RADIO ACE

VINTAGE RADIO KIT

Experiment Manual

Thames & Kosmos®

Please Observe these Safety Warnings!

Warning! Use only under the direct supervision of an adult! Keep out of reach of very young children! Only appropriate for children at least 12 years of age. Instructions for parents or other responsible individuals are included and must be followed. Retain the packaging, as it contains important information! Not appropriate for children under 3 years due to choking hazard posed by small pieces!

Caution! The experiment kit contains objects with sharp edges and points. There is a danger of injury!

8 1.5 Volt AA batteries are required.

Do not mix old and new batteries.
Do not mix alkaline, standard (carbon-zinc), or rechargeable (nickel-cadmium) batteries.

Attention! If you configure your radio to broadcast a signal, you must adhere to all applicable federal regulations regarding broadcasting.

1st Edition, Franckh-Kosmos Verlags-GmbH & Co., Stuttgart / 2004

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VINTAGE RADIO KIT

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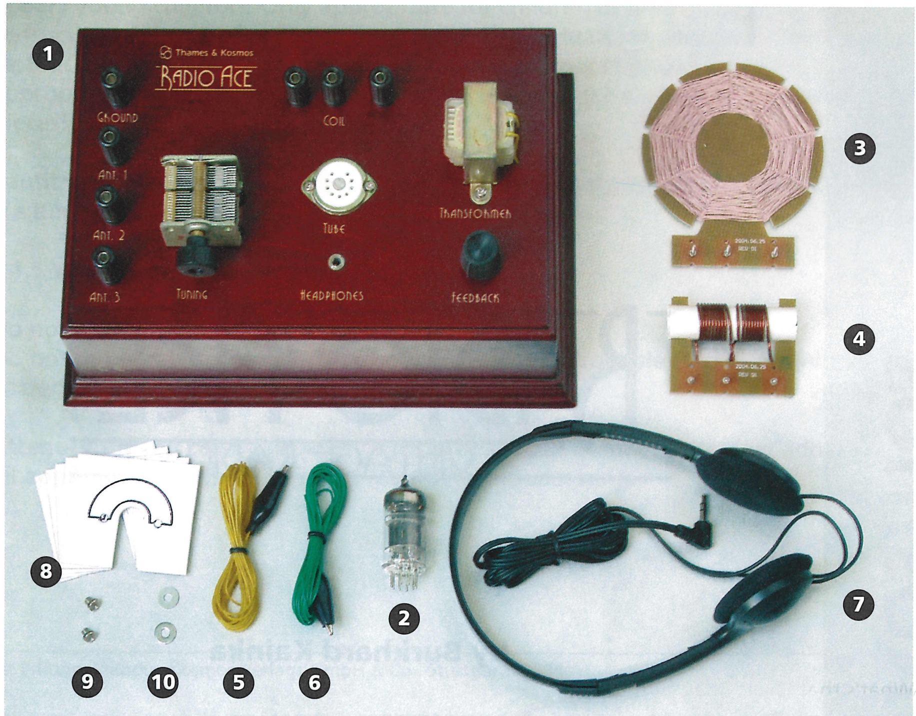
Kit Contents



What You Need to Be a Radio Ace

No.	Item	Quantity	Article No.
1	Pre-wired wooden base	1	771 047
2	12AU7 (ECC82) tube	1	702 891
3	MW coil (Medium Wave Coil)	1	702 886
4	SW coil (Shortwave Coil)	1	702 887
5	Antenna wire (yellow)	1	702 892
6	Ground wire (green)	1	702 893
7	Headphones	1	702 897
8	Radio dial sheets	5	702 894
9	Attachment screws for dial	2	702 895
10	Washers	2	702 896

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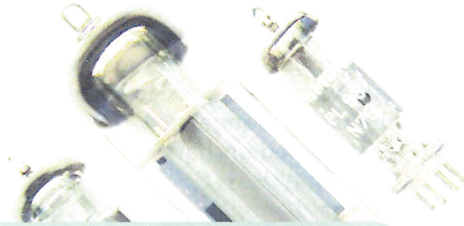


Information for the Future Pro

Foreword

Seventy years ago, about ten years after the introduction of wireless broadcast technology, Thames & Kosmos' German partner company, Kosmos, came out with the first edition of a radio-building kit called **Radiomann**. Radiomann was wildly popular in Europe until the 1970's, when it was discontinued. The interest in old vacuum tube radio technology had given way to the excitement of transistors and computers. But now after thirty years, we have created a 70th anniversary Radiomann to take us back to those early days of radio. **Radio Ace** is the first North American edition of the Radiomann kit.

What was your first experience with radios? Maybe you remember hearing the radio in the car when your parents were driving you to kindergarten. Maybe you remember singing along to your favorite songs. Maybe you had a combination radio-tape player and made tapes of songs on the radio. You probably had a favorite station on the FM band, but knew less about the stations on the AM and shortwave bands. Whatever your specific experiences, it is safe to say that radio technology has touched the lives of most people over the past seventy years. Radio Ace, your new vacuum tube radio, will give you an altogether different experience.

If you, dear reader, are 70 or 80 years old, you have lived through the very beginnings of wireless broadcast technology. Back then, the radio was much more in the center of family life than it is now. You might have had a vacuum tube radio, and maybe you can still remember your experiments with it. No doubt, you can recall the excitement you felt back then, and you can explain to your grandchildren what a radio meant to you in those days. Maybe you assembled your own radio in the 1950's or 1960's. If so, you are already familiar with tube technology, and you probably know the ECC82 dual triode — the very same tube that we have included in this kit. Even if you have never experimented with radios yourself, you can certainly recall the magical glow of vacuum tubes.

It was no easy task to assemble this anniversary radio kit. Many of these tubes are no longer produced today. But the ECC82 is one of the few tubes that has remained unchanged over the last 50 years, and is today used primarily in stereo amplifiers. Nor was it easy to find an old-fashioned variable capacitor. This radio has a modern headset, which is a lot more comfortable than the old-style ones from the 1920's through the 1960's. The housing is reminiscent of the style of the very first tube radios from the 1920's. This anniversary radio kit is no mere imitation, but a completely new creation.

We wish you happy experimenting and excellent reception on your way to becoming a Radio Ace!

1. Around the Dial

Your radio is mostly pre-assembled. All you have to attach are the tube and the particular coil you want to use. There are also some loose radio dial sheets that you can fill in yourself. Right now, we will just list the most important components and their functions. You will learn how everything works in greater detail when you perform the experiments on the following pages.

Here you can see the radio with its tube and medium wave coil attached. On the left, you see three different connectors for the antenna, and one for the grounding wire. The variable capacitor and its dial will help you find the station you want. The headphone jack is where you insert the headphone plug. The vacuum tube, which is the most important part of the radio, sits securely in its socket. To its right, you can see the transformer, which conveys the audio signal to the headphones after it has been amplified by the tube. At the lower right you see the feedback control knob, which also serves as an on-off switch.

In addition to the tuning knob for selecting a station, most radios have a knob for adjusting the volume. Your radio has a feedback control knob instead, which can also be used as a volume dial. But it should never be simply turned all the way to the right—for any particular station, there is an ideal setting that you just have to find by feel. The reason for that will be explained in due course. In the early days of radio, many sets had a feedback control knob. The name for a radio of that type is an "Audion," as opposed to the "superhet" type that took over in the 1950's. An Audion like this radio is very simply constructed and yet, if used skillfully, also has very good reception. The most interesting component of your radio is the tube, because it has been many years since vacuum tubes have been part of the construction of common radios. Most radios these days contain transistors, which are the successor to the tube. It is just like with railroad trains: since most locomotives have become diesel- or electric-powered, steam locomotives (like vacuum tubes) are something really special now. One of the beautiful things about tubes is that you can look inside them and see a magical glow while the radio is in operation. The bulb of the 12AU7 tube actually contains two identical devices called triodes — but all of that will be explained in more detail later on. To complete the radio, a lot of other parts are needed, some of which are on the underside of the box. That is also where you will find the battery holders.

FIGURE 1: *The assembled radio*

FIGURE 2: *The battery holders inside the radio base*

Assembling Your Radio

The radio uses eight 1.5 Volt AA batteries. They are not included in the kit, because they have to be fresh. Alkali batteries are best, because they have the longest lifespan. **Do not use rechargeable batteries**, because their voltage of 1.2 V is too low, and they can sometimes deliver too much power.

Before inserting the batteries, be sure the power switch is off by turning the feedback control knob all the way to the left. You will hear a click when you rotate the knob into its on or off position. Turn the housing box upside down and insert the batteries, paying attention to their proper polarity.

