louis Brown, and Dear, p. 330.

[236] Schneider.

[237] Quoted in J.E.D. Williams, p. 3. Williams, historian of navigational science, writes (p. 68) that Hertz's experiments in late 1880s "led to the greatest transformation of navigation in its history."

[238] Hartcup 1970, pp. 108–110.

During the war, Germany introduced a system of radio navigation called Sonne, which means sun. It was widely adopted after the war and continued in use for decades, known usually by the name given it in England, Consol. The system was a major breakthrough in navigational science, as it allowed accurate determination of direction over a large area with only an ordinary radio receiver. The operational range of a station was as much as 1200 nautical miles (1500 at night). During the war Sonne was regularly used by U-boats, fishing boats, and airplanes.[239] A somewhat similar system, called Decca, was set up by the British during the war and used for the D-Day invasion. It, too, found widespread use after the war.[240]

New navigational techniques were important to navies also. An aircraft carrier might sail a hundred miles in the time that one of its planes is airborne, so the use of homing signals, sent from the carriers, was extremely valuable in the recovery of planes.[241] The U.S. Navy developed a navigational buoy (used, for example, in guiding transport vessels) that could be laid through the torpedo tube of a submarine; it anchored itself to the bottom, sent out a coded underwater signal from one predetermined time to another, and then destroyed itself. There were also buoys that would, at a set time, rise to the surface and send out a coded radio signal.[242]

Shipboard radar, especially when equipped with the Plan Position Indicator, greatly aided navigation. A convoy-escort captain reported that radar saved three days in bringing a convoy across the north Atlantic because it allowed sailing at full speed in fog-bound coastal waters, since it outlined every headland, and allowed him to track all convoy ships at night, in fog, and in storms.[243] Radar navigation in various forms played a large part in the Normandie invasion and, together with radar countermeasures that restricted the German response to the invasion, may have been decisive for the success of that operation.[244]

Navigational radar for airplanes was also invaluable. In October 1941 P.I. Dee, while testing centimetric air-interception radar, noticed that when the system looked downward rather than ahead certain ground features could be distinguished. There resulted a program to develop a navigational radar, which became known as the H2S.[245] In addition to giving an accurate altitude reading, the H2S pictured topographical features on a PPI—an image easily compared with an ordinary map—so that fliers could identify targets at night or through clouds.[246] The crash in July 1942 of an airplane used in testing prototypes slowed the H2S project and cost the engineering profession one of its most brilliant members, Alan Blumlein, a 38-year-old electronics engineer who had made many contributions to sound recording, television, and radar.[247]

[239] J.E.D. Williams, pp. 224–226.

[240] J.E.D. Williams, pp. 226–227.

[241] A.H. Taylor, pp. 215–216.

[242] Thiesmeyer, pp. 342–343.

[243] A.H. Taylor, p. 213.

[244] Louis Brown.

[245] Hartcup 1970, pp. 142–143.

[246] J.E.D. Williams, p. 212.

[247] Hartcup 1970, pp. 143–144.

One of the first uses of H2S-directed bombing was a successful raid on Hamburg, during very bad weather, on 31 December 1942, and in early 1943, aircraft of the British Coastal Command used H2S with great effectiveness against U-boats.[248] The Germans built receivers so that the H2S radar acted as a beacon drawing the fighter aircraft.[249] When this became known, air commanders ordered that it be used for short periods only, to check navigation and to find targets.[250]

Besides the British H2S, other ground-mapping radars used during the war were the H2X and APS-20, both developed by the U.S.[251] Such radar began to be placed on B-24 bombers in August 1943; it allowed ships to be located and attacked at night.[252] Pathfinder bombers used airborne mapping radar to locate targets, which they then marked by flares or incendiary bombs. Other bombers, not equipped with the mapping radar, could then find the targets. These airborne mapping radars evolved into the weather radars carried by many aircraft after the war.[253]

Other navigational uses of radar were altimeters—some 50,000 were produced worldwide during the war[254]—and the so-called "ground control of approach" (GCA). At Rad Lab, Don Kerr, who had earlier worked on blind-landing system, developed a system in which most of the equipment was on the ground. Using 10 cm radar, ground controllers brought the plane into the landing course, and an approach controller, using 3 cm radar, guided the pilot through the landing itself.[255]

One of the original projects of the MIT Radiation Laboratory was a navigational system intended to give longer-range guidance for both ships and aircraft over the oceans. First known as LRN, for Long Range Navigation, the system was soon given the more pronounceable name "LORAN". Pulsed signals (of low frequency, so as to achieve greater range) were sent out from stations of known locations. Time differences of arrival of these pulses at the ship or aircraft were measured from traced appearing on a cathode-ray tube.[256]

Henry Tizard believed that such a system could be more easily developed in North America than in areas of Europe accessible to the British, and most of the development work was done at the Radio Research Laboratory at Harvard.[257] In 1942 an operational system was in place in North America, by the end of 1943 all of Europe was covered as well, and by the end of the war the Pacific, including the supply routes into Burma, India, and China, were covered.[258] After the war Loran

[248] Hartcup 1970, p. 146.

[249] Louis Brown.

[250] R.V. Jones, p. 466.

[251] Dear, p. 330.

[252] Louis Brown.

[253] Kayton.

[254] *Encyclopedia of Electronics*, p. 12.

[255] Wildes and Lindgren, p. 198.

[256] Guerlac, p. 285.

[257] A.H. Taylor, p. 236.

[258] Bowen, pp. 192–193, and J.E.D. Williams, p. 232.

came to be commonly used by ships, but only rarely by aircraft.[259] One of the reasons hyperbolic systems were not adopted for civil aviation is that until about 1960, computer technology was not advanced enough to make them easy to use.[260]

10.5.3 The Identification Problem

Recognizing a plane or ship as friendly or not was frequently difficult, and in World War II many planes were downed by friendly fire. For example, a number of U.S. planes, in the air at the time of the attack on Pearl Harbor, were shot down by U.S. gunners. In many situations—such as the bombing of England, the struggle for air superiority over Malta, and the naval engagements in the Pacific—there were enemy and friendly aircraft in the air at the same time, so radar would have been a much less useful tool if it provided no way of distinguishing between them.

