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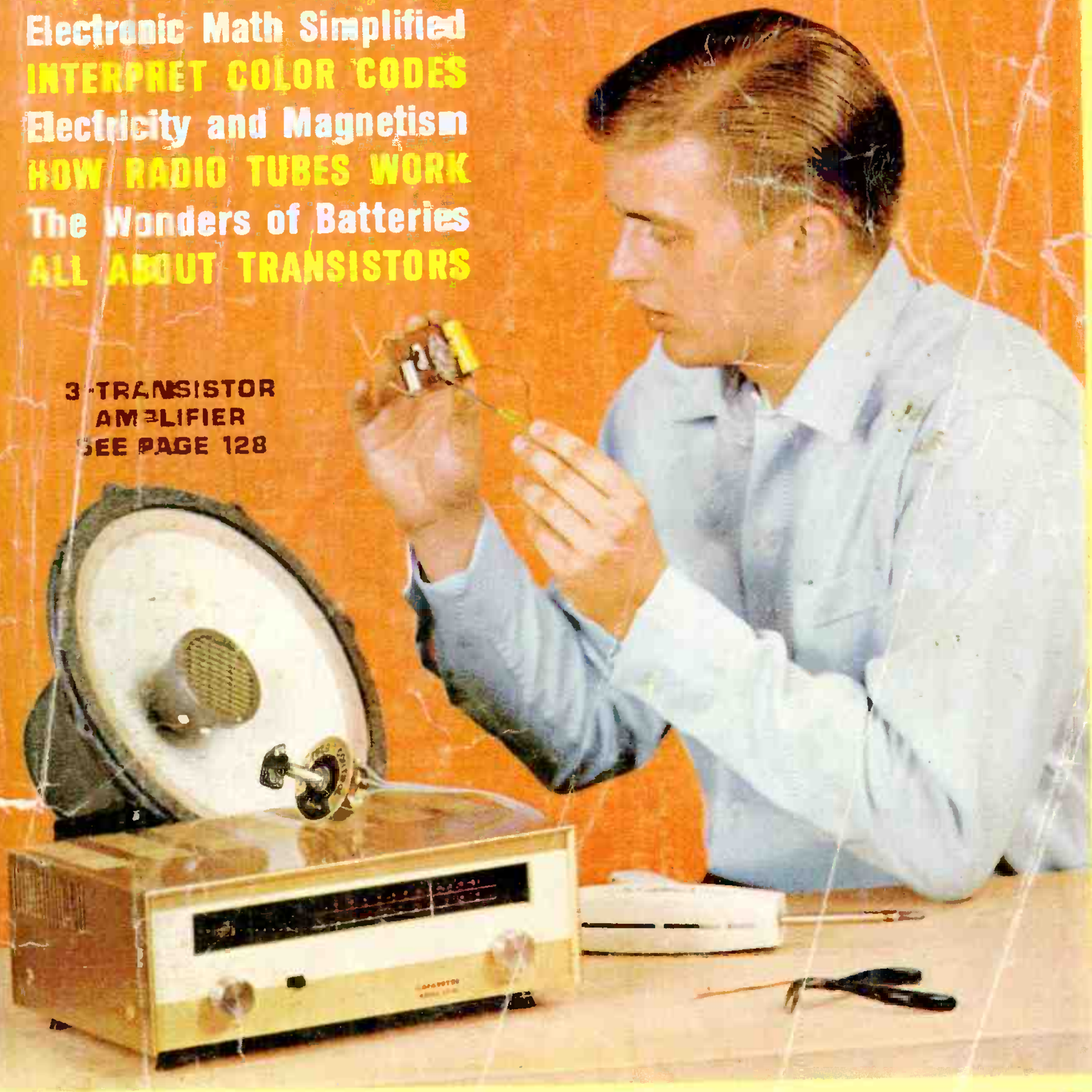

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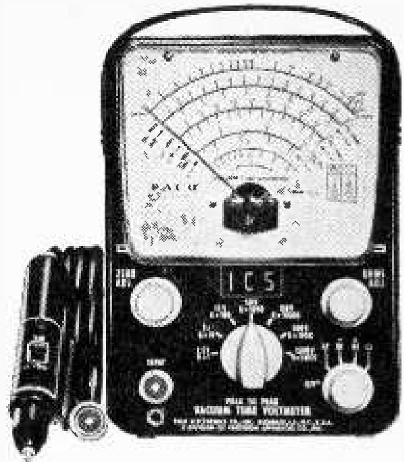

ELEMENTARY ELECTRONICS

A SCIENCE and MECHANICS Handbook

No. 657 — 1963 Edition

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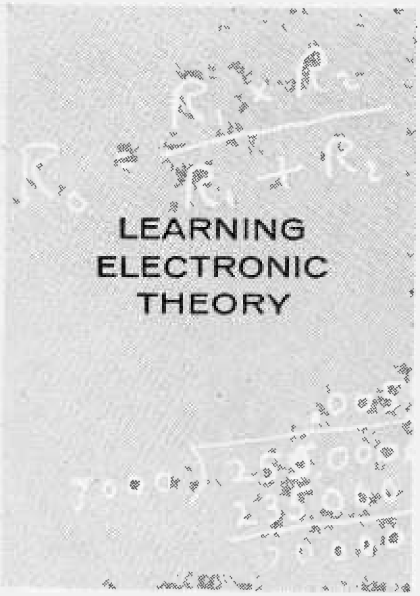

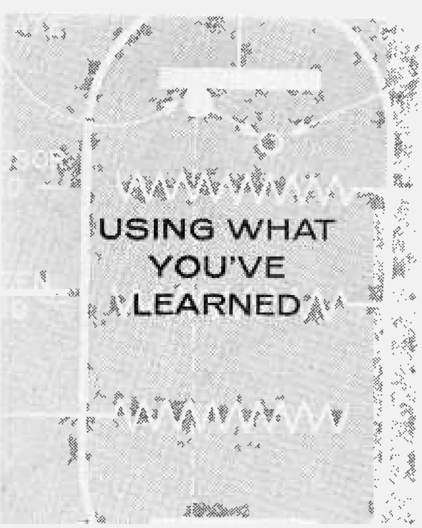

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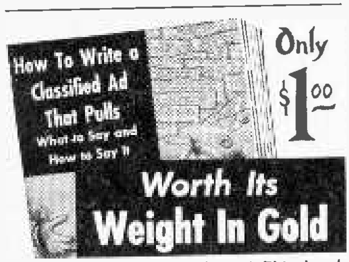

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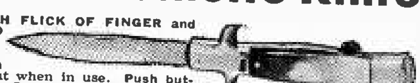

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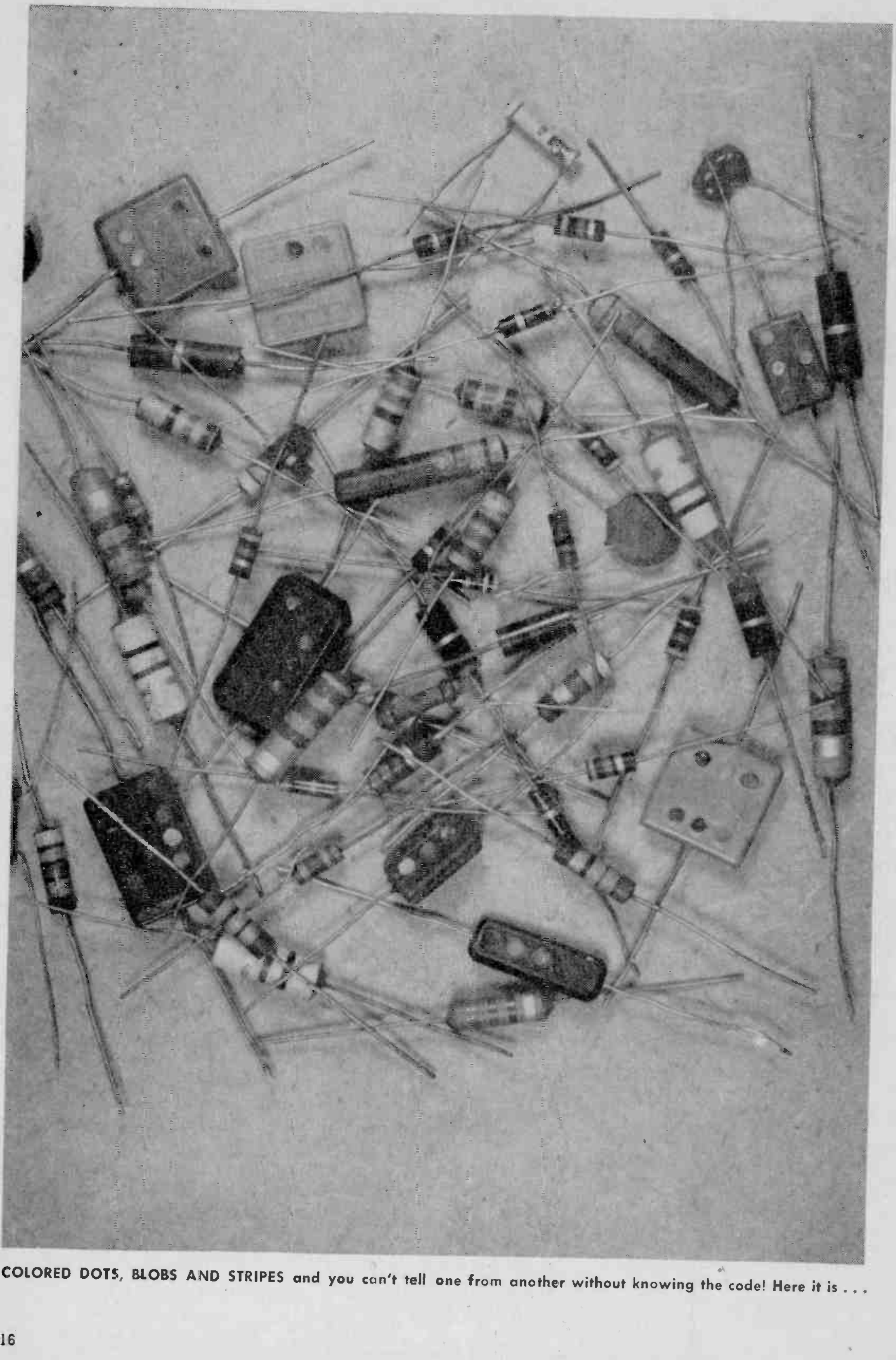


COLORED DOTS, BLOBS AND STRIPES and you can't tell one from another without knowing the code! Here it is . . .

The meaning of colored dots or stripes on resistors . . . capacitors, and the significance of colored wires

EVER looked under the chassis of a piece of electronic equipment and seen a number of small parts with colored dots or stripes on them? Some may be resistors and some capacitors, but without a knowledge of the color coding system, it is hard to tell which is which, much less what values are involved.

Some years ago the electronic industry set up certain standard color codes to label resistors and capacitors, and to identify leads from certain other components. This system is known as the *RMA Standard Color Coding Plan*. While color coding for wires had been used previously, there was no standard, and the manufacturer's data sheet had to be available in each case to know what each color represented.

In resistors and capacitors, any value

RMA Color Codes

By W. F. GEPHART

printed on the unit may become obscure and, as units got smaller, there wasn't room to print the necessary information on them. So a color code was adopted which is based on each of ten digits being represented by a color, as follows:

Black 0
Brown 1
Red 2
Orange 3
Yellow . . . 4
Green 5
Blue 6
Violet 7
Grey 8
White 9

Before going into how these colors are used, let's look at the color sequence. It is essential that this sequence be remembered, to save having to refer to a chart every time you see a resistor.

Notice that the sequence starts with "Black," which is the absence of color and therefore represents "O." The next four col-

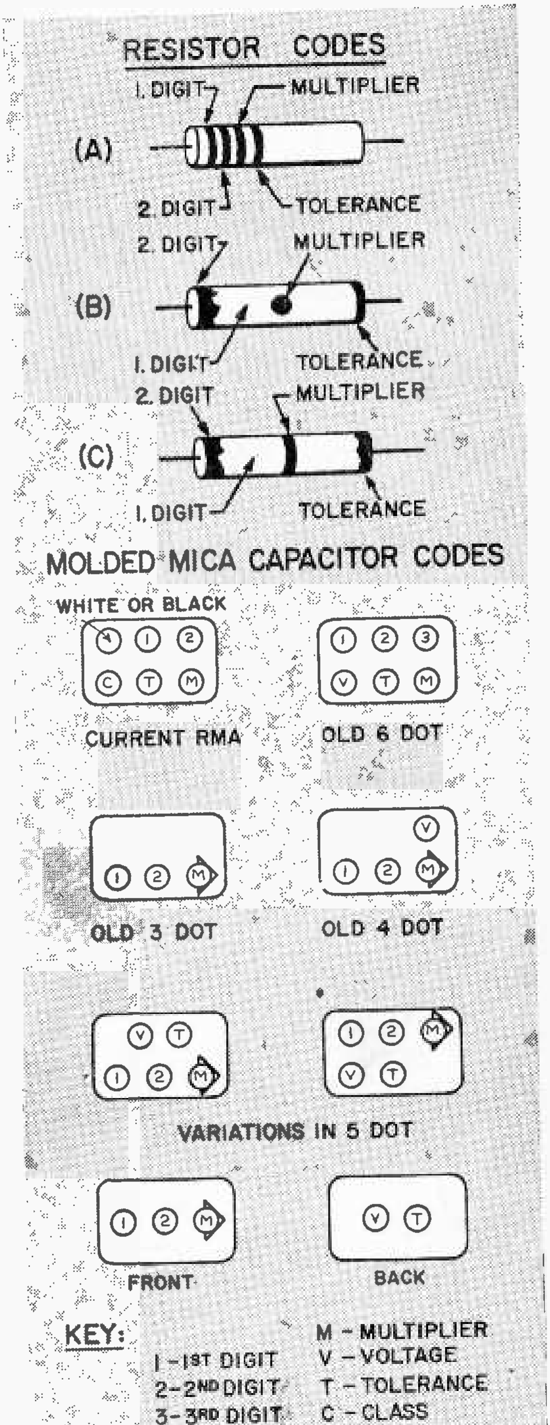


FIGURE 1

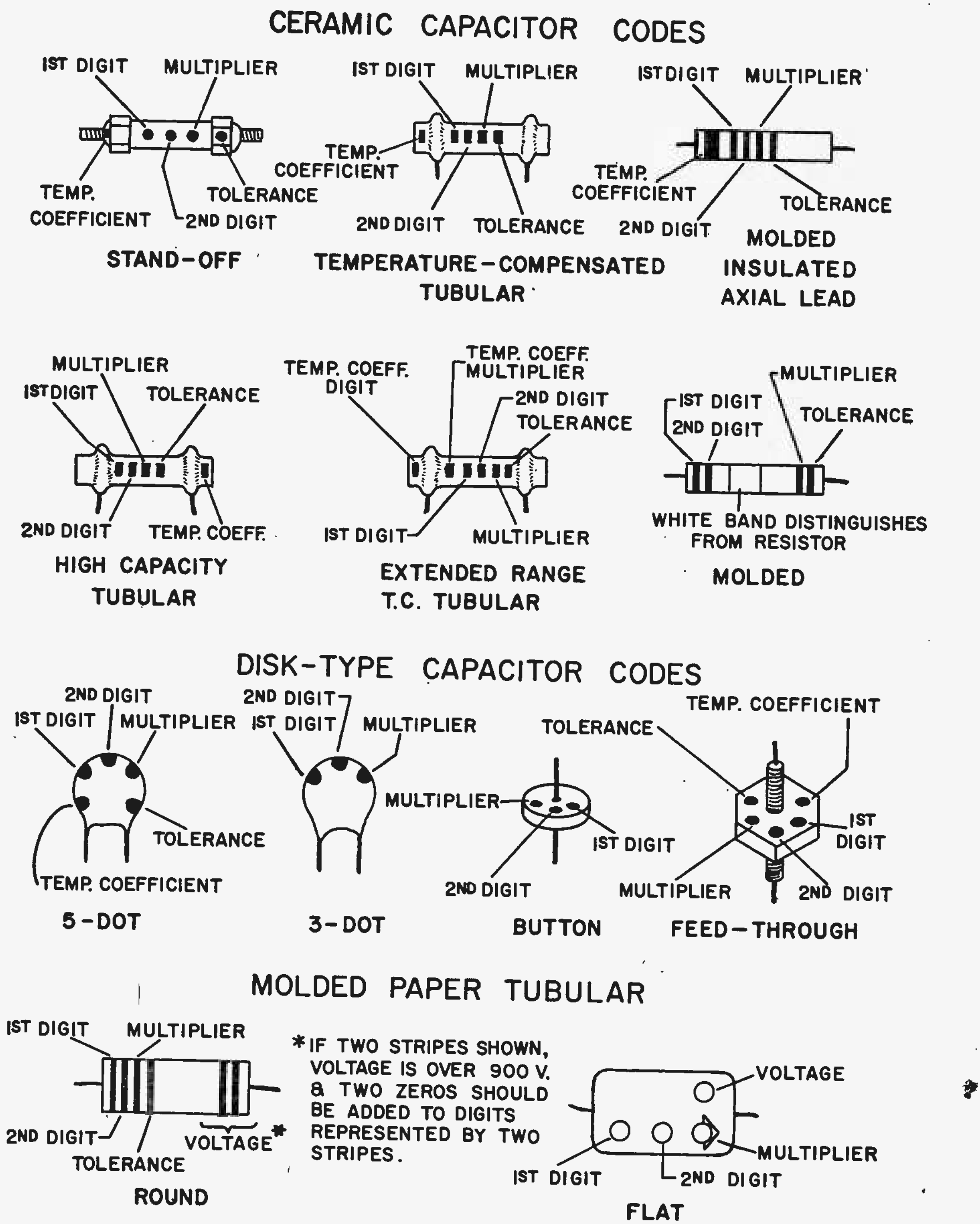
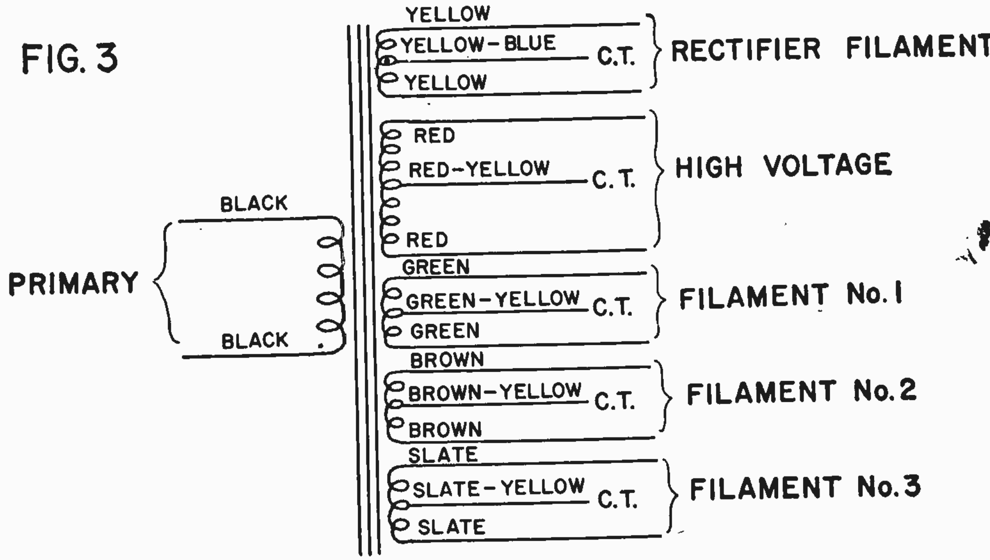
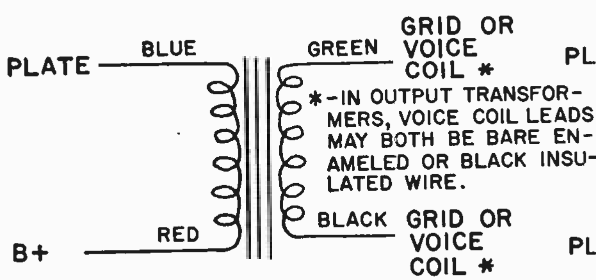

CERAMIC CAPACITOR CODES
1ST DIGIT
MULTIPLIER
TEMP. COEFFICIENT
TOLERANCE
2ND DIGIT
STAND-OFF
1ST DIGIT
MULTIPLIER
TEMP. COEFFICIENT
2ND DIGIT
TOLERANCE
TEMPERATURE-COMPENSATED TUBULAR
1ST DIGIT
MULTIPLIER
TEMP. COEFFICIENT
2ND DIGIT
TOLERANCE
MOLDED INSULATED AXIAL LEAD
MULTIPLIER
1ST DIGIT
TOLERANCE
2ND DIGIT
TEMP. COEFF.
HIGH CAPACITY TUBULAR
TEMP. COEFF. DIGIT
TEMP. COEFF. MULTIPLIER
2ND DIGIT
TOLERANCE
1ST DIGIT
MULTIPLIER
EXTENDED RANGE T.C. TUBULAR
MULTIPLIER
1ST DIGIT
2ND DIGIT
TOLERANCE
WHITE BAND DISTINGUISHES FROM RESISTOR
MOLDED
DISK-TYPE CAPACITOR CODES
2ND DIGIT
1ST DIGIT
MULTIPLIER
TOLERANCE
TEMP. COEFFICIENT
5-DOT
2ND DIGIT
1ST DIGIT
MULTIPLIER
3-DOT
MULTIPLIER
1ST DIGIT
2ND DIGIT
BUTTON
TEMP. COEFFICIENT
TOLERANCE
1ST DIGIT
MULTIPLIER
2ND DIGIT
FEED-THROUGH
MOLDED PAPER TUBULAR
1ST DIGIT
MULTIPLIER
2ND DIGIT
TOLERANCE
VOLTAGE*
ROUND
*IF TWO STRIPES SHOWN, VOLTAGE IS OVER 900 V. & TWO ZEROS SHOULD BE ADDED TO DIGITS REPRESENTED BY TWO STRIPES.
VOLTAGE
MULTIPLIER
1ST DIGIT
2ND DIGIT
FLAT

FIGURE 2

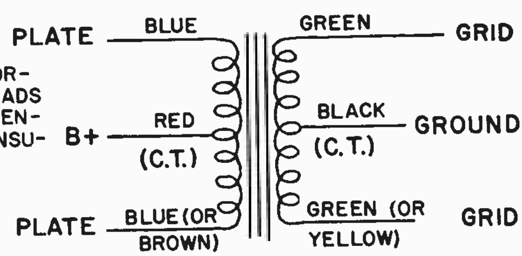
FIG. 3



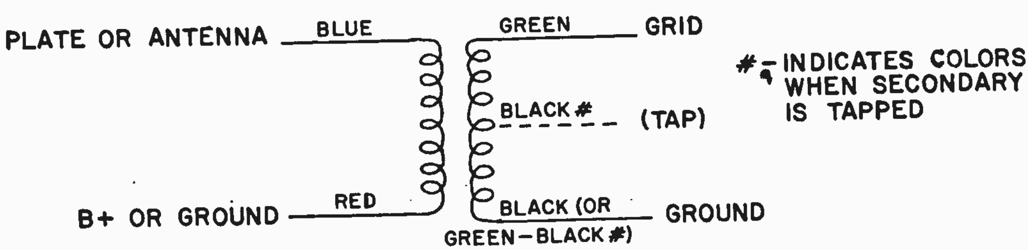
POWER TRANSFORMERS



SINGLE-ENDED AUDIO



CENTER-TAPPED AUDIO



R.F. COILS & I.F. TRANSFORMERS

ors are "warm" colors, progressing from dark to light (brown, red, orange, yellow). At this halfway point, the sequence shifts to the "cool" colors, with green for "5" and blue for "6". The next color is a close relative of blue, or violet, and represents "7." By this time, most colors are represented, and if combined might give grey, which is "8." The last color, which includes all hues, is white, and represents "9."

Practice memorizing this code by thinking of colors in terms of numbers, and numbers in terms of color. For example, if you see a brown, yellow, and white fabric, think of it as a "one-four-nine" fabric. If you see a street number of 3725, think of it as "orange-violet-red-green." This practice, plus remembering the sequence of colors (from warm colors to cool colors to all colors) will help you remember the code.

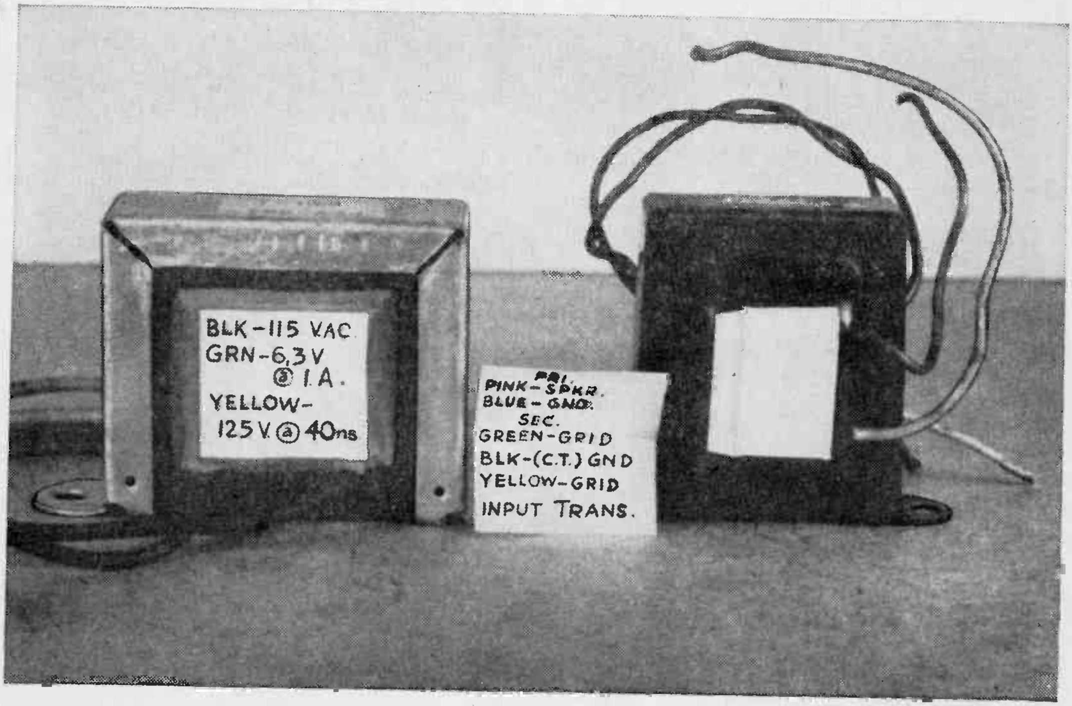
Now let's see how the code is used, looking first at resistors. In looking at a manufacturer's list of resistors, you'll find that they run in value from 1 ohm to 22 megohms. You'll also notice that (with certain exceptions) *standard* values never have more than two significant digits. You will find values such as 47, 470, 4700, 47,000, etc. ohms, but not 47.5, 475, 4750, 47,500, etc. Exceptions to this are certain military, precision, and high-wattage resistors. Special coding, sometimes used on these resistors, will be mentioned later in this chapter.

Since most resistors will then be a value which can be represented by two figures followed by a number of zeros, three colors can be used to indicate the value. Two of the colors will represent the significant digits, and the third will represent the number of zeros following the two digits.

Under this plan, a 47,000 ohm resistor can be represented by three color marks in sequence; yellow for "4," violet for "7," and orange to indicate that the two numbers are followed by "3" zeros. A 22-megohm resistor would be red (for "2"), red (for "2"), and then blue (for "6" zeros). A low-value resistor, such as 47 ohms, would be represented by yellow (for "4"), violet (for "7"), and then black, indicating that the two numbers are followed by "0" zeros.

The plan is simply that the first two numbers indicate the first two numbers of the value, and the third color is the *multiplier*, indicating the *number of zeros* that follow the first two numbers.

In most cases, two other "colors" are often used, representing tolerance to stated value. These are metallic colors, with "gold" indicating a 5% tolerance, and "silver" indicating 10% tolerance. Most resistors are marked with four colors, three of which represent value, and one metallic color representing tolerance.



You'll notice that wattage is not included in the plan. Wattage can usually be determined by physical size, since the larger the wattage, the larger the resistor must be to dissipate heat. While no fixed standards have been set, the difference in size between various wattages is apparent, and the differences in size between units of different manufacturers (for equal wattage) is too small to be apparent.

Figure 1 shows the marking system for resistors. Since the sequence of the colors is so important, a standard plan of showing them on the resistor was adopted. The current system (Fig. 1A) involve four colored bands around the resistor, starting at one end The band closest to the end represents the first digit, the next band the second digit, the third band the multiplier, and the band farthest from the end represents the tolerance. Sometimes, on small resistors, the bands cover the whole body of the resistor, and appear to "start" at both ends. It is important to remember that, when viewed properly, the code *ends* with the metallic tolerance color (gold or silver), and the value reading should start with the color at the opposite end.

In a few cases, you might find *four* colored bands followed by gold or silver. These are military standard resistors, which sometimes involve three significant digits, such as 4750 ohms. The system is basically the same, however, in that the last color (excluding gold and silver) is the multiplier and the preceding colors are significant digits. The 4750-ohm value would be yellow-violet-green-brown, followed by gold or silver. Occasionally, a four-band system will also be used on precision resistors.

Figures 1B and C show the system as it was formerly used. In this case, the body of the resistor was painted, and this body color indicated the first digit. One end was colored, indicating the second digit. The multipler was then shown as a colored dot or band around the body. The tolerance, when used, was sometimes a metallic color on the other end of the resistor, or a metallic band around the body. While this system is not being used now, it may be found on resistors used in older equipment.

While this system has been adotped by foreign manufacturers, it may not be used on some resistors you find. Precision resistors, which may have a number of significant digits, usually have the value printed on the resistor, either in actual ohms, or manufacturer's code. The color code is normally not used on high-wattage resistors, since the heating of the resistor would burn off the colors.

If it is necessary to replace a resistor where the code is discolored or obscure, the important color to look for is the third, or multiplier, color. If this can be determined, at least the range of resistance involved is known. For example, if the exact value was 560,000 ohms (yellow multiplier color), the circuit would probably work (though not at optimum performance) with anywhere between 330,000 and 820,000 ohms. But it probably wouldn't work with values of 56,000 ohms (orange multiplier), 5600 ohms (red multiplier), or 5.6 megohms (green multiplier). Where the multiplier color of the resistor to be replaced is in the low range (brown and red), the value of the significant digits color becomes more important.

When applied to capacitors, the color-coding system becomes more complicated. In the first place, there are different types and shapes of capacitors. Secondly, in many cases, two new factors, voltage and temperature coefficient, have been added. However, the basic colors for each number remain the same. Since this system is normally used only for small capacitance values, the multiplier color becomes a decimal multiplier in some cases.

Figure 1D shows how the codes are applied to molded mica capacitors, and Fig. 2 shows them applied to other types. Temperature coefficients, while not too important in many applications, are shown to explain the additional dots or bands used with some systems. The measurement is in "parts per million per degree centigrade" temperature increase. For example, if you had a 1.0 mfd. (1,000,000 mmf.) capacitor with a green temperature coefficient dot on it, it would *decrease* (since the sign in front of the value is minus) in capacitance by 330 mmf. for every degree centigrade temperature increase. If the dot were grey, the capacitance would *increase* (since the sign in front of the value is plus) by 30 mmf. for every degree temperature increase.

By studying the drawings of the capacitor in Fig. 1D and 2, you can determine the sequence system that applies to various types of units. For example, in the six-dot molded mica codes, tolerance is always shown in gold or silver, and placing this dot in the center of the bottom row aligns the capacitor properly for reading the code. On three- and five-dot codes, an arrowhead molded around one of the dots helps alignment. On ceramic and disk capacitors, the spacing of the dots indicates proper alignment.

Color-coding is also used in a standard fashion on certain transformers. These systems are shown in Fig. 3. There are some options involved in center-tapped windings on audio and RF-IF transformers, but standards are fixed for power transformers. All power transformers do not have all of the multiple filament windings shown here, and when only one filament winding is provided (in addition to the rectifier filament) it usually follows the code applicable to filament No.

COLOR CODES FOR WIRING

Color	Circuitry*
Black	Ground leads
Brown	Filament or heater leads
Red	B-plus power leads
Orange	Screen grid leads
Yellow	Cathode leads
Green	Control grid leads
Blue	Plate leads
Violet	(Not used)
Grey	AC power leads
White	Common off-ground leads

* The codes generally refer to connections made directly to element involved; for example, lead from plate pin to plate load resistor would be Blue, but lead from other side of plate load resistor to B-plus power would be red.

1, regardless of voltage.

In universal output, and multi-tapped audio transformers, the code is sometimes not followed. While the ends of the windings may follow the code, there can be no standard system for coding taps, due to the variance in taps possible, and the various impedances that might be represented by the taps. In these cases, a manufacturer's data sheet must be used to determine the impedance or turns ratio value for each color wire.

Quite often surplus transformers, originally made on special order for certain installations, will not use a standard color code system on leads. Do not place much reliance on the colors of wires used on surplus transformers for this reason.

To keep a permanent record on non-standard coding on transformers, a label may be pasted on the side of the transformer. It there are a number of leads involved, or if the transformer face is too small to write all the necessary data on a label, make a small open-top envelope and paste it on the side of the transformer, including the data on a folded sheet in the envelope (Fig. 4). In either case, be sure to remove the wax from the side of the transformer with a solvent, so the label or envelope will stick to the surface.

While not used too frequently, color codes have been standardized for wiring. These codes provide that certain colors of wire be used for certain leads in equipment wiring. Since hook-up wire is available in small spools for all of these colors, it helps in wiring and signal tracing to follow these codes. If the color of wire is entered on the schematic when wiring is done, it is also a great help in subsequent trouble-shooting.

The codes use the same colors as the resistance and capacitor codes (with the exception of violet), as shown in Fig. 5. If the code is to be followed consistently, it is important to remember the note at the bottom of the chart.

There is another common coding system which, while not based on colors, is fairly standard and used by many manufacturers. This relates to tapers on potentiometers.

The "taper" on a potentiometer is the relationship of the change in resistance to the amount of rotation. You may have noticed that in some cases, a quarter-turn at one part of the control changes the resistance only slightly, while a quarter-turn at another part makes a great change in resistance. This would indicate that the potentiometer has a logarithmic taper, such as shown in curves B and C in Fig. 6.

Notice that even with a linear taper (Curve A in Fig. 6), rotation in the first and last 10% does not change the resistance as much as the same amount of rotation in the middle 80% of the arc. Usually a linear taper is used for miscellaneous electronic circuits, where the scale is to be calibrated in a linear measurement such as "speed," "time," "voltage," etc. Where other tapers are more desirable, specifications for the circuit usually indicate the proper taper to use.

Figure 7 is a summary chart of color codes as applied to resistors and capacitors. It will be a help in using color codes if the drawings (Figs. 1, 2, 3, 5 and 6) and this chart (Fig. 7) be cut out and posted by your test bench. Some coding, such as that for resistors and power transformers, should be memorized; but the coding on capacitors is so complex, and that on wiring and tapers so seldom used that reference can be made to the drawings and chart.

To check your understanding of these codes, try the quiz that follows. Answer the first four questions without referring to the drawings or chart, but use them for the rest of the questions. (Answers on Page 24).