Next, place the vacuum tube in its socket. Be careful not to bend the terminal pins. The tube has nine pins, with a relatively large distance between pins 1 and 9. There is only one way that the tube will fit properly in the socket. The radio has two different coils: one for medium wave and one for shortwave reception. But before we complete the initial assembly by installing one of the two coils, we should introduce you to the basic vocabulary you will need to understand the radio.

The Language of Radio:

Frequency, Speed of Light, Wavelength, & The Electromagnetic Spectrum

As you enter the world of radio, you may hear people begin to use unfamiliar vocabulary such as "I am *receiving* in the *30 meter band*," or "This station is *transmitting* at *800 kHz* (pronounced: "keh low hurtz")." This is basic radio lingo, and learning this new language is crucial for all beginning radio engineers.

You must begin by understanding what a wave is. Think about when you have seen someone throw a stone into calm water. You must have noticed the disturbance in the water caused by the stone. It is always in the form of a circular group of waves that are evenly spaced around the point where the stone broke the surface of the water. Each hump in the water is an individual cycle in the wave group. Each wave cycle has three distinct points connected smoothly together, the **peak**, the **zero point** and the **trough**. One simple way of distinguishing one wave from another is its **amplitude**, which is the distance between the peak and the zero line. The other is its **period**, which is the time it takes for the wave to move from one peak to the next peak, and thus complete a **cycle**. So now using our understanding of period we can learn the first major term in radio: **frequency**. Amazingly, frequency is just another way of writing period.

Frequency = 1 Wave Cycle / Period

So, a period is the measure of how long it takes, in seconds, for each wave to finish one cycle. Inversely, frequency is the number of cycles in each second. Scientists use the term **Hertz** as an abbreviation for the number of cycles in each second. To

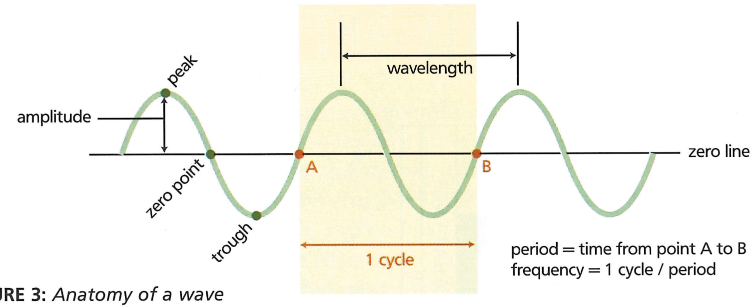


FIGURE 3: *Anatomy of a wave*

make it simpler to write in mathematics, we abbreviate Hertz even further to the letters **Hz**.

That wasn't so hard. Let's continue. Now that we understand frequency we have to speak about the speed of light. You may not realize that light always travels at a specific speed, which is expressed by the number of meters it travels in one second (meters/second). It is extraordinarily fast: 299,792,458 meters per second. No human has ever traveled as fast as light! But radio waves always travel that fast!!! The length of a wave, or its **wavelength**, is directly related to its frequency and how fast the wave is traveling though the air. So now we know all we need to know to describe wavelength. The **wavelength of a radio wave** is the length of one cycle of the wave at a specific frequency traveling at the speed of light.

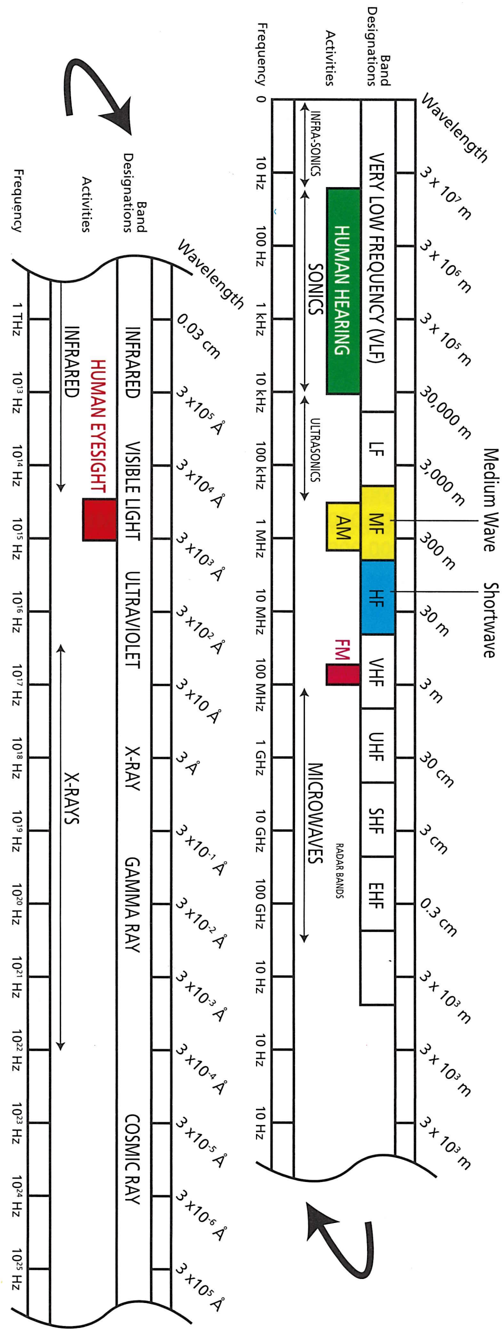
Wavelength = (Speed of Light) / Frequency

Wavelength also directly relates to the length of the antenna (coil) required to pick up signals at any one frequency. A **shortwave** antenna can use less wire than a **medium wave** antenna since the wavelength of the shortwave signal is much shorter. With that in mind, it is easy to distinguish between the flat medium wave (MW) coil and the cylindrical shortwave (SW) coil by the length of wire required to create each.

Have you ever wondered why you cannot see sound or hear color? This all comes down to the way the eyes and the ears are tuned. The ears can only hear frequencies between 20 Hz and 20,000 Hz and the eyes can only see frequencies between 400,000,000,000,000 Hz (400 MHz) and 800,000,000,000,000 Hz (800 MHz). Also, one other important distinguishing fact is that your ears vibrate due to a pressure wave — particles in the air bumping into one another and thus transmitting the vibration to your ear — while light does not need any medium to travel through, such as air or water. Light travels through empty space.

This brings us to the most important concepts of all: **electromagnetic waves** and the **electromagnetic spectrum**. Electromagnetic waves are disturbances that transfer energy from place to place.

Now, imagine if I told you that light waves, radio waves, microwaves, and some other types of waves that you cannot feel, hear, touch, or see are all related to each other. All of these waves can be organized according to their wavelengths and frequencies on the electromagnetic spectrum (pictured on the next page). As you can see, many familiar devices lie along its range along with sonics and light. With that in mind, it becomes obvious that it would never be possible for you to see sound and hear light, just as it is not possible to hear radio waves without



the help of a radio to bring the transmitted wave back into the frequency range and wave type of human hearing.

Now that you are armed with the basic radio vocabulary, we should revisit the initial statements above for your final review. "This station is *transmitting* at *800 kHz*" and "I am *receiving* in the *30 meter band*." I imagine that these sound a bit less daunting after our language lesson. The first person is referring to a radio station that is sending out a signal (transmitting) at a frequency of 800,000 Hz (800 kHz). The second person is receiving a signal on a radio with a wavelength of 30 meters. He uses the wavelength to express the range of frequencies that he is planning to receive with his radio.

MF vs. HF Frequencies

Medium Wave Frequency (MF) = 300 kHz to 3000 kHz

AM Radio = 540 kHz to 1630 kHz
(Traveler's Info = 1610 kHz)

Shortwave Frequency (HF) = 3 MHz to 30 MHz

Shortwave Radio =
5.95 MHz to 26.1 MHz

1 MHz = 1,000,000 Hz
1 KHz = 1,000 Hz

FIGURE 4: *The electromagnetic spectrum*

2. Catching the Medium Wave!

Let's continue assembling our radio for medium wave reception. Notice that the flat medium wave coil has a lot of coil windings so that it can pick up longer wavelengths. But by contrast, the cylindrical shortwave coil has fewer coils so that it can receive shorter wavelengths. Together with the capacitor, the coil forms a so-called oscillator, which you can set to a specific desired frequency by turning the knob on the variable capacitor. Turned to the left, the frequency is lower and the wavelengths are longer, to the right, the frequency is higher and the wavelengths shorter. Throughout the rest of the manual, frequency will be measured in kilohertz (kHz) or megahertz (MHz), and wavelength in meters (m).

1. Firing Up Your Radio

Install the flat coil for medium wave reception. To do this, unscrew the caps of the connector jacks a little. The screw contacts of the coil must then be inserted through the holes in the middle of the jacks. After that, screw the cap on tightly again. This way the connections are clamped tightly and make good contact.

The coil only fits in the connector jacks in one direction. On the left is the ground pin which is wired to the inner winding of the coil. In the middle is the center tap pin which is wired to the tenth winding from the inside. On the right is the pin we have utilized as the main connection into the radio's circuitry.