A solution was found in the radar system known as IFF for Identification, Friend or Foe. The British put such a system into operation early in 1939, and an improved system (IFF Mark II) was in place before the outbreak of war. RAF aircraft carried a transponder, a device that transmitted a signal of its own when it received a particular signal. The transponder, when receiving a radar pulse, periodically sent a signal of the same frequency in response. This caused the radar image of the plane to intensify periodically.[261]

The steady increase in the number of different radar systems—and different radar frequencies—required a new system. It was decided to separate the two functions, locating and identifying. The resulting system (IFF Mark III) used special interrogating transmitters (at the radar site) and appropriate transponders (in the aircraft).[262]

The Tizard scientific mission to the U.S. disclosed the British IFF, and shortly afterward the British sent to the U.S. an air search radar (Mark II ASV) and an air interception radar (AI Mark IV), along with an IFF Mark II. By the end of 1940, all three had been installed and successfully tested on U.S. planes. The importance of a common radar identification of British and U.S. planes was recognized, and the IFF Mark II was adopted for both U.S. Navy and U.S. Army Air Corps planes.[263]

Something akin to IFF was developed for rescue of aircrews forced down at sea. Beginning in 1943 Allied crews were equipped with an automatic oscillator ("Walter") that registered on the radar of searching aircraft. With the aid of Walter

[259] Kayton.

[260] J.E.D. Williams, p. 100.

[261] Hartcup 1970, pp. 122–123. Something similar to IFF occurs in nature. Bats navigate by sonar, locating prey by hearing the echoes of ultrasonic pulses. Some foul-tasting moths, when they hear a bat's pulses, emit a series of clicks that are audible to the bat, which then avoids eating the moths. This might be called Interrogate Food or Filth, no response being taken to mean the former.

[262] Hartcup 1970, p. 123.

[263] Bowen, pp. 178–181.

and the Gibson Girl radio transmitter (which the Allies copied from a German sea-rescue transmitter captured in 1941), the vast majority of U.S. aviators forced down in the latter years of the war were rescued.[264]

IFF was sometimes used by the enemy. Since the RAF planes often left the IFF switched on over enemy territory, the Germans built devices to trigger the IFF response and were thus able to track the British flights.[265] The Germans estimated that 210 bombers lost by the Allies in the first two months of 1944 were downed because of IFF tracking.[266] In 1944 the RAF used a device (Serrate) that identified German fighter aircraft by the radar they used; later the RAF achieved the same end with a device (Perfectos) that transmitted interrogating pulses for the German IFF system.[267]

In 1943, because of inadequacies of the Allied IFF Mark III system, a team of British, U.S., and Canadian specialists began developing a new system known as the United Nations Beacon; although the project was cancelled at war's end, the work done had a profound effect on the postwar systems, such as the NATO IFF system.[268]

10.6 GOVERNMENT-INDUSTRY-ACADEMIA COLLABORATION

10.6.1 Technology by Command

A clear lesson of World War II was that one could sometimes command new technologies into existence. Radar is the best example: the recognized need for air defense led to the invention, rapid development, and widespread deployment of radar; other military needs led to many other types of radar. The atom bomb, long-range missiles, and highly mobile field-communications also illustrate technology by command.

The interwar years in the U.S. had seen little activity in military research and development. There was, it is true, the 1923 establishment of the Naval Research Laboratory—a delayed effect of the wartime interest in military R&D—as well as the impressive work of the National Advisory Committee for Aeronautics (NACA). But the research budgets for these and other institutions, such as the National Bureau of Standards and the Army's Signal Corps, were small.[269]

[264] Dear, p. 23. The name of the transmitter came from its hourglass shape; this etymology might remind one of the aviator's life vest, called a Mae West after its appearance when inflated. It seems that a similar device to Walter was Eureka, a navigation beacon used by U.S. and British airborne forces; a plane or boat equipped with the Eureka detector could thus be guided directly to the beacon [Dear p. 342].

[265] R.V. Jones, pp. 388–389.

[266] R.V. Jones, p. 465.

[267] Dear, p. 333.

[268] Trim.

[269] Swain.

In June 1940—Germany had overrun most of Western Europe and it appeared likely the U.S. would be drawn into the war—Vannevar Bush presented to FDR a plan for an independent agency, the National Defense Research Committee (NDRC), to coordinate military research. Roosevelt approved it immediately, and it became the principal means of organizing military R&D in the U.S. By the end of 1940, NDRC had let 126 contracts to academia and industry.[270] The formation of the NDRC was influenced by the World War I submarine project and the work of the NACA.[271]

In 1941, NDRC was subsumed by the newly created Office of Scientific Research and Development (OSRD).[272] The OSRD not only brought about collaboration of industry, academia, and government within the U.S., but also between U.S. organizations and ones in Allied—particularly British Commonwealth—countries.[273] While mobilizing the scientific and engineering community, the OSRD respected the traditional boundary between state and private spheres.[274] By the end of the war the OSRD had administered some $3 billion in research, some $1 billion of it in fiscal year 1945.[275]

The war institutionalized the "research contract". Traditionally the military contracted for equipment or parts. Here it was R&D, but not production, that was contracted for. Bush insisted on this as a way of allowing universities and industrial research laboratories to continue to function much as they had earlier and to retain a large degree of independence from the military.[276] The percentage of government research conducted in non-government facilities grew from 30% in 1940, to 70% in 1944 (50% in industry, 20% at universities).[277] Bush later argued for the efficacy of this arrangement: "… most of the worthwhile programs of N.D.R.C. originated at the grass roots, in the sections where civilians who had specialized intensely met with military officers who knew the problem in the field and who often … saw to it that the civilians got their own impressions in the field."[278]

Leading centers of industrial research, such as Bell Labs and General Electric Research, contributed enormously to the war effort. During the war, Bell Labs

[270] Eckert and Schubert, p. 139.

[271] Burke, pp. 31–34, and Swain.

[272] In early 1941 President Roosevelt felt the need to coordinate medical research better, so prevailed upon Bush to take responsibility for this as well. Bush became director of OSRD, whose two main subdivisions were NDRC and the Committee on Medical Research [Wildes and Lindgren, p. 185]. The scope of OSRD was larger than that of NDRC in two other respects: the inclusion of engineering development and the coordination of research with other groups such as the NACA [Snyder and Bragaw, p. 316].

[273] Fagen 1978, p. 8.

[274] Dear, p. 831.

[275] Swain. Different figures are given by Dear (p. 831), who credits the OSRD with 2300 contracts at a total cost of $500 million.

[276] Mindell 1995c. Mindell points out (p. 93) that the NDRC contracts were intended to cover "the *full cost of research*, which included not only equipment and salaries, but also indirect costs, the now-famous factor of *overhead*." (italics in the original)

[277] Noble, p. 11.