* * * * * * * *

1. What are the values of resistors with the following color codes?
   a. White-red-red-silver
   b. Brown-black-yellow-silver

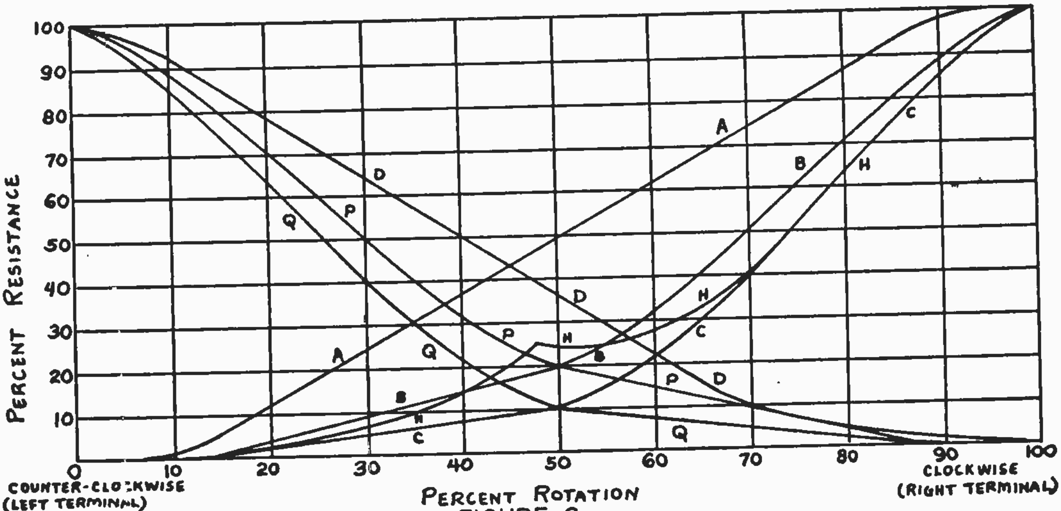


FIGURE 6

POTENTIOMETER TAPERS

A (1)—Linear, where resistance change is uniform

B (4)—Modified log (20% res. @ center)—audio volume or tone control

C (2)—Semi-log (10% res. @ center)—audio volume or tone control

D (6)—Tapered at both ends for grid bias and antenna circuit control; important where bias control is important to volume control

H (8)—Tapped log curve for tone control with bass compensation

P (5)—Reverse of B (4); used as contrast controls in television

Q (3)—Reverse of C (2); used as picture control in television

Notes: Numbers in parenthesis are sometimes used instead of letters. Taper D (6) also available in reverse.

c. Yellow-violet-orange-gold
d. Brown-black-black-silver
e. Blue-grey-red-gold

2. Give the color codes for the following resistances:
   a. 10 megohms, 10%
   b. 47 ohms, 5%
   c. .51 megohms, 10%
   d. 3300 ohms, 10%
   e. 86,000 ohms, 5%
3. You have a power transformer and want to check its voltage.
   a. What color leads do you connect to the 115-volt line?
   b. In checking the voltages, would you use a high or low ac voltage range (on the meter) with the following pairs of colored wires?
   b1—Yellow-yellow
   b2—Brown-brown
   b3—Red-red
   b4—Green-green
4. You have an audio transformer with five leads; blue, red, brown, green, and black.
   a. Which side (plate or grid) is tapped?
   b. Where does each wire go?
5. You have a small round capacitor with five colored bands on it, the one at one end being wider than the rest. The colors, starting with the wide band on the end are white, green, brown, brown, and blue.
   a. What type is this?
   b. What is its value, temperature coefficient and tolerance?
6. You have a molded mica capacitor with five dots on it. When the dot with the arrowhead around it is in the upper right corner, the dots in the top row are yellow, violet and brown, and the dots in the bottom row are red and silver (reading from left to right in each row). What is the value, voltage rating and tolerance?
7. A fairly large round cylindrical capacitor has four colored bands around it at one

Fig. 7 COLOR CODE SUMMARY

	RESISTORS			CAPACITORS								
				MMF			TOLERANCE			Extended range Temperature Coefficient Capacitors		
Color	1st & 2nd #	Multiplier	Tol.	1st & 2nd #	Multiplier	* Voltage	10 mmf. or less (mmf)	Over 10 mmf. (%)	# T.C. PPM/°C	1st #	Multiplier	Color
Black	0	1	—	0	1	—	±2.0	±20	0	.0	−1	Black
Brown	1	10	—	1	10	100	± .1	±1	−33	—	−10	Brown
Red	2	100	—	2	100	200	—	±2	−75	1.0	−100	Red
Orange	3	1,000	---	3	1,000	300	—	±2.5	−150	1.5	−1000	Orange
Yellow	4	10,000	—	4	10,000	400	—	—	−220	2.2	−10,000	Yellow
Green	5	.1 meg.	—	5	—	500	—	—	−330	3.3	+1	Green
Blue	6	1 meg.	—	6	—	600	± .5	±5	−470	4.7	+10	Blue
Violet	7	10 meg.	—	7	—	700	—	—	−750	7.5	+100	Violet
Grey	8	—	—	8	.01 MFD	800	± .25	—	+30	—	+1,000	Grey
White	9	—	—	9	.1 MFD	900	±1.0	±10	"x"	—	+10,000	White
Gold	—	—	5%	—	—	—	± 5%	± 5%	"y"	—	—	Gold
Silver	—	—	10%	—	—	—	±10%	±10%	+100	—	—	Silver

Notes

*– Where color code is shown. Where not shown, some manufacturers standardize at 1000 volts others at 500 volts.

#– Temperature coefficient in parts per million per degree centigrade temperature increase.

"x"– General purpose type.

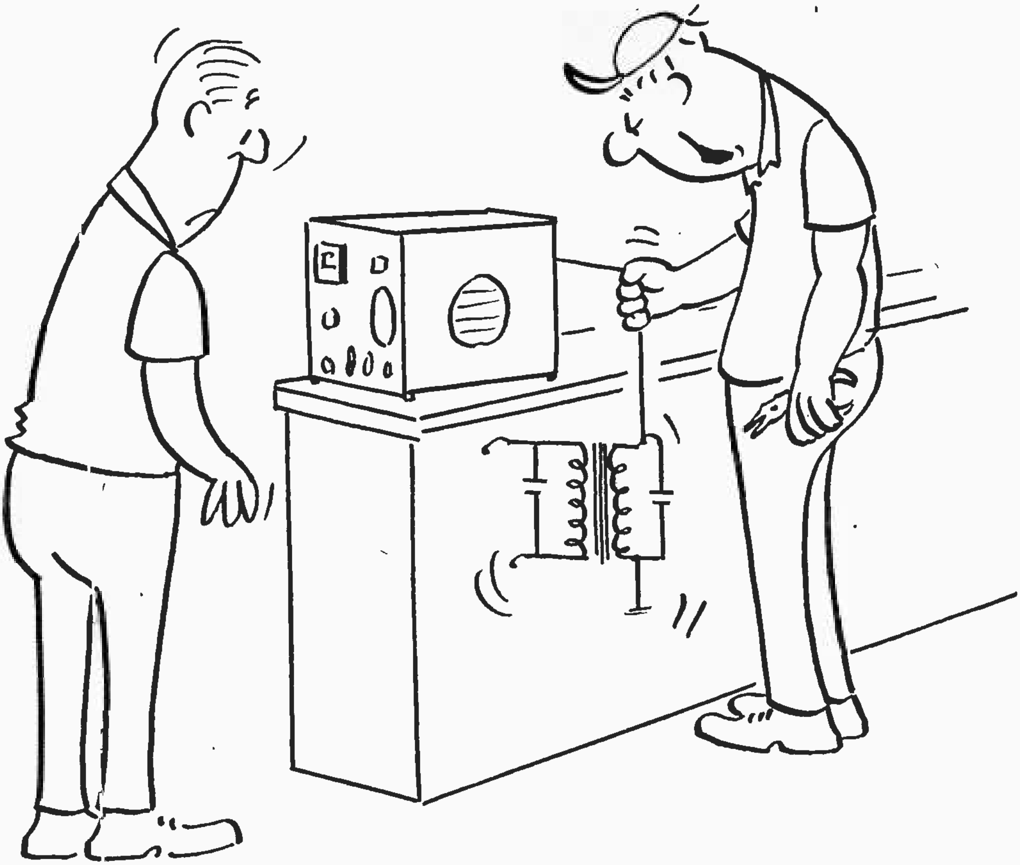
"y"– By-pass and coupling types

end, and a single band at the other end. The four bands are (reading from end to center) brown, black, green, and white. The band at the other end is yellow.

a. What type is it?
b. What is its value, voltage rating and tolerance?

Answers to Quiz

1. (a) 9200 ohm, 10% (b) 100,000 ohm (.1 meg.) 10%
(c) 47,000 ohm (47K) 5% (d) 10 ohm, 10%
(e) 6800 ohm, 10%
2. (a) Brown-black-blue-silver (b) Yellow-violet-black-gold (c) Green-brown-yellow-silver (d) Orange-orange-red-silver (e) Grey-blue-orange-gold
3. (a) Black (b1, b2 & b3) low range (b3) high range
4. (a) Plate side (b) blue; plate, red: B-plus, brown: plate, green: grid, black: ground
5. (a) Molded, insulated axial-lead ceramic (b) 510 mmf., general purpose, ±5% tolerance
6. 470 mmf., 200-volt, 10%
7. (a) Molded paper tubular (b) 10,000 mmf., (.01 mfd.) 10% tolerance, 400-volt.



"I finally got that darn transformer out, Mr. Peak."

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Working with Electronic Circuits

The techniques, tools, and hardware involved in building electronic equipment

By W. F. GEPHART

FOR best results, certain specialized techniques, tools and hardware are required when working with electronic circuits. Some of the tools and hardware to be discussed are not absolutely essential; however, they do make the job easier or the equipment better.

One of the most important techniques involved in electronic circuitry is soldering. All connections must be soldered, and soldered properly for optimum, trouble-free results. Finding an intermittent short or loose connection in a piece of electronic equipment is a hard, time consuming job, and most are due to poor soldered joints.

Soldering: Most technicians use a soldering gun, or, in the case of printed circuit work, a very small pencil iron. The soldering gun tip is fairly small, heats rapidly, and stays hot only while the trigger is pressed. This prevents excessive heating and oxidation of the tip. Tips are available in various sizes and shapes and are readily replaceable.

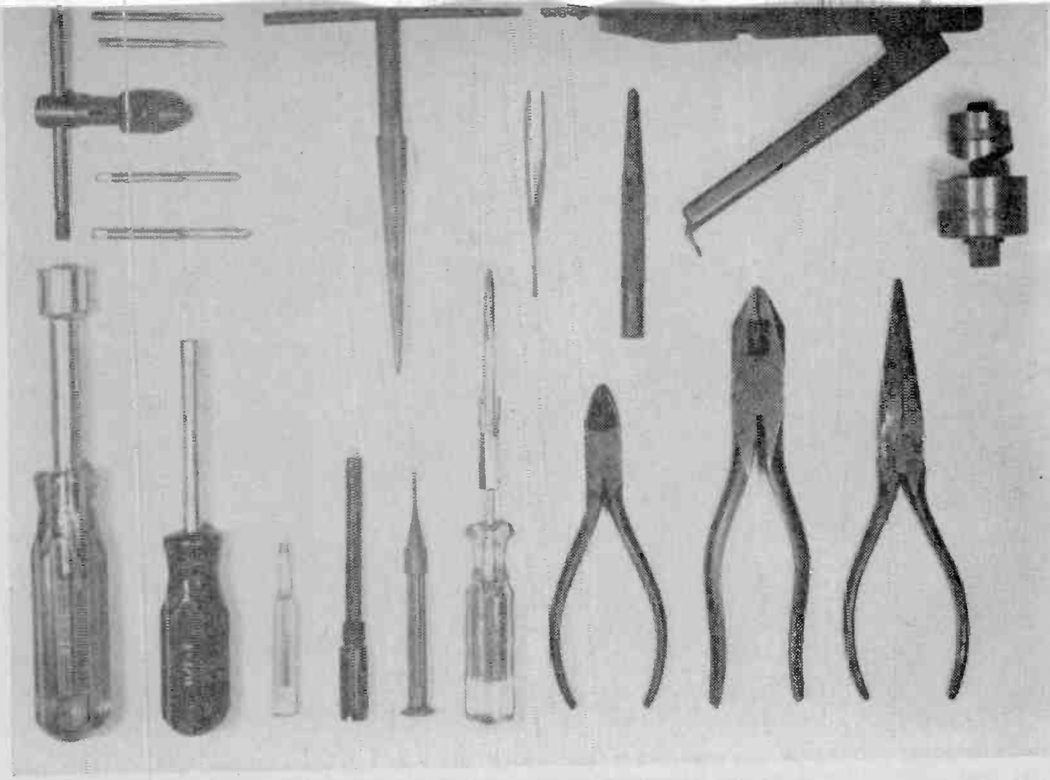
A soldering gun works on a transformer principle, with the ac line being connected to the primary. The secondary consists of a very few turns of very heavy wire, with the copper tip being connected across this secondary. Due to the very few turns involved (compared to the primary), there is a very low voltage, but very high current in this secondary. This high current flowing through the tip causes it to get hot. The high current flows through the secondary, causing it to get warm. For this reason, soldering guns are rated for cycling use. (i.e., two minutes off for each minute on, etc.)

Small soldering irons, often referred to as pencil irons, are usually of low wattage, and are used where delicate work is required. Screw-in tips for this type of iron are available in various forms, including specialized tips for de-soldering printed circuit components. Even with regular spade or diamond tips, they are extremely handy in working with transistor circuits or where space is limited.

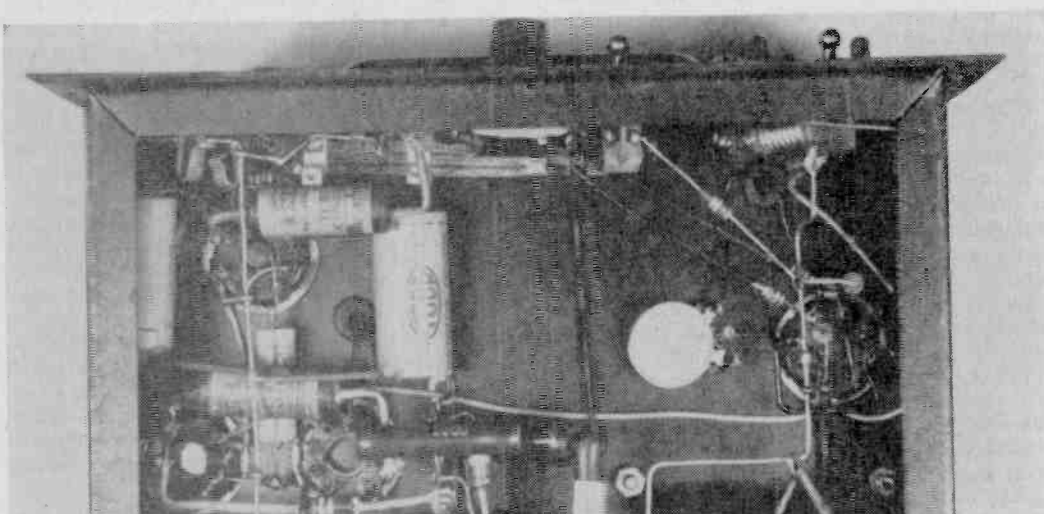
Regular irons come in different sizes, both physically and electrically. Irons designed for general use usually have tips (spade or diamond-shaped) about ⅜-in. diameter, and are rated at 75-100 watts. Heavy-duty units may have tips as large as 1-in. diameter and be rated as high as 400 watts.

A soldering gun, rated as between 100 and 200 watts, is the best general purpose soldering tool. If a lot of work is to be done with transistorized circuits, a small pencil gun is useful, and, equipped with various de-soldering tips, is essential for extensive printed circuit work. The best soldering iron for general use would be a 75-150-watt unit, but, unless a thermostatic iron holder is used, care must be taken to unplug the iron at times to keep it from getting excessively hot. Larger irons, and even propane torches are sometimes required for special work involving heavy-duty components.

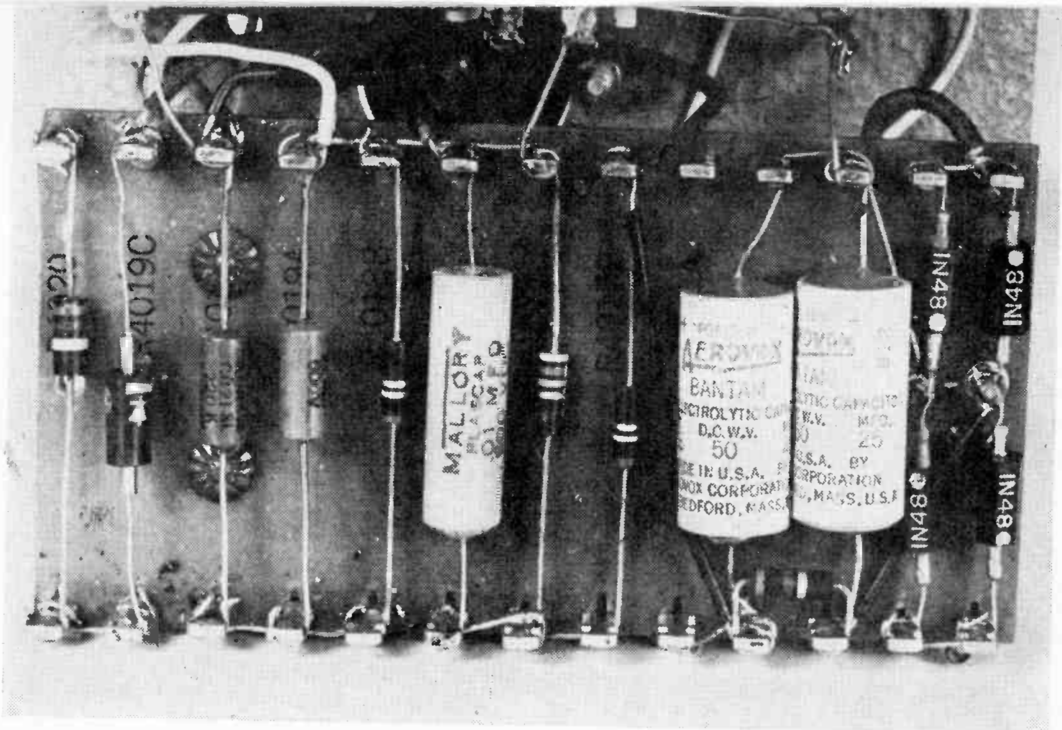
Solder comes in various mixtures of tin and antimony, and the exact mixture is usual-



METAL-WORKING TOOLS for electronics include an assortment of taps and a tap-handle, a reamer, tweezer, center punch, hand nibbler, chassis punches, nut-drivers, screwdrivers, wire cutters and pliers. Have tools on hand.



NEATLY WIRED CHASSIS may look like a rat's-nest maze to a neophyte, but notice that all wiring is neatly dressed, and squared off. No loose components to flop around here! All filament wires twisted help avoid hum.



TERMINAL BOARD MOUNTING was pioneered for the military. It's easy to make a chassis look neat this way! Wires lead to and from the board, component parts mount on the board, are easy to service or replace.

ly a matter of individual choice. It is essential that only rosin core solder be used in electronic wiring. Good joints are hard to make with plain solder, and acid core solder should not be used under any conditions.

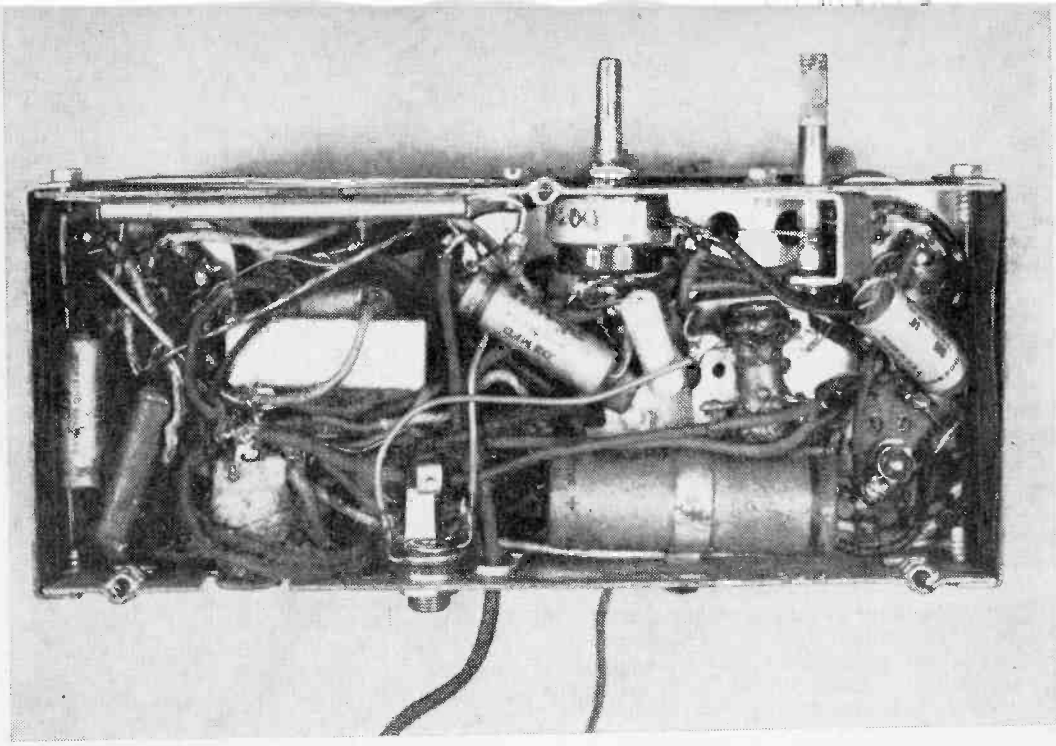
Acid core solder, or acid fluxes should never be used because of their electrolytic action. Wet batteries consist of two metals in an acid solution, and the acid residue and the metals of the connection (zinc and copper, tin and copper, etc.) made with acid core solder or flux may create a small battery. The minute voltage and current from this battery would interfere with circuit operation, and the continued action of the acid residue would corrode the metals.

The same is true, to a lesser degree, of other soldering fluxes. Most kit manufacturers specify that flux not be used, and guarantees are void if they are. The purpose of a flux is to keep the air from oxidizing the metal as it is heated during soldering, and different fluxes have different acid contents. There may be cases where it is necessary to use a flux to get a good connection with a minimum of heat. But if used, the flux should have a very low acid content and should be used sparingly.

In soldering, the joint or connection should be heated enough to permit the solder to flow readily, and then not moved until the solder has set. The most common types of poor solder joints are those where the heat was insufficient, and the solder is merely tacked on (usually in the form of globules). Another type of poor joint is where the heat is sufficient and the solder flowed, but the joint was disturbed before the solder set, and the joint cracked.

The first step to good soldering is to have the joint clean. Terminal lugs and wire should be scraped with a knife or razor blade until the metal shines. Where wires are involved, the dry joint (before the solder is applied) should be made as tight as possible, by crimping the wire. The soldering gun or iron tip should then be placed against the joint until it gets hot. Solder is then applied to the JOINT, still holding the tip against the joint. Allow the solder to flow over the joint. If a small amount is used, where the weight isn't a factor, it will tend to flow toward the heat. When the entire joint is covered with a thin coat of solder, remove the heat and the solder, taking care not to disturb the joint until the solder sets. When liquid, solder shines brightly, and glazes over or dulls when it sets.

In applying heat to the joint, be careful to prevent excessive heat from damaging components. This is particularly important in transistors, which can be ruined by excessive heat. One precaution is to limit the heat by using the proper size gun or iron, and applying it only long enough to properly melt the solder. Another is to grasp the wire leading to the component with long-nose pliers to dissipate the heat from the wire, through the



THE OTHER SIDE OF THE STORY is this cluttered hodge-podge, so typical of small, inexpensive radio sets. Costs are held down at all costs, so appearance suffers. You can bet manufacturer uses lovely plastic cabinet!

pliers, before it reaches the component.

Various types of wire are used in electronic wiring. Plastic insulated wire, either solid or stranded, is often used for general wiring, and is referred to as hook-up wire. Shielded wire, with a braided shield over a central conductor, is used for some low-level audio or RF applications, and may or may not have an insulated covering over the braid. Occasionally cable is used in wiring, and sometimes a number of wires are collected in cable form by lacing cable, or waxed string.

Wiring: Stripping the ends of wire for connection purposes consists of removing the insulation from the wires at both ends. This can be done with special stripping tools, but the more common way is to cut around the insulation (about ¼-in. from the end of the wire), and then pull the insulation off.

Stripping shielded wire requires two operations: cutting the shielding back about ⅜-in. from the end, and then preparing the inner wire as above. One way to do this (if braided, uninsulated shielding is used) is as follows: Cut the wire to the desired length, and then bunch up the shielding somewhat, by pushing each end in toward the center. Then the shielding can be slid along the wire. Slide it until one end of the shield is about 1-in. from one end of the wire. Then, holding that end of the shielding in position, smooth it out to its original length, and cut off the part that extends beyond the other end of the wire. Bunch it up again, slide it back so equal parts of wire stick out at each end, smooth it out evenly, and you'll have about ½-in. of insulated inner wire sticking out of each end of the shielding.

In stripping cable, the first step is to remove the sheath. With plastic or rubber sheaths, one way to do this is to bend the cable double at the point where the sheath is to be cut. Holding the cable in a tight bend, lightly cut through the sheath at the top of the bend. Due to the tension at the top of the bend, the sheath will split open before you cut into the insulation of the wires inside. By turning the cable, bending it double, and making cuts around the sheath, you can cut completely around the sheath without damaging the inner wires, and then pull the section of sheath off the end. If quite a bit of sheath is to be removed, a series of cuts such as this might have to be made.

In wiring, sequence is most important. It is highly desirable to have all connections to a given lug made before soldering, but in wiring procedures and spacing of components, all connections might not be made at the same time. In a kit, instructions usually tell you when to solder, and in other cases, if a pictorial diagram is available, you can readily see all of the connections that have to be made to a given point. When working from a schematic only, however, care must be taken to be sure all connections have been made to a point before soldering, and that all joints have been soldered before the job is finished.

Generally speaking, straight wiring (where only wire leads are involved) should be done first. This permits the wires to lie flat on the chassis allowing components (resistors, capacitors, etc.) to hold them in place. Furthermore, it places the most trouble free thing (wiring) at the bottom, allowing accessible space above for components that might have to be replaced later. ac filament leads (where one side is not grounded) should be twisted together to minimize hum induction into other leads or components.

Wiring appears neater if kept straight, running directly between connection points, or making right angle bends around components. It makes wiring easier to trace, but takes more time, and usually requires the use of solid, rather than stranded, hook up wire, to make them stay in the desired position.

When a number of components have to be connected to ground or chassis, a bare ground wire lead running through the chassis is helpful. This lead should then be connected to the chassis at one point. This not only simplifies connecting components to ground, but prevents the possibility of eddy through the chassis at grounding points.

All components and wiring should be securely mounted, lest movement of the unit create loose connections, or even broken wires. Each unit should be built as though it were to be placed in mobile service, as far as component mounting is concerned. If not, even moving a unit across the bench might cause enough component movement to result in a loose or broken connection.

Handling Parts: While some components (such as tube sockets, some transformers, etc.) have lugs to which components can be fastened, tie points are usually necessary. These come in a variety of forms and are bolted to the chassis (perhaps with a mounting bolt used for a component, such as transformers, etc.). The tie point lugs, most of which are insulated from the chassis, can then be used as connection points for various components and wiring.

Vector tube sockets are another means of mounting components. These are sockets with an insulated rod molded to the bottom of the socket, at the end of which are a number of mounting lugs. Small components, such as resistors and capacitors can then be mounted between the regular tube socket pin lugs and the lugs at the end of the rod. They are available for many types of sockets, in various rod lengths, depending on the size of the components and chassis depth.

All components, no matter how small, should be properly supported. You should never make a connection between a component (without a lug connection) and a wire, except at a tie point or other lug, such as on another component or grounding lug. One exception to this might be a connection between a small component and a stiff, well-mounted grounding buss wire. Many small components are small and light enough, and have stiff enough leads that soldering the leads to lugs or tie points is suitable. In large tubular capacitors, however, a mounting strap for the body of the capacitor should be used, unless the leads are particularly stiff and short.

One method of wiring, which insures excellent component mounting, is the use of terminal boards. Here, all parts are mounted between lugs on a terminal board, and the board mounted on the chassis. Wire then runs between lugs on the terminal board and and those on other terminal boards or other chassis-mounted components. Using terminal boards results in efficient, compact wiring, and ready accessibility for parts replacement.

Metal Work: In building electronic units, certain metal work is involved in chassis and panel preparation, unless kits are involved. If layouts are furnished (as in most RADIO-TV EXPERIMENTER articles), the chassis and panel can be marked by making a full-scale drawing of the layout, taping it to the chassis or panel, and then center punching all of the holes. If desired, pilot holes can be drilled through the paper layout and metal, using the drill for the smallest hole involved. Then the layout can be removed, and the various holes enlarged to the proper size.

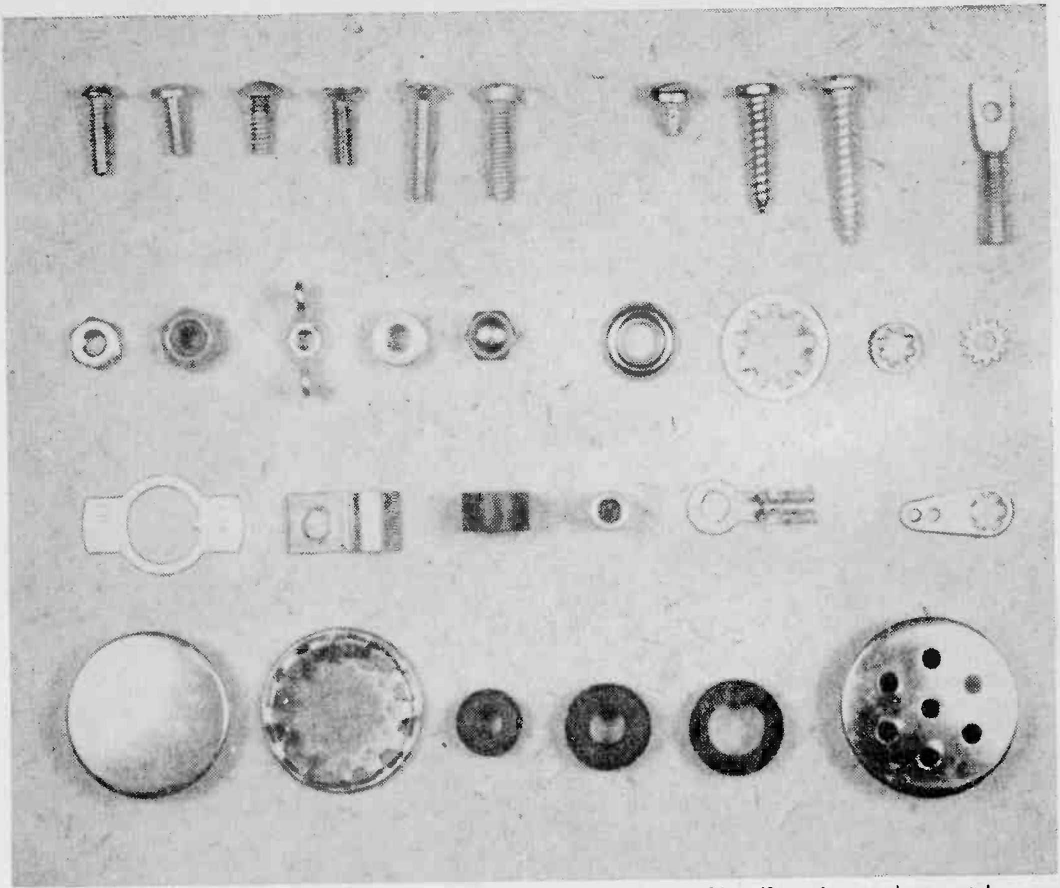
In drilling larger holes (1/8 to 1/2-in. a pilot hole should be drilled first to assure proper centering. Larger round holes (1/2-in. and up) are best made with metal screw punches, which come in various sizes from 1/2-in. up to nearly 3-in. Punches are also available for special-shaped tube socket holes, and square holes up to 1 1/2-in.

Large square holes can be made with a hacksaw or nibbling tool. In either case, the first step is to scribe the area to be cut out. If a hacksaw is to be used, a hole big enough for the hacksaw blade is drilled at each corner of the square, and then saw cuts made along the scribed lines. The corners are then squared off with the hacksaw or a file.

With the nibbling tool, a 3/8-in. hole is drilled at one corner, the tool inserted in this hole, and then the metal is cut out along the scribed lines. This tool can also be used for making slots (1/4-in. wide or larger), or cutting irregularly-shaped holes.

After the chassis and panel have been completely drilled and punched, all chassis- and panel-mounted components should be fastened in place before wiring starts. When it is known that tie points are to be used, they should also be mounted.

In some cases it is necessary to drill a hole in a chassis or panel after wiring is completed.



MORE HARDWARE YOU'LL SEE includes assorted machine screws (above left), self-tapping or sheet metal screws, spade bolts, various nuts, lockwashers, switch plates, cable clamps, solder lugs, grommets and snap-hole plugs.

This involves the danger of damage due to the blow of center punching, short circuits due to metal drilling chips getting in the wiring, and the possibility of the drill breaking through into a component or wiring. These dangers can be minimized by:

a. remove all delicate removable components, such as tubes, meters, etc.
b. Place a square of heavy adhesive tape over the point where the hole is to be drilled. Mark the center on the tape, and center-punch through the tape, using a fairly light blow.
c. Build a circular dam of putty around the center point, to catch the drilling chips.
d. Place a section of tubing around the drill, whose length will just permit the drill to penetrate the metal.
e. Drill through adhesive tape to minimize need for deeply-punched center.

Shielding is sometimes required in electronic circuits. Sometimes it is for low frequency ac (to minimize hum), and sometimes for high frequency RF (to prevent interference between circuits). If required for ac, a ferrous magnetic-type metal, such as soft iron, must be used for effective shielding. These metals are also effective for RF, but if only RF is involved, aluminum or copper may be used, the latter being the most effective.

Tube shields are usually made of steel for complete shielding, but usually coil shields are aluminum, since RF shielding is the object.

Sometimes it is desirable to shield an area in the unit from the rest of the unit. This is usually done by covering the entire area with a shield can. For most effective results, sometimes the area is shielded both above and below the chassis. Sometimes the desired result can be secured by only a partition shield between the two areas, without completely covering the area.

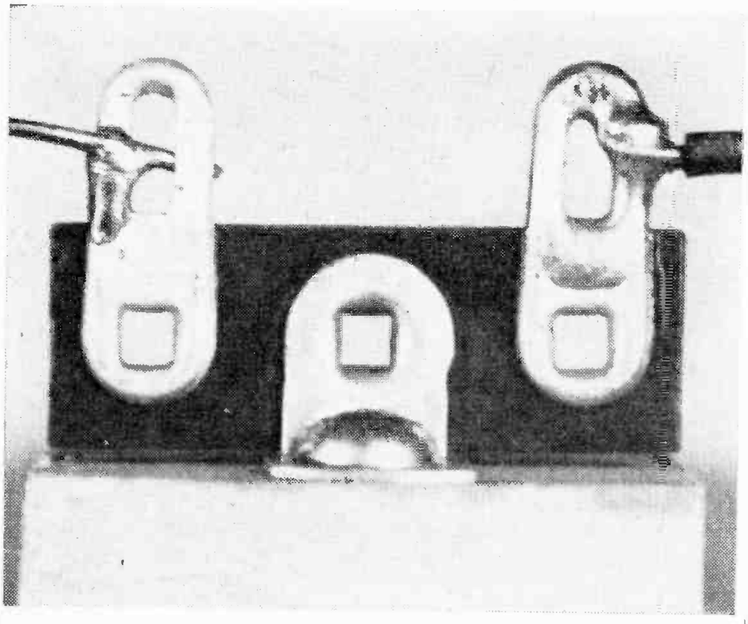
In all shielding, wires, individual components, or areas, it is essential that the shielding material be well-grounded. If low frequency ac is involved, it is important that the chassis, as well as the shielding material, be

SOLDERING TOOLS are very important. The three most commonly used varieties are in the photo at left. The soldering gun, the standard iron and pencil iron.

steel. Proper grounding not only involves bolting the shielding material to the chassis, but a soldered wire braid connection between the two.

Electronic Hardware: Certain specialized hardware is used in electronic units. Machine screws and nuts are often used in assembly, varying from the small 2-56 size up to 12-24 size. For fastening parts to a chassis, round head, truss head or binding head screws are usually used. For panel mounted parts, these may be used, or sometimes countersunk flat head, or oval head screws with cup washers are used. The spade bolt, which comes in several styles, is convenient for mounting terminal boards or shielding sections or cans to a chassis.