You should notice that the center tap pin (on both coils) has two wires twisted together attached to it. You can think of each coil truly as two coils wrapped on the same housing and then attached together at the center tap pin.

Now for the big moment! You've put in the batteries and it's time to turn the radio on. Turn the feedback control knob a bit to the right until it clicks. At first nothing will happen. After about ten seconds, will you see two glowing red spots in the tube. When the tube has warmed up, you will see two small metal rods glowing along their entire length. With all tube radios, you have to wait a while after you turn them on until they can play at full volume.

When your tube has been on for several minutes, its outer surface will also

The Voltage Has To Be Right

Like the filament of a light bulb, the heating element in the tube is intended for a very specific voltage. On the tube, you can read the model number 12AU7. This tells you that the tube element is designed for 12 V. Eight new 1.5 V batteries add up to 12 V. But the radio will still work when the batteries only have 9 V. During operation, a small current of only 150 mA is flowing. With one set of batteries you can listen to the radio for many hours. Alkali batteries are best, because they last particularly long.

FIGURE 5: *Connect the coils here.*

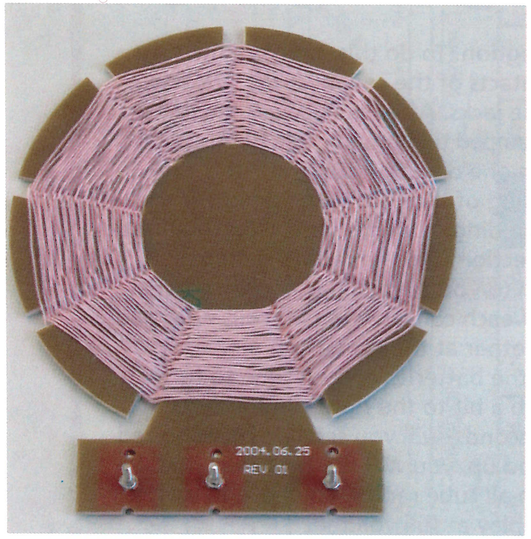


FIGURE 6: *The medium wave coil.*

warm up. The glass bulb will be pleasantly warm. In some radios, the tubes can get very hot. The tube in your radio, on the other hand, will get just a little warm, because it uses a low voltage. That way, you don't have to worry about burning your fingers.

2. Familiar Sounds – the Local Station

Start your trip through the airwaves with your local medium wave station (your local AM radio station), the strongest station in your area. It probably works without any antenna at all. Insert the plug of the headset into the connector jack of the radio, wait until the tube has heated up, and put the headset on. Turn the feedback control knob far to the right. Then, use the variable capacitor to very slowly tune the radio along its entire reception range.

At some spots, you will hear a whistle or a chirp. That is where individual stations are. Search for the loudest station and tune in the variable capacitor so that you only hear a low-pitched tone or no tone at all. Then turn the feedback control knob back until you can receive the station clearly. The flat coil works simultaneously as an antenna, like a ferrite antenna in modern radios. Turn the radio a little and try to see in which direction the volume is loudest.

3. Changing the Volume

The feedback control knob has one most sensitive setting for each station, just before the so-called "singing point" — the point when you hear the whistling sound. The radio has no volume control. But you can actually use the feedback control knob to reduce the volume. If the station is too loud, simply turn the knob a little bit to the left, too soft turn it a bit to the right.

IMPORTANT NOTE

You must have a sufficiently strong AM radio station in your area in order to hear it. If you are far away from civilization, you may not be able to pick up any stations. If you do not hear a station right away, DO NOT GIVE UP. Keep reading the instructions to make corrections and adjustments that will help you pick up a signal.

4. Stick Out Your Feelers!

With a wire antenna, you can also receive weaker or more distant stations. Set up the antenna as high as possible in the room. You can attach it to the cover of a heavy book in your bookcase, for example, with the alligator clip at its end. Connect the yellow antenna wire to antenna connection 1. Here too, as with the coil, the wire must be pulled through the middle hole and screwed on tight. Be careful not to push the wire so far in that it clamps to the yellow coating: you want metal to metal contact at the connector. Your local station reception is now substantially louder. And you will also find other stations. For each station's frequency, try to find the best feedback setting.

5. Finding the Right Connection

Now try antenna connection 3. Depending on how you hang the antenna, you can get a louder volume than with connection 1. But with this connection, you often can't get the higher medium wave stations, because the whole tuning range is shifted somewhat lower. In other words you will loose stations in the upper range but the lower range will be clearer and louder than ever. So the antenna choice just depends on which station you want to hear.

6. Staying Well-Grounded

Reception is even better with a ground connection. Connect the green ground cable to the radio's ground connection, and clamp the ground cable's alligator clip securely to a metal water faucet, a bare-metal radiator, or a non-insulated metal heating pipe. So why is ground important anyway? Imagine that you need directions to a friend's house. You need not only his home location but also your own. The directions would be very hard, if not impossible, to follow without a clear starting point. Ground in an electrical circuit performs a similar func-

FREQUENCIES

The medium wave coil spans the entire frequency range from 530 kHz to over 1600 kHz. If the variable capacitor is turned all the way to the left, the frequency is lowest. One kilohertz (kHz) means 1000 oscillations per second. Therefore, in the middle of the medium wave band at 1000 kHz, transmission is at one million oscillations per second. The wavelength there is 300 m.

FIGURE 7: *Our grandparents back in the good old days — with food and radio.*

FIGURE 8: *Transmission lines*

tion as this starting point. It tells the circuit at what point to reference the incoming signal. This way, the radio signals reference the same point at both the transmission tower and your radio.

Incidentally, the earth in your flower pot doesn't help here. It has to be the whole Earth, the very same ground on which the transmission tower of the radio station stands.

7. When Night Falls on Medium Wave

Try turning on your radio late one evening. During the day, the broadcast range of medium wave transmitters is reduced to about 100 kilometers. But in the evening and at night, it rises to more than 1,000 kilometers. Now you can hear stations from all over the region. It is often amazing how clearly you can hear stations that are so far away. Their reception is often better than that of local transmitters close by.

Take your time listening to stations from across many states. You will often be able to discover new stations and programs you've never heard before. Don't be surprised if you can pick up Radio England (The BBC). Radio stations from some faraway countries operate transmitters in the U.S. You might suddenly hear the sounds of India on middle wave, broadcasting from a private transmitter in the next city or state.

Components and Connections

On page 13, you see the complete circuit diagram for your radio. In the back of this manual, you will find an overview of all the schematic diagram symbols used here. The 12AU7 (ECC82) is a dual triode. Compared to some earlier vacuum tube radios, these allow you to obtain quite a high sound volume. The 12AU7 was actually built for larger voltages. But two tubes instead of one compensate for the lower voltage.

The left tube works in the Audion circuit, and is thus the actual receiver. The oscillating circuit composed of the coil and variable capacitor at the input of the Audion determines the reception frequency. There are three antenna connections, from which you can choose the most desirable one, depending on antenna and frequency. The tube on the right works as an amplifier. The transformer at the output is connected directly to the headphones. An unusual feature of this circuit is that the batteries supply the heating voltage as well as the anode voltage (see page 15).

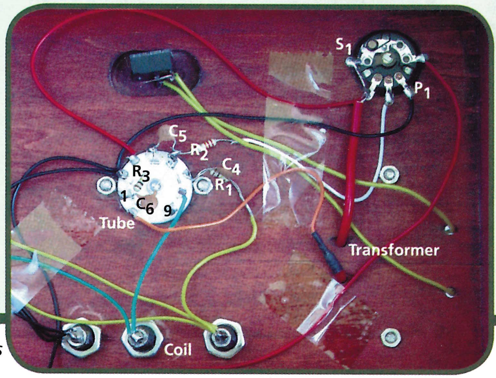


FIGURE 9: *The wiring of the components*

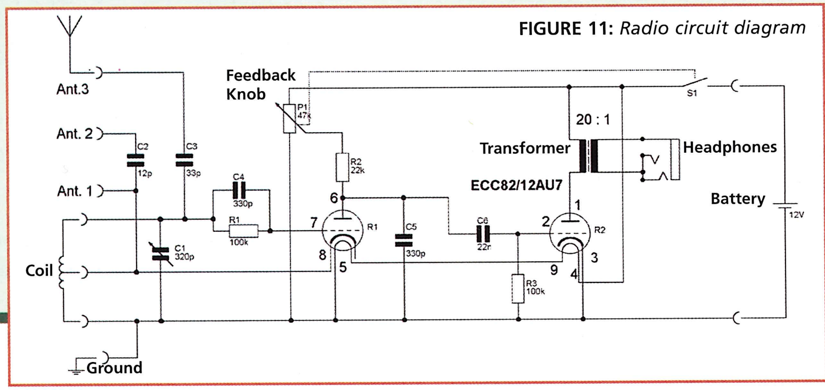


FIGURE 11: *Radio circuit diagram*

3. Around the Globe on Shortwave

While medium-wave transmitters have only a limited range, shortwave can have an enormous reach around the globe. Many countries therefore operate foreign services with shortwave transmitters. They are meant partly for their own citizens abroad and partly for interested people from other countries. That is one reason you can often hear transmitters from distant countries broadcasting in the English language.