[278] Bush 1970, p.49.

conducted more than 2000 projects (mainly communications and radar systems) for the military or NDRC.[279] In radar, GE engineers participated in the design and manufacture of more than 50 different radar sets,[280] and half of the radar sets purchased by the military during the war were designed at Bell Labs and manufactured by Western Electric.[281]

In the U.S., major laboratories were created at universities, such as the Radiation Laboratory at MIT, the Radio Research Laboratory at Harvard, and the Applied Physics Laboratory at Johns Hopkins. (In Great Britain and most other belligerent countries, military and government laboratories carried out most major projects.)[282] As already related, Rad Lab was the center for radar R&D in the U.S. Set up to develop centimetric radar, it recruited mainly from academia; since industry was already recruiting people to expand its efforts to develop radar, it could hardly be the main source of recruits.[283] Rad Lab, which employed 4000 people at its peak, was nevertheless non-bureaucratic (people could easily cross the lines separating the different groups) and exceptional camaraderie prevailed.[284] More than 100 radar systems were developed there during the war.[285]

Similar in organization and spirit was the Radio Research Laboratory, whose mission was the development of radar countermeasures, such as systems for locating radars, determining their characteristics, and rendering them ineffective.[286] In the U.S., thousands more worked on radar at other institutions such as the Aircraft Radio Laboratory, the U.S. Signal Corps Laboratory, and the Naval Research Laboratory.

Great Britain, like the U.S., pushed military R&D vigorously during the war. As already related, the Committee for the Scientific Survey of Air Defence attracted top minds to work on a particular technical problem,[287] and work was done at many institutions. University-based research produced the cavity magnetron and many other advances. Industrial research, such as that by the Salford Electrical Instrument Company on the proximity fuse, was extremely important.[288] But government

[279] Fagen 1978, p. ix.

[280] Miller, p. 109.

[281] Fagen 1978, p. 5.

[282] R.V. Jones writes (in Dear, p. 987): "The difference between the American and British patterns in defence research had an important legacy after the war. The British continued to build up government establishments at the expense of the universities, and so tended to lock up research staffs in establishments where they had no part in bringing on new generations of students, while in the USA the universities kept research, even of the most applied kind, and teaching together."

[283] Bowen, p. 173. Bowen (pp. 174–175) describes the role of the telephone in the recruiting for Rad Lab. When the decision to establish Rad Lab was made on 14 October 1940, Ernest Lawrence, who agreed to be principal recruiting agent, "began using the telephone right there in Alfred Loomis's apartment …" and within a few weeks he called "every physicist of consequence in the United States." Bowen comments that "the telephone bill must have been astronomical."

[284] Guerlac, p. 265, and Bowen, p. 181.

[285] Brittain 1985.

[286] Kraus, pp. 118–119.

[287] Dear, pp. 985–986. At least four people who worked on British radar later won Nobel Prizes: M. Ryle, A.L. Hidgkin, A.F. Huxley, and G. Porter.

[288] Dear, p. 986.

institutions were probably most important. The Telecommunications Research Establishment (earlier the Bawdsey Research Station) employed, at its height, about 3000 people—almost all of them working on radar—and the Admiralty Signals Establishment about 4700 people—most of them working on radar.[289] The Admiralty, which conducted research in numerous technical areas at a number of locations, engaged all together some 40,000 scientists, engineers, and technicians by the end of the war.[290]

Germany lagged in the development of radar, not from any deficiency in electronics expertise—in the late 1930s, Telefunken, Siemens, and AEG engineers were doing some of the most advanced work in world—but from initial failure of political and military authorities to recognize the importance of radar and, when it was recognized, from the meager and uncoordinated response symptomatic of a war-strained economy and a political structure rife with infighting. Germany had outstanding researchers in academia (notably in the 30 research institutes of the Kaiser Wilhelm Gesellschaft), in industrial R&D departments (such as those of Siemens and I.G. Farben), and in military establishments, but failed to bring about—indeed, even discouraged—cooperation between these three main groups of researchers.[291] In 1943 the "High Frequency Research Authority" reported:

> *German research capacity in this field is about 10 times less than that of the enemy and is still divided up among about 100 different laboratories, which are mostly small to very small. … As a result of this splintering of effort, most the institutes and laboratories have not been able to work on the really large problems of electronics in warfare or have not been able to do the job adequately. … The research assignments from the various organizations requiring such work were given out without adequate coordination. There was hardly an exchange of information among the various institutes, so that frequently there was considerable duplication of work.*[292]

The Germans were slow to recognize the value of centimetric radar. When an Allied radar set, from a bomber shot down in February 1943 over Rotterdam, came into the hands of German engineers, they copied its magnetron and used it in a radar installation set up on a tower in Berlin. When it was turned on, according to one account:

> *The head physicist adjusted the knobs and he turned pale as he stared at the screen: the city of Berlin appeared on the screen with its principal streets, residential buildings, parks, and lakes. The screen showed more than was visible to the human eye from the tower. Because of their "grazing incidence" the centimeter waves penetrated everywhere, into the streets, into the courtyards within a radius of 70 km, and they faithfully reflected all outlines with a greenish phosphorescence. … The engineers on the antiaircraft tower knew what this meant. Göring and navy headquarters were notified immediately. … The Allied air forces were able to see*

[289] J.E.D. Williams, p. 221.

[290] Hartcup 1970, p. 25.

[291] Dear, p. 986. Beginning in 1943 with Göring's appointment of W. Osenberg to head the Reichsforschungsrat Planungsamt (State Research Council's Planning Office), some efforts were made to coordinate R&D, but these had little effect.

[292] Han Plendl, quoted in Eckert and Schubert, p. 152.

> *German cities, villages, industrial sites, and the attack targets among them, at night and under foggy conditions as if they were being shown on film. It was as if scales fell from the eyes of the men on the antiaircraft tower. …*[293]

The Germans did, as we have seen with submarines and long-range missiles, conduct major R&D projects.[294] But in 1939 and 1940 such efforts appeared unnecessary, as it was thought the war would be short, and in 1944 and 1945, projects not expected to reach production rapidly were terminated.[295] Yet Hitler, at least, retained faith in the R&D effort; just six weeks before his suicide he told a visiting doctor that "in no time at all I'm going to start using my victory weapons and then the war will come to a glorious end."[296]

Italy resembled Germany in the lack of collaboration between scientists and the military.[297] There was another similarity in the considerable exodus of scientists in the years before the war, Enrico Fermi and Bruno Pontecorvo among them. (In the Soviet Union, Stalin's purges certainly slowed radar development.)[298]

In Japan the war, which there began in 1937, led to a sharp rise in both private and government R&D, with the number of R&D institutions doubling between 1935 and 1942 to about 1150.[299] The National Mobilization Law of 1938 provided for a Planning Agency (Kikaku In) to contract for research in the national interest. In three years beginning in April 1940, this agency sponsored more than 500 projects.[300] Rivalry between the army and navy, however, slowed the development of radar and other technologies, as did the suspicion the military establishment had for scientists, many of whom had received some training in the West.[301]

Japan, too, sought wonder weapons that would win them the war. They devoted considerable resources to develop a "death ray" that would disable enemy aviators. They never achieved an effective weapon, but an experimental model, which used a magnetron to generate electromagnetic waves at 50 kilowatts continuous power, could kill a rabbit at three meters in less than a minute.[302]

For the belligerents as a whole, radar was by far the largest area of military R&D. In the U.S., however, the atomic bomb project was a rival for resources, but radar development was larger (costing $2.5 billion, while the bomb project cost $2 billion).[303] We might point out the large role of electrical technologies in the

[293] C. Bley quoted in Eckert and Schubert, p. 153.