Lock washers, or self locking nuts should be used with machine screws, and care should be taken to be sure that the washer is small



GOOD AND BAD soldering techniques illustrated. Wire at left is simply poked through and tacked. Wire at right is first made mechanically sound, soldered.

enough to permit the teeth to press against the nut if regular nuts are used. Both internal and external lock washers are used, and some are large enough for use with controls and switches.

As well as regular hex nuts and self locking nuts, wing nuts and binding post nuts are used where frequent loosening is required. Cap nuts are used where appearance is important, as on panels.

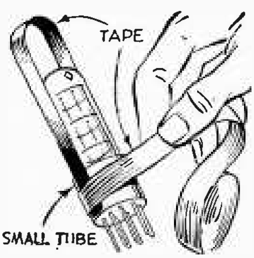
Wherever wires go through holes in chassis or panels, rubber grommets should be used to protect the insulation from the sharp edges of the hole. Hole plugs can be used to cover access holes (for seldom used controls), or even to plug mistakes. Other items of specialized hardware include spacers (both metal and fiber), lugs, cable clamps, switch and control plates, etc.

In addition to soldering equipment, certain specialized tools are required for electronic work. Some are essential, others merely helpful. Below is a list of tools for an electronic shop, including comments about certain specialized types:

Utility screwdriver (1/8- to 3/16-in. blade width)
Screw-holding screwdriver, with 1/8-in. blade (for starting and holding screws in those hard-to-reach places)
Screw-holding screwdriver, with 1/4-in. blade
Thin 3/32-in. blade screwdriver (for knobs and other set screws)
Jeweler's screwdriver (for extremely small screws)
Phillips screwdrivers #0, #1, and #2
Diagonal wire cutters
Side cutter pliers
Longnose pliers
Needlenose pliers (for holding wires, etc., where space is very limited)
Tweezers (for picking up objects in cramped quarters)
Socket wrench assortment (for holding, tightening, or loosening hex nuts and screws)
Hole punches (1/2-in. for switch mounting holes, 5/8-in. for 7-pin sockets, 3/4-in. for 9-pin sockets, 1 3/16-in. for octal sockets, etc.)
Taper hand reamer (to enlarge round holes to odd sizes)
Nibbling tool (to cut square holes and slots)
Taps and tap wrench (4-36, 6-32, 8-32, 10-24; to thread holes in metal)
Jeweler's files (small set, to enlarge small holes, cut small slots or irregular holes)
High speed drills; 1/16 to 1/4-in. by 64ths, and 5/16, 3/8 and 1/2-in. (High speed give longer service and cleaner holes than carbon drills)
Center punch
Alignment tools (assortment, to permit adjustments with minimum body or metallic effect on the circuit)

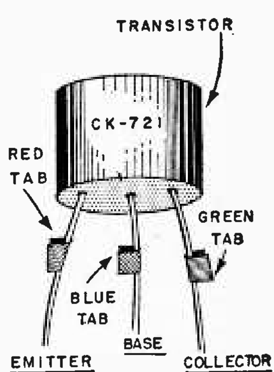
By having the proper tools, and by using the proper techniques with electronic circuits, you can get a neater, better working, trouble free piece of equipment. It takes very little more time and expense to build it right; but it might save untold time, trouble and frustration later.

Tape Tube Handle



• Pulling miniature and sub-miniature tubes from their sockets in crowded electronics hookups will be much easier if you provide each tube with a handle. Use a strip of masking or *Mystik* tape looped over the top of the tube and secured around the bottom with another strip of tape. Don't use tape on tubes that heat up excessively, because of the possible danger of fire due to tape igniting. *Never* use plastic tape for this purpose as it ignites easily.

Color-Code Transistor Leads



• Accidentally connecting the leads of a transistor to the wrong terminals in a circuit may ruin it. Prevent this costly mistake by color-coding each wire lead with a small tab of colored plastic gift-wrapping tape. Use red (hot) tape for the emitter, blue for the base, and green (cold) for the collector.— J. A. C.

Reading

Confused by schematic diagrams? Well, it's no wonder because you can't tell all the players without a scorecard! The schematic diagram helps find your way through the circuit

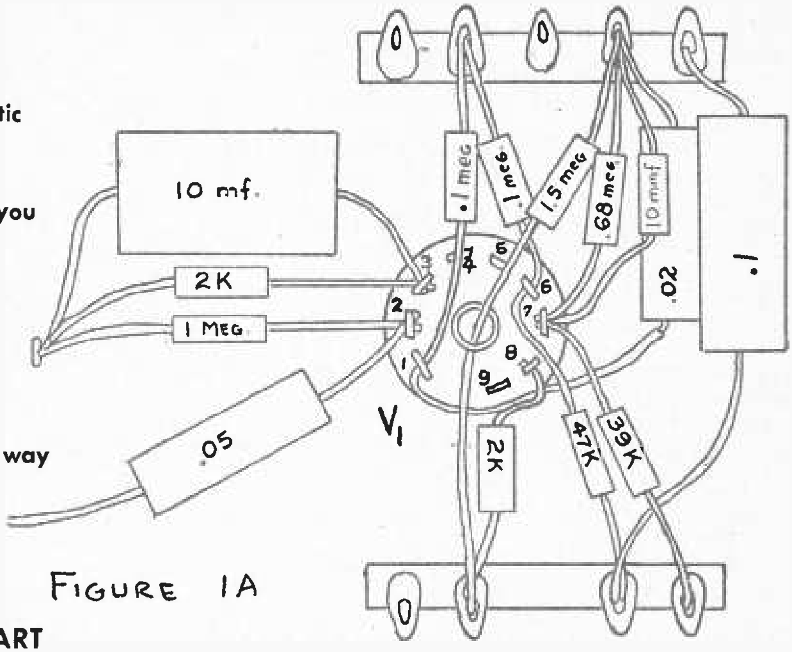


FIGURE 1A

By W. F. GEPHART

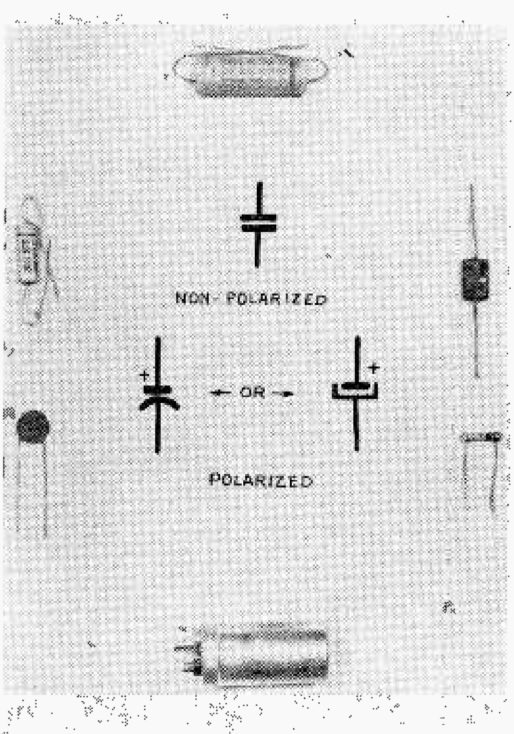


Fig. 2: Fixed capacitors are shown in photo above with the schematic representation most often used.

TO MOST people, an electronic circuit shown in schematic diagram form is a meaningless mess of lines and mysterious symbols. In reality, it is the simplest means of showing the circuitry, and the best way of being able to understand the circuit. Pictorial wiring diagrams are a great help in building electronic equipment, but of little help in trouble-shooting or understanding circuit operation.

In Pictorial Diagrams, parts and wires are shown where they are actually located, without any reference to circuit path. In construction, parts and wiring are placed by physical necessity, with signal paths as a second consideration. After construction, a pictorial diagram is worthless, since it is merely a drawing of the equipment that has been built.

Figure 1A shows the pictorial representation, and Fig. 1B the schematic representation of the same circuit. The pictorial diagram shows the placement of parts, and (where resistance and capacitance values are shown) helps identify parts. It is a great help when building the unit. But it doesn't show what type of circuit is involved, where the input and output are, etc.

In the schematic representation (Fig. 1B), you can't tell where the parts are physically located, but you can tell it is a two-stage audio amplifier, using a dual triode. It also shows where input and B+ voltages are applied,

Schematic Diagrams

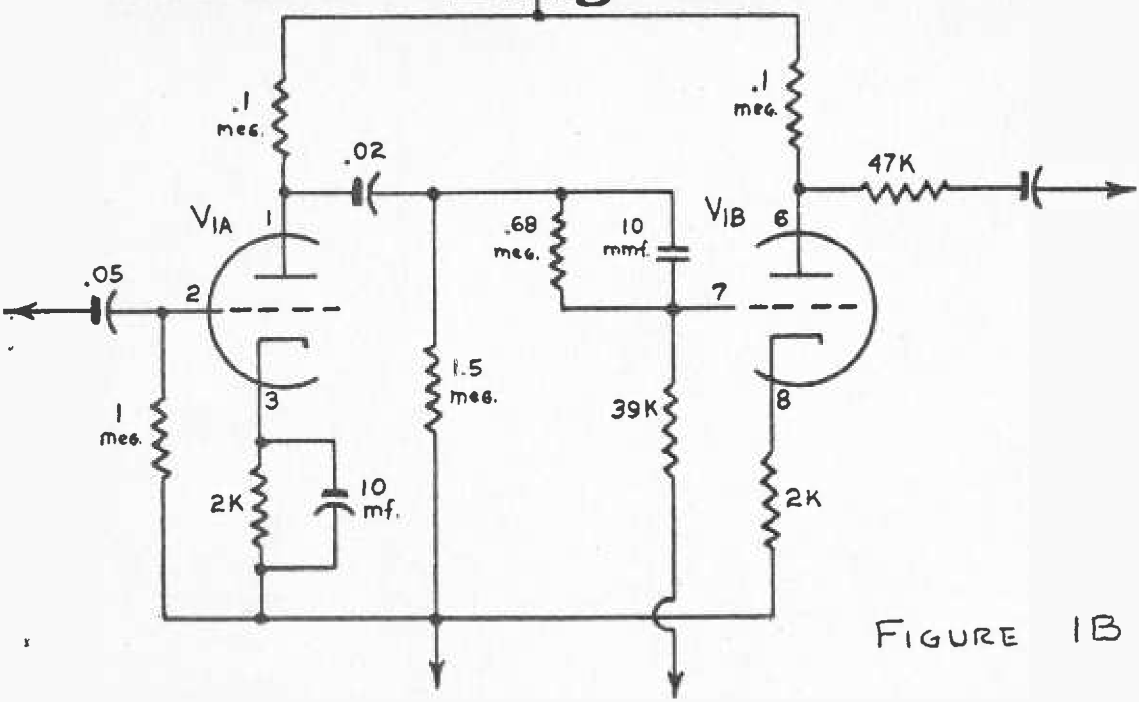


FIGURE 1B

and where output is secured.

Suppose, in a case of trouble with a kit-built unit (built with instructions and pictorial diagrams) you find a lack of voltage on a certain tube pin. Without a knowledge of symbols and schematic diagrams, the next step would be to laboriously trace out a lot of wiring, and check a lot of parts. But, with a knowledge of symbols and the ability to read a schematic, you can, at a glance, tell:

a. Where the voltage is supposed to come from,
b. What tube element the tube pin represents,
c. What parts are between the tube pin and voltage source.

Schematic diagrams are usually drawn in an organized fashion. Usually the signal input is in the upper left-hand corner, with the output in the upper right-hand part, so the signal path reads left-to-right across the diagram. Power supplies and auxiliary circuits are usually shown at the bottom, with the battery (or ac input) at one edge of the diagram (lower left, bottom, or lower right).

Before looking at any schematics, let's look at the symbols used. Figs. 2 through 15 show a number of common symbols, and in some cases, pictures of typical parts that the symbol represents. Notice that, for several parts, there are several acceptable type of symbols.

With fixed capacitors (Fig. 2), polarity sometimes is not shown, even though the

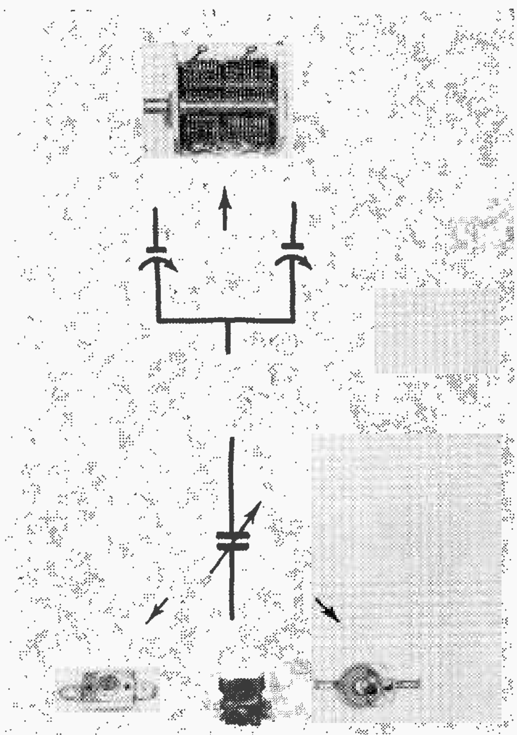


Fig. 3: Variable capacitors are sometimes multi-gang as at top, sometimes are trimmers, or padders shown below.

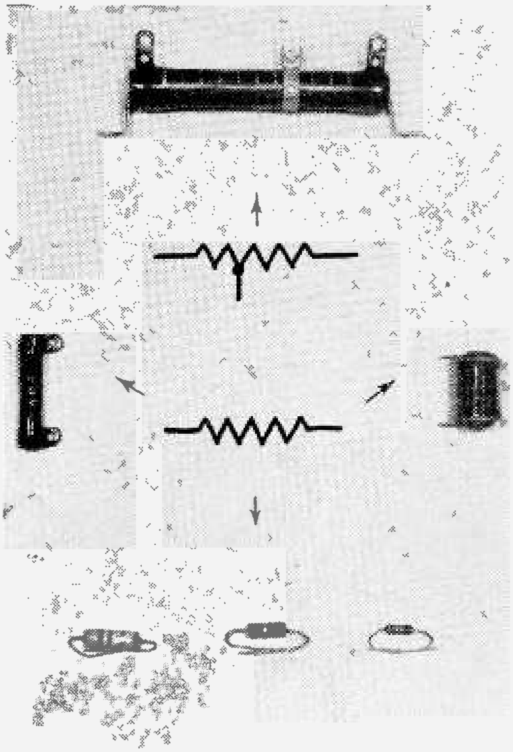


Fig. 4: These are all fixed resistors, even the adjustable at top is considered as fixed for most applications.

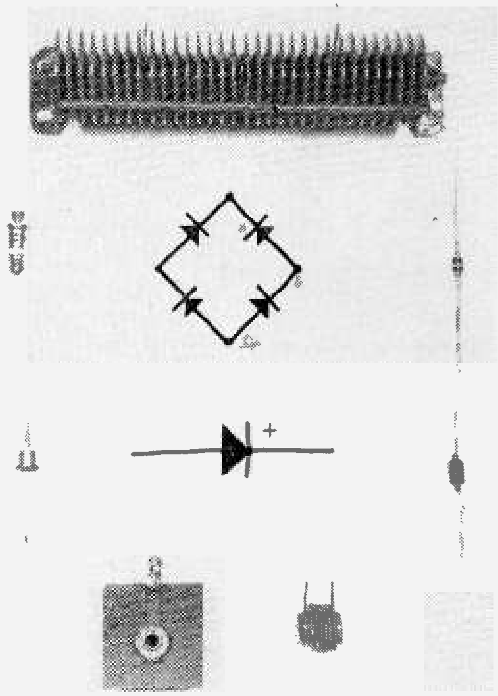


Fig. 6: Rectifiers are bridge-type (top) or single unit. Known by material i.e., selenium, silicon, germanium.

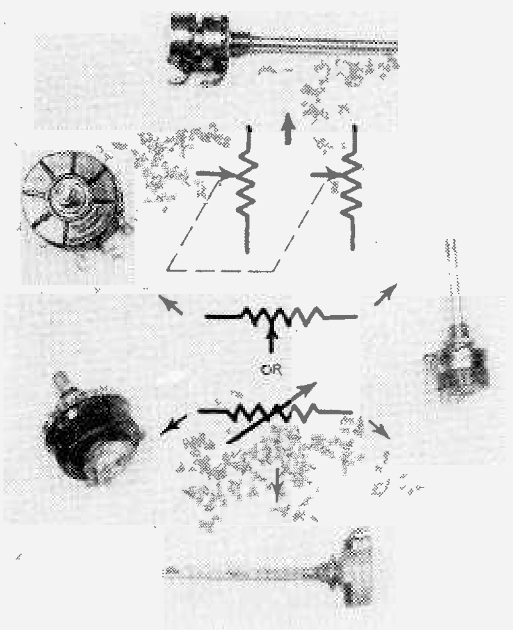


Fig. 5: Variable resistors include numerous types, many with different names, such as potentiometers, rheostats.

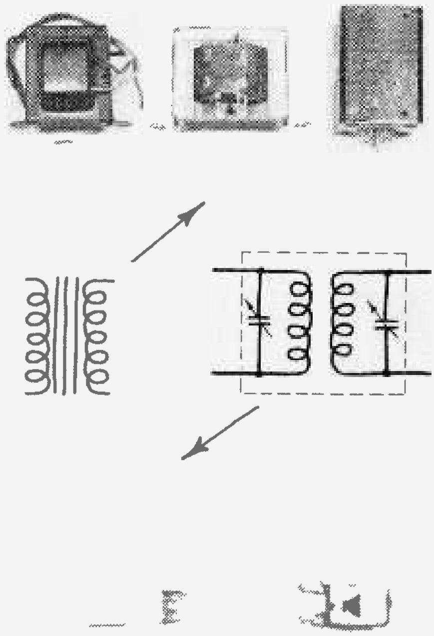


Fig. 7: Transformers diagrammed. Lines through center indicate iron core, others are air-core for RF.

polarized symbol is used. When the polarized symbol is used without a sign, the curved or angled plate is negative. When the upper symbol is used, the polarity is not important, and most capacitors represented by this symbol do not have polarity marked on them.

With varaible resistors (Fig. 5), the bottom symbol is usually used in connection with rheostats, where only two connections are involved.

The symbol (and unit) at the top of Fig. 6 is a bridge rectifier, which is actually four single rectifiers built and connected together. It is readily recognizable by having four connections. Units with two connections are single rectifiers, and occasionally you'll find one with three connections. This is a dual unit, with a common cathode connection.

Radio frequency transformers (Fig. 7) sometimes have powdered iron cores, which is indicated by dashed lines in the coil windings of the symbol. Sometimes the transformers are tuned by moving this core. In these cases, a small arrow is shown above the coil winding, and the capacitors (if used) are fixed type instead of trimmers.

There are two basic symbols for rotary switches (Fig. 9). Either may be used for multi-gang switches, and when the "pictorial wafer" symbol (lower left) is used for multi-gang switches, they are usually not tied together with a dashed line (as in the top symbol), but indicated by "A," "B," "C," etc.

In Fig. 10, the bottom symbol represents leaf-type switches and push-buttons, and the arrow indicates the direction of movement. The symbols at the top may be used for toggle switches, micro-switches, regular push-buttons, etc.

Battery symbols (Fig. 12) are used with considerable variance. Usually the single symbol (at top) indicates a single cell (1.2 or 1.4 volts). For higher voltages, sometimes individual cells are not shown (as in lower left), and the exact voltage noted, either by the symbol or in a parts list. In other cases, a number of cells is shown (lower right), but the number of cells do not necessarily indicate the exact voltage.

The jacks shown in Fig. 13 represents only two possibilities. Jacks, like leaf-type switches and relays, come in a wide variety of contact arrangements.

The tube symbols (Fig. 15) show only some typical examples. All of these involve heater-cathode tubes, but in battery-type tubes, with dc on the filaments, cathodes are not involved. In addition to the types shown, there are many other combinations of multipurpose dual and triple tubes. The basic symbol principles apply to all combinations.

Now let's look at a simple schematic (Fig.

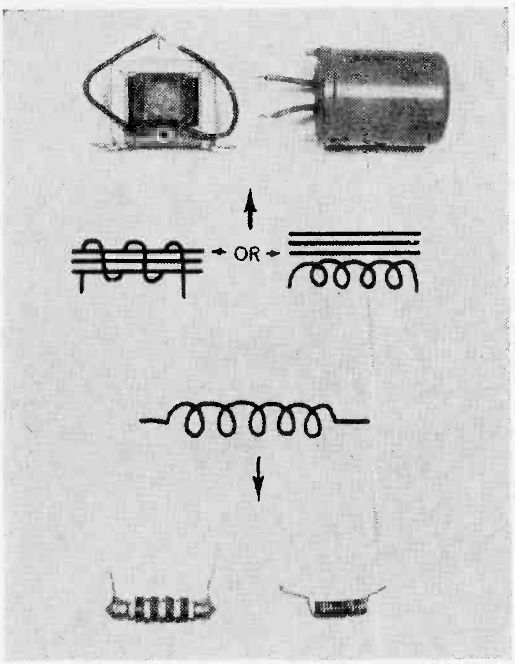


Fig. 8: Choke symbols closely follow transformer types. Simple wire helix can serve as air core transformer too!

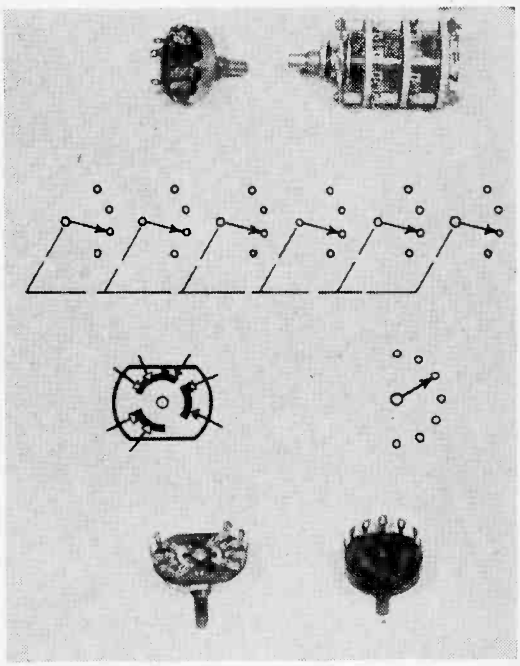


Fig. 9: Various rotary switches are usually shown by breaking out the circuit functions the sections perform.

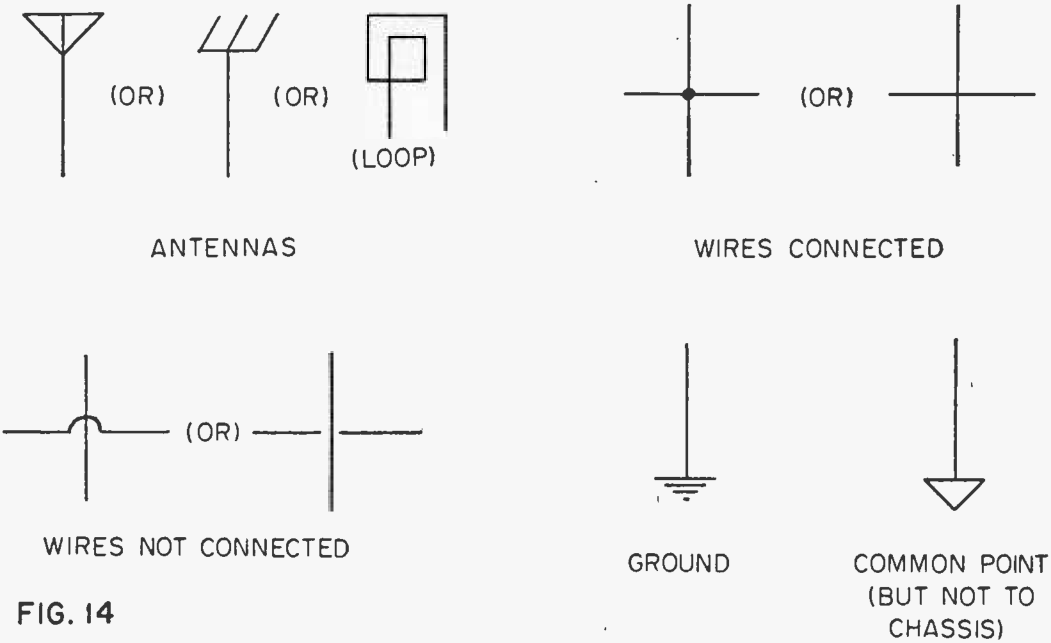


FIG. 14

16). This is a three-stage battery amplifier circuit, using pentode tubes. The input (a jack) is on the left, and the output (speaker) is on the right. This diagram uses symbols for transformers, two types of resistors, two types of condensers, two types of batteries, and a switch.

The arrows show how easy it is to trace signal paths through a schematic diagram. One side of the incoming signal is grounded, and goes through ground to one side of the output. The other side of the input goes

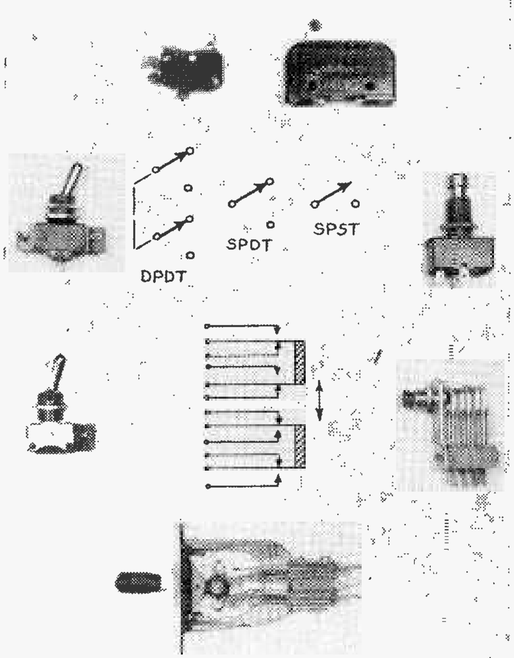


Fig. 10: Various laver and toggle switches. Cross-hatched actuator section indicates insulating material.

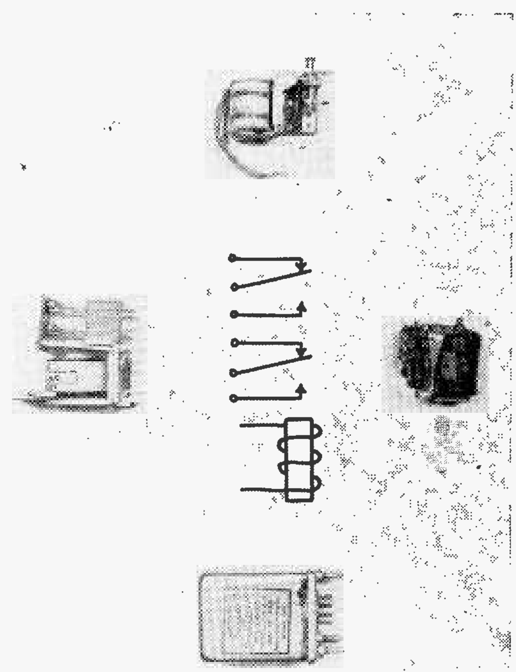


Fig. 11: Relays are drawn by separating the coil which is actuated by different voltages from the contact.

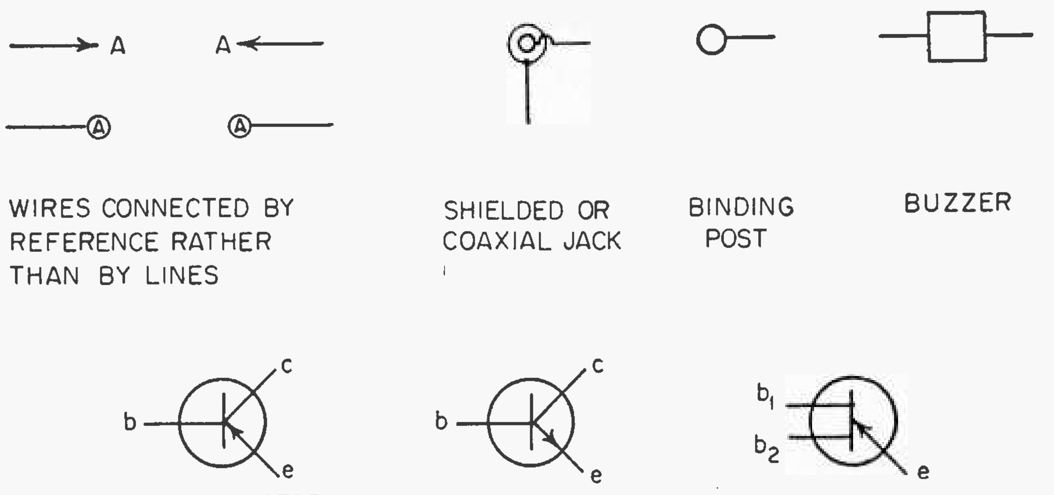


FIG. 14 (cont.)

through the input transformer, from grid to plate of the first tube, through a coupling capacitor to grid of the second tube, etc., as shown by the arrows.

In this case, the plate voltage battery symbol uses a two cells separated by a dashed line and shows the voltage by the symbol. In some schematics, actual values of all parts are shown by the symbol; in others, the part is given a code (such as R_2, C_7, etc.) which is shown by the symbol, and then a parts list gives the value for each code designation.

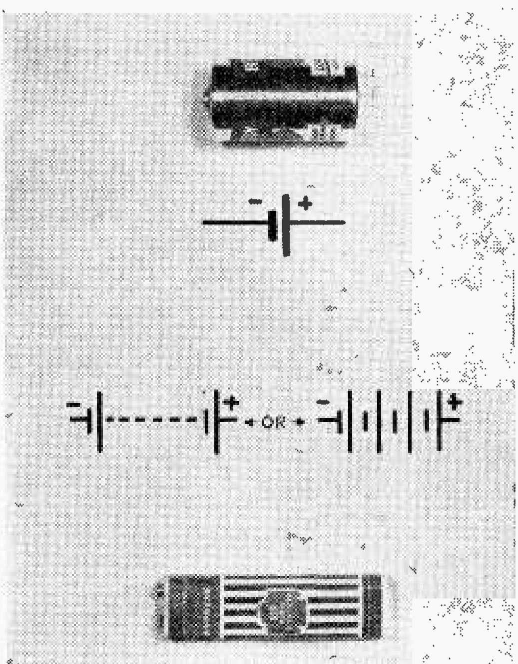


Fig. 12: A battery is a group of cells. Therefore, if you simply draw a group of cells, you have drawn a battery.

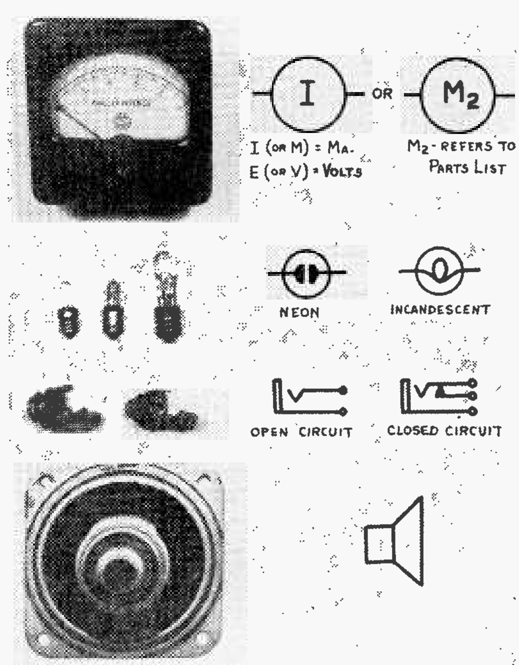


Fig. 13: Meters, pilot lamps, jacks and speaker are almost graphic or pictorial representations of the units depicted.

Suppose you wanted to make some voltage measurements on this equipment, between ground and certain points. A quick glance at the schematic will tell you when to use a 1.5-volt meter range, and when to use a 90-volt range.

Most circuits are broken down into stages, or sections. Due to the organization of a schematic, it is easy to visualize each separate section. The dashed lines in Fig. 16 show this circuit broken down into four stages or sections. Sometimes schematics will include dashed lines, showing this sort of breakdown. In more complicated equipment, such as TV receivers, oscilloscopes, etc., the lines will include several tubes in one section, but the enclosed area will be a single function (such as video amplifier, horizontal sweep, etc.) and will usually be labeled.

These enclosures are an aid to trouble-

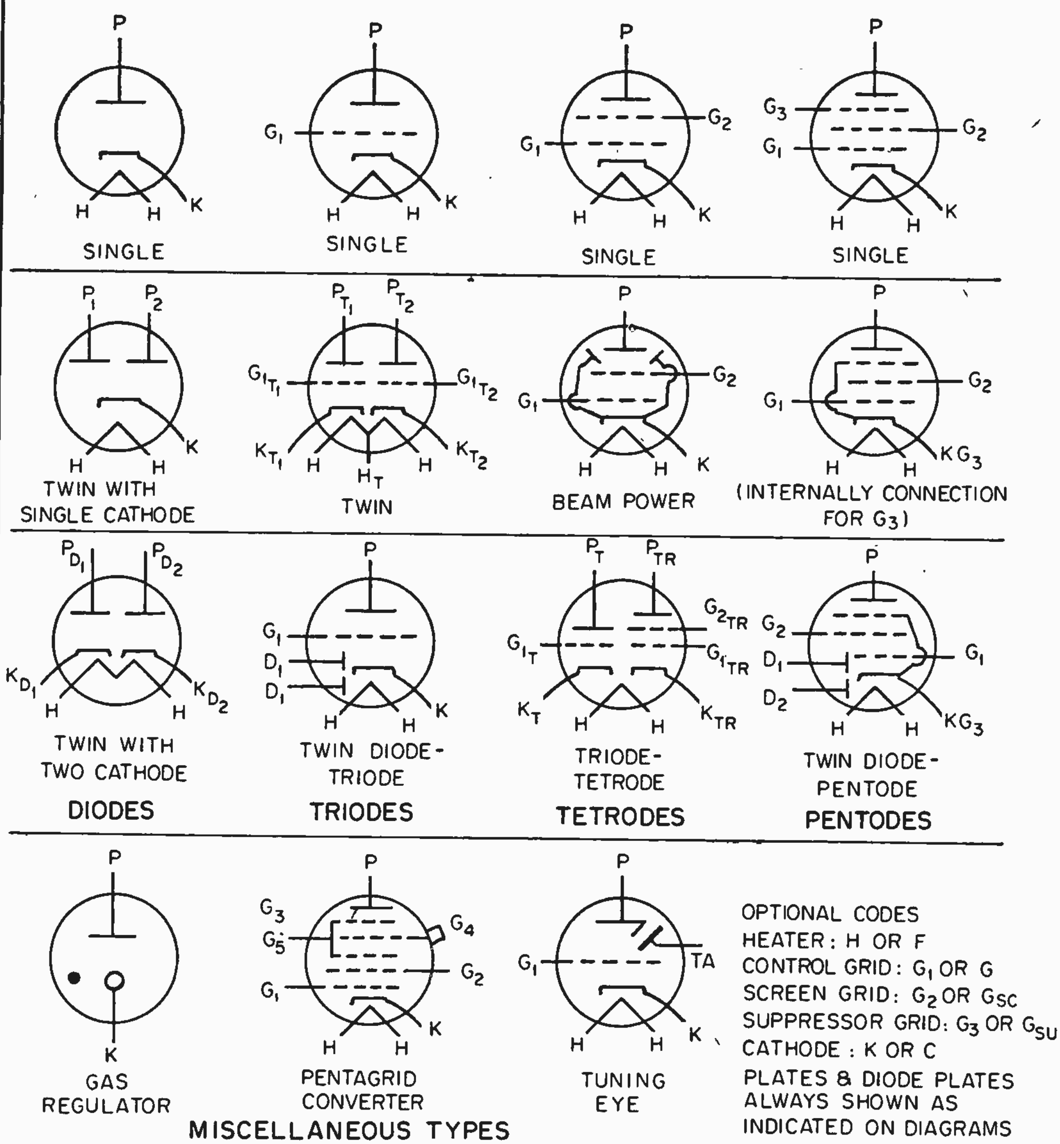


FIG. 15

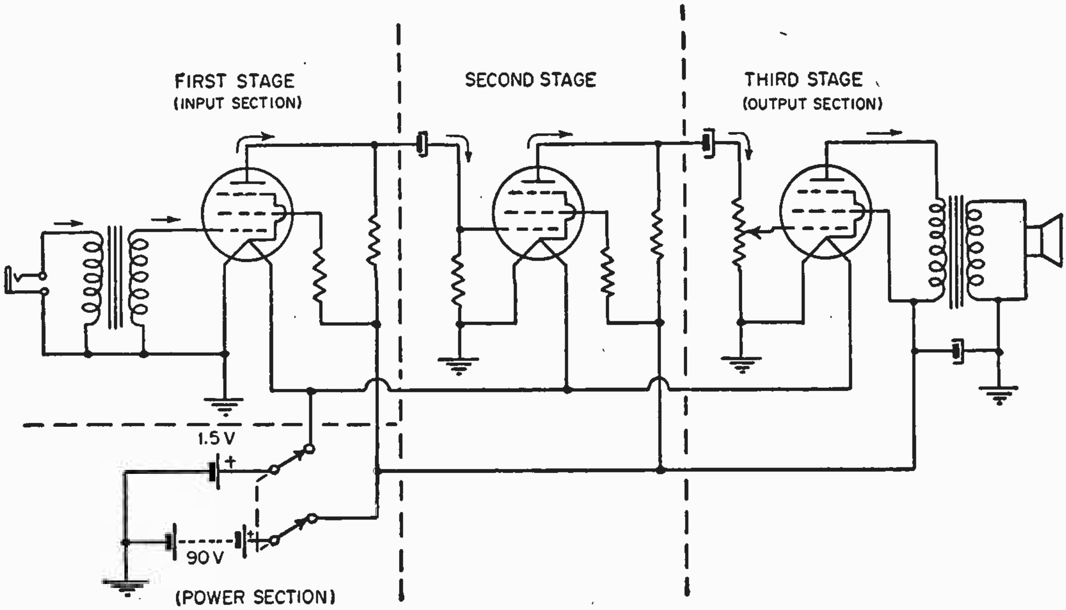


FIG. 16

shooting when using a schematic. For example, if you have no sound in a TV set, the enclosed areas on the schematic such as "Sound IF," "Sound Limiter," "Sound Output," etc., will tip you off where to start looking for the trouble.