8. Changing the Coil

Install the shortwave coil. Connect the wire antenna to antenna connection 2 and also use the ground wire. Turn the feedback up and search for frequencies where a strong transmitter makes itself heard with a loud whistling. Then turn the feedback far enough back for you to receive the station clearly.

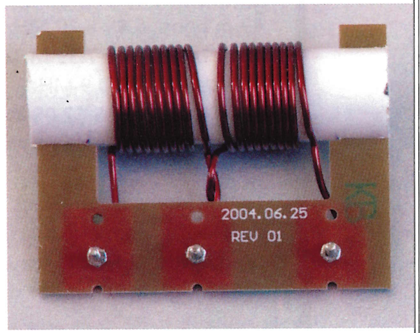


FIGURE 10: *The shortwave coil*

The tuning of shortwave stations demands a fine touch. While only about 100 stations fit into the medium wave band, more than 1,000 stations can transmit side-by-side on the shortwave band. That means the adjustment of the variable capacitor has to be ten times more precise than in medium wave.

It requires a little practice. You will quickly find that a lot of stations always lie close together on a radio band. In between, the station density is indeed lower, but you can still find some interesting ones. In shortwave, you get large

Shortwave Bands

FIGURE 12: *Using the shortwave coil*

In addition to medium wave, your radio receives shortwave frequencies from 5.5 MHz to over 16 MHz. Certain frequency bands were established for radio. The most important bands for your receiver are:

49-m band: 5.95-6.20 MHz
41-m band: 7.10-7.39 MHz
31-m band: 9.5-9.9 MHz
25-m band: 11.65-12.05 MHz
19-m band: 15.10-15.60 MHz

The different frequencies behave quite differently from one another in their propagation of radio waves. During the day, great ranges of up to several thousand kilometers are obtained in the higher frequencies. In the 49-m and 41-m bands, you can hear stations from your own state and neighboring ones. Later in the evening, the broadcast range improves at the lower frequencies as well. Many broadcasters adapt to the requirements and change their frequency several times a day.

transmission ranges even during the day. Transmitters from other countries can sometimes be heard. In the evening, the transmission range rises yet further, and even stations in Europe, South America, or Africa can be heard.

9. External Antenna

Run your wire antenna out the window and stretch it out freely on the outside. Tie the end of the wire to a cord, which you can fasten to a tree or to a garden shed, for example. Just be sure that nobody falls out the window or out of the tree. Let your parents help you out. If a storm gathers, take the antenna in immediately! An external antenna gives you much better reception than a wire stretched out in your room. If you are able to do so, hang a wire antenna up to 10 meters long. The higher above the ground you extend it, the better it works. But even at a height of 2 meters, you can achieve satisfactory results.

10. Sharpen Your Hearing

How far can your radio reach? Could you manage to hear a weak signal from India or Africa? Wave hunting can become an exciting hobby for anyone. But it requires some practice to be able to find the best settings for the feedback control and variable capacitor knobs. In return, you will be rewarded with programs that you can't otherwise hear. What's new in Bangkok? What hits are they listening to in New Delhi, and how do you like the latest music from Morocco? Or try hearing what it's like to listen to news in a language you don't know...

4. Noises — Loud and Soft

This radio is much more than just an ordinary radio. You can also carry out other tube experiments that can lead you to some surprising discoveries.

11. Amplifiers and Loudspeakers

Maybe you'd like to show off your radio with the help of a speaker. Instead of the headphones, hook up an amplifier. For example, you can use the amplified speaker of your computer. A stereo connection cable with a 3.5 mm plug will fit nicely in the headphone jack. You can also use a stereo system as an amplifier, if it has the right connection.

If you have a computer with a sound card, you can also make a connection to the "line in" input. Of course, you can also save recordings with the computer. You could, for example, make a collection of the call signals of all the radio broadcasters.

Direct and Indirect Heating

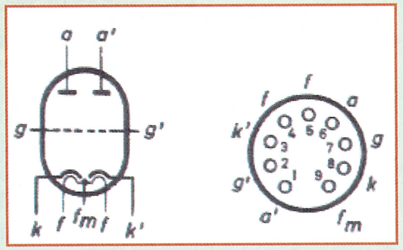


FIGURE 13: *Diagram of the ECC82 socket*

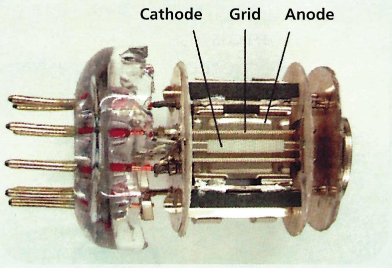
The European model number for the 12AU7 tube is ECC82, whereby the E identifies all tubes that are heated with 6 V. This tube can be heated with 6 V or with 12 V, since both heating elements can be connected in series or in parallel. We have chosen the series circuit so that the same voltage of 12 V can be used as the anode voltage. That is why the RE074D tube in earlier vacuum tube radios had a directly heated cathode in the form of a filament similar to that in a light bulb. There, the filament was also the cathode. The later EF98 as well as the currently-used ECC82 employ indirectly heated cathodes. The actual cathode tube contains an isolated heating element, which causes it to glow from inside.

12. What's that Buzzing?

Turn the radio over carefully, and touch the control grid of the output tube (pin 2) with your finger or with a piece of wire. In the headphones you will hear a buzzing. This "finger test" works with every Audio Frequency (AF) amplifier when electrical outlets and cords are nearby. An electron tube is usually used as an amplifier, as is the case in your radio. A small input voltage is amplified and delivers a larger voltage to the headphone output.

Electrons Flying in a Vacuum

The tube consists of an airless glass container. When the radio is in operation, electrons fly through the vacuum. Electrons are the smallest, negatively charged particles of an atom. Free-moving electrons are found in all metals. But they cannot be freed from the metal easily, because they are attracted by the positively charged nucleus of the atom. A high temperature helps here. These high temperatures cause the electrons to fall into such rapid movement that some are shed from the surface of the metal.

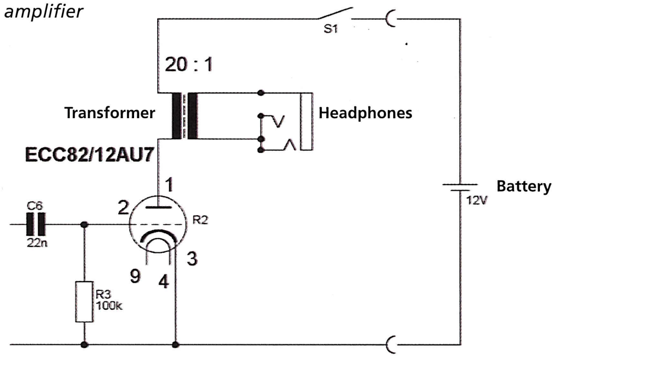


This type of tube, called a **triode**, has four components: the heater, the cathode, the anode, and the grid. The heater is used as the heating source that frees the electrons from the cathode. The cathode is the hot metal electrode that supplies the electrons to the tube. It can be seen glowing when the radio is in operation. The anode, the metal outer plate rapped around the cathode, collects the freed electrons that flow though the tube. In operation, it is given a positive charge. Since electrons are negatively charged, the anode attracts the electrons that have been freed from the cathode within the tube. Near to the cathode is a wire grid, it can be seen though the slits in the side of the anode. This is the control grid of the triode. The electrical voltage on the grid guides the current to the anode. If the grid has a strong negative charge, electrons are repulsed. If the there is no charge on the control grid, nearly all the electrons can reach the anode. The ECC82 is a double tube, more precisely a doubled triode. Every triode has four connections: one each for the heater, the glowing cathode, the anode in the form of an outer plate, and the control grid, the fine wire spiral around the cathode.

The Tube Amplifies

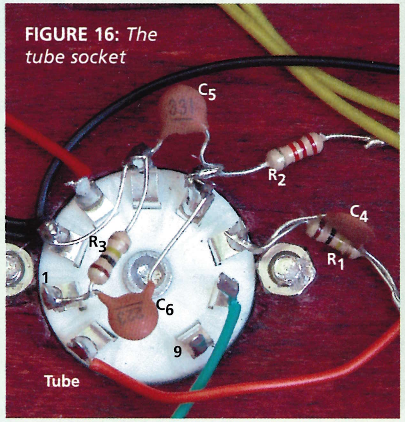
The circuit diagram shows the essential parts of your radio, including the basic circuitry of a vacuum tube amplifier. The heating, which is necessary for all triodes, has not been included here as to simplify the diagram.