[294] For example, the Germans worked on a long-range missile, the A-10, intended to be able to reach the U.S. [Sanders].

[295] Milward, p. 184.

[296] In Keegan 1987 p. 254.

[297] Hartcup 1970, p. 30.

[298] Dear, p. 984.

[299] Morris-Suzuki, pp. 149–150.

[300] Morris-Suzuki, p. 147.

[301] Hartcup 1970, p. 30, and Harries, p. 354.

[302] Harries, p. 356.

[303] Eckert and Schubert, p. 131, and Noble, p. 7.

Manhattan Project: power generators, transmission lines, transformers, motive power, thermal power, air-conditioning, and instruments of research and process control. The gaseous diffusion plants (used to separate isotopes) called forth great advances in industrial control: these plants required eleven miles of control panels with 10,000 instruments per mile.[304] Most of the U-235 used in the Hiroshima bomb was obtained by electromagnetic separation, using some 900 so-called "calutrons", each a large vacuum chamber surrounded by electromagnetics.[305]

Other areas of intense work during the war were computers, jet engines, rockets, and industrial automation. There was a great deal of work in what is today called biomedical engineering. There was already a well-established field of radiology. During the war a great deal of work was done in aerospace medicine (which later expanded to include space medicine), which is the study of the effects of flight (especially high in the atmosphere) on the human body and of treatments and cures for the physiological or psychological ailments of flight.

The success of wartime R&D had lasting effects. A. Hoyt Taylor of the Naval Research Laboratory wrote in 1948

> *As I look back on thirty years of Naval experience I am profoundly impressed with the great change in the official attitude with respect to scientific research. Even thirty years ago there were officers here and there who had respect and appreciation for research in the field of radio and, no doubt, in many other fields as well. But these officers were in the minority. It could be said that the official attitude was either a mild tolerance or indifference. Today that is all changed.*[306]

Research on radar and other technologies established institutional links between government, industry, and academia, some of which were maintained after the war. Perhaps more importantly, such research established personal ties between thousands of engineers and scientists, with different backgrounds and employers. Wartime research drew many outstanding physicists and mathematicians into practical work, and many of these people—John von Neumann and Alan Turing are examples—continued such work after the war. And the disbanding of Rad Lab, the University of California Division of War Research, and other institutions spread technological capability throughout the country.[307]

The war brought engineers and scientists into government decision-making at a high level. An example is Vannevar Bush, who, as head of OSRD, which was part of the Executive Office of the President, had direct access to Roosevelt.[308] Another example is Frank Jewett, president both of Bell Labs and of the National Academy of Sciences, and another is Karl T. Compton, president of MIT. Vannevar Bush, in his 1945 book, *Science: The Endless Frontier*, argued for large-scale governmental support of scientific research during peacetime, pointing to advances made during

[304] Noble, p. 60.

[305] Livingston, p. 185.

[306] A. Hoyt Taylor, p. 248.

[307] Burdic, p. 12.

[308] Sanders.

the war in military technology, in medical treatment, and in industrial techniques as having resulted from research and development.[309]

The historian Alex Roland, pointing out that World War II was the first war in which weapons changed greatly during the course of the war (jet aircraft, ballistic missiles, radar, proximity fuse, atomic bomb), concluded:

> *These developments convinced the services that the desideratum of modern war was shifting from industrial production to technological development. … Thus began the hothouse environment of military research and development that produced the international arms race, military-industrial complexes here and abroad, and the expansion of military interest and funds into new realms such as computers, communications, spaceflight, microelectronics, astrophysics, and a host of other fields. Scientists and engineers took up positions of power and influence in government, two of them—Harold Brown and William Perry—rising to become Secretary of Defense.*[310]

The war established the practice of government support of large-scale directed research, as seen in the U.S. with the Atomic Energy Commission, the Office of Naval Research, the National Aeronautics and Space Administration, and the National Science Foundation. The historian William McNeill wrote "… the normalization of deliberate invention begins to look like the most significant single achievement of World War II."[311] Government, able to provide large funding, helped bring about an era of "big science", as large collaborative projects, such as particle accelerators, space research, radio observatories, and medical research institutions attracted much attention. In the words of the historian A. Hunter Dupree, "The mighty edifice of government science dominated the scene … as a Gothic cathedral dominated a thirteenth century landscape."[312]

10.6.2 Radar's Legacy

The effects of World War II on the postwar world were unquestionably profound—politically, economically, socially, and technologically. This section considers one of the most important, though seldom discussed, legacies—the military, scientific, technological, and social consequences of the development of radar—beginning with an assessment of the difference radar made to the war itself.

If there had not been radar, Germany would probably have won the Battle of Britain, and radar might have been decisive in the Battle of the Atlantic.[313] If Great Britain had lost either of these, it would have been forced out of the war. Radar may have been decisive in the Allies' victory in North Africa and in the success of the

[309] Bush 1945.

[310] Roland 1995.

[311] McNeill, p. 90.

[312] In Swain, p. 543.

[313] Though cognizant of the extensive of radar by the Allies in this conflict, Louis Brown [1994] nevertheless argues that the Battle of the Atlantic would have been won without radar.