Now let's look at a schematic which, even though it has fewer tubes, is a little more complicated (Fig. 17). Again the input is on the left, output on the right, and power supply at the bottom. Here, since higher voltages are involved, polarity is shown for many capacitors, both by the nature of the symbol and by signs. Here the parts have code numbers where the exact value would be shown on a separate parts list, and the tube pins are

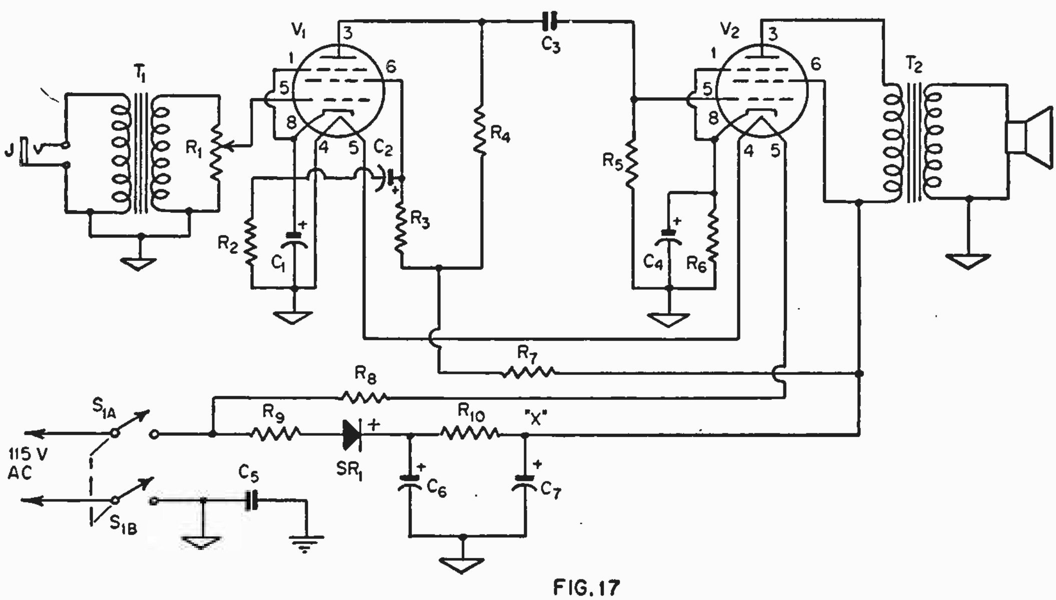


FIG. 17

numbered. Notice too, that since this unit is connected directly to the ac power line that there is a common lead that is not connected to the chassis.

Looking at this schematic, ask yourself what tube pins will have high voltage dc on them? Which will have ac on them? Which will have virtually no voltage on them?

If point "X" is +150 volts dc to the common lead, there should be relatively high dc voltage on Pin 6 of V_1. But suppose this pin shows no voltage? Isn't it easy to tell from the schematic what resistors might be open, or what capacitors might be shorted out?

Schematic Diagrams on complicated equipment such as TV sets, communications receivers, etc., may appear confusing at first glance, but understanding and reading them can be simple if you keep three things in mind:

a. Know your symbols
b. Remember the usual organization; input (antenna, microphone, etc.) on the left, output (speaker, relay, meter, etc.) on the right, with supplementary circuitry below.
c. Look at the circuit by stages, or sections

To check yourself on your knowledge of schematic diagrams, try the following quiz (Answers on Page 45).

1. Refer to Fig. 18. Without referring to previous figures, identify all of the numbered symbols.
2. A functional section or stage of a schematic diagram only includes one tube or transistor (True) (False).
3. Which type of drawing, schematic or pictorial, is most useful in:
   a. Trouble-shooting
   b. Construction
   c. Signal Tracing
   d. Circuit Understanding
4. In schematics, all connections between points are represented by a line (True) (False)
5. In schematics, inputs are always on the left with outputs always on the right (True) (False)

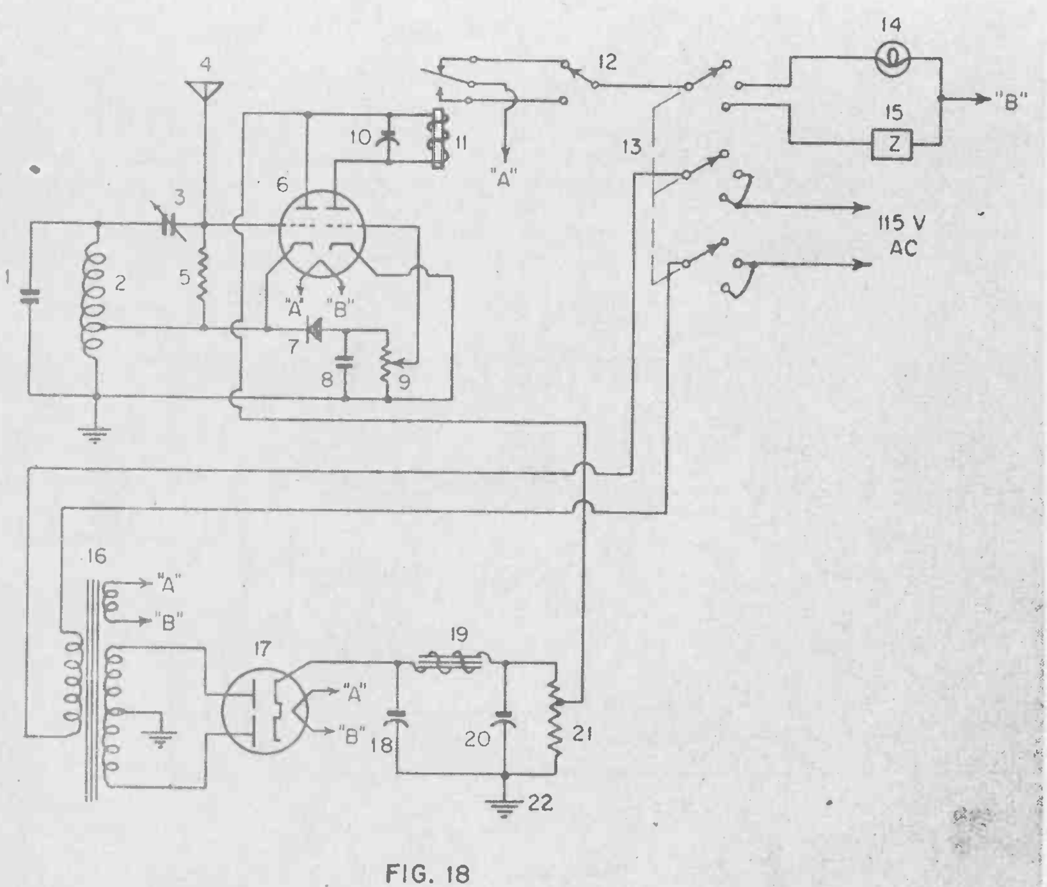
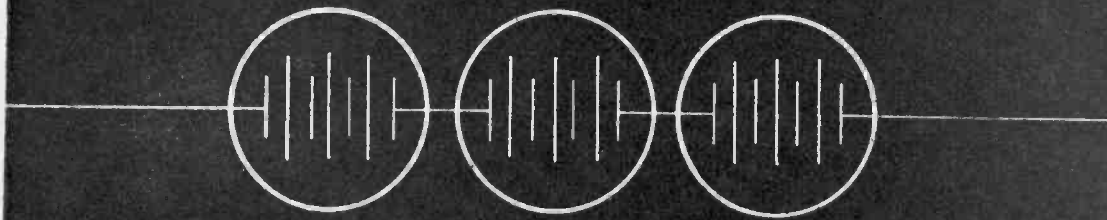


FIG. 18

Answers to Quiz

1. Symbol representations are:
 1—Non-polarized fixed capacitor
 2—Tapped coil
 3—Trimmer condenser
 4—Antenna
 5—Fixed resistor
 6—Dual triode tube
 7—Solid-state rectifier
 8—Non-polarized fixed capacitor
 9—Potentiometer
 10—Polarized capacitor
 11—Relay
 12—SPDT switch
 13—3-pole, 3-pos. rotary switch
 14—Incandescent pilot light
 15—Buzzer
 16—Power transformer
 17—Duo-diode tube
 18—Polarized capacitor
 19—Iron-core capacitor
 20—Polarized capacitor
 21—Tapped fixed resistor
 22—Ground
2. False. Often dual-purpose tubes, or several tubes or transistors may be included in one stage or section, such as a push-pull audio output stage.
3. (a) Schematic (b) Pictorial (c) Schematic (d) Schematic.
4. False. Sometimes leads stop with a code letter, and pick up elsewhere in the diagram with the same code letter. (See "A" and "B" in Fig. 18.) This minimizes the lines required in the schematic and makes it simpler.
5. Neither. *Usually* inputs are on the left and outputs on the right. In some cases, where there are multiple inputs or outputs, or mixing of signals is involved, etc., this usual procedure may be varied.

"I was watching the parade, then they started showing those darn elephants."



BATTERIES: THE INSIDE STORY

The more new and different portable electronic devices that man invents require new and different sources of energy. As a result, there are new batteries being used today in greater quantities than before. Here's a rundown on how they operate.

By JOHN POTTER SHIELDS

THE invention of the first electrochemical battery, or more correctly "cell," is credited to the Italian physicist Allesandro Volta. Volta noticed that an electric current would flow between copper and zinc electrodes immersed in acetic acid. From this crude beginning, the chemical "battery" has evolved to a highly developed state, although the basic electrochemical principles demonstrated in Volta's original cell still form the basis for present-day cells.

The first relatively practical electrochemical cell was developed by a Frenchman by the name of George Leclanché in 1868. Leclanché substituted a carbon rod for the copper positive electrode originally used by Volta, and an electrolyte consisting of ammonium chloride in place of the acetic acid. A "depolarizer" consisting of manganese dioxide (MNO_2) was placed around the positive carbon electrode.

The first "dry cell" was produced by Dr. Gassner in 1888. This unit consisted of a zinc container which also served as the cell's negative electrode. A central carbon electrode formed the positive electrode and the electrolyte was absorbed in a porous container . . . the complete cell being sealed off at the top. This cell formed the prototype of our modern dry cell battery industry. The internal construction of a modern dry cell is shown in Fig. 1.

To get a good understanding of just how electricity is produced from chemical action, let's go back to Volta's original zinc-copper cell, although this time, substituting dilute sulphuric acid for his original acetic acid electrolyte. Let's take a look at Fig. 2. Here we see two strips of metal, one of copper and the other zinc, immersed in a dilute sulphuric acid solution (electrolyte).

The following is the action that takes place between the sulphuric acid (H_2SO_4) and the zinc strip (ZN). In going into solution, the sulphuric acid breaks down into its constituent atoms. It's SO_4 molecules accept electrons from the H_2 atoms, with the result that the sulphate molecules become *negatively charged* sulphate ions and the hydrogen atoms become *positively charged* ions. Remember, a deficiency of electrons results in a positive ion while a surplus of electrons produces a negative ion.

The presence of the zinc strip in the electrolyte causes an immediate reaction between it and the electrolyte to take place. Zinc atoms enter the electrolyte; these atoms readily releasing free electrons from their valance rings which are deposited on the zinc electrode. The resulting positive zinc ions go into the electrolyte, leaving the zinc electrode with a negative charge due to its surplus of free electrons. After a short while, a point is reached where no more ions can go into the electrolyte as they are attracted back to the zinc electrode by virtue of its acquired negative charge. Thus, a state of equilibrium is reached, and no further chemical action takes place between the zinc strip and sulphuric acid electrolyte.

The chemical action between the copper strip and electrolyte is essentially the same as with the zinc strip, although not intense. As a result, while the copper electrode does develop a negative charge, it is not as great as that developed on the zinc electrode. Since the copper electrode is thus "less negative" than the zinc electrode, a *potential difference* will be developed between the copper and zinc electrodes. This potential difference amounts to 1.1 volts. This is the open circuit voltage for this type of cell.

Now, let's see what happens when we connect an electrical conductor between the zinc and copper electrodes as illustrated in Fig. 2. The surplus of electrons acquired by the zinc electrode flow through the conductor to the less negative (positive) copper electrode. As this occurs, more zinc dissolves into the electrolyte; additional positive zinc ions are introduced into the electrolyte, driving hydrogen ions over to the less negative copper electrode. Each hydrogen ion reaching the copper electrode combines with an electron

CROSS SECTION VIEW OF "EVEREADY" No. 6 DRY CELL

Fig. 1

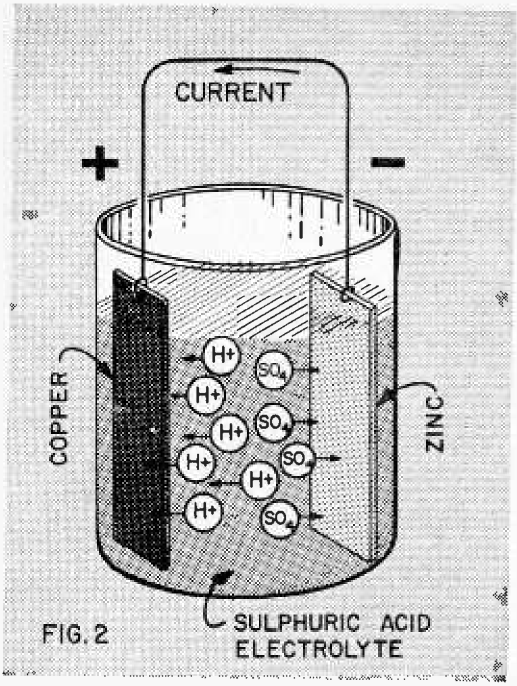


FIG. 2

reaching the copper electrode via the conductor. This reaction causes hydrogen gas to be developed at the copper electrode until the electrode becomes completely covered with hydrogen. This effect is known as *polarization*. When polarization occurs, no copper is presented to the electrolyte; chemical action stopping, and the cell ceases to deliver current. In present-day cells, the problem of polarization is largely eliminated by the use of *depolarizers* which convert the hydrogen gas into water.

The Modern Dry Cell: Earlier, we mentioned that Dr. Gassner had developed the dry cell to the point as we now know it.

Figure 3 is the "cut away" sketch of an Eveready flashlight cell which is typical of the hundreds of thousands of such units now in service. The zinc container serves as the cell's negative electrode, with a central carbon rod forming the positive terminal. The cell's electrolyte consists of a paste of ammonium chloride and manganese dioxides, the latter serving to take up hydrogen gas developed at the positive electrode during operation of the cell. The cell is sealed at the top to prevent leakage, or drying out, of the electrolyte.

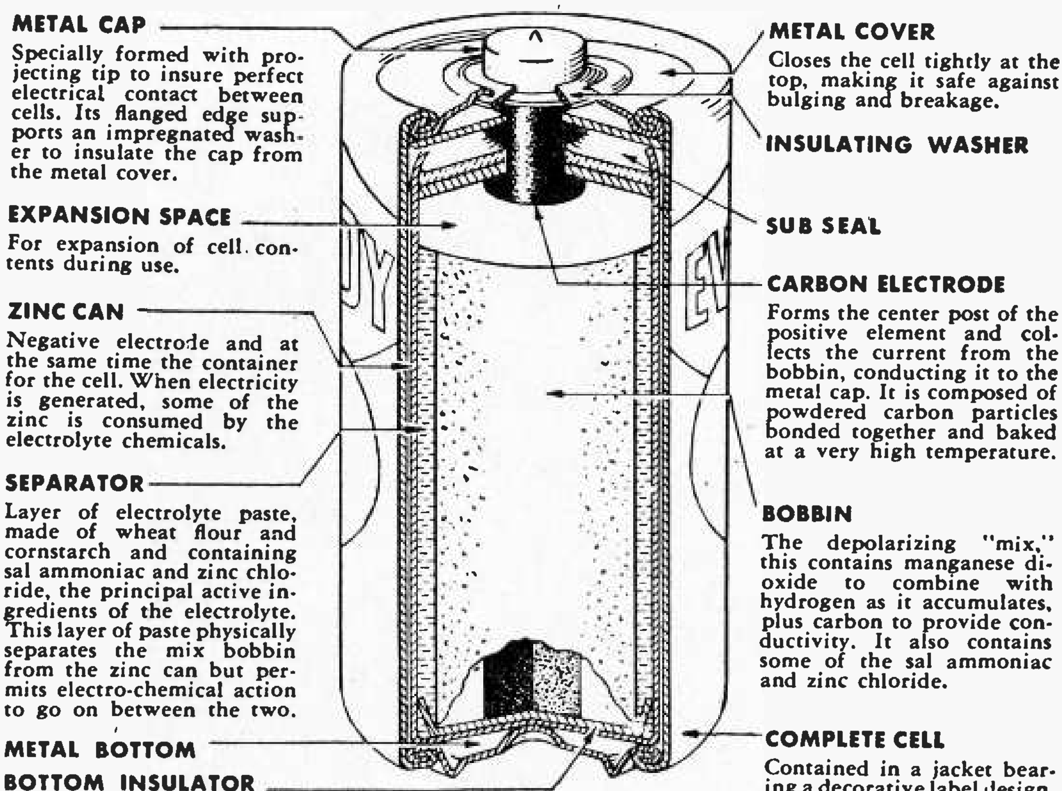


Fig. 3

This type of cell will generate an open circuit voltage of just about 1.5 volts. It's interesting to note that regardless of the physical size of this type of cell . . . whether it be a #6 dry cell or a tiny "pen lite" cell, the open circuit voltage will always be 1.5 volts. This is because the cell's generated voltage is determined by the chemicals used in its construction, not the quantity of chemicals. However, the size of the cell does determine its electrical capacity (not capacitance) as we shall see a bit later on a number of specialized forms of the basic zinc-carbon cell have been developed to meet specific needs.

For example, in an effort to obtain the maximum amount of productive cell in a given volume of space, the type of construction illustrated in Fig. 4 has been developed. Notice that the cell assumes a flat, square shape rather than the more familiar cylindrical form. The various components of the cell (zinc, carbon, electrolyte, etc.) are neatly stacked to form a package that makes maximum utilization of the available space. An assembled cell of this type is shown in Fig. 5. A number of these cells can be stacked to form a battery . . . such a battery being shown in Fig. 6.

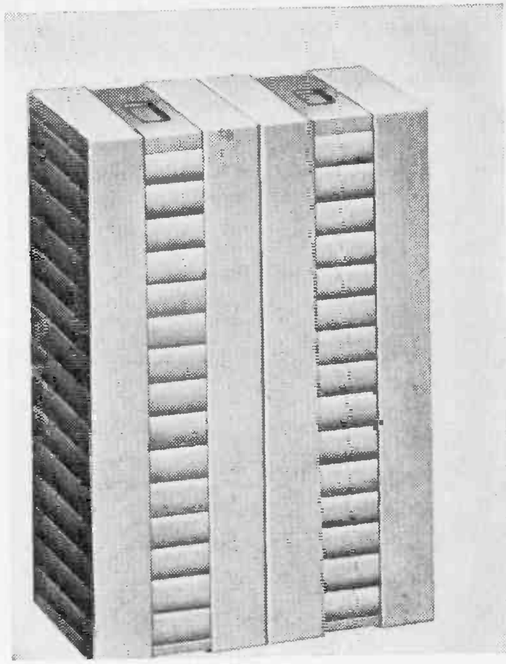


Fig. 6: Make a stack of flat cells, piling one upon the other, tape together as shown, you have a battery.

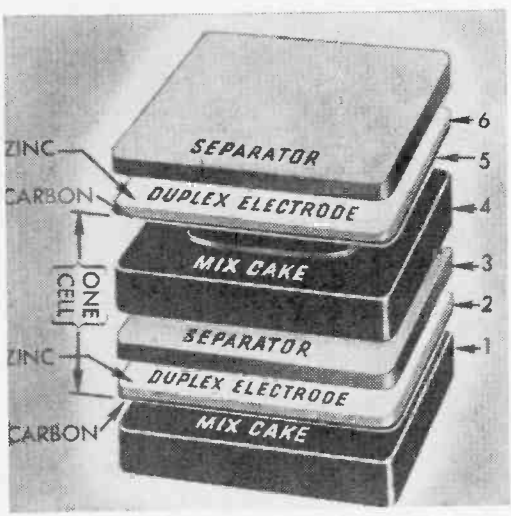


Fig. 4: The new look in batteries is a very flat look.

Fig. 5: After assembly, the above cell looks like this.

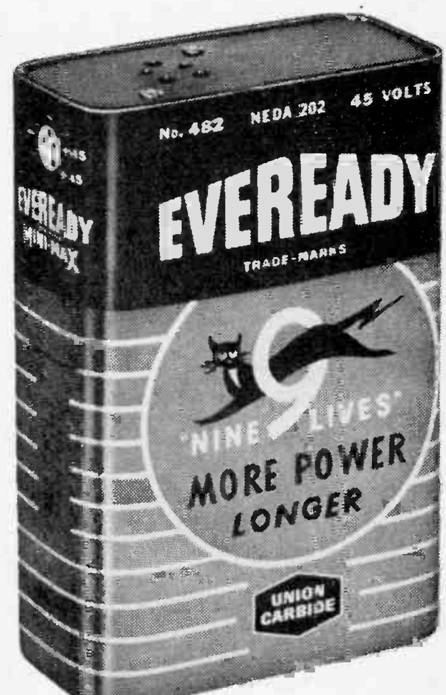


Fig. 7: Finish the job off with a decorative container.

Secondary Cells: So far, we've been talk-
cell is the lead-acid storage battery which lies
The chemical action in a primary cell cannot be reversed, that is, once its electricity producing chemicals (and electrodes) are exhausted, they cannot be efficiently rejuvenated by the passage of an electric current through the cell.

On the other hand in a "secondary" cell, the chemical action can be reversed, the passage of current through it causing a chemical reaction that restores it to its original condition.

The most familiar example of a secondary cell is the lead-acid storage battery which lies under the hood of your automobile.

The positive electrode of the lead-acid storage battery consists of a grid structure coated with porous lead peroxide (PBO_2). The cell's negative plate is also a grid structure on which is deposited spongy lead (PB).

Let's take a look at the basic electro-chemical reaction that takes place in a lead-acid

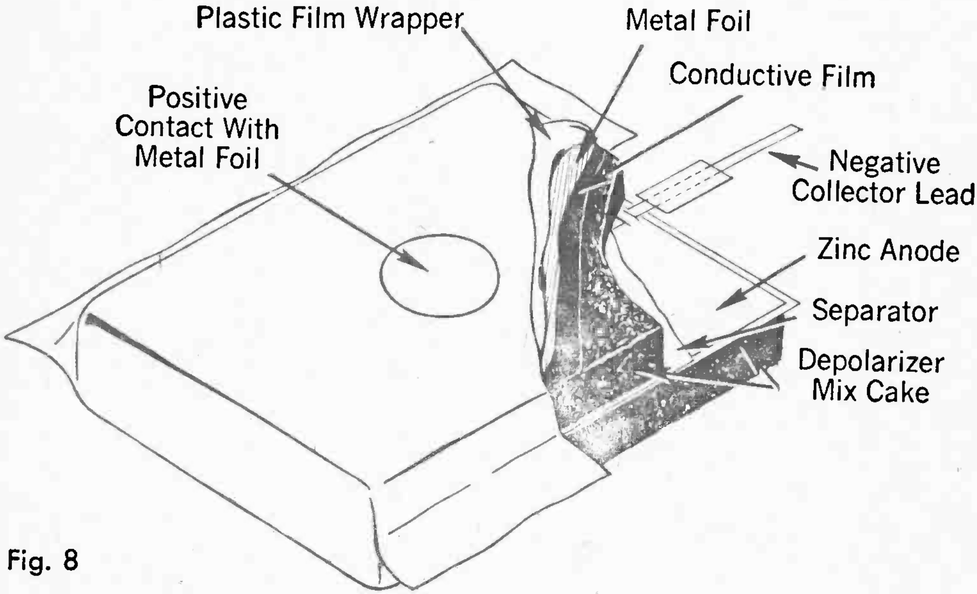


Fig. 8

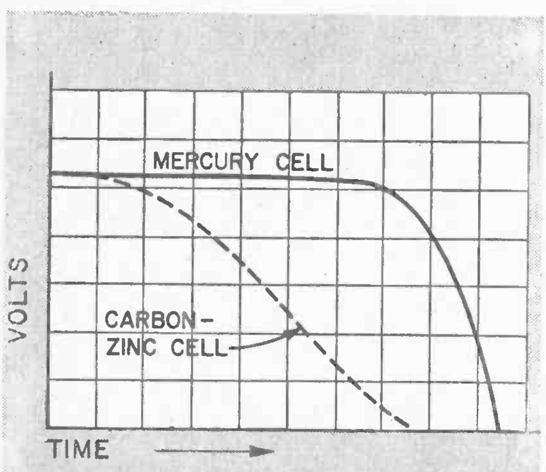


FIG. 9

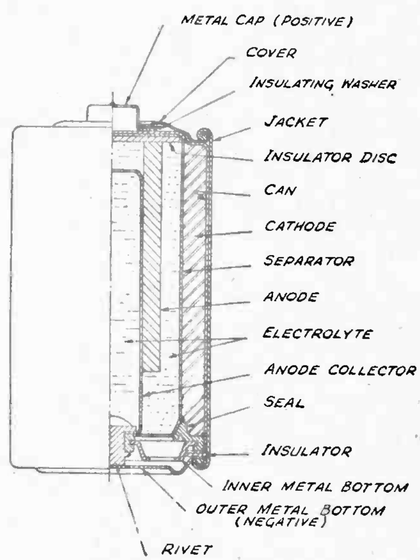


Fig. 10

storage cell . . . first under conditions of discharge (cell delivering current to load). The sulphuric acid electrolyte is broken down into positive hydrogen ions and negative SO_4 ions. The spongy lead negative electrode dissolves slightly in the electrolyte, forming positive lead ions and free electrons which flow through the negative terminal to the external circuit. The negative sulphate ions combine with the positive lead ions to form lead sulphate which is deposited on the negative electrode.

The lead peroxide at the cell's positive electrode first reacts with the electrolyte to form positive lead ions. These ions now react with electrons released by the spongy lead to form lead sulphate which builds up on the positive electrode.

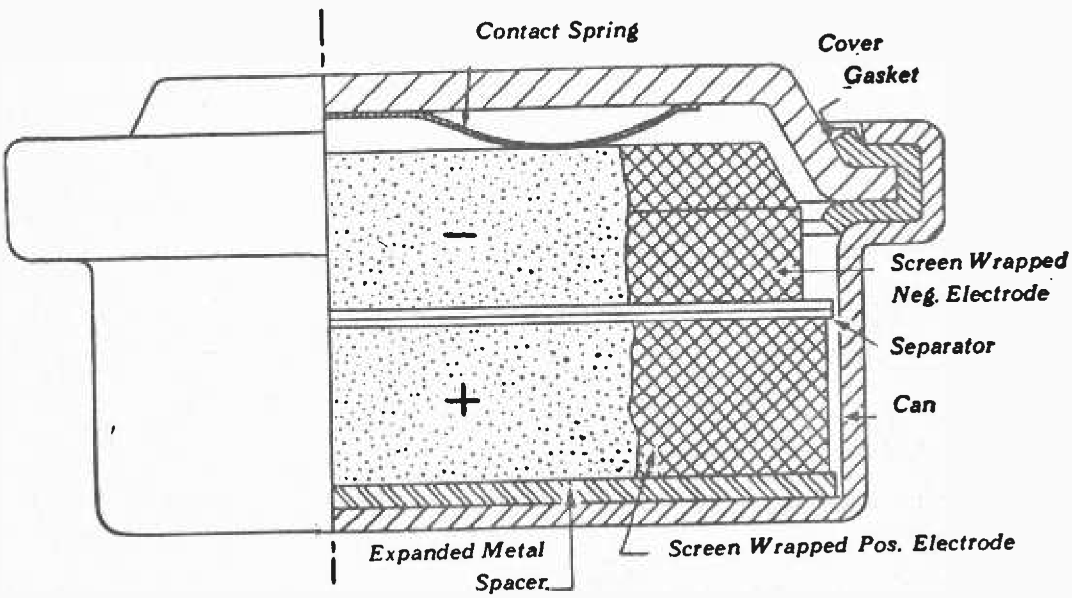
The electro-chemical reaction during discharge of the lead-acid cell partially replaces the sulphuric acid on the electrolyte with water. This lowers the *specific gravity* of the electrolyte . . . thus it is possible to determine the condition of charge of this type of cell by checking its electrolyte's specific gravity. This is done by means of *hydrometer*.

To charge a lead-acid cell, current is sent through it in a direction opposite to its discharge current. Although the electro-chemical processes involved in the recharging operation are quite involved, basically what happens is that the chemical reactions involved in the discharge of the cell are reversed. The lead sulphate deposited on the positive electrode is converted back to lead peroxide, and the negative plate is restored to spongy lead.

The open circuit voltage of a lead-acid storage cell is 2.0 volts.

Specialized Cells and Batteries: The *cathodic envelope* battery, a modified version of the standard carbon-zinc configuration, has been developed for low voltage, relatively high current requirements of modern semiconductor circuits. Fig. 8 shows the construction of "Eveready" cathodic envelope cell. Notice that this cathode is made up of two cakes of depolarizer mix, with the zinc anode sandwiched between them. This doubles the effective anode area and reduces the chemical mix's current density . . . the net result being a much greater electro-chemical efficiency under conditions of heavy current drain.

Another type of cell, which is becoming increasingly popular due to its high efficiency and relatively constant output voltage, is *the mercury cell*. This type of cell consists of a depolarizing mercuric oxide cathode, amalgamated zinc anode, and an electrolyte of potassium hydroxide saturates with zincate.



Cutaway of Typical Button Cell

Fig. 11

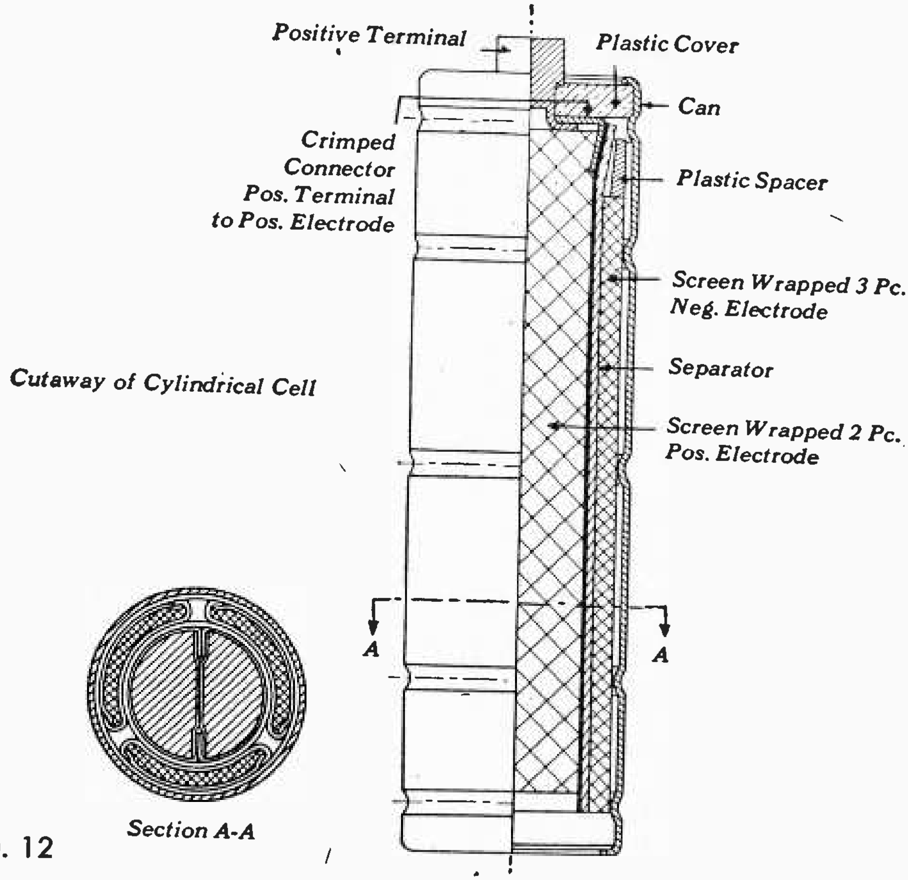


Fig. 12

The mercury cell offers the highest efficiency of any primary cell, converting between 80% and 90% of its active chemicals into electrical energy.

Mercury batteries are unique in that they provide a nearly constant output voltage during almost their entire useful operating life. This is in contrast with other types of primary cells such as the zinc-carbon variety. This fact is shown in Fig. 9, which represents the voltage versus life of a mercury cell (curve A) and a conventional zinc-carbon cell (curve B).