FIGURE 15: *The amplifier*



Your radio uses an anode voltage of just 12 V. On the grid inside the tube, a small negative voltage arises spontaneously as electrons land on it. If you touch the grid connection with your finger, a small alternating voltage is added. The anode current changes in synch with this alternating voltage. An alternating current arises in the headphones, which you hear as a buzzing sound.

FIGURE 16: *The tube socket*



Modern headphones have a resistance of 32 Ohms, which does not fit well with the small anode current of a tube. To get a sufficient volume in spite of that, the resistance must be balanced by the output transformer, which transforms the voltage down and thereby increases the current through the headphones. Without the transformer, it would be next to impossible to hear anything from the radio since the anode's signal is so very small.

Amplifiers in Tandem

Some older vacuum tube radios had a particular low-voltage tube (e.g. EF98), which was specially developed for an anode voltage of 12 V and was intended primarily for auto radios. Even with a low anode voltage, this tube managed to achieve high amplification. The ECC82, on the other hand, was developed primarily for television receivers and is actually intended for a large anode voltage of up to 250 V. The amplification of an individual triode is thus indeed smaller, but two of them working together get an even better volume than the EF98.

FIGURE 17: *A two-stage amplifier*

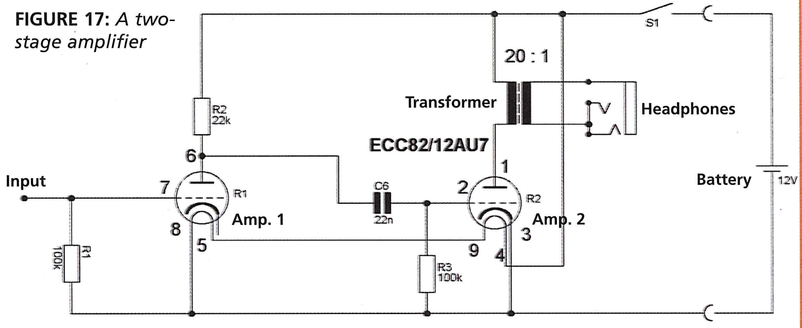


FIGURE 18: *A modern vacuum tube amplifier*

13. Louder, Please!

For this experiment, first install a coil and turn the feedback control halfway up. Now touch your finger to the grid at pin 7 of the first triode. You will hear a loud buzzing, substantially louder than when you touch the grid of the second triode.

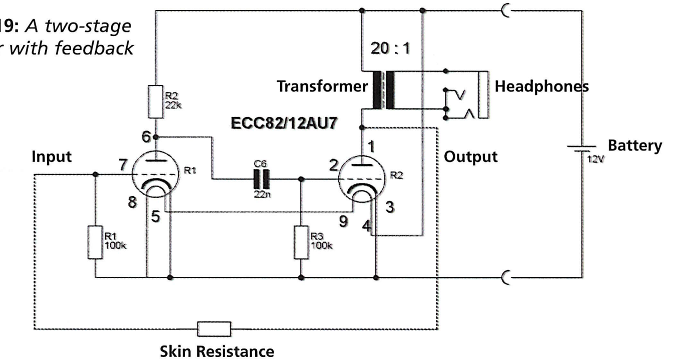
14. What's chirping?

With two fingers, touch the grid of the first tube (pin 7) and the anode of the second tube (pin 1) at the same time. Through the headphones, you will hear a loud, high whistling. The sound can be changed with the feedback control. The pitch will also change if you touch the connections relatively firmly. So your tube apparatus can amplify sounds and even produce tones.

AF Feedback (Audio Frequency Feedback)

You can create feedback with your finger. Not the high-frequency noise you hear at a rock concert when the singer steps too close to the speakers. Rather, a part of the audio frequency signal that is going to the headphones is doubled back to the input of the entire circuit and at the same time it seems to be amplified and heard at the output. A single sound is thus continuously amplified and self-sustaining. Try it by touching both pin 7 and pin 1 of the tube as described above.

FIGURE 19: *A two-stage amplifier with feedback*



5. The Coil and Capacitor

Now imagine energy at all different frequencies flying though the air. You cannot see it or feel it or touch it but it is there, as we described earlier, as part of the Electromagnetic Spectrum. One end of your radio antenna is placed into the air, into the stream of energy all around you, while the other is connected into the beginning of the radio circuitry. The antenna is not only picking up the one radio channel you want to hear, but all the energy, and other radio channels, around. You need to "zoom in" on the one channel you want to hear, and to block out all the rest. The resonant circuit consisting of the coil and variable capacitor allows you to do this. It is truly an elegant way of "zooming in" on only the channel you want to hear.

The resonant circuit works by forming an oscillator. Electrical energy oscillates back and forth between the coil and capacitor at the frequency of the chosen station. The resonant circuit has a characteristic frequency that depends on the coil as well as the capacitor. The more wire windings the coil has and the more of the entire plate surface of the variable capacitor is utilized, the slower the oscillation and the lower the frequency of the resonant circuit. That is why the medium wave coil has more wire windings than the shortwave coil.

15. Just a Touch is Enough

Install the shortwave coil and tune the radio so that you can receive a station clearly. Then touch the resonant circuit with your finger. The radio goes silent. Apparently, your finger draws energy from the resonant circuit. The same thing happens if you insert a screwdriver into the coil.

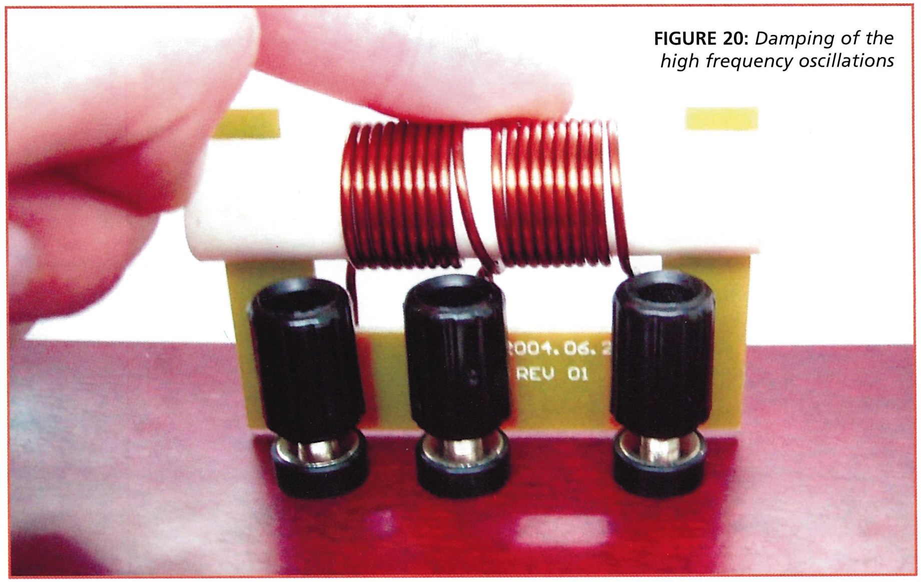


FIGURE 20: *Damping of the high frequency oscillations*

The Resonant Circuit

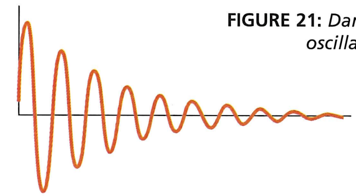


FIGURE 21: *Damped oscillations*

The resonant circuit in your radio can be compared to a guitar string. Like the circuit, the string is also tuned to a certain frequency or pitch. When you pluck it, it makes a very specific tone. If you make the same exact tone with another instrument, the string will begin to vibrate. The string becomes an acoustic receiver for precisely that frequency, which you can see in its vibrations. This phenomenon is called **resonance** (literally, "re-sounding"). Touch the vibrating string with your finger. You will feel the vibrations. At the same time, the vibrating string loses energy as the vibrations are damped and rapidly die out.

An electrical resonant circuit usually consists of a coil and capacitor. In the coil, a magnetic field forms which contains electrical energy. Meanwhile, the capacitor stores energy in its electrical force field. The energy oscillates back and forth between the coil and variable capacitor at the specific frequency of the resonant circuit.

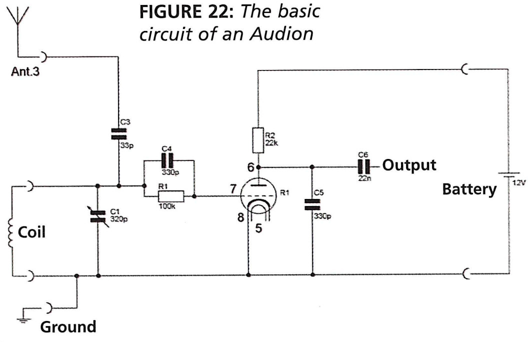
When there is resonance — in other words, when the frequency of the circuit matches the frequency of the station — the radio's resonant circuit is stimulated into electrical oscillation by the antenna. This gathers the signal that corresponds to the tuned-in station.