Normandy invasion.[314] For the invasion, Allied radar not only assured control of the air, but was essential for the blind-bombing and naval bombardment of shore targets and for the coordinated movement of a huge air and sea armada.[315]

Allied superiority in radar was frequently decisive at sea. For example, on the sinking of the German *Scharnhorst*, Arthur Hezlet writes, "There is little doubt that without radar the battle would never have been fought at all, let alone won. As it was, radar turned the Arctic night into day for the British but for the Germans it remained an Arctic night. Their radar was greatly inferior for surface search and gunnery. …"[316] The Germans could make use of a large warship such as the *Bismarck* only if it could remain unlocated for long periods of time (the tactic being to appear briefly for an attack and then disappear again), but radar—on both ships and aircraft—made this impossible.[317] Because of Allied technical superiority, radar had quite different consequences on submarine warfare in the theaters of war: in the Atlantic radar helped eliminate the U-boat threat, while in the Pacific radar made U.S. submarines effective destroyers of Japanese shipping.[318]

In the Pacific, the Allied superiority in radar was frequently decisive both offensively and defensively. The U.S. Navy made great use of radar detection of enemy ships and aircraft and radar direction of fighter aircraft.[319] The early-warning and fire-control capabilities of radar made it possible for ships to defend themselves against aircraft, and radar also gave the Allies navies a great advantage in night action.[320]

On the other hand, the German use of radar made the British and U.S. bomber offensives extremely costly for the Allies, and without German radar the strategic bombing would have been much more effective. Louis Brown writes, "… radar changed antiaircraft fire from a nuisance to a deadly danger. …"[321] Yet on balance, the substantial Allied superiority in radar technology and deployment may well have provided the margin of victory.[322] Solly Zuckerman, scientific advisor to the

[314] Louis Brown.

[315] Sean Swords writes [in Dear, p. 922], "In the assault phase of the Normandy landings … [Chain Home] played an essential part: its radar coverage was extended by three specially equipped fighter director tenders … and by the GCI (ground control of interception) and other sets which were landed on the bridgehead. The landings, involving accurate blind-bombing and naval bombardment of shore targets, and the expeditious movement of a huge air and sea armada, would have been impossible without a heavy involvement of radar."

[316] Hezlet, p. 245.

[317] Devereux. Devereux discusses at length the role of radar in the destruction of the Bismarck.

[318] Devereux.

[319] Sean Swords writes [in Dear, p. 922], "The balance of naval battles [of the Pacific war], in both defensive and offensive phases of the campaign, was determined largely by the effective of the American Task Forces' radar directed fighters."

[320] Hezlet, p. 263. Hezlet argues that without radar, surface ships would have had a much smaller role in the war.

[321] Louis Brown, p. 133.

[322] Finn 1967.

British government, concluded, "… without radar the war would have assuredly been lost."[323]

In the postwar world the main effect of radar for the military has been to make surprise more difficult. The long peace between superpowers owed something to deterrence—the policy of nuclear retalitation in the event of an attack—and deterrence could work only if there was an ability to provide early warning of attack. Radar provided this early-warning ability.[324] Continuing the wartime trend toward automatic control of guns, in the postwar years anti-aircraft and naval fire-control systems became much more sophisticated and required less human input, and the V-1s and V-2s and the proximity fuse started the trend toward placing more of the control system in the projectile itself (as in the Nike and other guided missiles).[325] The rapid development of new military systems was a result of the fact, as expressed by Arthur Hezlet, "… [electronics] in its various forms conferred advantages of the same order as the advent of the gun or steam power in naval warfare in the past."[326]

The enormous wartime advances in electronic techniques for radar came to have applications in countless technical areas: generation of electromagnetic waves at higher frequencies and greater power, waveguides, timing techniques, rapid switches, antennas, and electronic instruments.[327] One participant wrote, "Since a fairly large percentage of the effort of physicists and electrical engineers in this country and in England was expended on radar development during the war, techniques in electronics have advanced at possibly ten times the normal peacetime rate."[328]

Electronic computing, which developed with great rapidity in the postwar years, drew heavily on radar techniques, such as pulse circuits (including means for amplifying and regenerating pulses), electronic switching, and ultrasonic delay lines (used as a memory device in early computers).[329] For example, multivibrators (oscillators employing two electron tubes, with the output of each coupled to the input of the other) were developed for radar pulse-shaping and timing; after the war these multivibrators served as counters, shift registers, and clocks for digital processors.[330] Techniques for storing radar signals (so that the motion of targets could be determined) were, for many computer pioneers, starting points for the development of memory circuits and devices after the war (such as the Williams tube and the mercury delay line).[331]

323 Zuckerman, p. 14.

324 Fisher, p. xi.

325 Mindell 1995b.

326 Hezlet, p. 266.

327 Electronic switching circuits were developed before the war for television and for some instruments (notably the particle counters discussed in Chapter 8), but radar engineers carried this work much further during the war.

328 Edwin G. Schneider, p. 528.

329 Wilkes, pp. 108, 121, 127–128, and Bennett 1996.

330 Millman, p. 110.

331 John M. Bennett.

Out of the U.S. radar effort came the M.I.T. Radiation Laboratory Series of books, for which Louis N. Ridenour served as editor in chief. The 28 volumes of this series encapsulated a huge amount of knowledge generated during the war and strongly influenced many areas of postwar engineering.[332] An indirect result of the war were two landmark publications of the information age that appeared in 1948, both written by people who worked on fire control during the war: Claude Shannon's "A mathematical theory of communication" and Norbert Wiener's *Cybernetics*.

One of the most significant technological legacies of wartime radar research was the stimulus it provided to the development of semiconductor electronics. Semiconductors played a role in electronics as early as the first decade of the century when many radios incorporated a solid-state device. If the tip of a fine tungsten wire touched a crystal of galena (lead sulfide), the combination acted as a rectifier (permitting passage of current in one direction only), just what was needed to detect radio waves. However, the fickleness of these cat's-whisker detectors—the slightest movement of the wire could change perfomance greatly—relegated them to the least expensive receivers. Electron-tube diodes worked much better.

There were, however, significant disadvantages of tubes, such as their expense, fragility, and propensity to burn out. In 1936 Mervin Kelly of Bell Laboratories described the requirements for a solid-state amplifier, and work began toward this seemingly distant goal.

Radar gave another reason for looking to semiconductors. With the high frequencies used for radar, rectifier tubes did not work well, while crystals seemed just as effective as at lower frequencies. Hence, researchers in a number of institutions, notably Bell Labs and Purdue University, developed semiconductor diodes as radar detectors. At Bell Labs and elsewhere, silicon received much attention. At Purdue, a team led by Karl Lark-Horowitz pioneered in investigations of germanium. The earliest of these were clearly descendents of the cat's-whisker detectors (Figure 10.12).[333] German radar engineers, too, developed semiconductors diodes for radar detectors.[334]

During the war scientists and engineers made progress in several areas: the physics of semiconductors, the theory of rectification, the technology of cat's whiskers, and the manufacture of crystals with controlled levels of impurities.[335] The successful development of semiconductor diodes for radar was a principal reason for a reorganization of physical research at Bell Labs in 1945: of nine research groups, three were to concern themselves exclusively with solid-state phenomena. Within one of these groups was a team headed by William Shockley, under whom John Bardeen and Walter Brittain in 1947 discovered how to make a solid-state amplifier, soon given the name 'transistor'.[336] In the subsequent decades transistors

[332] Wildes and Lindgren, p. 190.

[333] Eckert and Schubert, pp. 143–148.