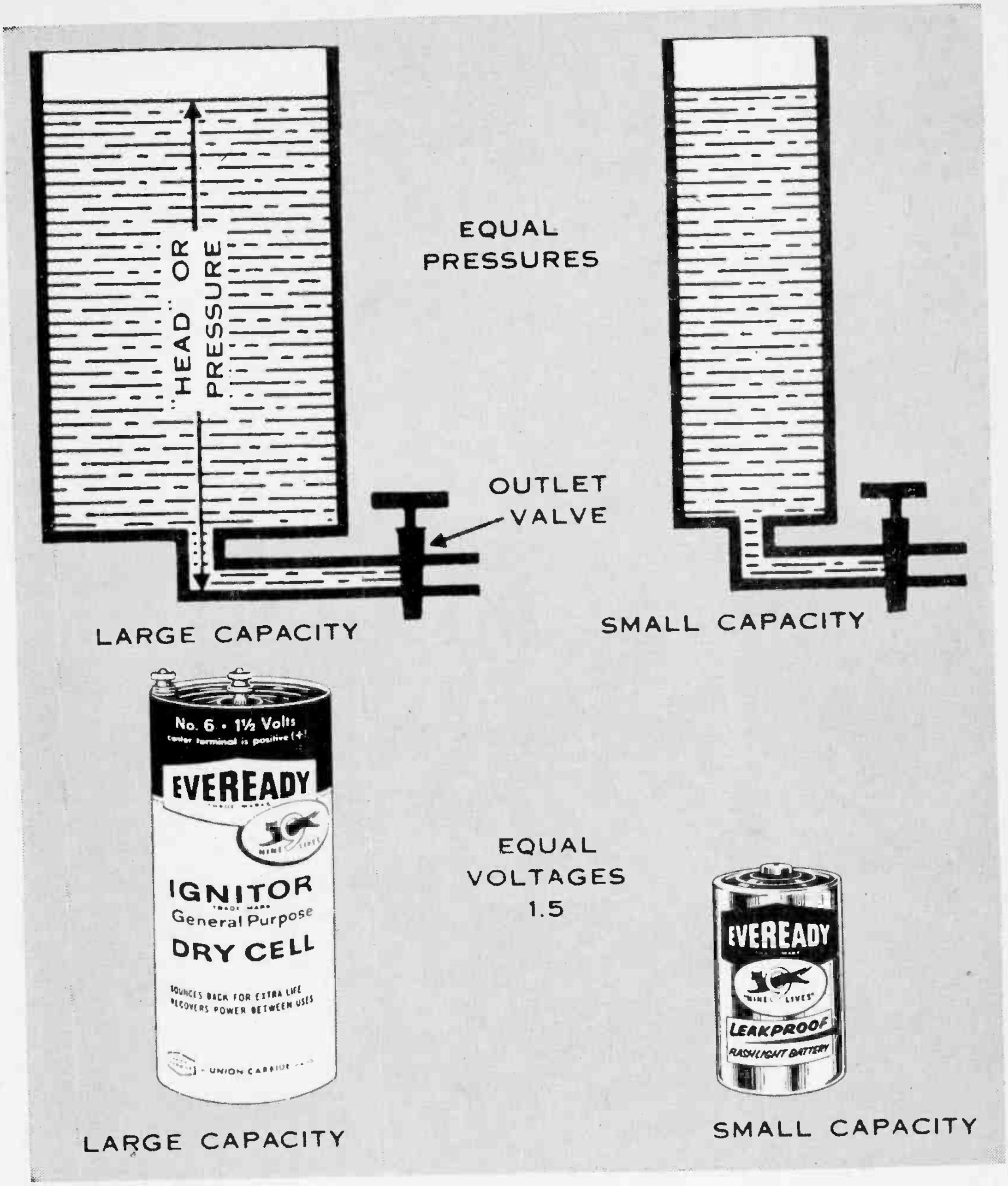
Since the open circuit voltage of mercury cells remains constant approximately 1.25 volts during their life, they are often used as a "poor man's" voltage standard or reference.

The *Alkaline battery* is a fairly recent primary cell development which offers superior performance in application requiring high current drain over extended periods of time.

Figure 10 shows the internal construction of an "Eveready" alkaline cell. Alkaline cells differ from conventional carbon-zinc cells in that they make use of a highly alkaline electrolyte. A high density manganese dioxide cathode material is used in conjunction with a steel can which serves as the cathode current collector. A large area of metallic zinc serves as the anode. The cell is hermetically sealed and encased in a steel jacket. The open circuit voltage of the alkaline cell is 1.5 volts.

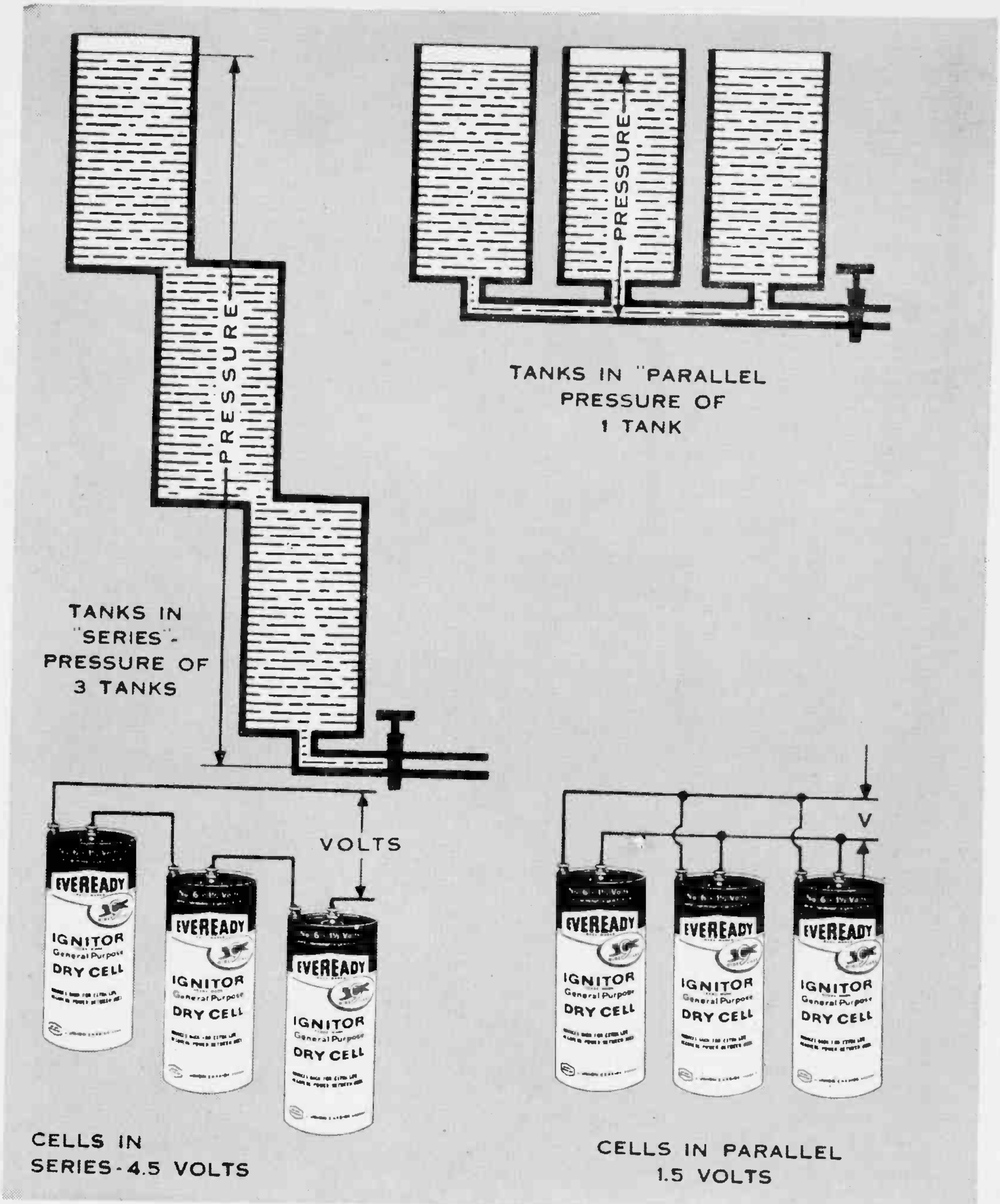
The *nickel-cadmium* cell, while used extensively in Europe for many years, has only recently become popular here in the U. S. While these are like lead-acid storage cells in that they are "secondary" cells and may be recharged, they offer none of the disadvantages of the lead-acid cell such as the constant addition of water and the problem of leakage.

Figure 11 illustrates an Eveready "button" nickel-cadmium cell, while Fig. 12 shows an Eveready "cylindrical" nickel-cadmium cell. In its charged condition, a nickel-cadmium's positive electrode is nickel hydroxide and its negative electrode is metallic cadmium. The electrolyte is potassium hydroxide. The open



Current flows in a circuit as water flows in a pipe . . . .

Fig. 13: The voltages in both cells shown above is the same. In this case, it's 1.5 volts. In the analogy, the valve diameter is the same for both tanks, but the tank at the left has a greater capacity due to its larger size. While the water pressure will be the same in either case as the valve opening is similar, the larger tank can provide water flow for a greater length of time. Similarly, the larger cell, while it will produce current for a longer period of time, will produce no additional voltage or pressure at the terminal. Voltage is pressure, current is analogous to capacity.



You can "stack" batteries for more pressure . . . .

Fig. 14: Three tanks stacked up in a line as in the left above, will provide three times the pressure. In right above, the tanks are on the level, and the total pressure is that of one tank. However, there is three times as much water, so the water will flow for a longer time. Batteries in series provide three times the pressure or voltage. The current remains the same as for a single cell. If the batteries are connected in parallel, the voltage is the same as for one cell, but the current capacity is the same as for three cells. Remember that current is capacity, voltage pressure.

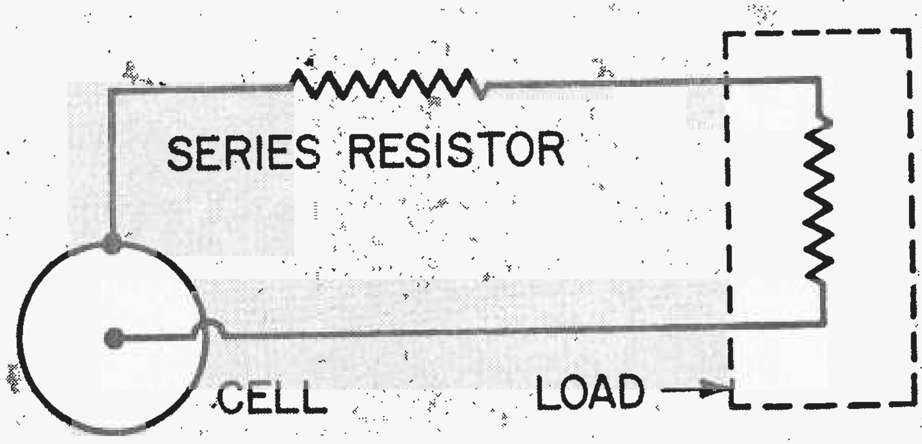


FIG. 15

circuit voltage of a nickel-cadmium cell is 1.2 volts.

Voltage: As was mentioned earlier, the physical size of a given type of cell has no bearing on its output voltage. The size does, however determine the cell's *capacity,* or the overall quantity of electricity which it can deliver. This is shown in Fig. 13. Although both tanks provide the same pressure, the tank on the left holds a greater quantity of water than the tank on the right, and thus can supply water for a greater length of time. By the same token, the large dry cell shown on the right.

Cells may be connected in *series* to increase the total available voltage . . . the voltage being the *sum* of the individual cell voltages. This is illustrated in Fig. 14, which shows three water tanks connected "in series." The total water pressure is the sum of the individual water pressure in each tank.

The total current capacity of a group of cells may be increased by connecting the cells in parallel. In this connection, the total current capacity is the *sum* of the capacities of the individual cells. This is illustrated in Fig. 14 which shows three water tanks connected in "parallel." The total water capacity is the sum of the water in the three tanks. Notice that the water *pressure* remains the same as one tank. This also holds true for parallel connected cells, where the electrical pressure, *voltage*, is the same as for a single cell.

Internal Resistance: Let's take a look at Fig. 11. Here, we see a cell, series resistor, and load. The series resistor represents the *internal resistance* of the cell. Assume for a moment, that the load current increases. This will draw more current through the series resistor, and an old friend, Ohm's law tells us that the voltage across the load will drop due to the increased voltage drop across the series resistor.

The series resistor shown in Fig. 11 is actually an internal part of the cell. Thus, as the current drawn by a load connected to the cell increases, the cell's output voltage will drop due to the increased voltage drop across the cell's internal resistance.

The internal resistance of a cell is lowest when it is new, increasing as the cell is used. This is why the output voltage of a cell drops after it has been in service for some time.

Shelf Life: Cells placed in storage or which are idle for periods of time, gradually deteriorate. This deterioration is the result of slow chemical changes which take place within the cell. This effect is known as the cell's *shelf life,* and is the reason why many cells bear dates indicating that the cell should be placed in service before the time indicated. Certain types of cells, such as mercury cells, have the desirable characteristic of almost no deterioration when inactive over extended periods of time.

Temperature: Temperatures very much in excess of 70° F can reduce the life of most types of cells due to both accelerated chemical action within the cell and loss of moisture from the cell.

Extremely low temperatures will reduce the current delivering capacity of most cells, although the cells will return to normal when brought back up to normal operating temperature. Cell shelf life is enhanced at low temperatures due to the fact that chemical action within the cell is retarded.

Testing Cells and Batteries: Cells and batteries should always be checked for proper output voltage under normal load conditions. If they are checked under no-load conditions, they may deliver their rated voltage which will then drop when they are placed in service due to their increased internal impedance. Therefore, it is always best to check battery voltage connected to the entire load.

BASIC ELECTRICITY

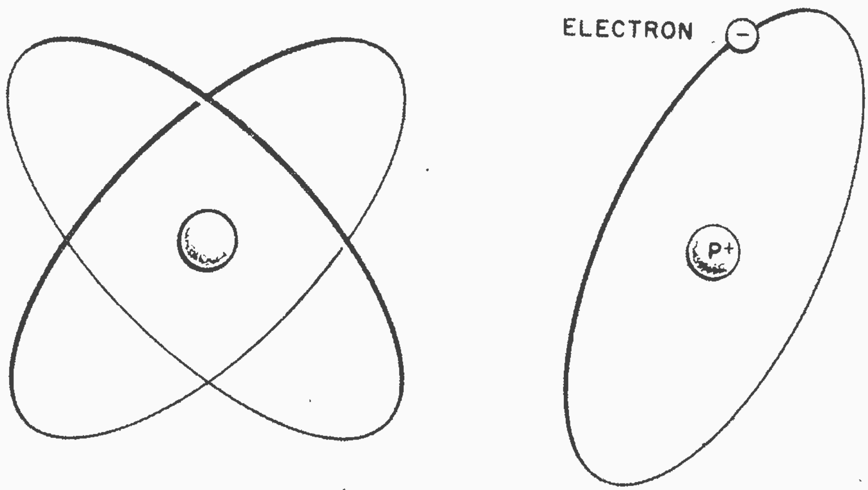


FIG. 1

By JOHN POTTER SHIELDS

IN ORDER to gain a clear understanding of basic electricity, it is first necessary that we take a close look at the structure of the atom. As you know, all matter can be broken down into basic chemical elements. These basic elements in turn can be subdivided into minute particles, called atoms; the smallest state in which chemical elements can exist without losing their identity.

Early in the 19th century it was revealed that the atom, which up until this time, had been considered the fundamental particle of matter, could be subdivided still further into even smaller particles. These smaller particles—electrons, protons and neutrons, are present in all atoms . . . their number determining the particular type of atom, carbon, hydrogen, etc. For example, the element hydrogen has one electron and one proton, while the silicon atom has 14 electrons, 14 protons, and 14 neutrons.

The structure of the atom is very similar to our own solar system as shown in Fig. 1. The atom's central nucleus consists of protons which carry what is known as a positive electrical charge and neutrons which possess a zero electrical charge. Around this positively charged nucleus, orbit negatively charged electrons. In a normal atom, the number of electrons in the orbits exactly equal the number of protons in its central nucleus. Thus, the negative charged orbiting electrons neutralize the positive protons and the atom has a zero net electrical charge.

Almost the Entire Weight of any atom is concentrated in its nucleus, both the electrically positive proton and electrically neutral neutron being about 1800 times heavier than the orbiting electrons. Actually, "weight" is a rather poor term to use here as the weight of even the heavier protons and neutrons is

In case you're wondering why a section on electricity belongs in a book of elementary electronics, these are the basics . . .

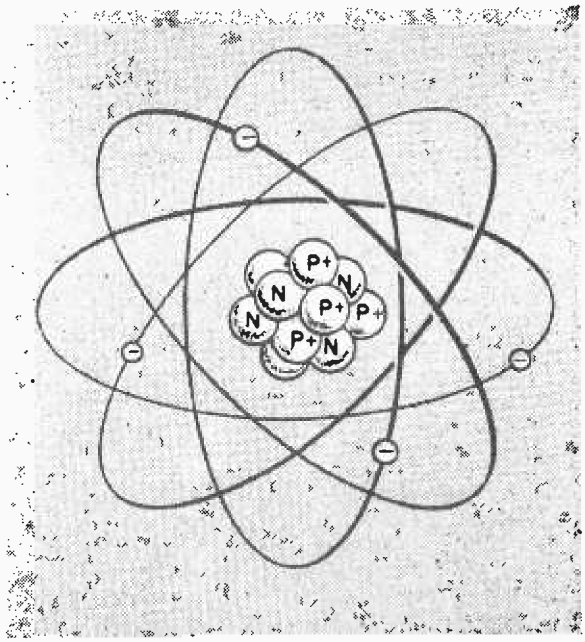


FIG. 2: THE FIRST ELEVEN ATOMS

Symbol	Element	At. No.	At. Wt.	Pro-tons	Elec-trons	Neu-trons
H	hydrogen	1	1	1	1	0
He	helium	2	4	2	2	2
Li	lithium	3	7	3	3	4
Be	beryllium	4	9	4	4	5
B	boron	5	11	5	5	6
C	carbon	6	12	6	6	6
N	nitrogen	7	14	7	7	7
O	oxygen	8	16	8	8	8
F	fluorine	9	19	9	9	10
Ne	neon	10	20	10	10	10
Na	sodium	11	23	11	11	12

infinitesimal compared to objects we are familiar in dealing with. The approximate weight of one electron is .(27 zeros) 9 gram.

A moment ago, we said that all atoms are composed of three basic types of particles, electrons, protons, and neutrons, and that the different elements are determined by the number and arrangement of these particles. The atomic number of an element's atom is equal to the number of electrons orbiting about its nucleus. Thus, the hydrogen atom, with its single electron is given the atomic number of one. On the other hand, the element fluorine has nine electrons and is thus given the atomic number of nine.

An atom's atomic weight is determined by the number of protons and neutrons in its nucleus. Atomic weights are relative and are useful in comparing the weight of one atom against that of another. Since the atomic weight of hydrogen is one, and the atomic weight of carbon is 12 the carbon atom is 12 times heavier than the hydrogen atom. Fig. 2 is a table of the atomic weights and numbers for various common elements.

Going back to our atom's orbiting electrons for a moment, these electrons are arranged in rings or shells around the central nucleus—each ring having a definite maximum capacity of electrons which it can retain. For example, in the copper atom shown in Fig. 3 the maximum number of electrons that can exist in the first ring (the ring nearest the nucleus) is two. The next ring can have a maximum of eight, the third ring a maximum of 18, the fourth ring a maximum of 32, and the outer shell never more than eight electrons.

The Ring of Electrons furthest from the atom's nucleus is known as the valance ring and the electrons orbiting in this ring are known as valance electrons. These valance electrons, being furthest from the nucleus, are not held as tightly in their orbits as elec-

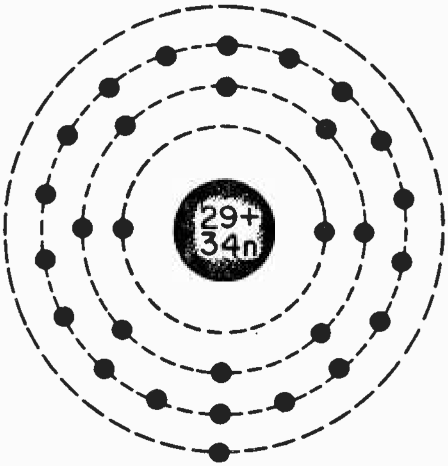


FIG.3 COPPER

trons in the inner rings and can therefore be fairly easily dislodged by an external force such as heat, light, friction, and electrical potential. The fewer electrons in the valance ring of an atom, the less these electrons are bound to the central nucleus. As an example, the copper atom has only one electron in its valance ring—consequently it can be easily removed by the application of only the slightest amount of external energy. Ordinary room temperature is sufficient to dislodge large numbers of electrons from copper atoms; these electrons circulating about as free electrons. It is because of these large numbers of free electrons that copper is such a good electrical conductor as you shall shortly see. There could be no electrical or electronics industry as we know it today if it were not for the fact that electrons can fairly easily escape, or be stripped from the valance ring of certain elements.

Electric Charges: If an electron is stripped from an atom, the atom will assume a positive charge because the number of positively charged protons in its nucleus now exceed the number of negatively charged orbiting electrons. If on the other hand, the atom should gain an electron, it will become negatively charged as the number of electrons now exceed the protons in its nucleus. The atom with the deficiency of electrons is known as a positive ion, while an atom with a surplus of electrons is known as a negative ion.

You are probably familiar with the "electricity" produced when you comb your hair with a hard rubber or plastic comb. What happens here is that the friction of passing the comb through your hair strips electrons from the atoms of the material from which the comb is made, leaving the comb negatively charged. This is the earliest form of electricity known to man and is known as "static electricity" as it simply accumulates on a surface rather than flowing continuously in an electrical circuit as does electricity produced from a battery, generator, etc.

So far, we've talked only about "static" electrical charges which accumulate either by a deficiency or surplus of electrons. Let's go a bit further and see what constitutes a continuous flow of electric current.

Fig. 4 shows two oppositely charged bodies. The negative charge of the right hand body is due to there being a greater number of electrons than protons in this body, while the left hand body is positively charged due to its having fewer electrons than protons. When an electrical conductor is placed between these two oppositely charged bodies as shown in Fig. 5 the negatively charged free electrons will be repelled into the connecting wire by the negative charge of the right hand body. At the same time, these free electrons are attracted by the positive charge of the left hand body—free electrons moving through the wire from the right hand body to the left hand body. This movement of

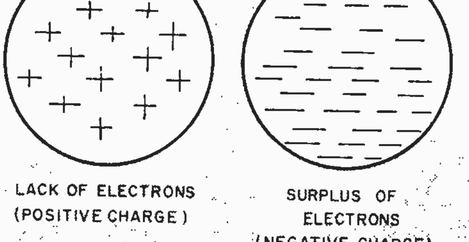
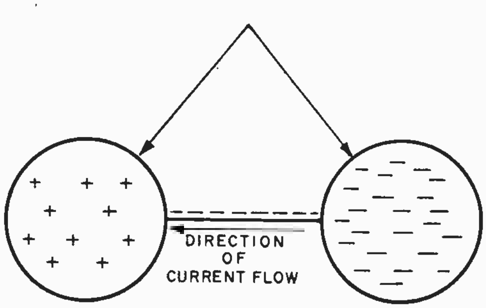


FIG.4

FIG.5 OPPOSITELY CHARGED BODIES



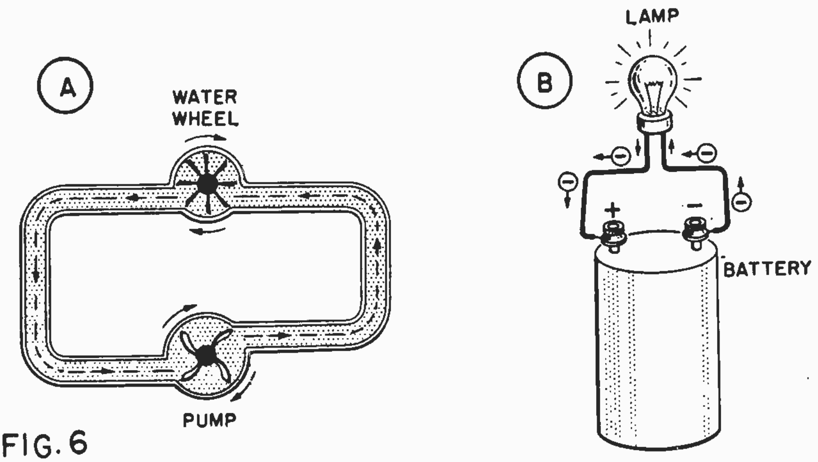


FIG. 6

free electrons will continue only until the right hand body loses its excess electrons and the left hand body gains enough electrons to equal its protons. Under these conditions, the charges on the left and right hand bodies will be equal and current flow will cease.

Electric Charges Produce Current: While the sketches, Fig. 4 and 5 serve to illustrate the basic flow of an electric current by means of electric charges, you can see that the flow of current will stop as soon as the charges are neutralized—this taking but a fraction of a second. What we need is some method of continuously maintaining a charge or potential difference between the two ends of the electrical conductor. In effect, what we are looking for is an "electric charge pump."

Let's take a look at Fig. 6a. Here we see a water wheel and water pump connected by a length of pipe. Mechanical energy applied to the shaft of the pump causes the water to flow through the pipe and turn the water wheel due to the difference in water pressure at the two ends of the pump. The pump, water wheel, and connecting pipe form a circuit through which the water can flow. Now, look at Fig. 6b. Here is a battery, lamp, and connecting leads between the battery and lamp. In this instance, the battery serves as the electric charge pump—free electrons continually developed at its negative terminal by chemical action flowing through the connecting leads and lamp back to its positive terminal of the battery by the attraction of oppositely charged bodies. The battery, connecting leads, and lamp form an electrical circuit which must be complete before the free electrons can flow from the battery's negative terminal to its positive terminal via the lamp. Thus, the battery serves as a source

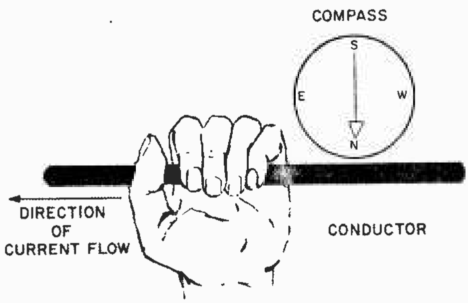


FIG. 7

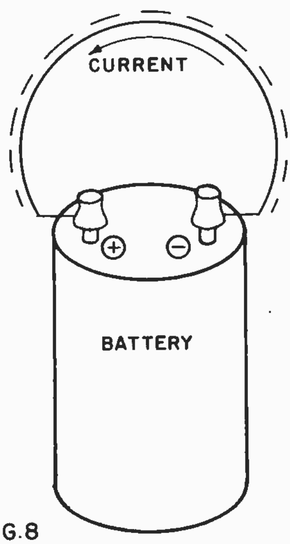


FIG. 8

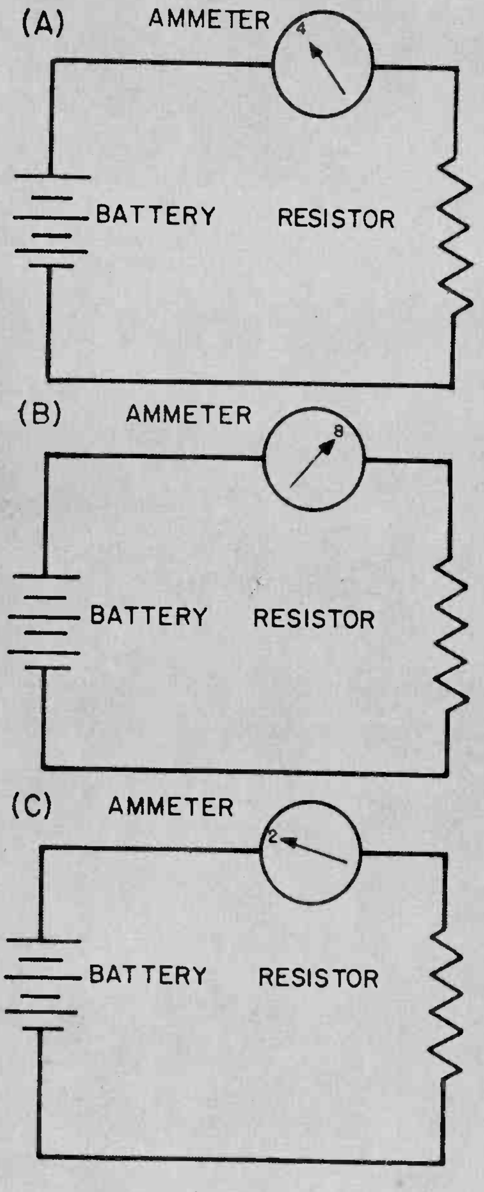


FIG. 9

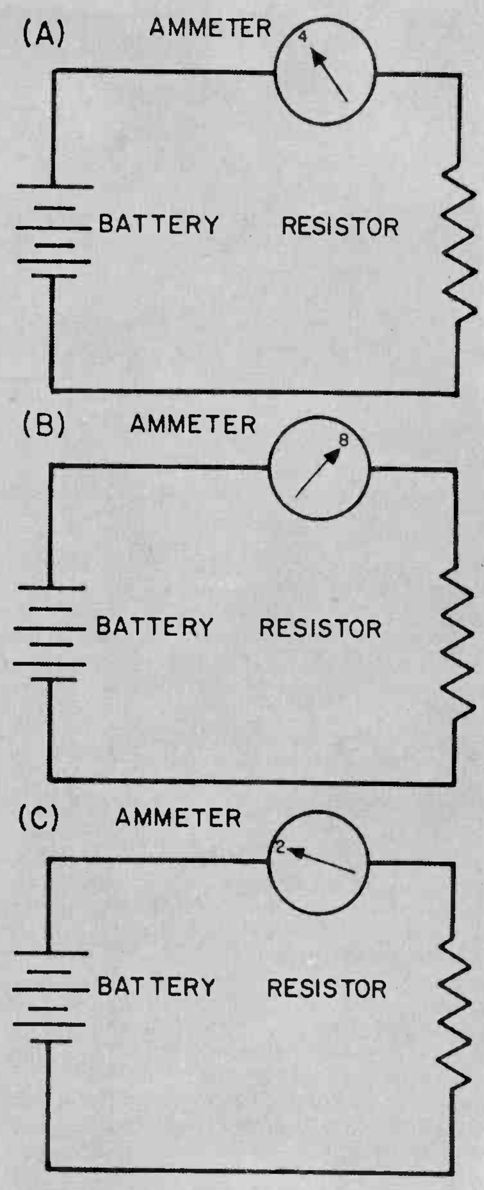


FIG. 10

of potential difference or voltage by continually supplying a surplus of electrons at its positive terminal. Summing this whole thing up, we can say that for all practical purposes, a flow of electric current consists of the movement of electric charges (electrons in most cases) between two oppositely charged bodies.

Now that we have seen just what makes up a flow of electric current, in which direction does the current flow . . . from positive to negative or from negative to positive? Actually, there are two schools of thought on this . . . the so-called conventional direction and the direction of electron flow. The conventional direction is the earliest, and assumes that an electric current flows from positive to negative. The more modern theory assumes that current flow is the same as electron flow (from negative to positive) since most cur-

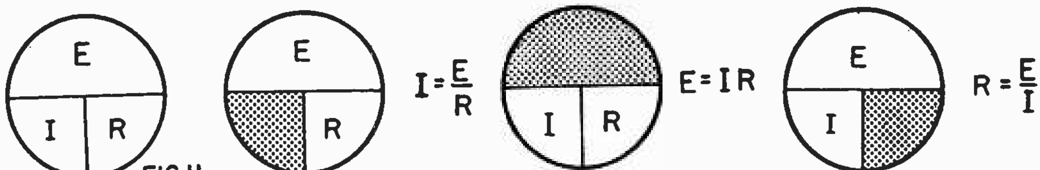


FIG.11

rent flow consists of the movement of free electrons.

The direction of current flow through a conductor can be determined with the aid of a compass as shown in Fig. 7. When the fingers of the left hand are wrapped around the conductor in such a manner that they point in the same direction as the north pole of the compass, the left thumb points to the direction of current flow.

Electrical Quantities: We cannot progress very far into the study of electricity without first becoming familiar with the basic properties of electrical circuits. Just as we define distance in feet and inches, so do we define electrical properties in specific terms and units.

Potential: Earlier, we saw that an electric charge difference has to exist between the ends of an electrical conductor in order to cause a flow of free electrons through the conductor . . . this flow of electrons constituting an electric current. This electric charge difference, or potential difference exerts a force on the flow of free electrons, forcing them through the conductor. This electric force or pressure is referred to as electromotive force, abbreviated EMF. The more common name for electromotive force is voltage.

The greater the charge or potential difference, the greater will be the movement of free electrons (current) through the conductor as there will be more "push and pull" on the free electrons. The symbol used to designate electrical potential is the letter E which stands for electromotive force. The quantity of EMF is measured by a unit called the volt.

Current Intensity: We have learned that an electric current consists of a flow of charge carriers (most generally free electrons) between two points of different electrical potential. The rate of flow of these charges determines the intensity or strength of this current flow.

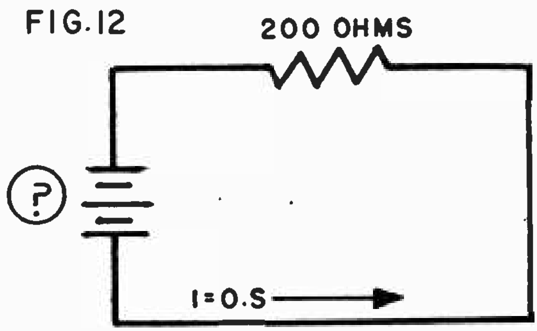
Let's take a look at Fig. 8 which shows a wire connected between the positive and negative terminals of a battery. Since the battery serves as a source of potential difference, free electrons will be repelled out of the negative terminal, through the wire, and back into the positive terminal which has a deficiency of electrons. The number of these free electrons flowing in the conductor determine the current strength. This current strength is expressed in units known as the ampere . . . 1 ampere of current flowing in the circuit when 6,240,000,000 electrons flow out of the battery's negative terminal, through the conductor, and back into the battery's positive terminal in one second. The symbol for the ampere is the letter I which stands for intensity.

Resistance: The flow of electric current through a conductor is caused by the movement of free electrons present in the atoms of the conductor. A bit of thought then indicates that the greater the number of free electrons present in the atoms of a particular conductor, the greater will be its electrical conductivity. Gold, silver, and copper rank as excellent electrical conductors as their atoms can accept and release large numbers of free electrons. On the other hand, the atoms of such elements as sulphur have almost no free electrons available and they are thus very poor electrical conductors . . . such materials are known as electrical insulators. Between these extremes, lie elements such as carbon whose atoms have a moderate number of free electrons available and thus are relatively good electrical conductors.

Even the best electrical conductors offer some opposition to the passage of free electrons . . . this opposition is called resistance. You might consider electrical resistance similar to mechanical friction. As in the case of mechanical friction, electrical resistance generates heat. When current flows through a resistance, heat is generated, the greater the current flow the greater the heat. Also, for a given current flow, the greater the resistance, the greater the heat produced.

Electrical resistance can be both beneficial

FIG.12



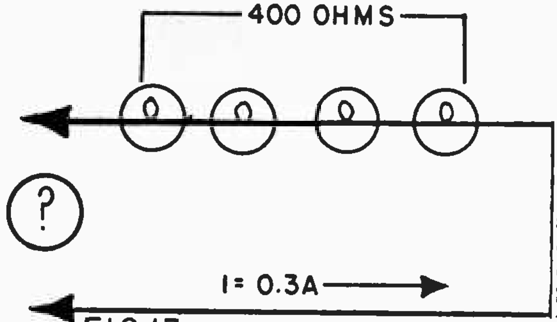


FIG.13

and undesirable. Toasters, electric irons, etc. all make use of the heat generated by current flowing through special wire which possesses a relatively large amount of electrical resistance. Resistance is also often intentionally added to an electrical circuit to limit the flow of current. This type of resistance is generally lumped together in a single unit known as a resistor.

There are also instances where resistance is undesirable. Excessive resistance in the connecting leads of an electrical circuit can cause both heating and electrical loss. The heating, if sufficient can cause a fire hazard, particularly in house wiring, and the circuit losses are a waste of electrical power.

Electrical resistance is expressed by a unit known as the ohm, indicated by the letter R which stands for resistance as you might guess. An electrical conductor has a resistance of one ohm when an applied EMF of one volt causes a current of one ampere to flow through it.