These electrical oscillations of the resonant circuit may not be visible, but you can hear the radio program corresponding to them. Just as with the vibrations of a guitar string, those electrical oscillations can be damped and stopped by your finger. Together with the coil wire and the insulation, your finger creates a capacitor through which a high-frequency current flows through your body — thus weakening the electrical oscillations.

16. A Different Kind of Connection

Until now, you have used antenna connection 2 with the shortwave coil. Now try connection 1. You will find that tuning to a stronger station is easier because the tuning does not have to be so precise. But stations lying close to one another can no longer be easily distinguished. Your radio is less selective. You can hear several stations through your headphone at one time. The precise setting of the feedback is no longer so important. With antenna connection 1, the radio has more volume, but also less selectivity.

FIGURE 22: *The basic circuit of an Audion*

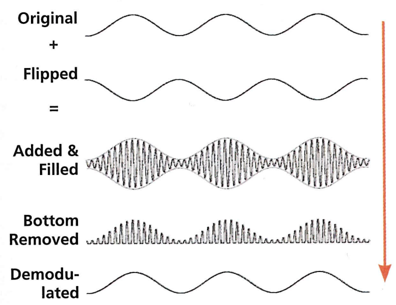


The Audion

The first triode in your radio is the actual receiver. The circuit diagram shows the simplified circuit without the feedback. It is a typical Audion circuit, as was used in the early days of radio technology. The word "Audion" comes from "audio" and means nothing other than a circuit for making radio signals audible.

Medium wave and shortwave broadcasters usually use so-called amplitude modulation (AM). In order to transmit voice or music using amplitude modulation you must first know the frequency you are going to transmit upon. Then you take the voice or music signal and "mix" the two together. The AM form of mixing is basically a simple form of coloring between the lines. Imagine taking the original voice signal and using it as the top line and then taking a copy of it and flipping it upside down to use it as the bottom line of our pattern. Finally you color between the two lines at the frequency that you are transmitting at. That is the visual representation of an AM signal transmitted from any radio tower.

FIGURE 23A: *Modulation and demodulation*



For something to be heard on the radio receiver's end, the received signal must first be **demodulated**, which means that we need to remove the transmission frequency that was colored between the signal lines. Also the original voice or music signal must be amplified. Most of the time this is accomplished in stages. First the signal is cut in half, removing the bottom signal line. Then the transmission frequency is removed and finally the signal is amplified. The beauty of the Audion circuit is the fact that it simultaneously takes on the functions of removing the bottom portion of the received signal and amplifying. The function is actually very simple; the received signal is fed into the control portion of the tube, the grid. Since, the amplification of the tube increases as the input signal voltage increases, the positive portion of the received signal is amplified more than the negative portion, leaving only small humps where the bottom portion of the signal once was.

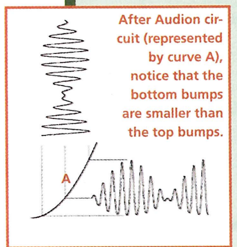


FIGURE 23B: *Demodulation with a tube*

17. Dull and Clear Sounds

Pick up a local medium-wave station without an antenna while turning your feedback knob to its loudest setting. The sound is very dull. The selectivity is too high and the bandwidth too low, so you can't hear the high tones.

Now connect the antenna to connection 3. The reception becomes clearer, with the higher tones transmitted much better.

A minimal antenna link to connection 1 and correctly adjusted feedback result in a low bandwidth and a dull sound quality. With antenna connection 3, by contrast, the damping effect of the antenna is greater. It also increases the bandwidth so that the full range of tones is transmitted.

Selectivity

How well a resonant circuit can differentiate stations lying next to one another depends on its quality factor (for short, quality). The quality (Q) is the ratio of bandwidth to resonance frequency. If a bandwidth of 10 kHz is desired with a reception frequency of 1000 kHz, the quality must be 100. Bandwidth represents the width of the peak of frequencies that surround the reception frequency. You may notice that b1 and b2 in the picture both center at the reception frequency, with an even amount on the right and left. So if the bandwidth is too large you will include many more of the frequencies that are around the reception frequency reducing the quality. High quality leads to good selectivity and to high volume. It is attained if as little as possible of the energy oscillating back and forth in the resonant circuit is lost. To achieve that, the coil must be wound out of wire with very low resistance as to not heat up and waste energy. In addition, it is important how the antenna is connected, because an antenna not only receives energy but also emits energy. Antenna connection 1 is connected to the central tap of the shortwave coil. The antenna therefore causes a large damping effect absorbing much of the energy hindering the resonance, which in turn reduces the quality and leads to a greater bandwidth. With connection 2, the connection between the antenna and the resonant circuit is loose because a small capacitor is in the connection line. One speaks of a fixed antenna coupling when the antenna is connected very directly, say at the upper end of the resonant circuit or at a high tap of the coil.

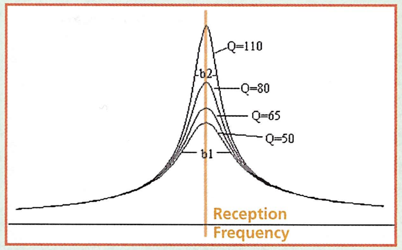


FIGURE 24: *Resonance curves with different qualities and bandwidths*

HF Feedback (High Frequency Feedback)

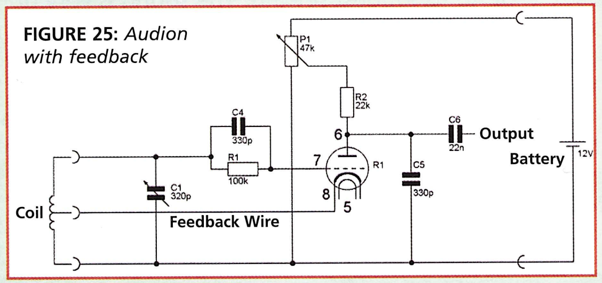


FIGURE 25: *Audion with feedback*

The quality of a resonant circuit depends on how much of the oscillating electrical energy is lost. A part of the available energy is continuously converted into heat. That means that the voltage at the resonant circuit remains low so weak stations cannot be received.

A critical discovery in the development of the Audion was **attenuation equalization** of the resonant circuit through feedback. A part of the high-frequency oscillation amplified in the tube is brought back into the resonant circuit. If just as much energy is conducted back as is lost in total, then the resonance circuit has been equalized and theoretically infinite quality can be achieved. In practice, the quality can rise 1,000 times, allowing us to pick up stations even if they have a low signal strength. Also, improved selectivity is another product of this.

The trick with the feedback control knob is to adjust it to just the right degree of amplification. If more energy is brought back than is lost, the circuit produces its own oscillations, just like a transmitter. You then hear the familiar whistling in the headphones. In your radio the anode voltage of the Audion tube is changed to adjust the amplification. The higher the voltage, the greater the amplification.

But if the attenuation becomes too great due to a very direct antenna connection, the tube's amplification may no longer be enough for optimal adjustment of the feedback. In the shortwave range, try connecting your antenna to antenna connection 3. Even if you turn the feedback all the way up, that familiar whistling sound is no longer to be heard, because the antenna exerts too much of a damping effect on the resonant circuit. But if you connect just a short antenna, for example a 50-cm length of wire, to antenna connection 3, your radio will once again work in its usual way.

6. Hear and Be Heard

Would you ever have suspected that your radio is also a transmitter? For the following experiments you will need a second radio, to use as a receiver for your very own transmitting station.

18. Your Own Transmitter

Get your radio ready with its medium-wave coil installed, but without any antenna or ground connection, and set it next to another radio on which you tune in a medium wave (AM) station. Then turn the feedback way up and rotate the variable capacitor slowly over its entire range. At one point you will hear a whistle from the other radio. Your radio has become a small transmitter.

19. The Whistling Concert

You can now use your variable capacitor to tune in whatever pitch you like. You will get an overlapping sound (interference) with the receiving radio transmitter. When the latter transmits at 720 kHz, for example, and your radio is tuned to 721 kHz, the difference of one kilohertz will be heard. You can try out whatever pitches you want. Move your hand around near the flat coil. You will get a small change in frequency, which will lead to a changed frequency of the interference tone. See if you can play a melody with the movement of your hand.

20. Can Anybody Hear Me?

Investigate the range of your transmitter. If the station you chose for the interference isn't too strong, your apparatus can bridge a distance of up to three meters. So it is not really a powerful transmitter, and you won't have to worry about disturbing your neighbors. If, however, you connect a long antenna to it, you should avoid setting the feedback knob to too high a setting.