[334] Eckert and Schubert, pp. 155–156.

[335] Hoddeson.

[336] Eckert and Schubert, pp. 158–166.

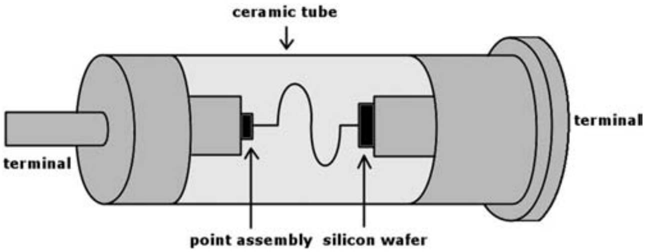

Figure 10.12. Schematic depiction of the silicon-crystal rectifier developed at Bell Labs for a radar detector.

gradually replaced, in almost all applications, the electron tubes that had opened up the many areas of electronics. The physicist Frederick Seitz wrote, "… the wartime research laid the groundwork for the invention of the transistor shortly after the war and ultimately the development of the integrated circuit. The work opened up a new age of electronics."[337]

Another consequence of the war was a change in the education of electrical engineers. Frederick Terman, director of the Radio Research Laboratory, commented that most of the new ideas generated at Rad Lab and the Radio Research Lab came from physicists: "The typical electrical engineer trained in the pre-World War II pattern did not know sufficient fundamental science and mathematics and did not possess the research seasoning to contribute in the creative electrical (electronic) developments of World War II."[338] After the war, Terman and many other EE professors who shared this view brought about a transformation of engineering education as "engineering science" came to be emphasized.[339]

Radar influenced science in many ways. The new capabilities of electronics, especially in measuring instruments and computers, came to be ubiquitous in science. More directly, radar gave rise to microwave spectroscopy, developed by Charles Townes and others after the war. The problem of the absorption of microwaves by the atmosphere led to Edward Purcell's discovery of nuclear magnetic resonance and eventually to magnetic resonance imaging. During the war many people noticed that radar sometimes made distant storms visible, and in the decades after the war radar meteorology grew into an important branch of that discipline. Wartime experience made it known that the sun, on occasion, emitted enough radio waves to jam radar systems, thus calling attention to the possibility of radio astronomy.[340] Radio

337 Seitz, p. 22.

338 Frederick Terman, "A brief history of electrical engineering education" [*Proceedings of the IEEE*, vol. 64 (1976), pp. 1399–1406].

339 Perkins, William R. "Introduction to 'A brief history of electrical engineering education'." *Proceedings of the IEEE*, vol. 86 (1998), pp. 1788–1791.

340 R.V. Jones, p. 507.

astronomy, opening up a new part of the spectrum for astronomers, began by using wartime radar equipment. Later radar astronomy emerged as an important means of investigating the planets.

The practical legacy of radar soon assumed major proportions. Shortly after the war radar came into use at major airports around the world for air-traffic control and for ground-controlled approach; harbor and coastal radar also was introduced.[341] Commercial airliners soon began using weather-avoidance radar (since thunderstorms show up clearly on microwave-radar displays),[342] and ships acquired radar in order to see coastlines and other ships at night and under all weather conditions.[343] Meteorological radar improved forecasts and understanding of weather phenomena.

The microwave realm opened up by radar was exploited for communications and other purposes, such as microwave heating. The Federal government had funded much of the development of microwave technology during the war, so the field was relatively free of patent protection, hence more readily commercialized.[344] By 1953 microwave radio-relay was used to build continent-spanning communications networks for telephone, radio, and television signals.[345]

The general advances in electronics due to radar and the large number of personnel trained in radar benefited almost all types of electronics. The advances made for radar were especially significant for television circuitry and screens. For example, in 1939 only some 50,000 cathode-ray tubes were manufactured; in late 1944 the annual production rate reached 2,000,000.[346] According to a history of the War Production Board, "The electronics industry expanded during the war to more than 12 times its monthly prewar net factory filling value on end equipments and from over 2 to 20 or 30 times on major components. The expansion of labor employment was from a prewar peak of approximately 110,000 workers to a war peak of 560,000."[347] Sales of the electronics industry increased by a factor of 20 during the war, employment by a factor of five.[348] A history of Japanese radar during World War II concludes, "… it was in those wartime laboratories that Japan produced the technical competence that made her a great postwar electronics power."[349]

[341] Gerlitzki.

[342] Bryant.

[343] J.E.D. Williams, p. 216.

[344] Cantelon.

[345] DuBridge.

[346] Peter Keller, p. 63.

[347] In Editors, p. 44.

[348] Noble, p. 7.

[349] Nakagawa, p. 4. In postwar Japan the Allies imposed a general prohibition against doing military R&D, so engineers necessarily looked to non-military markets. For example, some Japanese engineers who had worked on sonar during the war developed, not long afterward, successful sonar fish-detectors.

A recent history of radar commissioned by the Alfred P. Sloan Foundation is entitled *The Invention that Changed the World*.[350] Because today radar seldom obtrudes on the public consciousness, this may appear to be hyperbole. Yet a knowledge of the part radar played in World War II and in the Cold War, of its commercial and scientific significance, and of its crucial role in the development of electronics generally reveals it to be sober fact.

[350] Buderi.

Conclusion: Dawn of the Electronic Age

Despite frenzied preparation for war in Europe, 60 nations participated in the 1939 New York World's Fair, which many people consider the greatest world's fair of all time. It opened on 30 April 1939 with a speech by Franklin Roosevelt that was transmitted by RCA television; this broadcast was both the first time a U.S. president appeared on television and, so it was blazoned, the beginning of regular broadcasting.[1] (Disagreement over standards and U.S. entry into the war, however, soon put an end to regular broadcasting.) That evening Albert Einstein activated a cosmic-ray detector to turn on the fair's spectacular nighttime illumination.[2] Optimism bordering on utopianism suffused the fair, whose theme was "Building the World of Tomorrow". The visitor, it was hoped, would get "a vision of what he could obtain for himself, and for his community, by intelligent, co-operative planning toward the better life of the future."[3]

Attention focused on new technologies that would make a better life possible, and much of the fair dealt explicitly with electrical and electronic technologies. There were large exhibit halls for Communications, Business Systems, Electric Utilities, Electrical Products, and Industrial Science; there was an Electrified Farm; and there were buildings sponsored by GE, Westinghouse, AT&T, RCA, Consolidated Edison, NCR, Carrier (an air-conditioning manufacturer), and Crosley (a radio manufacturer).