There are other factors beside the composition of the material that determine its resistance. For example, temperature has an effect on the resistance of a conductor. As the temperature of copper increases for example, its resistance decreases. A little thought will show why this is so. You remember that heat is one of the external forces which will strip electrons from the valance ring of atoms comprising an electrical conductor. These electrons then circulate as current carrying free electrons. As the amount of heat is increased, the number of these free electrons increase, and the resistance of the conductor drops. This drop in resistance with an increase in temperature is known as a positive temperature coefficient. Not all conductors show this decrease in resistance with an increase in temperature . . . their resistance increasing with an increase in temperature. Such materials are said to have a negative temperature coefficient. Certain metallic alloys have been developed which exhibit a zero temperature coefficient . . . their resistance does not change with changes in temperature.

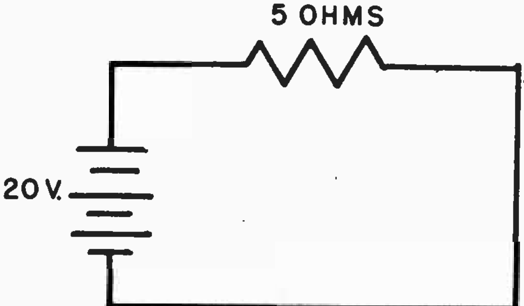


FIG.14

As you might suspect, the length of a conductor has an effect upon its resistance. Doubling the length of a conductor will double its resistance as the current carrying free electrons have twice as far to travel and thus twice the resistance. By the same token, halving the length of a conductor will cut its resistance in half. Just remember that the resistance of a conductor is directly proportional to its length.

The cross-sectional area of a conductor also determines its resistance. As you double the cross-section of a conductor, you halve its resistance . . . halving its cross-section doubles its resistance. Here again, the "why" of this is pretty easy to see . . . there are more current carrying electrons available in a large cross-section conductor than in a small cross-section conductor of the same length. Therefore, the resistance of a conductor is inversely proportional to its cross-sectional area.

Relationship—Voltage, Current, Resistance: Now that we have a basic understanding of voltage, current, and resistance. let's take a look at just how they interact.

Fig. 9a shows a battery, ammeter (a device to indicate current strength), and resistor connected in series. Notice that the ammeter indicates that 4 amperes are flowing in the circuit.

Fig. 9b shows the identical setup with the exception that the battery voltage has now been doubled. The ammeter now shows that twice the original current, or 8 amperes, are now flowing in the circuit. Therefore, we can see that doubling the voltage applied to the circuit will double the current flowing in the circuit.

In Fig. 9c the same circuit appears again, this time however, the battery voltage is one-half its original value. The ammeter shows that one-half of the original current, or 2 amperes, are now flowing in the circuit. This shows us that halving the voltage applied to the circuit will halve the current flowing through the circuit.

All this boils down to the fact that assum-

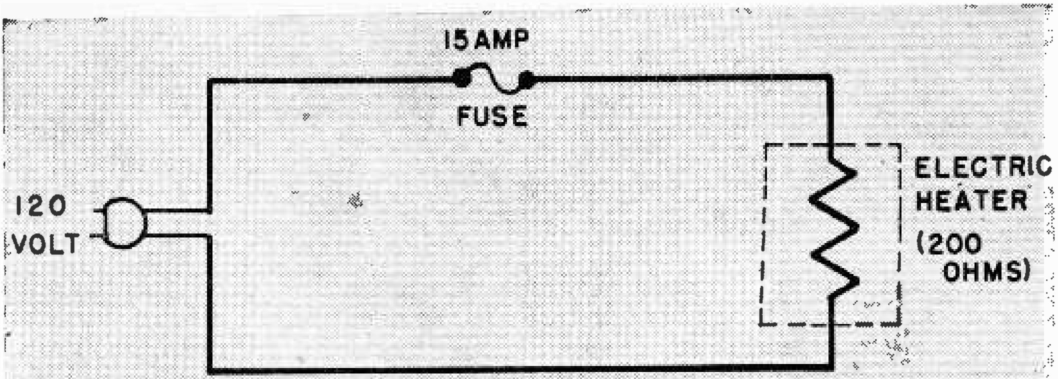


FIG. 15

ing the same circuit resistance in all cases, the current flowing in a circuit will be directly proportional to the applied voltage . . . increasing as the voltage is increased, and decreasing as the applied voltage is decreased.

In Fig. 10a we again see the circuit consisting of the battery, ammeter, and resistance. Notice that the ammeter indicates that 4 amperes are flowing through the circuit.

In Fig. 10b we see that the value of resistance has been cut in half and as a result, the ammeter indicates that twice the original current, or 8 amperes, is now flowing in the circuit. This leads us to the correct assumption that for a given supply voltage, halving the circuit resistance will double the current flowing in the circuit.

Fig. 10c again shows our basic circuit, but with the resistance now doubled from its original value. The ammeter indicates that the current in the circuit is now one-half of its original value.

Summing things up . . . for a given supply voltage, the current flowing in a circuit will be inversely proportional to the resistance present in the circuit.

Ohm's Law: From what you have seen so far, you are probably getting the idea that you can determine the current flowing in a circuit if you know the voltage and resistance present in the circuit . . . the voltage if you know the current and resistance, or the resistance if the voltage and current are known.

All this is quite correct, and is formally stated by Ohm's Law as follows:

$$E = \frac{I}{R}$$

Where: E = voltage
I = current
R = resistance

Now, let's take a look at how this formula is used.

To find voltage . . .
E (voltage) = I (current) times R (resistance)
To find current . . .

$$I\ (\text{current}) = \frac{E\ (\text{voltage})}{R\ (\text{resistance})}$$

To find resistance . . .

$$R\ (\text{resistance}) = \frac{E\ (\text{voltage})}{I\ (\text{current})}$$

A handy way to remember Ohm's Law is by means of the "wheel" shown in Fig. 11. Simply cover the quantity, voltage, current, or resistance, that you want to determine, and read the correct relationship of the remaining two quantities from the wheel. For example, if you want to know the correct current (I) put your finger over I and read $\frac{E}{R}$. Similarly, covering E or R will yield I X R or $\frac{E}{I}$ respectively.

Ohm's Law To Determine Voltage: Let's delve a bit more deeply into Ohm's law by applying it to a few cases where we want to determine the unknown voltage in an electrical circuit.

For a beginning, take a look at Fig. 12,

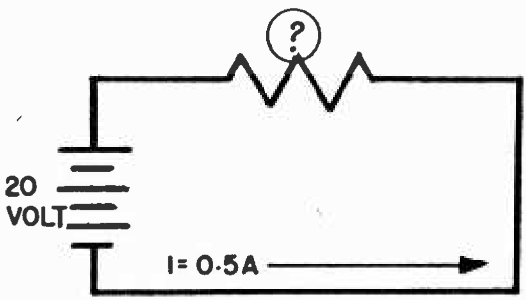


FIG. 16

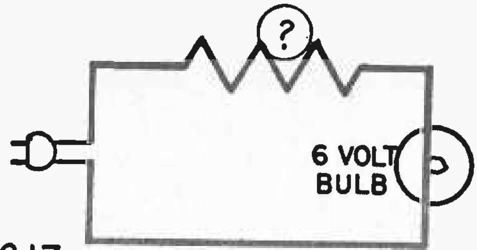


FIG.17

which shows a simple series circuit consisting of a battery and resistor. The value of this resistor is given as 200 ohms, and 0.5 amperes of current are flowing through the circuit. We want to find the value of battery voltage. This is easily done by applying Ohm's law for voltage as follows:

E = I X R

E (unknown voltage) = 0.5 (current in amperes)
X 200 (resistance in ohms)
E = 100 volts

Let's go through this again, this time using a more "true to life" illustration. Fig. 13 shows a string of light bulbs, the total resistance of which, is 400 ohms. You find that the bulbs draw 0.3 amperes when fully lit. Let's say you would like to operate this string of bulbs from the standard 120-volt house current, but you don't know the voltage rating of the individual bulbs. By using Ohm's law for voltage, you can easily determine the voltage to light the bulbs as follows:

E (unknown voltage) = 0.3 (amperes) x 400 (bulb resisance) = 120 volts

Ohm's Law To Determine Current: Now, let's take a look at a few examples of how to determine the value of unknown current in a circuit in which both the voltage and resistance are known.

Fig. 14 shows a series circuit with a battery and resistor. The battery voltage is given as 20 volts and the value of resistance is 5 ohms. How much current is flowing through the circuit?

Ohm's law for current $I = \frac{E}{R}$

$$\text{I (unknown current)} = \frac{\text{20 (battery voltage)}}{\text{5 (resistance in ohms)}}$$

I = 4 ohms

Again to get a bit more practical, let's take a look at Fig. 15. Here we see an electric heater element connected to the 120-volt house current. We know that this particular heater element has a resistance of 20 ohms. The house current line is fused with a 15-ampere fuse. We want to know whether the heater will draw sufficient current to blow the fuse. Here's how to find this out by use of Ohm's law for current.

$$\text{I (unknown current)} = \frac{\text{120 (line voltage)}}{\text{20 (Heater resistance in ohms)}}$$

I = 6 amperes

We find from the above use of Ohm's law for current that the heater draws 6 amperes, so it can be safely used on the line fused with the 15 ampere fuse.

Ohm's Law To Determine Resistance: Ohm's law for resistance enables us to determine the unknown value of resistance in a circuit. Here's how it's done. Fig. 16 again shows a simple series circuit with the battery voltage given as 20 volts and the current flowing through the circuit as 0.5 amperes. The unknown resistance value in this circuit is found as follows.

Ohm's law for resistance $R = \frac{E}{I}$

$$\text{R (unknown resistance)} = \frac{\text{20 (battery voltage)}}{\text{0.5 (current in amperes)}}$$

R = 40 ohms

Fig. 17 is a practical example of how to determine unknown resistance. Here, we want to operate a 6-volt light bulb from the 120 volt house current. What value of series

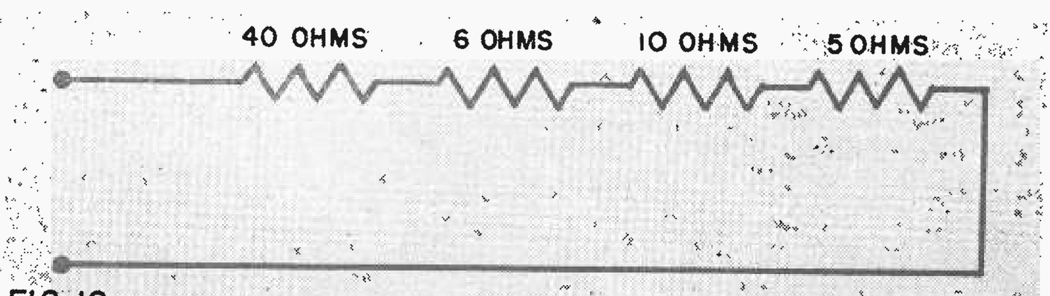


FIG. 18

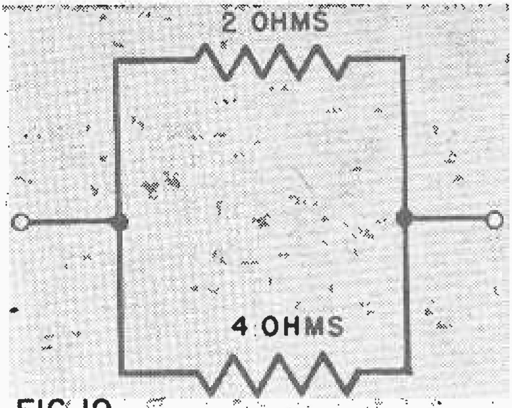


FIG. 19

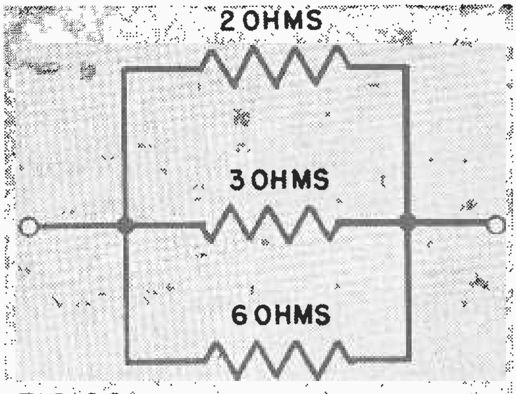


FIG. 20

dropping resistor do we need to drop the 120 volt house current down to 6 volts? The bulb draws 0.2.

We must first determine the voltage which must be dropped across the series dropping resistor. This is done by subtracting the line voltage (120) from the bulb's voltage (6). This gives us a value of 114 volts which we use in conjunction with Ohm's law for resistance as follows:

$$R \text{ (unknown resistance)} = \frac{114 \text{ (voltage dropped by resistor)}}{0.2 \text{ (bulb current in amperes)}}$$

$$R = 570 \text{ ohms}$$

Resistance In Series: Many practical electrical and electronic circuits use two or more resistances connected in series. The point to remember in this case is that the total resistance is the sum of the individual resistances. This is expressed by the simple formula:

R (TOTAL RESISTANCE) = $R_1 + R_2 + R_3$ — — — — —where R_1 R_2 R_3 are the individual resistances (the dashed line indicates any additional resistances). Thus, in Fig. 18 the total of the individual resistances is R(total) = 40 + 6 + 10 + 5 + 61 Ohms.

Resistances may also be connected in parallel in a circuit as in Fig. 19. In this case the current flowing in the circuit will divide between the resistances; the greater current flowing through the lowest resistance. Also, the total resistance in the circuit will always be less than any of the individual resistance as the total current is greater than the current in any of the individual resistors. The formula for determining the combined resistance of the two resistors is:

$$R\text{(total)} = \frac{R1 \times R2}{R1 + R2}$$

Thus, in Fig 19 the combined resistance of R1 and R2 is:

$$R\text{(total)} = \frac{2 \times 4}{2 + 4} = \frac{8}{6} \text{ or } 1.33 \text{ ohms}$$

It is generally not necessary to carry the decimal point beyond two places.

In a circuit containing more than two parallel resistors as in Fig. 20 the easiest way to determine the total circuit resistance is as follows: First, determine the current flowing through each individual resistor by the use of Ohm's law:

$$I = \frac{6}{2} = 3 \text{ amperes}$$

$$I = \frac{6}{3} = 2 \text{ amperes}$$

$$I = \frac{6}{6} = 1 \text{ ampere}$$

Next, add the individual currents flowing through the circuit:

2 amperes + 3 amperes + 1 ampere = 6 amperes

Substituting this 6 amperes in Ohm's law, the total circuit resistance is found to be:

$$R = \frac{6}{6} = 1 \text{ ohm}$$

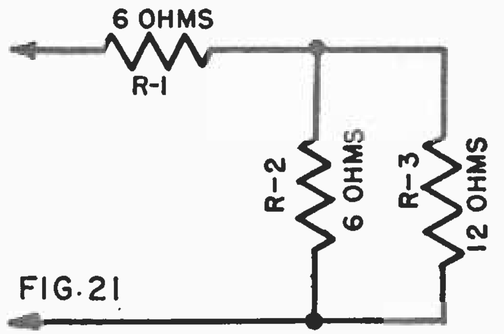


FIG. 21

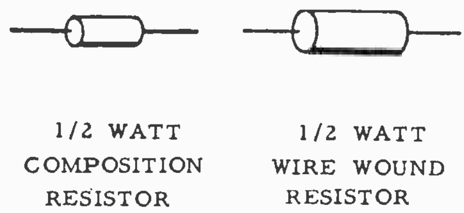


FIG. 22 RESISTORS

Quite often an electronic circuit will contain a combination of series and parallel resistances as in Fig. 21. To solve this type of problem, first determine the combined resistance of R2 and R3:

$$R\ (\text{total}) = \frac{6 \times 12}{6 + 12} = \frac{72}{18} = 4 \text{ ohms.}$$

This total value of R2 and R3 may be considered a single resistance which is in series with R1, and forms a simple series circuit as in Fig. 22b. This simple series circuit is solved as follows:

R (total) = 6 + 4 or a total of 10 ohms.

Power: The amount of work done by electricity is termed the Watt and one watt is equal to one volt multiplied by one ampere. This may be expressed as: $P = E \times I$ where E = Voltage in volts, I = the current in amperes. Also:

$$P = \frac{E^2}{R} \text{ and } P = I^2R$$

As an example, assume that a toaster draws 5 amperes at an applied voltage of 115 volts. It's wattage would then be: $P = 115 \times 5$ or 575 watts.

Methods Of Obtaining A Voltage: We've been talking about electric charges, what makes up a flow of electric current, and the properties of an electric current. It might be well to take a moment to look at some of the more common methods of producing electricity.

Electric Generator: Fig. 24 shows the basic principle of the electric generator. When a coil of wire is rotated between the poles of a magnet, a flow of current is developed in the coil by the action of the coil's winding passing through the magnetic field. You will learn more about this later in the section on basic magnetism.

Batteries: When two dissimilar metals are immersed in a chemical solution, and connected by a conductor, Fig. 25, a current will flow through the conductor. You will get a more detailed description of the "why" of this later in the section on batteries.

Thermocouple: If two dissimilar conductors are joined at each end, each end being maintained at a different temperature as shown in Fig. 26, a current will flow through

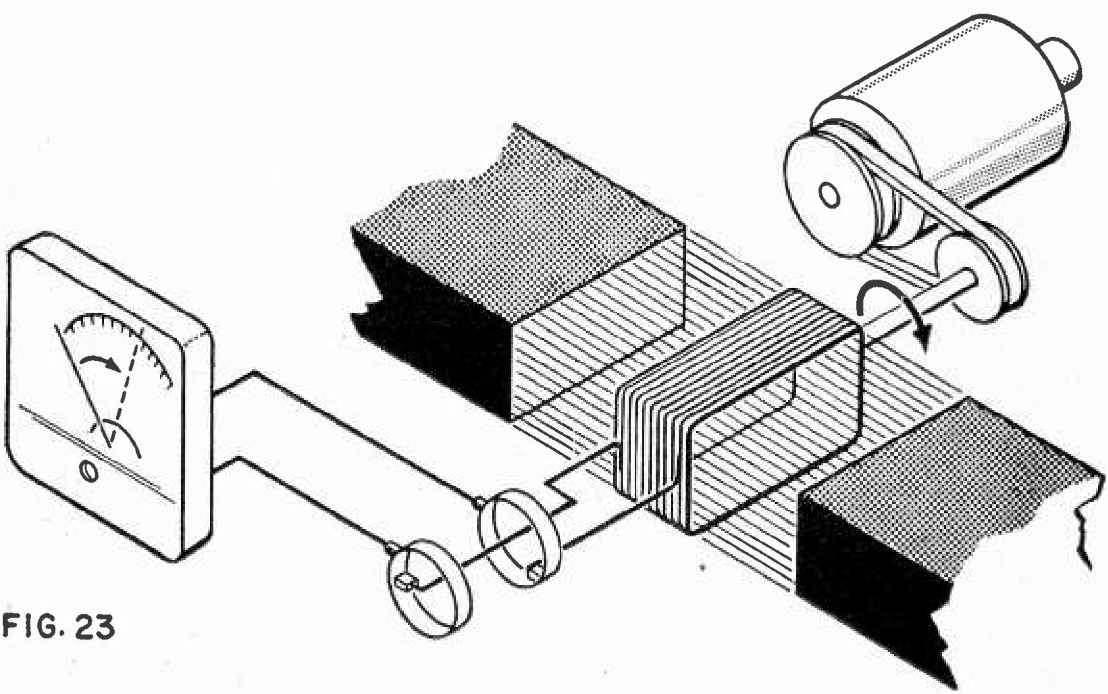


FIG. 23

the conductors. The amount of current developed depends upon both the materials from which the conductors are made and the temperature difference between the hot and cold junctions.

Piezoelectricity: Certain piezoelectric crystals, such as Rochelle salt and quartz are capable of generating a voltage when pressure is applied. Various "man-made" ceramic materials such as lithium sulphate and barium telanate. Piezoelectric materials are widely used in "crystal" microphones and phonograph cartridges.

Static Electricity: Earlier, we saw how friction can produce a static static electric charge. While not capable of being applied to the many uses of a continuous current flow, static electricity has found applications in such devices as electrostatic smoke precipitators, and electrostatic paint spraying. Machines used to develop static electricity can develop extremely high voltages.

Photovoltaic Cells: Certain materials have the property of generating voltage when exposed to light. Such materials include selenium, silicon and copper oxide. Specially processed silicon voltaic cells are capable of converting sunlight into electricity at efficiencies as high as 12%. Such cells are being used to recharge the batteries in space vehicles.

BASIC MAGNETISM

Before we go any further with our investigation of basic electricity, it might be well to become familiar with the basic principle of magnetism due to the very close relationship between electricity and magnetism.

Some of the basic principles and effects of magnetism have been known for centuries. The Greeks are credited as the ones who first discovered magnetism . . . they having noted that a certain type of rock had the ability of attracting iron. Later, the Chinese noted that an elongated piece of this rock had the useful property of always pointing in a North-South direction when suspended by a string as shown in Fig. 27. This was the beginning of our compass.

This strange stone which intrigued people over the centuries is actually a form of iron ore known as magnetite. Not all magnetite shows magnetic properties. Another name

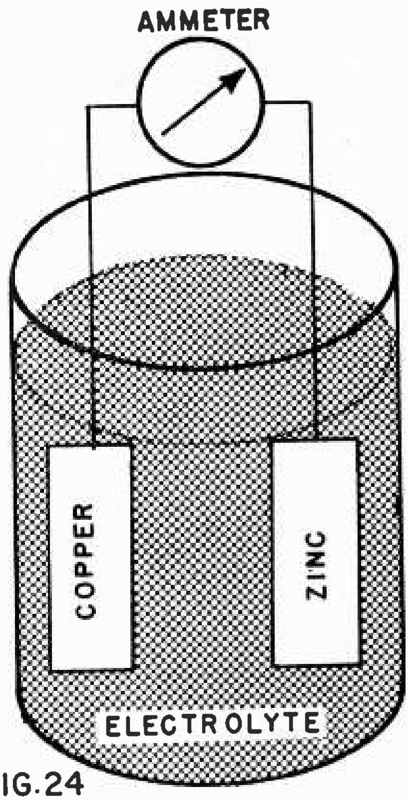


FIG. 24

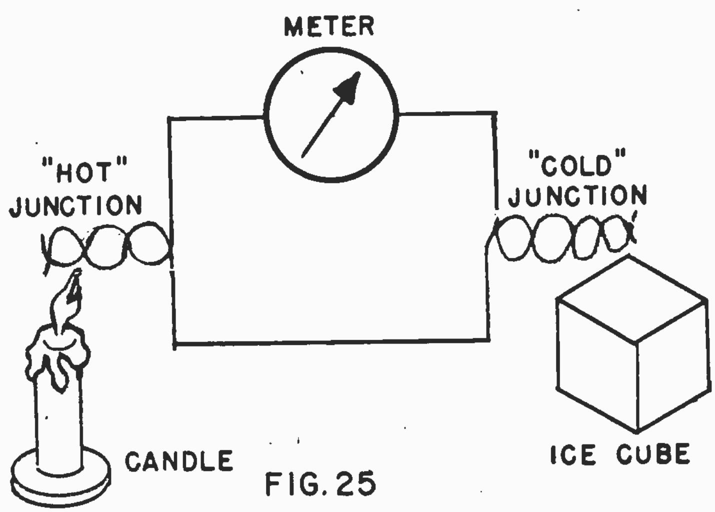


FIG. 25

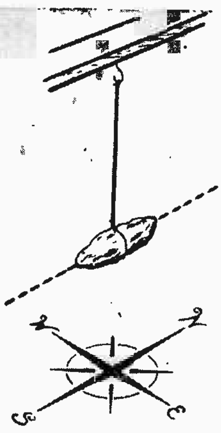


FIG. 26

for the magnetic variety of magnetite is lodestone . . . the term lodestone being derived from two separate words, lode and stone. The term lode stands for guide, hence lodestone means "guide stone."

All magnets, whether natural or man made, possess magnetic poles as illustrated in Fig. 28, which are commonly known as the magnet's north and south poles. As is the case of the electrical charges which we studied earlier between unlike magnetic poles and repulsion between like poles. It has been found that this magnetic attraction and repulsion force varies inversely as the square of the distance from the magnetic poles.

The Magnetic Field: We all know how a magnet exerts a force of attraction on a piece of magnetic material such as iron or steel. Also, when the north poles of two magnets are brought close together, they will try to repel each other, while there will be attraction between the north and south poles of two magnets. Although it is not clearly understood just what this force of magnetic attraction and repulsion is, it is convenient to visualize magnetic lines of force which extend outward from one magnetic pole to the other as illustrated in Fig. 29.

One way to visualize these magnetic lines of force is to compare them to taut rubber bands which will either expand or contract upon the application of an external force. The space around the magnetic poles which is influenced by these magnetic lines of force is termed the magnetic field.

What Makes A Magnet: One question that no doubt has cropped up in your mind is . . . Just what makes magnetic materials magnetic? Although we still don't have a really clear picture of what magnetism is, the following explanation seems to be pretty accurate as to just what makes some metals have the property of being able to be magnetized.

The atoms which compose such magnetic substances as iron and steel may be considered as tiny "magnets"; each with it's own north and south poles as illustrated in Fig. 30. In the non-magnetized state, the tiny magnets in the material are arranged in a random pattern so that their external magnetic effects are canceled out as in Fig. 30a. When an external magnetic field is applied, these minute magnets align themselves with the magnetic field so that their north and south poles are all facing in the same direction as in Fig 30b. The number of magnets aligned will depend upon the strength of the applied magnetic field. However, a point will be reached where a further increase in applied field strength will cause no further increase in alignment. This point is known as the material's saturation point.

A "permanent" magnet can be demagnetized if subjected to high enough temperature. This is because as the temperature of the magnet is increased the random vibration of its molecules increase until a point is reached where the magnetic domains are "shaken" out of the aligned position and assume a random orientation. The temperature at which this occurs is known as the Curie Temperature. This Curie Temperature varies for different magnetic materials.

A magnet can also be demagnetized by shock. Striking a magnet will cause it to lose all or part of its magnetism as this will "shake" the magnetic domains out of their aligned position. For this reason, you should never subject a permanent magnet to any sharp blow, or place it where it can be accidentally struck by other objects.

The force which produces this magnetic field is termed magnetomotive force and its relationship to a magnetic circuit is similar to electromotive force in an electrical circuit. Magnetic flux is the term applied to the total number of lines of magnetic force in a magnetic circuit and finds its counterpart in current in an electrical circuit. The unit of flux is the Maxwell.

Permeability: Magnetic lines of force can pass through various materials with varying ease. Iron and steel for example, offer little resistance to magnetic lines of force. It is because of this that these materials are so readily attracted by magnets. On the other hand, materials such as wood, aluminum and brass offer great resistance to the passage of magnetic lines of force, and as a consequence are not attracted by magnets.

The amount of resistance a material offers to magnetic lines of force is known as its permeability. Iron and steel for example are said to possess high permeability as they offer little resistance to magnetic lines of force. Non-magnetic materials have low permeability. For practical purposes, we can say that permeability is to magnetic lines of force as resistance is to an electrical circuit.

Electromagnetism: Any electrical conductor through which flows an electrical current will generate a magnetic field about it which is perpendicular to its axis as shown in Fig. 31. The direction of this field is dependent upon the direction of current flow, and the magnetic field strength proportional to the current strength. If this current carrying conductor is wrapped into a coil, forming a solenoid, magnetic field will be increased due to the fact that the field generated by each individual turn is added to the field generated by the other turns in the coil. If an iron core is inserted in this current carrying coil the generated field will be increased still further. This is because the lines of force are concentrated within the iron core which has considerably less reluctance than

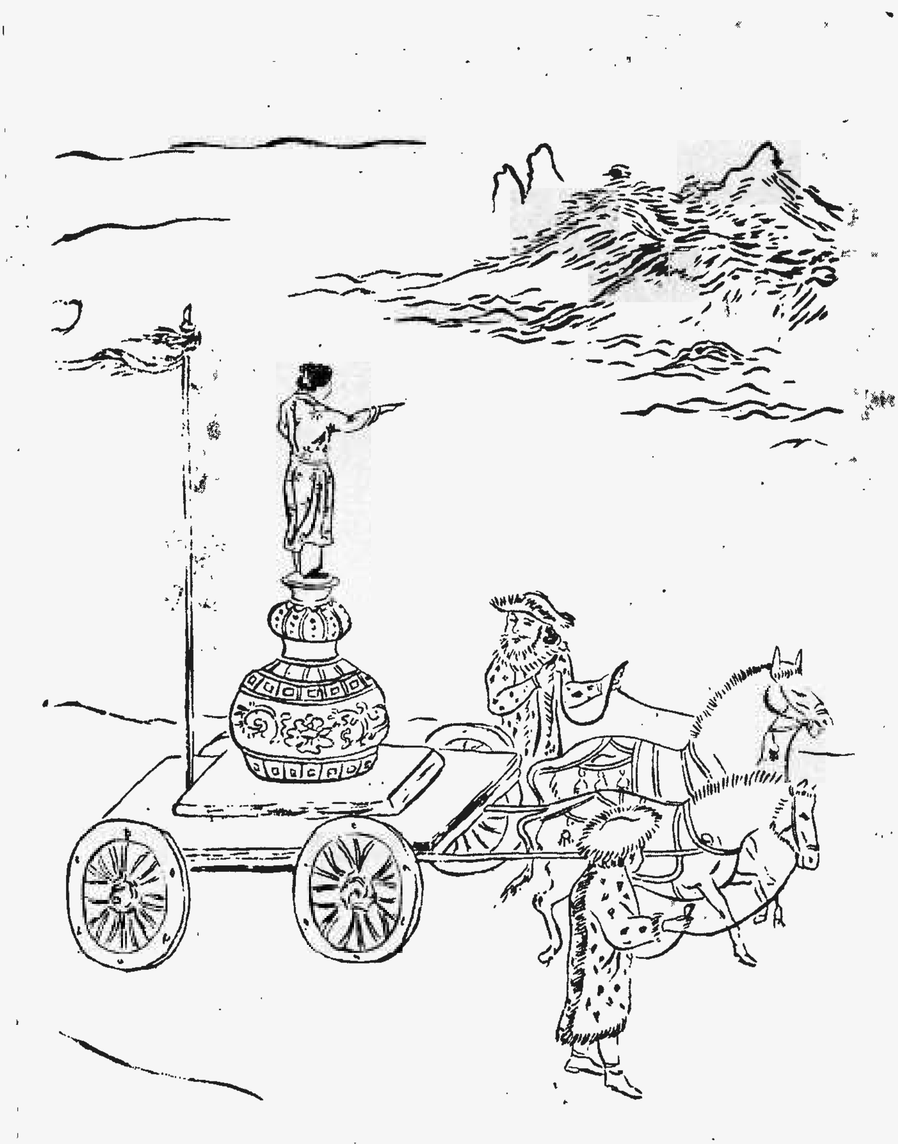


FIG. 27: Ancient Chinese print of the famous "south-pointing car." If such a device existed, it could have been nothing more than an oversize compass.

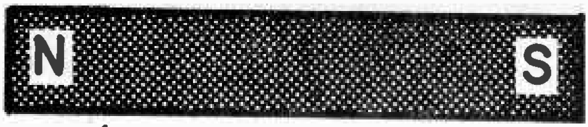


FIG. 28 BAR MAGNET

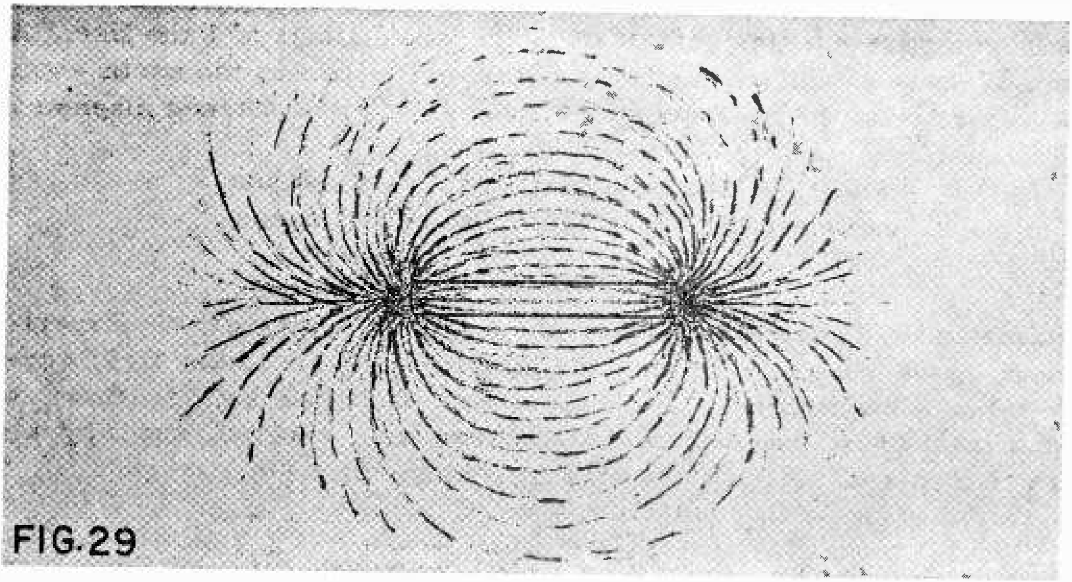
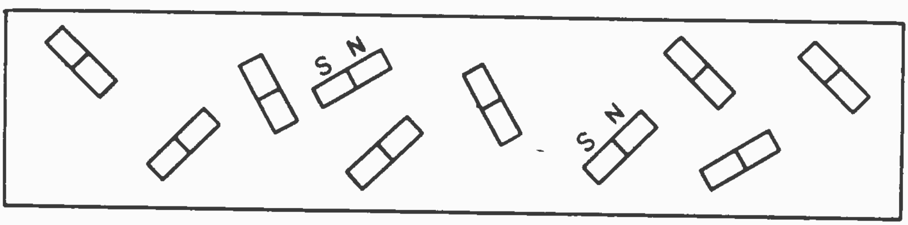
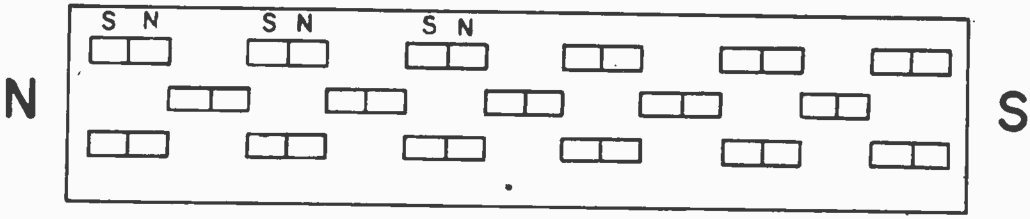


FIG. 29



(A)



(B)

FIG. 30

the surrounding air.

The magnetizing power of a multi-turn current carrying coil through which a core is inserted is proportional to the current flowing through the coil as well as the number of turns in the coil. The current through the coil is termed ampere turns. As an example; if a coil consisting of 200 turns is carrying 2 amperes, its ampere turns equal:

Ampere turns = 200 turns x 2 amperes or 400 ampere turns.

On the other hand, a coil of 100 turns through which a current of four amperes flows also has 400 ampere turns.

Ampere turns = 100 turns x 4 amperes or 400 ampere turns.

Electromagnetic Induction: We saw earlier how a current carrying conductor will generate a magnetic field which is perpendicular to the conductor's axis. Conversely, a current will be induced in a conductor when the conductor is passed through a magnetic field. The strength of this induced current is proportional to both the speed at which it passes through the field and the strength of the field. One of the basic laws pertaining to electromagnetic induction is Lenz's Law which states: "The magnetic action of an induced current is of such a direction as to resist the motion by which it is produced."

Fig. 32 illustrates two coils, A and B, which are placed in close proximity of each other. Coil A is connected in series with a switch and battery so that a current may be sent through it when the switch is closed, and coil B is connected to a current indicating meter. When the switch is closed, current will flow through coil A, causing a magnetic field to be built up around it. In the brief instant that the field is building up to maximum, it will "cut" the turns of coil B; inducing a current in it, as indicated by a momentary flick of the indicating meter. When the switch is opened; breaking the current flow through coil A, the field around coil A will collapse, and in so doing, will again induce a current in coil B. This time however, the flow of current will be in the opposite direction. The important thing to remember is that the conductor must be in motion with respect to the magnetic field or vice versa in order to induce a current flow.