By the way, a normal medium-wave radio is also a weak transmitter of interference. The transmission frequency usually lies around 450 to 470 kHz above the tuned reception frequency. You can hear this "interference signal" with your radio if you set the feedback just above the singing point. At just the right spot, you will be able to hear the signal from the other radio as a sort of whistling sound.

21. A Dial Shows the Frequency

Until now, you have found radio stations purely by chance, or by noticing how far the capacitor was turned. But with a dial scale it's easier to find specific stations you like. Inside your Radio Ace kit, you will find empty dial scale sheets that you can fill in yourself. The picture shows you an example. In this example, the shortwave frequencies are entered on the outside (above), and the medium-

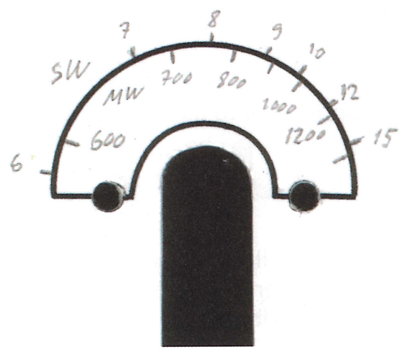


FIGURE 26: *The frequency dial scale*

wave frequencies on the inside (below).

But how do you know the frequency of a radio station? One possibility is to look for stations whose frequencies you already know or were just announced on the air. An easier way is to use another radio for comparison. Turn up the feedback dial high enough for your radio to become a little transmitter. Then tune your station so that it comes in on the other radio. Now you can read the frequency on the other radio's dial and enter it into your own dial scale sheet.

Please notice how the antenna and your chosen antenna connection have some degree of influence on the frequency. At the upper end of the frequency scale, in particular, the frequency is usually a little lower with an attached antenna. Antenna terminal 3 has an especially noticeable lowering effect on the frequency. So your dial scale should be filled in to match the specific relevant conditions.

22. The Station Dial

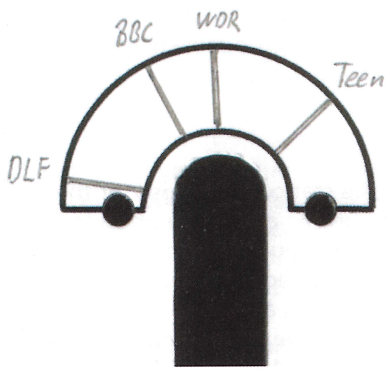


FIGURE 27: *A dial with the names of stations*

You can also enter the names of the transmitters (in other words, the stations) directly onto the dial instead of filling in frequency numbers. That way, if you enjoyed listening to BBC World Service last night, you can easily find it again today.

7. Experiments for High-Frequency Enthusiasts

Shortwave radio is its own special hobby. All across the world, there are amateur radio enthusiasts who contact each other with their own radio transmitters. You can get a taste of the fascination of high frequency by performing the following Radio Ace experiments.

23. 1,000 Kilometers without an Antenna!

With its shortwave coil attached but without an antenna, set your radio to a frequency of over 10 MHz by turning the capacitor dial far to the right.

Next, turn the feedback all the way up. You will hear static. Search through the upper part of the range. You will hear a few very distant transmitters, which will come in loud and clear in spite of the lack of antenna. The radio's behavior is completely different from usual. The loud static sound always gets quieter in the places where a station comes through. In the background, you will still hear a very high whistle.

The Oscillating Audion

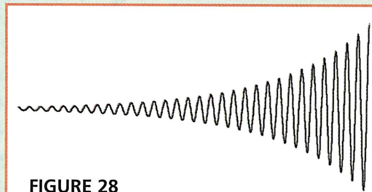


FIGURE 28

In Experiment 23, we are operating our radio like an oscillating Audion. The turned-up feedback dial leads to strong high-frequency oscillations. A large grid current flows and negatively charges the grid to the point that the tube is blocked. Now the oscillations subside. After a short period of time, the resistance has sufficiently discharged the grid for the tube to initiate new oscillations. So the circuit swings quickly back and forth between a blocked and an oscillating state. The oscillating frequency of about 10 kHz is audible as a very high tone.

Each new cycle resumes at zero. The tube can only amplify an oscillation that has already begun. If a weak station lies on the resonant frequency, its oscillations form the starting point. A voltage of one millionth of a volt is enough. So the oscillating Audion is very sensitive, and achieves an audible long-distance reception without an antenna.

With each new cycle, the oscillating Audion needs up to 1,000 high-frequency oscillations to block the tube. It therefore only works at higher frequencies above 10 MHz.

24. Morse Code Reception

The first transmitters were telegraphs. Before the introduction of radio technology, there were ships' transmitters sending **Morse code**. Even today, you can find Morse transmitters with your radio. Various radio transmitters such as weather stations and amateur radio operators still use this particularly simple and reliable means of transmitting data.

Search the area between 7.0 and 7.1 MHz, below the 41-m radio band, with the feedback strongly turned up. You may find a few Morse transmitters there. These are radio amateurs from all over the world, conversing via Morse code. The language most commonly used is English, with many international abbreviations. People exchange information about location, equipment, and weather, and they can converse quite clearly about personal matters. A short example from the beginning of a typical radio contact:

G3abc de dk7jd – tks fer call – rst 599 – name is burkhard – qth is essen

In plain language, that means: G3ABC (English call sign) from DK7JD (German call sign). Thanks for the call. I am receiving you with readability 5, strength 9, and tone 9. My name is Burkhard, and my location is Essen.

MORSE CODE

A	• —
B	— • • •
C	— • — •
D	— • •
E	•
F	• • — •
G	— — •
H	• • • •
I	• •
J	• — — —
K	— • —
L	• — • •
M	— —
N	— •
O	— — —
P	• — — •
Q	— — • —
R	• — •
S	• • •
T	—
U	• • —
V	• • • —
W	• — —
X	— • • —
Y	— • — —
Z	— — • •
1	• — — — —
2	• • — — —
3	• • • — —
4	• • • • —
5	• • • • •
6	— • • • •
7	— — • • •
8	— — — • •
9	— — — — •
0	— — — — —
Á (*A with accent*)	• — — • —
Ä (*A with two dots*)	• — • —
É (*E with accent*)	• • — • •
Ñ (*N with tilde*)	— — • — —
Ö (*O with two dots*)	— — — •
Ü (*U with two dots*)	• • — —
, (*comma*)	— — • • — —
. (*period*)	• — • — • —
? (*question mark*)	• • — — • •
; (*semicolon*)	— • — • —
: (*colon*)	— — — • • •
/ (*slash*)	— • • — •
- (*dash*)	— • • • • —
' (*apostrophe*)	• — — — — •
() (*parenthesis*)	— • — — • —
_ (*underline*)	• • — — • —

25. Mickey Mouse Voices

Search the shortwave regions between the radio bands. The feedback dial should be set just over the singing point. In some spots, you will hear strange sounds—maybe a static sound followed by a crackling or lilting. You might hear strangely altered voices. It is usually particularly easy to find such radio signals in the 40-m amateur band.

In amateur, or ham radio, people use speech in addition to Morse code signals. The amateur transmitters work differently from the radio transmitters with SSB (single side band) modulation, using less bandwidth and transmission power. Worldwide radio range can be achieved with a 100-Watt transmitter, while a broadcasting service transmitter usually uses a transmission power a thousand times greater.

A standard shortwave radio cannot receive SSB, but an Audion is well-designed to do so. As with Morse transmitter reception, the feedback has to be set just above the singing point. Then try to fine-tune it to the exact frequency. The tiniest deviations will make the transmitter's voice sound too high or too low. Sometimes, it can sound just like Mickey Mouse. Working with the capacitor alone, tuning is difficult. But you can hold your hand in the vicinity of the circuit and fine-tune it that way. The closer you get to the coil, the lower the frequency becomes. With a little practice, you will be able to hear the voice clearly. Use the same technique to listen to other radio services in addition to Morse and SSB transmitters. There are a lot of automatic transmitters in the shortwave region. Among them are radio telexes whose transmissions sound like some kind of warbling or chirping. Other transmitters broadcast images, such as weather maps. The transmitted data may be impossible to see, but it is still interesting to explore the cacophony of sounds cavorting around in shortwave airspace.

Often, you can find strong transmitters in the middle of radio bands, whose signals just make a loud rushing sound. An example is the new digital radio broadcaster DRM, which transmits speech and music over large distances with particularly good sound quality. These stations can also be received by your radio, but can only be decoded with the help of a computer and special software.

26. Radio Interference

Turn on a light switch and you will hear a crackling in your receiver. There are little sparks created in the light switch, which, together with the electrical wiring, form a transmitter. But other things such as motors can cause radio interference too. The very first transmitters were spark transmitters.