Electrical technologies were ubiquitous. There were electric taxi chairs and the longest escalators in the world. Buildings were air-conditioned. Everywhere the visitor heard music (even from the horn of the shuttle bus, which sounded the opening bars of "Sidewalks of New York"). Electric lighting made the indoor and—at night—outdoor scene dazzling: the new fluorescent lighting ("cold daylight in a tube") was abundant; capillary mercury tubes lit up trees from below (giving them a blue-green tinge); and ultraviolet spotlights and fluorescent paint combined

[1] Gelernter, pp. 36–37. Herbert Hoover had appeared on an experimental telecast in 1927, but at the time he was Secretary of Commerce (Barnouw 1990, p. 61).

[2] Gelernter pp. 348–349. The lighting ceremony did not go as planned: Einstein activated the detector that was supposed to turn on the lighting on the arrival of the tenth cosmic ray, but the lighting did not turn on; a fireworks show, though, satisfied the crowd.

[3] The quotation (in Gelernter, p. 343) is of Grover Whalen, president of the Fair Corporation.

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Figure 11.1. The HM226 television receiver, which included a radio (photo courtesy of the Schenectady Museum & Suits-Bueche Planetarium).

to make parts of exhibits glow.[4] (We note that, to avoid a tawdry style, the fair's design board had prohibited neon lighting.)[5]

At the AT&T building people were invited to make free long-distance calls—then still a rarity for most people—from glass booths. (This boon came at the price of letting other fair-goers listen in.)[6] The "living room of the future" at the RCA building included a fax machine.[7] GE demonstrated FM radio; amazingly its performance was not disturbed by the 30-foot-long bolts of artificial lightning created in the same building.[8] One put on special glasses to see a 3-D movie. And television was much flaunted: a demonstration in the British pavilion and displays in the RCA, GE, Westinghouse, and Ford buildings (see Figure 11.1).

There seemed to be no end of the technological marvels. There was sterilizing light, an automatic dishwasher, an electric motor running on solar energy, and a

4 Hall, and Gelernter, after p. 146.

5 Gelernter, p. 87.

6 Gelernter, p. 39.

7 Gelernter, p. 40.

8 Gelernter, p. 45.

model train responding to a human voice. In the Westinghouse building there were hourly demonstrations of the robot Elektro, which stood seven feet high and, on command, did 26 different tricks (including walking, saluting, smoking a cigarette, and counting on its fingers).[9] Elektro even had a robot dog, Sparko. At the Ford building visitors could hear the "Novachord", a music synthesizer of the Hammond organ type, and at the AT&T building they could see human speech synthesized by the "Voder" (short for Voice Operation Demonstrator). At the Firestone building was a "singing color fountain", where jets of water, colored lights, and music were pleasingly coordinated. More spectacular was the show in the Lagoon of Nations: 1000 water nozzles, 400 gas jets, 350 fireworks guns, 3 million watts of lighting, and music provided in stereo—all controlled by three technicians at a organ-like console.[10]

There were many depictions of the future, notably Democracity (inside the Perisphere, the huge sphere that, together with the Trylon, a needle-like pyramid, formed the fair's icon) and Futurama (in the General Motors building). In both of these, visitors looked down upon models of future communities. Democracity showed an inner city with pedestrian malls, shopping centers, and a sports complex connected to suburbs by superhighways, and the scene was described by the recorded voice of H.V. Kaltenborn, sounding, according to one account, "almost like God himself".[11] In the Futurama ride, a sophisticated sound system, involving soundtracks on loops of film and transmission of the signal through rails beneath the cars, provided the narration and music appropriate to each section of the ride.[12]

The fair showed both the technologies themselves and the high hopes people had for a world these technologies would make possible. Some of the predictions were fairly accurate (that all families would have cars, which would allow most people to live in suburbs, and that every home would contain a television), some were wrong (that automobile speeds would be regulated automatically, that cities would be free of slums, and that there would be a cure for cancer); and many new technologies were not foreseen at all (such as computers).[13] The fair guidebook told visitors "The true poets of the twentieth century are the designers, the architects and the engineers who glimpse some inner vision … and then translate it into valid actuality for the world to enjoy."[14] (The writer of this guide and many of his readers would have had in mind Percy Bysshe Shelley's assertion that poets are "the unacknowledged legislators of the world".)

The fair's designers did not imagine that technological advance itself determined how society would change. Quite the contrary, it was their expressed objective "to show the average visitor what things are available to him and, above all, what

9 Hall.

10 Gelernter, p. 335.

11 Hall, pp. 8–9.

12 Gelernter, pp. 175–176.

13 Gelernter, p. 40.

14 In Gelernter, p. 169.

ideas and forces are at work which he should recognize as potential tools with which he, with his fellow men, would build [the world of tomorrow]."[15] Besides celebrating technology, the fair raised questions about it. One exhibit concluded thus: "Network of communications systems makes for speedy exchange of ideas; can we improve the spiritual side of life as we did the physical apparatus? Can serious breakdown be avoided in such a complex system? Will increased leisure bring political and cultural renaissance?"[16] The fair's theme exhibits asked how, in a democratic society, the decisions should be made and distinguished between "what can be done with technological tools, what needs to be done, and what it is morally right to do."[17] No doubt the celebration was heeded more than the question-raising, but it was a forward-looking celebration, giving fair-goers even greater ambition to make the work better.

The message of the fair resonated with visitors because, in the words of Frederick Lewis Allen, "It was still their instinct to transform a suburban swamp into a city of magic and call it 'The World of Tomorrow.' … They still liked to build the biggest dam in all creation and toy with the idea of the happy farmsteads it would water, the enormous engines it would drive, the new and better business it would stimulate."[18] The optimism and long-range vision of that generation, as reflected in the 1939 Fair, must have contributed to the postwar economic and social achievements.

Just three months after the fair opened, however, a world war broke out, causing people to attend to the immediate need—for the individual—of surviving from one day to the next and—for the nation—of winning the war. Many efforts to make daily life better had to be postponed, but people still held a vision of an improved world. Ironically, the war itself, as we have already seen, greatly stimulated technological advance, and thus, in the postwar world, provided even more effective means of achieving social goals. Technology transfer, too, was stimulated by the war. There was sharing between allies and between companies as never before, and at the end of the war there were massive transfers of technology, notably from Germany to the Soviet Union and from Germany to the U.S.[19]

The legacy of electrical technology for the postwar world was enormously richer than that of 1914. Electric power networks had been vastly extended and improved, and there was the exciting prospect of nuclear power. Communications, both wired and wireless, had been revolutionized. In 1945 Arthur C. Clarke began arguing that rockets such as the V-2 and radio technology made possible what he called "artificial satellites", which, in geostationary orbits, could provide global

[15] These words, written in 1939, come from Robert D. Kohn, Chairman of the Fair's Committee on Theme [Kohn].