Self Induction: As mentioned a short while ago, a magnetic field is built up around a coil at the application of current through the coil. As this field is building up, its moving lines of flux will cut the turns of the coil; inducing a counter electromotive force or counter EMF which opposes the current flowing into the coil.

The amount of counter EMF generated depends upon the rate of change in amplitude of the applied current as well as the inductance of the coil. This value of inductance is

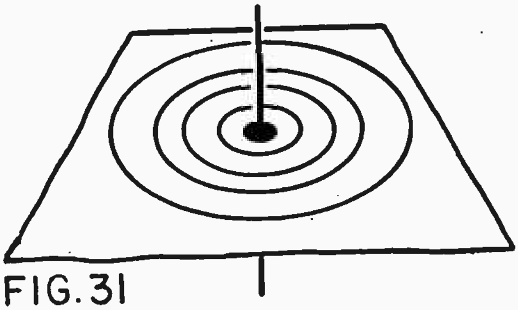


FIG. 31

dependent upon the number of turns in the coil; a coil with many turns will have greater inductance than a coil with few turns. Also, if an iron core is inserted into the coil, the inductance of the coil will increase sharply. The unit of inductance is known as the Henry.

Due to this counter EMF the current flowing through a coil does not reach a maximum value at the instant current is applied, but rather builds up slowly at first; increasing as the counter EMF decreases as illustrated by the curve in Fig. 33. Also, the current flowing in the coil does not immediately drop to zero the instant current is removed from the coil, but instead decreases as illustrated in Fig. 34. This is due to the stored magnetic field in the coil inducing a current in the turns of the coil as it collapses. The above effects are similar to mechanical inertia in which it takes a finite time for an object to get in motion after force is applied and also a finite time for it to stop when this force has been removed.

The Transformer: One of the most important and widely used application of magnetic induction is the transformer. Transformers find the major application in stepping up or down voltage and current.

Fig. 35 shows the basic construction of a typical transformer. While two separate winding core shown here, some transformers such as those used in radio and receivers, can have as many as five or six individual windings.

A transformer consists of two or more separate windings, electrically insulated from each other. One winding which is known as the primary winding, is fed from a source of alternating current.

The alternating current flowing through the primary induces a current in the secondary winding by virtue of magnetic induction. The transformer core is constructed from a relatively high permeability material such as iron which readily conducts magnetic flux between primary and secondary windings.

The alternating current flowing in the pri-

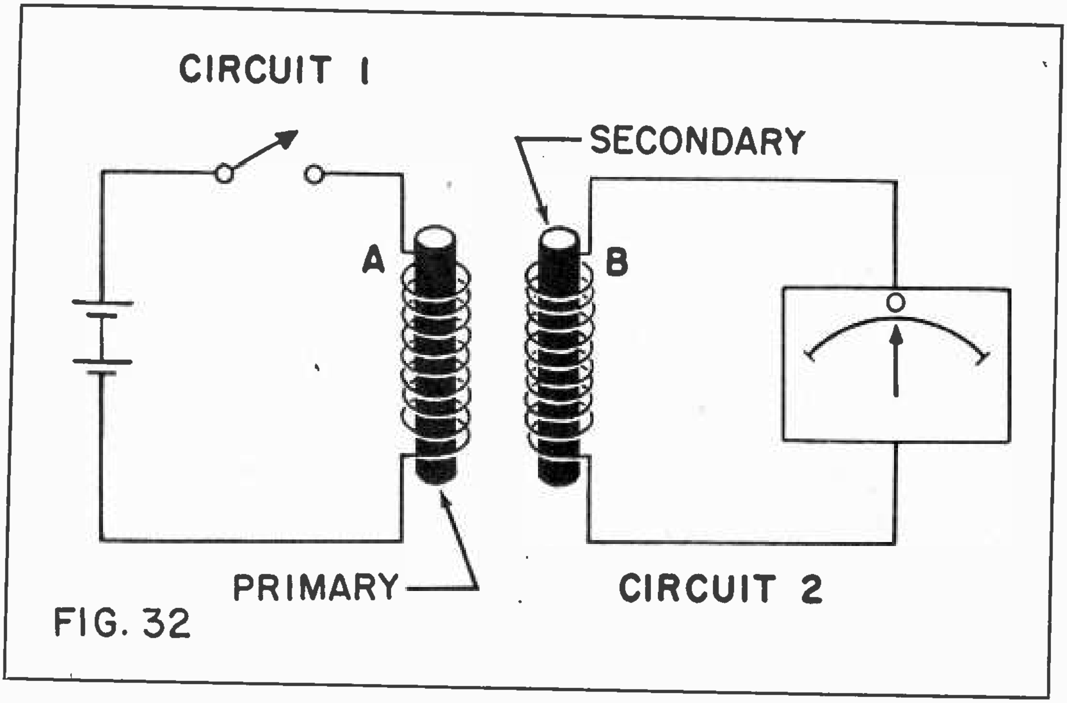


FIG. 32

mary of the transformer produces variation in the magnetic flux circulation in the transformer core which tends to oppose the current flowing in the primary winding by virtue of self-induction. This counter EMF is just about equal to the voltage applied to the primary winding when no load is connected to the transformer's secondary winding. This accounts for the fact that very little current flows through the primary winding when no load is connected to the secondary. The negligible current that does flow under this no-load condition is known as the transformer magnetizing current. As the current drawn from the secondary winding increases, the primary current will increase proportionately due to the reduction in the counter EMF developed in the primary winding.

In any transformer the ratio of the primary to secondary voltage is equal to the ratio of the number of turns in the primary and secondary windings. This is expressed mathematically as follows:

$$\frac{Ep}{Es} = \frac{Np}{Ns}$$

where Ep = primary supply voltage
Es = voltage developed across secondary
Np = number of primary turns
Ns = number of secondary turns

The above formula assumes that there are no losses in the transformer. Actually, all transformers possess some loss which must be taken into account.

Transformer Losses: No transformer can be 100% efficient due to losses in the magnetic flux coupling the primary and secondary windings, and eddy current losses in the transformer core.

Loss from magnetic flux leakage occurs

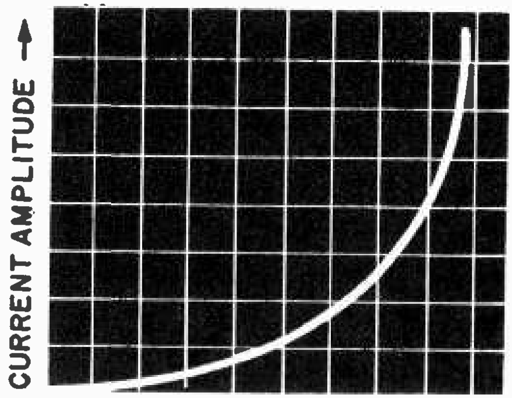


FIG. 33

when not all the flux generated by current flowing in the primary reaches the secondary winding. The proper choice of core material and physical core design can reduce flux leakage to a negligible value.

Practical transformers have a certain amount of power loss which is due to power being absorbed in the resistance of the primary and secondary windings. This power loss, known as the copper loss appears as heating of the primary and secondary windings.

There are several forms of core loss . . . hysteresis and eddy current losses. Hysteresis losses are the result of the energy required to continually realign the magnetic domain of the core material. Eddy current loss results from circulating currents induced in the transformer core by current flowing in the primary winding. These eddy currents cause heating of the core.

Eddy current loss can be greatly reduced by forming the core from a stack of individual sheets, known as laminations, rather than from a single solid piece of steel. Since eddy current losses are proportional to the square of core thickness, it is easy to see that the individual thin laminations will have much less eddy current loss as compared with a single thick core.

Another factor which effects eddy current loss is the operating frequency for which the transformer is designed to operate. As the operating frequency is increased, the eddy current losses increase. It is for this reason that transformers designed to operate at radio frequencies have air cores.

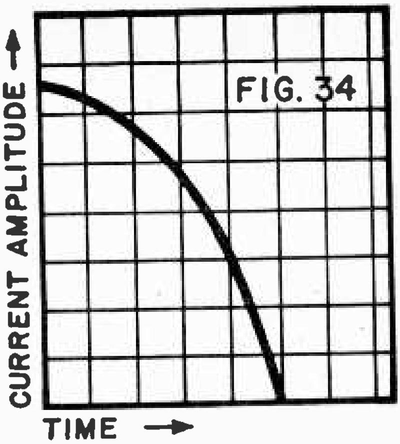


FIG. 34

Autotransformers: Another type of transformer, which uses a single tapped winding is shown in Fig. 36 and is known as an autotransformer. Although this type of construction does not permit electrical isolation between primary and secondary circuits, it is an inexpensive type of construction when compared with the conventional two winding transformer.

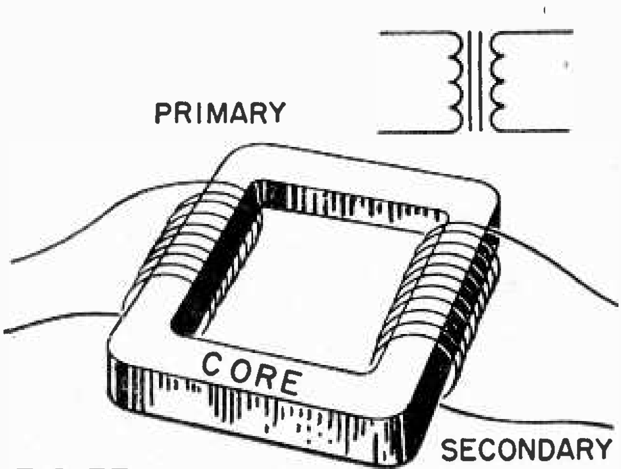


FIG. 35

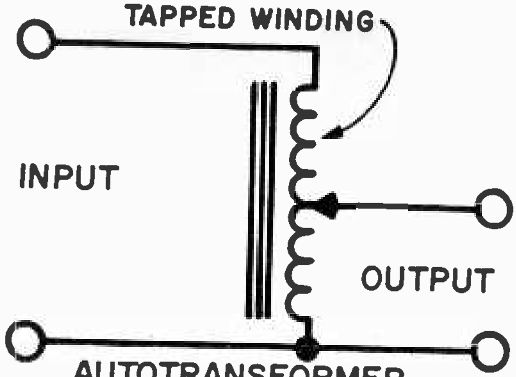


FIG. 36

Capacitance: Fig. 37 illustrates a battery and switch connected to a pair of slightly separated metal plates. When the switch is closed electrons from the upper plate are attracted to the positive terminal of the battery, and an equal number of electrons are repelled from the negative terminal of the battery into the lower plate. If the switch is now opened, the upper plate will have an excess of electrons while the lower plate has a deficiency of electrons. These two plates have thus become a charged electrical capacitor. If a conductor is now connected between the two plates, it will discharge the capacitor by allowing electrons from the lower plate to flow to the upper plate.

A capacitor thus has the property of storing electrical energy much as does an inductance with the exception that a capacitor stores the energy as an electrostatic field whereas an inductance stores electrical energy in the form of an electromagnetic field.

The quantity of electrical energy that can be stored in a capacitor depends upon the voltage applied to it as well as its capacitance. The capacitance of a capacitor depends upon the area of the two plates as well as the dielectric material between the plates. The larger the area of the two plates the greater will be the capacitance; also, as the spacing between the plates is increased, the capacitance will decrease for any given dielectric material.

The unit of capacitance is the farad. However, since this is much too large an amount of capacitance to be handled conveniently in practice, units of 1 millionth of a farad (microfarad) and 1 millionth of a microfarad (micromicrofarad) are employed instead.

Capacitors, the same as resistors, may be connected in either series or parallel in practical circuits. The formula for capacitors in parallel is:

$$C\ (total) = C1+C2+C3 \text{———}$$

Note that this formula is the same as that used for determining series resistance with the exception that units of capacitance are substituted for resistance.

In Fig. 38, three capacitors are shown connected in parallel. Their total capacitance is found as follows:

$$C\ (total) = .01mfd. + .02mfd. + .05mfd. \text{ or } .08mfd$$

When two capacitors are connected in series, the formula for determining their combined value is the same as used for de-

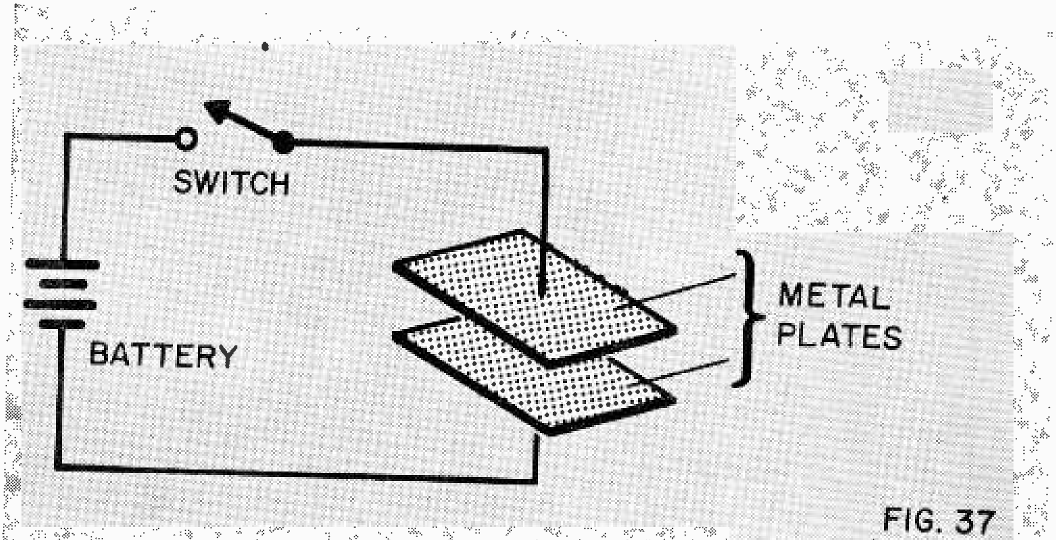


FIG. 37

termining parallel resistance except that units of capacitance are used instead. Thus:

$$C\ (\text{total}) = \frac{C1 \times C2}{C1 + C2}$$

Thus in Fig. 39, the total capacitance is:

$$C\ (\text{total}) = \frac{2\times 6}{2+6} = \frac{12}{8} = 1.5\ \text{mfd.}$$

If more than two capacitors are connected in series, the formula for determining their combined value is:

$$C\ (\text{total}) = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}$$

The dashed line indicate any additional capacitors that may be in the circuit.
By the use of this formula the total parallel capacitance in the circuit of Fig. 40 may be found as follows:

$$C\ (\text{total}) = \frac{1}{\frac{1}{2}+\frac{1}{3}+\frac{1}{6}} + \frac{1}{\frac{3}{6}+\frac{2}{6}+\frac{1}{6}} =$$

$$\frac{1}{\frac{6}{6}} = \frac{6}{6} = 1\text{mfd.}$$

It should be pointed out that the same units of capacitance should be used when solving a particular formula . . . either microfarads or micromicrofarads.

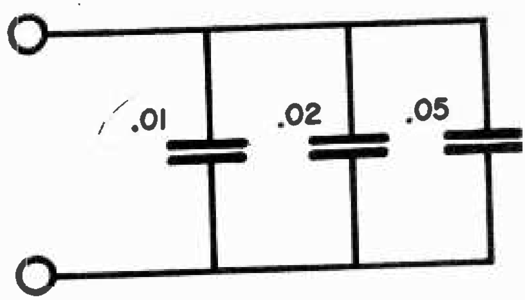


FIG. 38

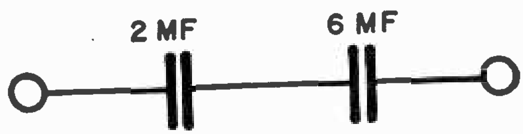


FIG. 39

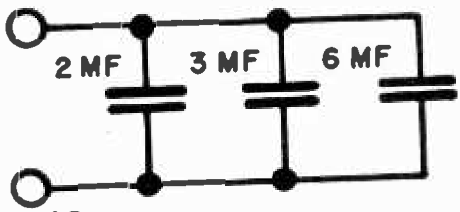


FIG. 40

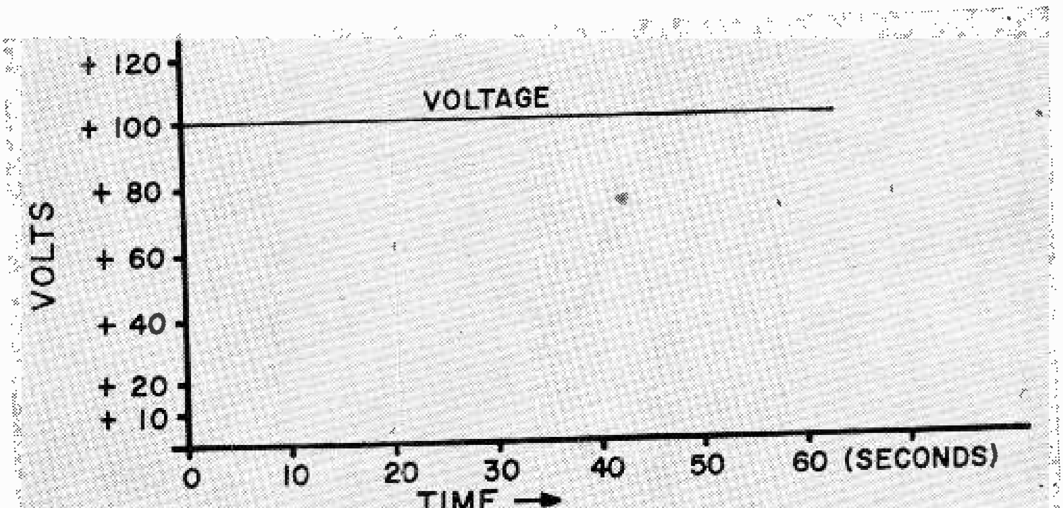


FIG. 41

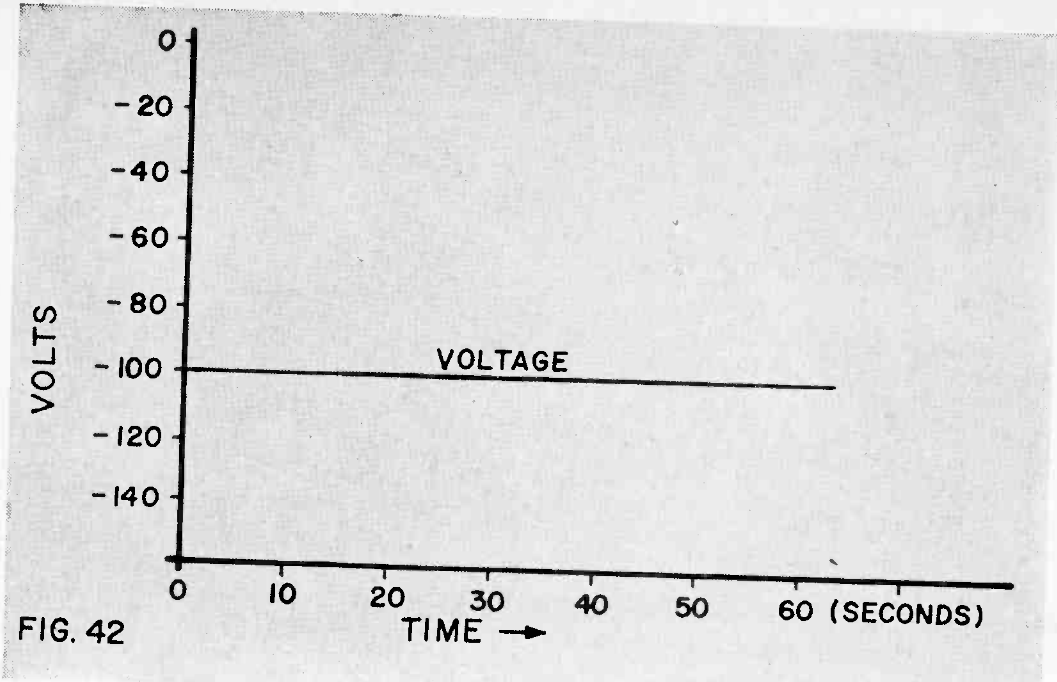


FIG. 42

ALTERNATING CURRENT CIRCUITS

Up to this point we have been dealing with direct current which, when once started, flows continually in one direction through the electrical circuit.

The second basic type of current is known as alternating current which as the name implies, alternates back and forth in an electrical circuit. To get a good understanding of the basic difference between alternating and direct current, let's take a look at Fig. 41, which shows a graphic representation of a direct current. The horizontal axis of the graph represents time in seconds, while the vertical axis is sealed off in voltage units. As you can see, the line indicating voltage remains constant at +100 volts over the entire length of time (60 seconds) indicated on the

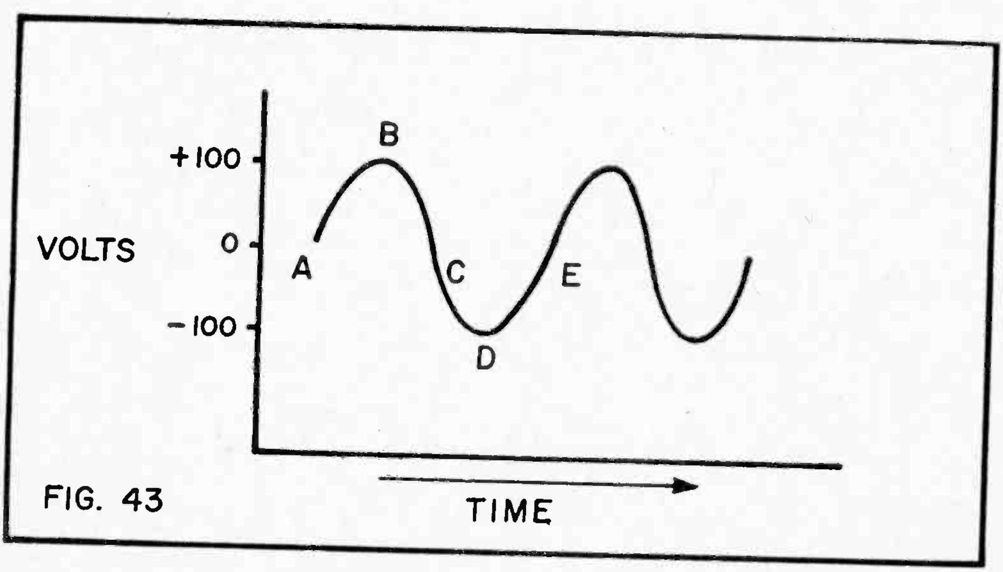


FIG. 43

graph of time vs. voltage.

Now, take a look at Fig. 42. Here, we see the same type of graphic representation of a direct current, although this time, −100 volts is indicated. Here again the value of direct current remains constant over the entire length of time indicated on the graph. (60 seconds)

The Sine Wave: The most common form of alternating current is the sine wave. Fig. 43 is the graphic representation of a sine wave, and as you can immediately see, it differs from the graph of direct current, in that value of voltage is constantly changing or alternating. Let's examine the curve a bit more closely. Starting at point A—the voltage rises to a maximum or peak value of +100 volts. (point B) At point B, the voltage starting to fall until it again reaches 0 volts (point C). From this point, the voltage becomes negative, increasing to a maximum negative value of −100V (point D). At this point, the voltage again reverses direction, falling to 0 volts (point E). This process continues as long as current is flowing in the circuit.

The alternating current (ac) curves shown in Fig. 43 is known as sinusoldal waveshape. Other ac waveshapes include square, sawtooth, and pulse.

Cycles, Period, and Frequency: Fig. 44 again shows a graph of a sine wave. The portion of the sine wave between points A and C represents one complete cycle of the wave, while the portion of the wave between points A and B equal a half-cycle. The length of time it takes the wave to complete a full cycle is called the period of the wave.

A common method of describing the repetition rate of the wave is in terms of frequency . . . A common measure being cycles per second. The frequency and period of a wave are directly interrelated and is expressed as follows:

$$\text{frequency} = \frac{1}{\text{period}} \text{ or period} = \frac{1}{\text{frequency}}$$

Thus, if the period of a wave is .001 second, the frequency of the wave is 1 ÷ .001 or 1000 cycles per second . . . abbreviated cps.

The same relationship holds true for waveshapes other than sine waves as illustrated in Fig. 45.

Peak, Average and Effective Values: Fig. 46 illustrates three basic waveshapes. In each of these, the maximum value is known as its peak value. Thus the sine wave has a peak positive voltage value of +30 volts and a peak negative voltage value of −30 volts. The peak to peak value of the sinewave is 30+30 or 60 volts. Thus, a certain wave with a peak value of 60 volts will have a peak value of 30 volts.

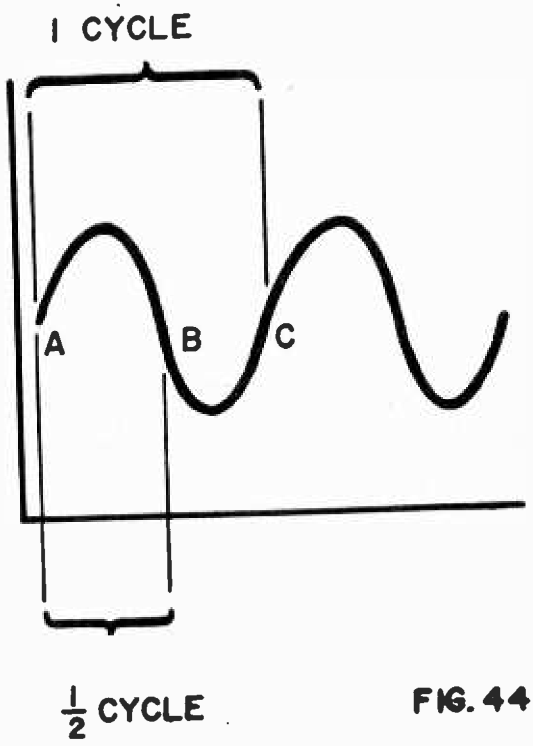


FIG. 44

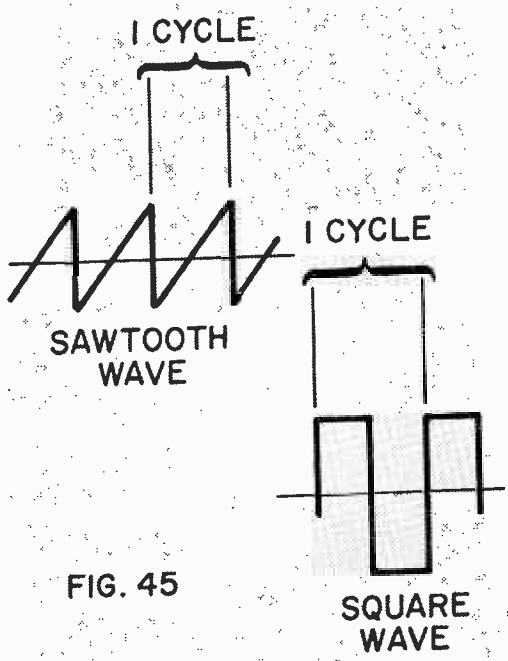


FIG. 45

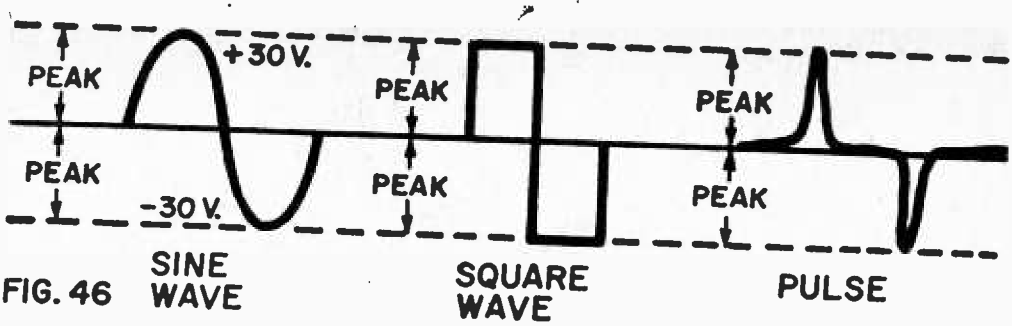


FIG. 46

The average value of a waveshape is the average height of the wave for one-half of its cycle as illustrated in Fig. 47a. While the average value of complex waveshapes, such as pulses, sawtooth, etc., varies for the particular waveshape, the average value of a sine wave is always 0.637 times its peak value. Thus, a 100 volt peak sine wave will have an average value of 100 x 0.637 or 63.7 volts.

The effective or root mean square (RMS) value of a sine wave is equal to 0.707 times its peak value. Another way of stating the RMS value will produce the same heating of a resistor as an equivalent amount of direct current passed through the same resistor. Thus, a waveshape with an RMS value of 100 volts will generate the same amount of heat in a resistor as 100 volts direct current passed through the same resistance value.

The effective or RMS value of sine wave voltages are almost always assumed unless otherwise stated. For example, the 120 volt house current is the RMS value . . . the peak value being 120x1.414.

The table, Fig. 48 gives the relationship between peak, average, and effective values of a sine wave. Note that these figures hold true only for a sine wave . . . being different for other waveshapes.

Phase: Fig. 49 is a graph of two sine waves. Sine wave A representing the voltage across a resistor and curve, B representing the current flowing through the same resistor. Notice that both the voltage and current start at the same point at the left-hand edge of the graph, (X) and rise to their maximum value at the same time. (Y) Thus, we see that the current flowing through the resistor is always in step, or phase, with the voltage across the resistor . . . both obtaining minimum and maximum values at the same time.

Fig. 50 again shows two sine waves, sine wave A representing voltage and sine wave B representing current. Notice that in this instance, the voltage sine wave starts earlier, and reaches its peak value sooner than the current sine wave. Under these conditions, the voltage sine wave is said to lead the current sine wave. Stating this another way, we can say that the current sine wave is lagging the voltage sine wave.

The amount of phase difference or phase angle is measured in degrees as shown in Fig. 51. The phase angle between two out of phase waves can be determined by marking their common time axes as shown in Fig. 51, and the phase angle read as the distance between the tow sine waves as they cross the time axes. Thus, the two sine waves shown in Fig. 51 are out of phase by 45 degrees.

Behavior of Capacitor in AC Circuit: Earlier, we learned that a capacitor consists of two metallic plates separated by a dielectric such as air. When a capacitor is connected to a source of direct current, it will become charged, one plate acquiring a surplus of electrons and the other plate a deficiency of electrons. If this charged capacitor is now short circuited by connecting a wire between its oppositely charged plates, it will discharge . . . electrons flowing through the wire from the plate with the surplus of electrons to the plate with the deficiency of electrons.

Now, let's see how a capacitor behaves when connected. to a source of alternating current, Fig. 52 represent the voltage im-

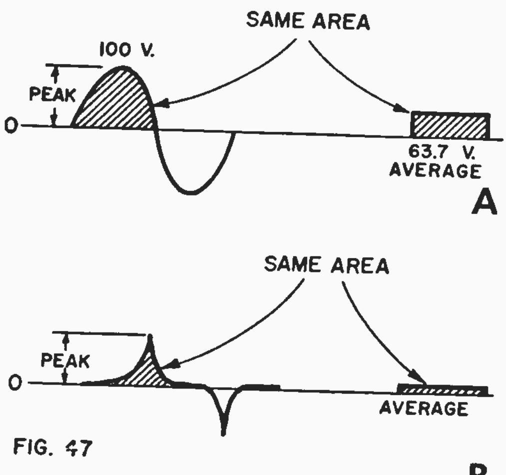


FIG. 47

pressed across the capacitor and the resulting capacitor charging and discharging current. During the first quarter cycle of voltage applied across the capacitor, the capacitor draws charging current. This charging current is maximum at point X (curve B) as the capacitor is fully discharged. As the voltage impressed across the capacitor rises to its peak value, point Y on curve A, the capacitor's charging current decreases as it is becoming fully charged as shown between points Y and Z in curve B.

During the next quarter cycle, the voltage applied across the capacitor begins to fall, reaching zero at point Z on curve A. The charged capacitor now discharges, current now flowing out of the capacitor in a direction opposite to the charging current. This discharge current is represented between points Y and Z in curve B.

Capacitive Reactance: Since we have seen that a capacitor has the ability to pass alternating current, we might suspect that a capacitor would offer some opposition to the flow of alternating current, much as a regular resistor does in a direct current circuit. This is quite true, although the opposition offered to the flow of alternating current by a capacitor is different in several respects. First, the flow of alternating current through a capacitor does not dissipate power. Second, the amount of alternate current passed by a capacitor is dependent upon the frequency of the applied voltage . . . the capacitor passing more current as the applied frequency is increased. Third, the voltage across a capacitor is out of phase with the current flowing through the capacitor . . . the current leading the voltage by 90°. The opposition offered to ac by a capacitor is known as reactance, and is measured in ohms as in the case of resistance. The symbol for capacitive reactance is Xc.

Behavior of Inductance in ac Circuit: In the section on magnetism, we saw that an inductance consists of a number of turns of wire wound into a coil. Direct current readily flows through such an inductance as it is limited only by the resistance of the wire which is used to wind the coil.

Let's now take a look at what happens when we pass alternating current through an inductance. Fig. 53 A, shows the ac voltage applied across an inductance, while Fig. 53 B, shows the current flow through the same inductance. When voltage is first applied to the inductance, point X on curve A, current tries to flow through the coil, but is "bucked" by the magnetic field which it immediately generates. When the voltage across the coil reaches its peak value, point Y on curve A, the current through the coil begins to build up, point X on curve B, reaching a maximum at point Y on curve B. Thus you can see that

Fig. 48: Ratios for the Sine Wave

Effective value to peak value	0.707:1
Peak value to effective value	1.414:1
Average value to peak value	0.637:1
Average value to effective value	0.902:1

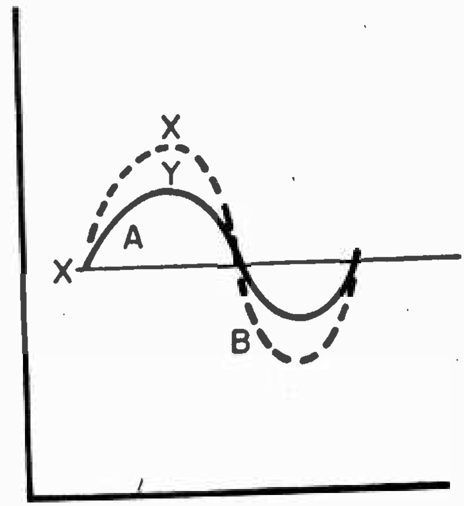


FIG. 49

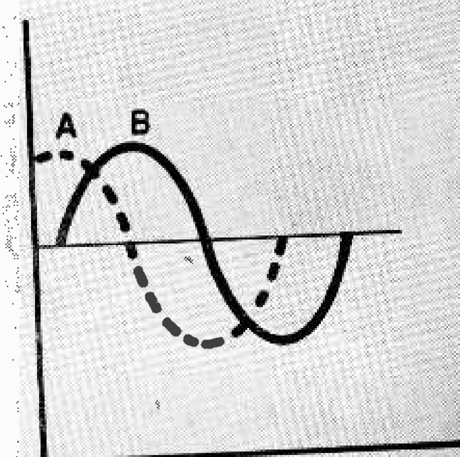


FIG. 50

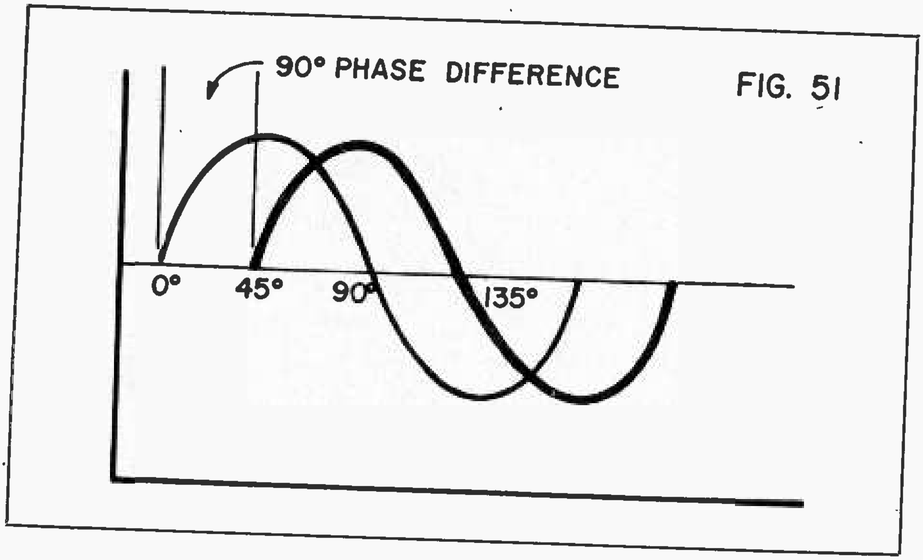


FIG. 51

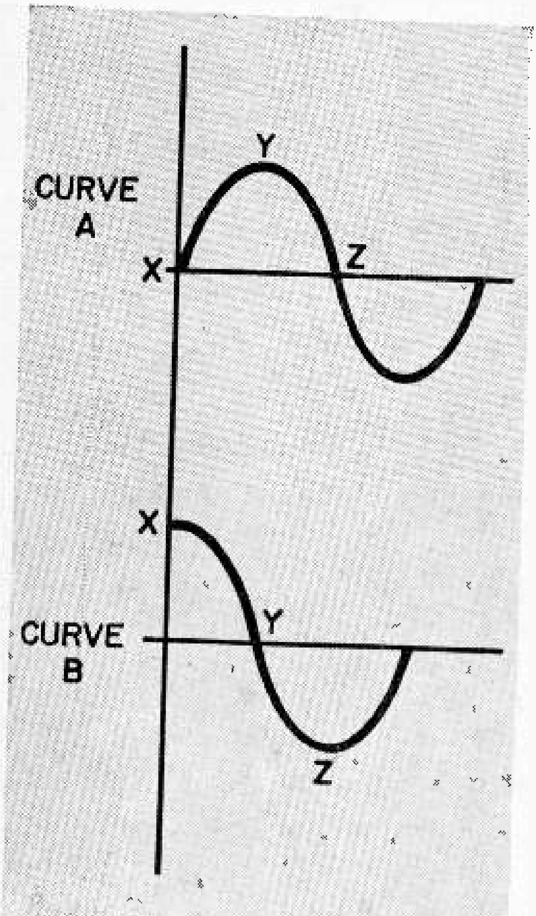


FIG. 52

the current through the inductance *lags* the voltage across the inductance by 90°.