Interference from electrical appliances in the house can sometimes be too strong for good reception. In that case, an external antenna can help.

8. Build It Yourself
(With or Without a Soldering Iron)

Maybe the experiments in this kit are not enough for you. But with a little wire and a few extra components, you can easily add to your radio, or even convert it into something completely different.

27. Who's Talking?

Build yourself a shortwave coil for higher frequencies. Especially interesting is the CB radio range around 27 MHz (11 m band). With the right coil, you can listen in on handheld radio signals, for example. The coil will need two pieces of wire, each wound five times in the same direction. You can use simple speaker wire wound onto a rolled-up piece of cardboard with a diameter of about 16 mm. The ends should be stripped of their insulation and bound with terminal clamps. In general, you can gauge the frequency of your own coil like this: Assuming a given diameter, twice as many turns of the coil yield half the frequency, and half as many turns correspond to twice the frequency.

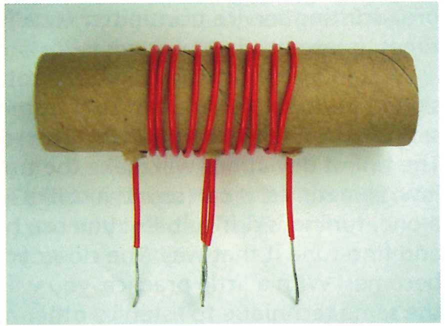


FIGURE 29: *Receiver coil for CB radio*

28. Between Medium and Shortwave

Construct a coil with a total of 40 turns and a tap after the tenth turn. Now you can pick up frequencies from around 3 MHz, which most shortwave radios miss because they lie between medium wave and the usual shortwave range. The 80-m amateur band (3.5 to 3.8 MHz) is particularly interesting. That is where you will find Morse stations and SSB transmitters. You can also receive the 75-m radio band at 4 MHz.

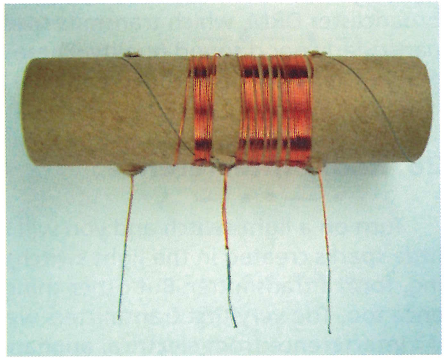


FIGURE 30: *A coil for the 80-m band*

29. Long Waves with a Ferrite Rod

If you want to receive signals in the long-wave range from 150 kHz and below, you have to coil a wire many times around a large object in order to pick up the low frequencies. But if you use a ferrite rod, you can get away with using less wire. It's often possible to get a ferrite rod from an old radio, sometimes even with the right coil. If you want to wind your own coil, try it with 300 turns of thin, lacquer-insulated copper wire (CuL 0.25). The tap should be at the 30th turn. If the frequency is too low, carefully remove a few turns of wire.

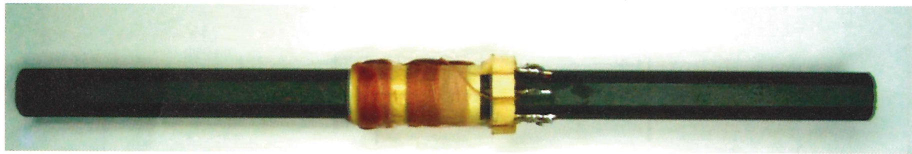


FIGURE 29: *A ferrite rod with a long-wave coil*

30. Fine Tuning

Convert your radio into a specialized receiver for a specific band. Granted, that will only be possible with a soldering iron and a few extra parts. The circuit diagram (on the next page) shows how to do the conversion for the 40-m amateur radio band. Audion tube receivers were often used as ham radios. Typically, exchangeable coils were used for specific bands. What is important is you should be able to tune the receiver very precisely. From that perspective, the wide range of your radio is actually a disadvantage. That is why people use wiring that restricts the tuning range to a single band. Then, a narrow range of frequency is spread out over the entire dial scale.

You can achieve the narrowing of your radio's tuning range through a serial connection of the variable capacitor with a smaller fixed capacitor. The lower end of the band is determined with a supplementary parallel capacitor. If an adjustable trim capacitor is used, the start of the band can be selected within general limits.

The suggested circuit can be used with the shortwave coil provided for the 40- and 41-m band. When the variable capacitor is turned quite far, the tuning is broadly spread out. The amateur radio band covers about half the scale from 7.0 to 7.1 MHz.

The rebuilt circuit also includes a different antenna hookup. Antenna attachment point 3 is more weakly connected via a very small capacitor. Then, the receiver can also be operated with a long external antenna.

Once you start to make your own alterations, there are no limits to your creativity. You could, for example, construct several coils with permanently soldered capacitors for the different radio bands.

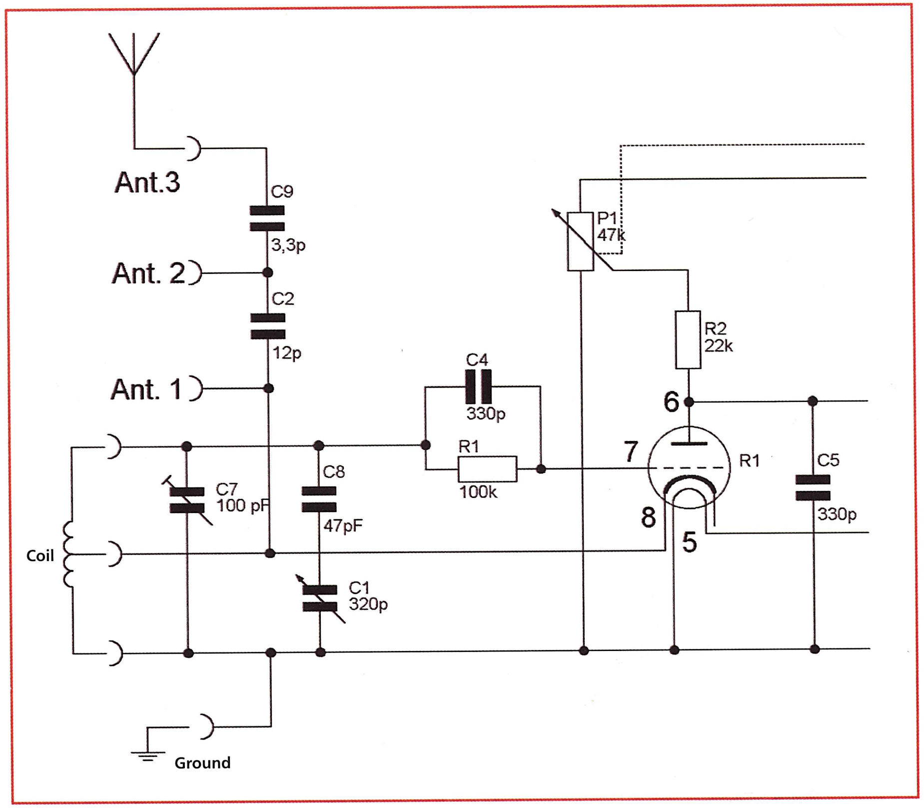
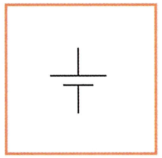
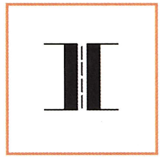
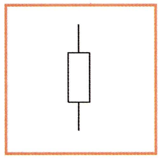


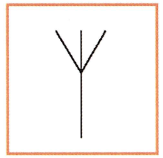
FIGURE 32: *Bandspread circuitry for the 40-m band*

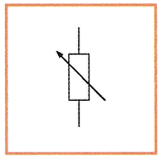
Overview of Circuit Diagram Symbols

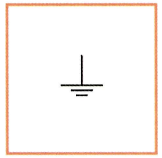

Battery

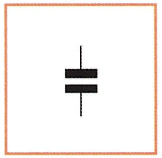

Transformer

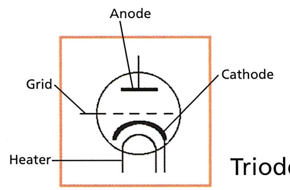

Resistor


Antenna

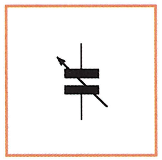

Variable Resistor

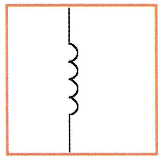

Ground Connection

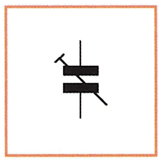

Capacitor

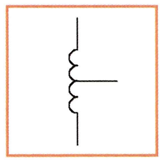


Triode


Variable Capacitor


Coil


Trim Capacitor


Coil with Tap