[16] In Gelernter, pp. 114, 260.

[17] Reaven, p. 96.

[18] Allen 1939, p. 171.

[19] The Soviets took enormous amounts of electrical equipment and technical documents from German factories and laboratories [Siemens, pp. 280–281]. The U. S. acquired German technology through Project Paperclip and other programs [Nebeker 1994, pp. 35–39].

communications.[20] A major new medium, television, was almost ready for service. Radar and sonar had been developed. There were sophisticated control systems, as in aircraft and missiles, and an entirely new device, the electronic digital computer. Electronic information processing opened new vistas, as in Vannevar Bush's 1945 article proposing a desktop information machine, the Memex, that would allow a person to search the equivalent of a library and immediately retrieve the relevant information.[21]

In these and many other areas the most striking characteristic of the years between 1914 and 1945 was the proliferation of the electron tube. World War I had transformed the electron tube from a laboratory device of low frequency and power to a mass-produced device with a wide range of frequencies and power. The years up to 1945 saw continued advances: tubes became more effective and less expensive, new types (the magnetron, the klystron, and countless others) were devised, and tubes continually found new applications. In April 1930 the editors of the new magazine *Electronics* wrote:

> *Already billion-dollar industries are built upon the vacuum tube—in telephony, in radio, in talking pictures, and in power applications. Electronics revolutionized the first three—made them possible. And in the power field, it is now affording an entirely new engineering approach to electrical problems of every kind. For although the electrical engineering of the past was built almost wholly upon the single principle of electromagnetic induction, the electrical designer of today finds … that in electronic apparatus he commands a medium paralleling magnetic-induction in importance and its equal in wide adaptability.*[22]

And:

> *There will be nothing that the average man sees, hears, or buys but what will be controlled, regulated or affected in some important respect by an electronic tube.*[23]

Events confirmed these predictions. In the U.S. in 1940 electronics manufacturing was worth $400 million; in 1950, its value reached $2.6 billion, and in 1960, $10 billion.[24] In 1946 the industrial designer Walter Dorwin Teague wrote, "It is not possible here to give even a hint of what electronics is contributing to our powers by its incredible versatility in transmitting, transforming and controlling energy."[25]

The new technologies often fit into existing social arrangements, but sometimes gave rise to new ones, such as new types of work, new ways of socializing, and new leisure-time activities. The chapters of this book catalog many such changes. Not mentioned have been some ways electrical engineering influenced the way people viewed the world.

[20] Clarke 1945a, Clarke 1945b.

[21] Burke, pp. xv, 9–10.

[22] Quoted in Editors of *Electronics*, p. 4.

[23] Quoted in Editors of *Electronics*, p. 6.

[24] Ryerson.

[25] Teague.

In many countries the war made it a usual practice to follow world events by radio, and television reinforced this practice in the postwar world. A result has been a world-consciousness, essential in recognizing and dealing with certain problems. Another result may have been greater pessimism, as the novelist Lloyd C. Douglas argued as early as 1944:

> *The world is in a muddle. This is no new sensation. The world has always been in a muddle. The muddle is simply more apparent than ever before. We know more about it. Improved processes of communication have multiplied a thousandfold, for every man, the sins and shames of all humanity. At present there is no grief, no greed, no guile anywhere on earth that we do not know about—hour by hour. …* The world is doomed! Stay tuned to this station![26]

Ways of thought, too, have been influenced. As engineers provided not so much individual tools, but integrated systems of tools—communications networks, power networks, machinery for mass-production, and defense systems—people began more frequently to conceive of portions of the social, biological, and physical world as systems, adopting engineering concepts such as input, output, and boundary conditions. Among scholars the borrowing was more extensive. In particular, the ideas and language of control theory—such as feedback, negative feedback, and closed cycle—which pervaded most branches of engineering by 1945, became common also in biology, economics, political theory, and sociology.[27]

Electrical technology has undergone two earthshaking enhancements: electronics and computing. Each pervaded the pre-existing realm of electrical technologies, and each enormously widened that realm.

Electrical technology emerged in the last half of the nineteenth century: people harnessed the motion of electrons in conductors to communicate, to provide light, and to perform work of countless varieties. Electrical technology spawned new industries: telegraph, telephone, lighting, electric power, and electric traction. Electronics emerged in the first half of the twentieth century: people harnessed the motion of electrons in vacuum or gas to communicate, to control, to measure, to visualize, and to calculate. Electronic techniques spread through most existing industries and spawned new industries: radio, transcontinental and intercontinental telephone, sound movies, television, measuring and imaging instruments, and radar. Computing—by which we mean electronic digital computing—emerged in the second half of the twentieth century: people harnessed the capability of digital electronic circuits to process information. Building computers became a major industry, writing computer programs became an even larger industry, and computing became part of most manufacturing and commercial operations.

Rather than three separate realms, electrical engineering, electronics, and computing should be thought of as stages in the exploitation of electricity. In the first half of the twentieth century, electronics entered into most areas of engineering,

[26] Douglas, p. 119.

[27] Bennett, pp. 4-5. Bennett writes (p. 5) "For the social sciences, the 20th-century metaphor is the 'feedback system'."

creating a markedly different technological world, which may be called the electronic age. In the last half of the twentieth century, computers—products of the electronic age—would do the same, that is, enter into almost all technologies and transform the human world. In the first half of the twentieth century, electronics was a principal engine for economic growth and transformation. In the last half of the century, the principal engine for economic growth has been the computer.[28]

It was, above all else, new technologies that made the first half of the twentieth century different from all earlier eras. People were highly conscious of this, and—what sets 1939 apart from today—they were optimistic about the future because of the prospect of still newer technologies. Today people are accustomed to continual technological change. People are also more skeptical that new technologies will improve life, and less optimistic about the future. The history of technology reveals grounds both for skepticism—even when the imagined technologies were fully realized, they were less beneficent than people imagined—and for optimism—in most cases the world is better off with the new technology.

Whether or not, on the whole, society has profited from particular technologies, it is clear that there is more freedom to act than ever before. The development of electronics unleashed human creativity in engineering design. Much more importantly, the proliferation of ever more effective electrical and electronic devices expanded human capabilities in all realms. Every technological advance removes a constraint on human action. Some advances permit entirely new actions. A very few make so many new actions possible that one might speak of the opening up of a new dimension of human activity. This happened thousands of years ago with the development of written language. It happened in the eighteenth century with the harnessing of steam power. And it happened in the first half of the twentieth century with the birth of electronics.

[28] Chandler 1991.

Notes on the Illustrations

All of the line drawings were created by David Lee Halik at the IEEE History Center, Rutgers University.

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