While the energy stored in a capacitor is the result of electrostatic charges, the energy stored in an inductance is the result of magnetic energy.

Inductive Reactance: Inductance like capacitance offers opposition to the flow of current. In the case of inductance, this is known as inductive reactance. As in the case of a capacitor, no heat is generated by the passage of current through an inductor. As in the case of capacitor reactance, inductive reactance is measured in ohms. The symbol for inductive reactance is X_L.

We stated that a capacitor will pass more alternating current as the frequency of the current is increased. Just the opposite is true in the case of an inductance which will pass direct current with essentially no loss but offer considerable resistance to the passage of high frequency currents. Thus we can say that capacitive reactance decreases with an increase in frequency, while inductive reactance increases with an increase in frequency.

Determine Reactance: The formula for determining capacitive reactance is:

$$X_c = \frac{1}{2\pi fc} \text{ where . . .}$$

X_c = capacitive reactance in above
f = frequency of applied voltage in cycles per second.
C = capacitance in farads.

When the capacitive reactance is known, the value of the unknown capacitor can be determined by transposing the above formula to read:

$$C = \frac{1}{2\pi f X_c}$$

The inductive reactance formula looks like this . . .

$X_L = 2\pi fL$ where . . .
X_L = inductive reactance in ohms
f = applied frequency in cycles per second
L = inductance in henrys.

This formula may be transposed to determine an unknown value of inductance as follows:

$$L = \frac{X_c}{2\pi fL}$$

Impedance: Let's take a look at Fig. 54 Here, we see an alternating current circuit composed of an inductance, capacitor, and resistor. The sum total of the inductive reactance of the inductance, capacitive reactance of the capacitor and the pure resistance of the resistor is known as impedance which is expressed by the symbol Z.

Impedance is expressed in ohms and the following modified form of Ohm's law can be used to determine impedance.

$$E = I\ Z,\ I = \frac{E}{Z},\ Z = \frac{E}{I}$$

Thus, the total circuit impedance of the alternating current circuit shown is 2000 ohms (1500 + 100 + 400 = 2000)

Pulsating Current: A third type of current that is neither purely direct or alternating current is known as pulsating current. Fig. 55 shows such a pulsating current. Notice that although the wave fluctuates from +50 to +70 volts, it always remains positive in value. This is in contrast to alternating current which fluctuates between positive and negative values.

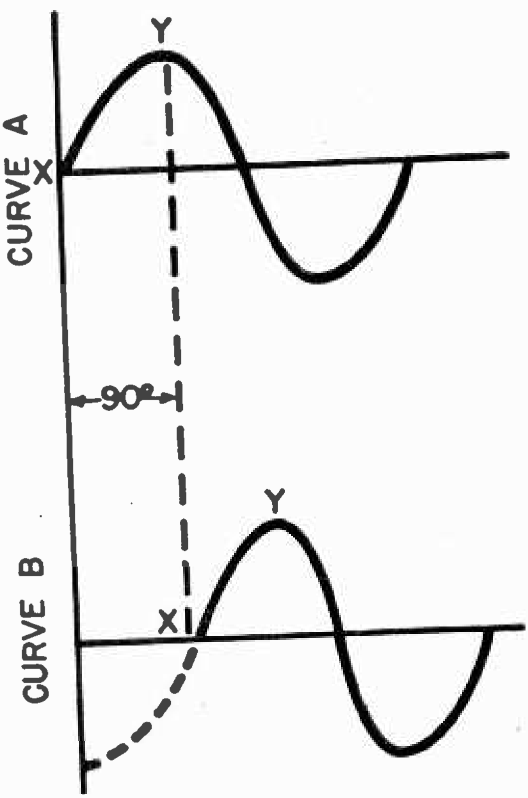


FIG. 53

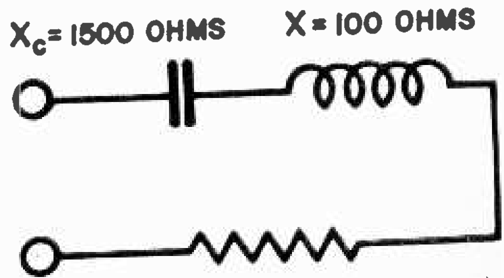


FIG.54

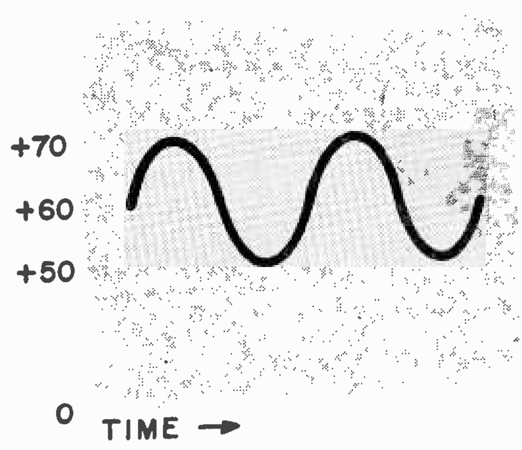
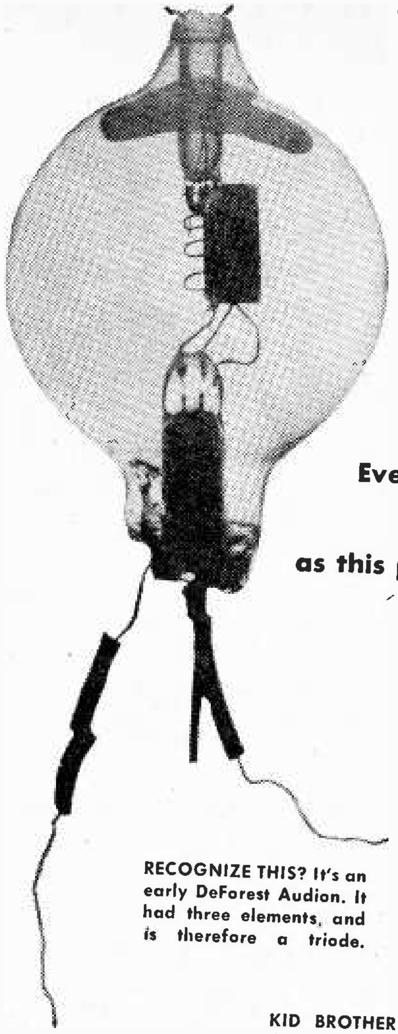


FIG. 55

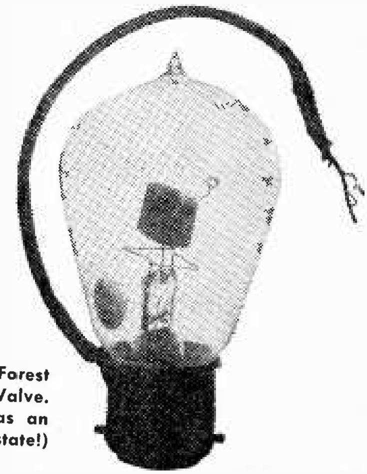
DOC'S LITTLE BOTTLE

Everything begins with a beginning, and the radio tube was no exception as this piece of history will prove

By C. F. Rockey



RECOGNIZE THIS? It's an early DeForest Audion. It had three elements, and is therefore a triode.



KID BROTHER to the DeForest Audion is this Fleming Valve. This two-element tube was an early diode . . . (Not solid state!)

JUST why was the vacuum tube invented? What needs or requirements inspired this device which has changed man's life almost as much as did gunpowder or the printing press? Was it the result of a lucky accident, or the end-product of hours of agony? Let us see.

Consider the state of the communications art at the turn of the century. Wire telegraphy was very much of a going business and was the nerve-system of the many railroads. Coast-to-coast telegraphy was a routine matter. What about telephony? In purely local service, the telephone was most effective. Talking beyond 50 miles was difficult however, and beyond five hundred, practically impossible. Clearly, something was needed to improve this situation before the telephone could grow up to what we know today.

Then There Was Wireless. True, Guglielmo Marconi had shown that transoceanic transmission was possible and each day more ships were being equipped with the spark-coils and coherers then used. Again, the range was limited. Only the extremely powerful coastal stations could be heard much beyond a thousand miles. Only telegraphy was practical; to talk via wireless was the dream of a few crazy experimenters. Television wasn't even considered.

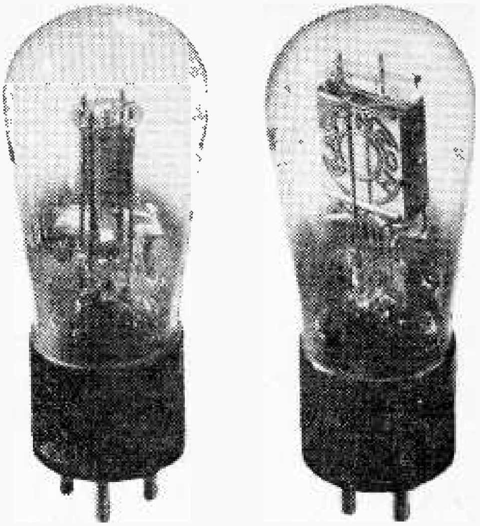
Behind all of these roadblocks was a common question. How can a weak ac signal voltage be made stronger without completely changing its characteristics?

A telephone signal is an ac voltage of widely-varying frequency and amplitude. As it travels down the line it gets rapidly weaker, due to the resistance of the line wires and the leakage of current between them. Even on a modern cable the signal power available at the end of a 50-mile line may be less than a thousandth of its original strength.

The wireless receiving problem is even tougher, for here we must deal with minute, 1/1,000,000 volt signals in all but the shortest-range communication.

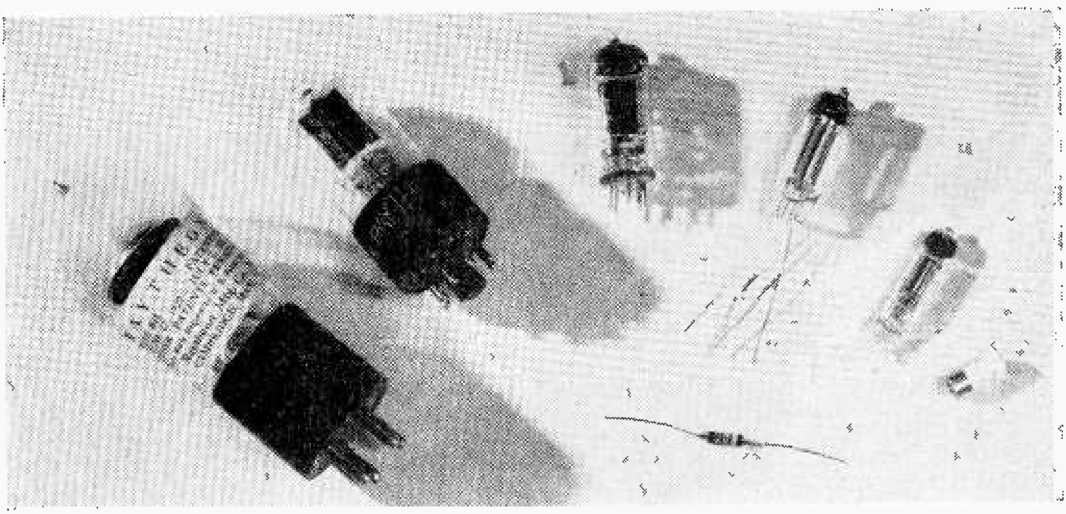
The Wire-Telegraph people had this problem neatly solved. Samuel F. B. Morse had found quite early that a telegraph signal too weak to operate the "sounders" then in use could still energize an electromagnet containing many hundreds of turns of wire. This magnet could close a delicate pair of contacts in series with a strong battery at the end of a long line. Thus the *telegraph relay* was born. By placing these relays strategically along the line, long-distance telegraphy becomes easy.

But a telegraph signal is the simple interruption of a steady current. You either have a dot, a dash, or nothing. Not so with a telephone signal. Here you have a continuously-varying current, not just an "off-on" one. So a telegraph relay won't work here. What to do? Of course there's always the possibility of fastening a sensitive telephone receiver directly to a transmitter, allowing the receiver to "talk into" a new, freshly-powered circuit. This should make a telephone relay or "repeater." Such gadgets were, in fact, made and sold under the name of "Multi-audi-phones" many years ago. But they're noisy, touchy in adjustment and distort the signal badly. Such a thing was hardly a commercial success.

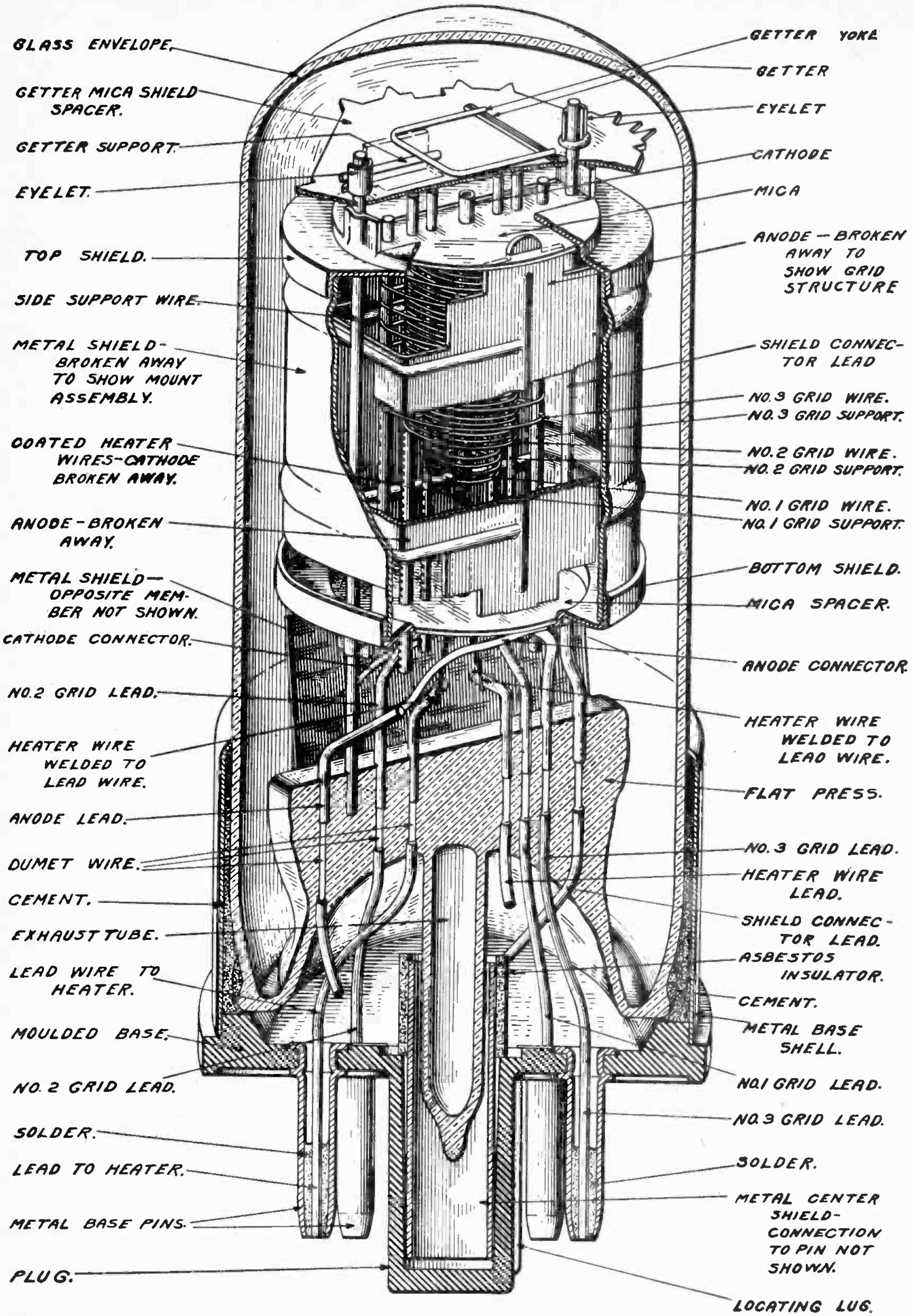


FAMOUS FIRST is this Type 27, believed to be the earliest of the indirectly heated cathode types (left) and Type 71, a directly-heated cathode type circa 1926. Note the addition of the base.

Dr. Lee DeForest, freshly graduated from Yale University, was interested in wireless reception. He was searching for a more-sensitive and reliable "detector" for wireless signals than the slow and delicate coherers then in use. He tried all kinds of gimmicks; he dipped silver and platinum electrodes into pastes made of various chemicals, and stuck wires into gas flames. But all that these things did was to make the weak signals audible in a pair of headphones, it didn't make them any louder or stronger. The same was true of an



FAMILY PORTRAIT. Here is a sum total of 25 years of tube development. At the far left is a BH Rectifier tube, then an octal-base tube followed by a miniature, two sub-miniatures and a germanium diode. At far right is transistor.


GLASS ENVELOPE.
GETTER MICA SHIELD SPACER.
GETTER SUPPORT.
EYELET.
TOP SHIELD.
SIDE SUPPORT WIRE.
METAL SHIELD- BROKEN AWAY TO SHOW MOUNT ASSEMBLY.
COATED HEATER WIRES-CATHODE BROKEN AWAY.
ANODE-BROKEN AWAY.
METAL SHIELD- OPPOSITE MEMBER NOT SHOWN.
CATHODE CONNECTOR.
NO.2 GRID LEAD.
HEATER WIRE WELDED TO LEAD WIRE.
ANODE LEAD.
DUMET WIRE.
CEMENT.
EXHAUST TUBE.
LEAD WIRE TO HEATER.
MOULDED BASE.
NO. 2 GRID LEAD.
SOLDER.
LEAD TO HEATER.
METAL BASE PINS.
PLUG.
GETTER YOKE
GETTER
EYELET
CATHODE
MICA
ANODE - BROKEN AWAY TO SHOW GRID STRUCTURE
SHIELD CONNECTOR LEAD
NO. 3 GRID WIRE.
NO. 3 GRID SUPPORT.
NO.2 GRID WIRE.
NO. 2 GRID SUPPORT.
NO. 1 GRID WIRE.
NO. 1 GRID SUPPORT.
BOTTOM SHIELD.
MICA SPACER.
ANODE CONNECTOR.
HEATER WIRE WELDED TO LEAD WIRE.
FLAT PRESS.
NO. 3 GRID LEAD.
HEATER WIRE LEAD.
SHIELD CONNECTOR LEAD.
ASBESTOS INSULATOR.
CEMENT.
METAL BASE SHELL.
NO.1 GRID LEAD.
NO.3 GRID LEAD.
SOLDER.
METAL CENTER SHIELD-CONNECTION TO PIN NOT SHOWN.
LOCATING LUG.

interesting device called a "Fleming Valve," invented by an Englishman at about this time.

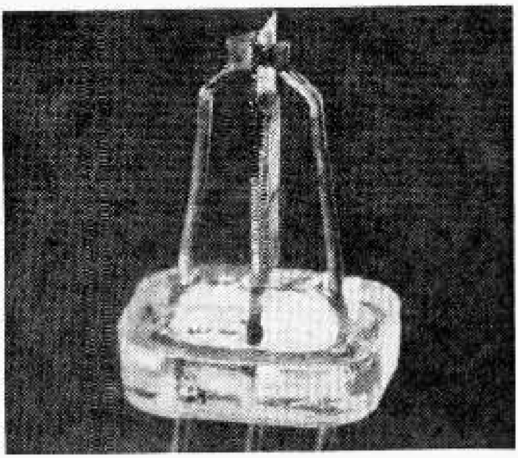
The Fleming Valve consisted of a wire filament, just like the filament in an ordinary incandescent lamp, sealed into a more-or-less gas-free glass bulb. Also within the bulb was a small sheet of platinum, about 1-in. square, fastened about an eighth of an inch from the filament. When the filament was brought to yellow heat, by means of a battery, and the filament and platinum sheet (henceforward called the "plate") connected to a wireless tuning coil and headphones, the signals became clearly audible, but they were still weak.

Then came one of those strokes of genius which occur so seldom, but when they do, result in a real breakthrough. Dr. DeForest went to a small lamp-factory in lower New York and had them make for him a *modified* Fleming valve. Sure, his gadget had the filament and plate as before, but between these was a little zigzag of platinum wire, which he called the *grid*. This is what put the kick into the electron bottle.

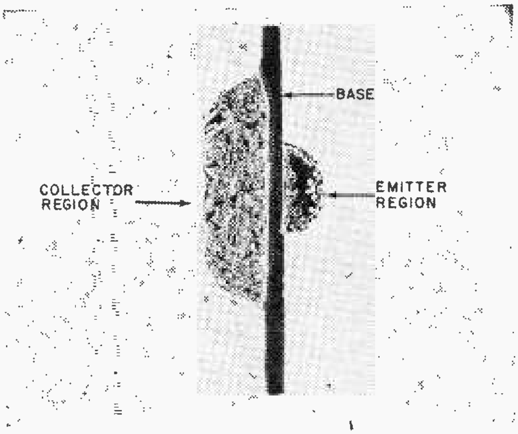
Doc DeForest Heated the filament of his new litle gewgaw and connected a battery and headphones between filament and plate, being careful to make the plate positive with respect to the filament. Lo and behold, the signals not only came through but were *four or five times stronger* than anything heard before! Not only did this thing 'detect' the signals, it also *amplified* them.

It seems that when the plate of this gadget is made positive with respect to the filament, the millions of electrons which are boiled out of the hot filament are attracted to the plate, resulting in a flow of current from filament to plate. These electrons have to pass between the wires of the grid. When a varying voltage is connected between the grid and the filament, the field about the grid may either add-to or subtract from the attractive field of the plate. Thus, as the grid voltage varies, it superimposes its pattern of variations upon the filament-plate current. A surprisingly small variation of grid voltage may cause thereby a large variation in filament-plate electron current. Thus, amplification is obtained. A further more-detailed discussion of this process may be found elsewhere within this book, but this is the approximate idea.

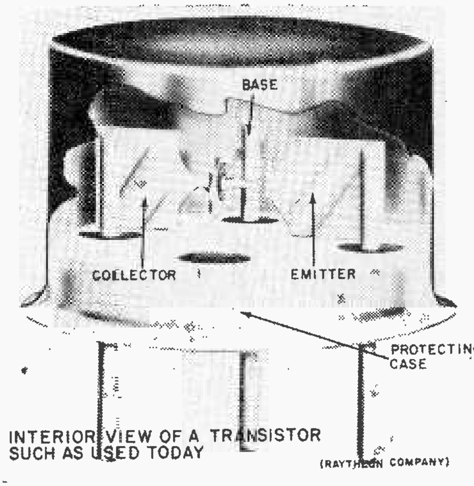
Not only did the three-element vacuum tube, or "Audion" as Dr. DeForest called it, revolutionize wireless, but it also solved the long-distance telephony problem. It proved to be the ideal telephone relay. Weak voice voltages, fed into the grid circuit became much stronger voice currents within the plate circuit. Thus the losses in the line are overcome and good communication is a reality. Just prior to World War I coast-to-coast telephony became practical, and it was the De-



HERE'S THE GUTS of a Raytheon CK-722 transistor, a great technological advance since the old tubes.



ACTUAL PHOTOMICROGRAPH of a typical fusion-alloy transistor. Note a dendritic assembly is used.



INSIDE A RAYTHEON transistor, we see the contact terminals and the supports for the fusion-alloy base.

Forest Audion, that *first amplifying vacuum tube,* in modified form that made it possible.

Before the Audion, speech by wireless was possible but it required the use of an electric arc, something like in a motion-picture projector, to generate the high-frequency signal. This sounds simple, but arcs have a habit of being unstable, noisy, and generally most impolite when used as practical radio signal sources. As a result most folks thought that voice transmission by wireless was a pipe dream. During his experiments with the Audion, Dr. DeForest discovered that if you take some of the signal energy from the plate circuit and lead it gently around to the grid circuit, the system will act like a generator of high-frequency currents. Furthermore this method is clean, noiseless and altogether much more satisfactory than anybody's huffy old arc. And, having such a nice high-frequency generator, all you had to do was to connect a carbon telephone transmitter in series with the antenna and you could transmit radio-telephone signals nicely. After designing a special higher-powered tube for this purpose in the early nineteen hundreds, the good Doctor tried it out. Response from the listening audience, then exclusively radio amateurs, experimenters and shipboard operators, was instant and drastic. Imagine the consternation in a listener's mind when those old headphones, which previously had produced only the raspy dit-dahs of spark telegraphy, suddenly spouted speech and music!

Not All Were Enthusiastic. The writer remembers reading in a wireless textbook, written about 1910, words to the following effect: "Although the Audion is an interesting and sensitive device, it is probably too delicate and difficult in adjustment ever to become truly practical." Today we have a multibillion

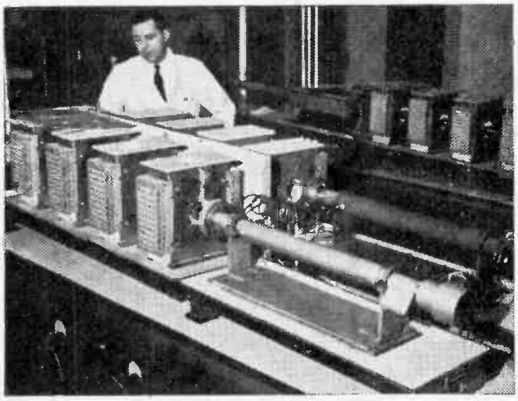
MINIATURE TUBE PRODUCTION is carried on in almost sterile conditions. Tubes are assembled from the inside-out, using small tack-welders. After assemble of parts, all metal parts are heat-cleaned, then assembled in glass.

dollar industry, largely based upon this "impractical" device.

World War I gave the vacuum tube the "economic vitamins" it needed to grow to real greatness. Men like Irving Langmuir, H. J. Van der Bijl and countless others transformed it from a delicate, temperamental gadget into a reliable device that could be mass-produced for military and civilian needs. The rise of radio broadcasting, during the early twenties brought it into the public eye. Thousands of people suddenly became concerned with the behavior of the filament, plate and grid as they built "neutrodynes" and "reflex circuits" and listened to jazz through tin-horn loudspeakers. The vacuum tube also gave voice to the formerly silent movies, and revitalized the phonograph.

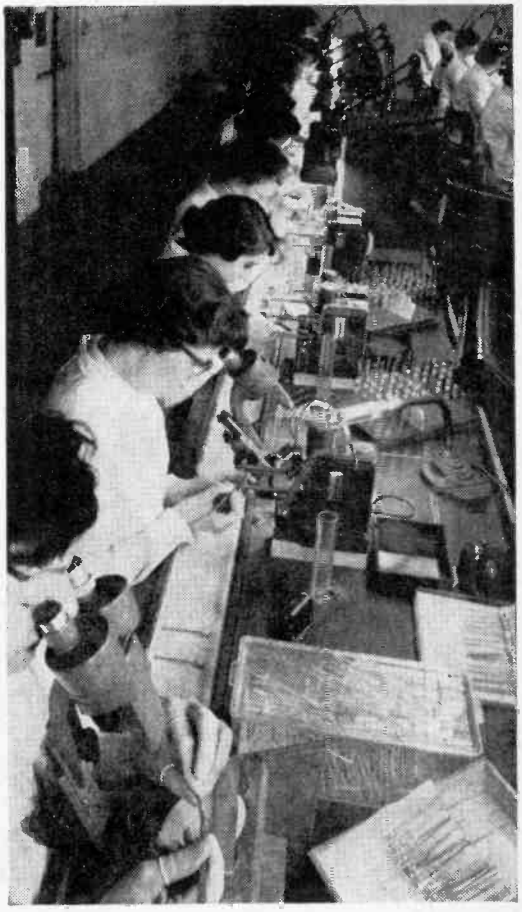
The Nineteen-Thirties saw the development of the modern, multigrid types; tetrodes and pentodes, as well as the "metal tube." Here the familiar glass bulb was replaced by a thin steel shell for better electrical shielding and mechanical durability. One story which arose at this time was told of a canny Scot who bought a metal tube to replace in his radio. The next day he returned it to the dealer with the comment: "It's nae guid, lad; a mon dinna' can read by its licht." The thirties also introduced the vacuum tube to industry as a sensitive and reliable control device in automatic manufacturing processes. All-electronic television as we know it today was developed then. It is safe to say that television would have been impossible without Doc DeForest's little bottle. And from television grew those radar techniques which helped win World War II.

Today the vacuum tube is being strongly challenged by the transistor. But it will be a long time before we drain the last slug from this most marvelous jug.



ZONE REFINING furnace is what this device is called. It's used for purifying Germanium in producing transistors. Selected blanks are heat-treated.

TRANSISTOR PRODUCTION is carried out in "dry boxes" to exclude dust and moisture. Operators work through gloves. Insides must be clean.



ASSEMBLING SUBMINIATURE tubes is done under microscopes. Each operator is equipped with microscope and miniature welder. Note rubber fingers.

The Vacuum Tube

We tend to take radio tubes for granted these days . . . Here's a complete rundown from the inside-out, how they work and why

THE vacuum tube is an inexpensive and practical device for controlling currents and voltages within an electrical circuit. Because it is non-mechanical it is capable of extremely fast and delicate action. It responds to millionths of a volt variations which may occur hundred of millions of times per second. Because of this sensitivity and rapidity of response, it is widely used in communications, science and industry. The vacuum tube operates by controlling electrons in free flight through empty space.

All Substances Contain Electrons. They are a part of every atom of every substance known. No one has the slightest idea what an electron looks like. All we know is that there *are* such things, that they have weight, and carry a definite negative charge. Beyond that, all is mind-spinning. In the study of vacuum tubes we will find it convenient to think of electrons as extremely small spheres, all exactly alike and each carrying with it an all-important charge. But this is how we will *imagine* them, remember, not how they *are*.

What is this thing called *charge?* Simply the ability to exert a force (over and above gravity) across space. There are two kinds, arbitrarily called positive (or plus) and negative (or minus). The negative charge is associated with the electrons, the positive with the rest of the atom. In normal matter there's an equal quantity of both kinds present. These exactly cancel each other. As a result normal matter possesses no *net* charge, or as we say, is electrically neutral.

An object acquires a positive charge by losing electrons, a negative charge by gaining extra ones from some other object. Objects possessing net charges of the same kind (or 'sign') will repel one another, try to get as far apart as possible, like two girls wearing the same kind of gown at a dance. On the other hand, objects with the same kind of charge will attract each other. This observable fact, called *the law of signs* is most important in our interpretation of electronic theory.

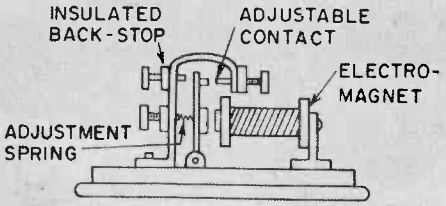
Metals, being electrical conductors, have their electrons relatively loose within them; that is, these may move about within the confines of the metallic system with little hindrance. This contrasts with the insulators, mostly nonmetallic substances, in which the electrons are normally tightly bound. We often imagine a metal as consisting of an orderly array of atomic nuclei, held in a rigid, three-dimensional crystal pattern. On the other hand, the electrons (or at least a sizeable percentage of them) are imagined as buzzing about among the nuclei in an apparently random manner; like a swarm of mosquitoes among the forest trees on a warm July evening.

When a sample of metal is heated, the array of atomic nuclei are set into vibration. This vibration energy is transferred to the surrounding electrons because of the attractive forces involved. When the temperature of the metal becomes high enough; that is, when the nuclear-electronic vibration becomes rapid enough, electrons are actually expelled—kicked right out of the metal and into the space beyond. This process is called *thermal emission,* and is central to the operation of most vacuum tubes.

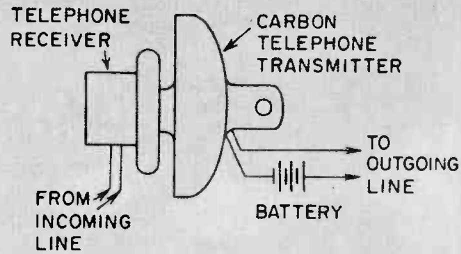
All of the Vacuum Tubes that we will discuss here are equipped with an internal conductor which may be heated, and which will then boil off, or emit large numbers of free electrons into the vacuum above it. This is called the *cathode,* and may be constructed in one of two general ways. The *directly-heated* cathode consists of a simple V or W shaped strip of nickel alloy, coated with the oxides of the chemically-enthusiastic metals, barium and strontium. A current is passed directly through the alloy strip, heating it in the same way that an ordinary lamp filament is heated. The second type, the *indirectly-heated* cathode, consists of a suitably-sized cylinder of nickel alloy, with the barium and strontium oxides coated upon the outside surface. Within this nickel alloy cylinder and normally insulated from it, is its own private little 'footwarmer' called the heater. A current is passed through the heater, thus heating the cathode cylinder to a ruddy glow. This indirectly heated arrangement is used because it is convenient to have the heater and cathode circuits separated from each other. This gives much more flexibility to the apparatus designer, and reduces hum and noise transfer between them. Then too, all parts of the indirectly heated cathode cylinder will have the same voltage—difference with respect to any other electrode within the tube. This cannot be so with the directly-heated cathode, since the heating current itself creates a voltage drop across it. This resulting voltage-difference may change the operating characteristics of the tube in certain sensitive

How Does It Work?

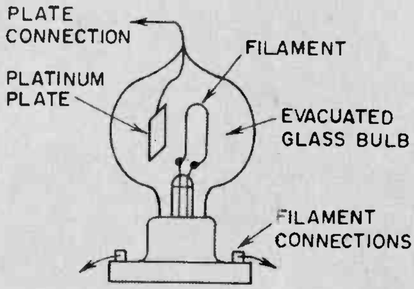
BY C. F. ROCKEY



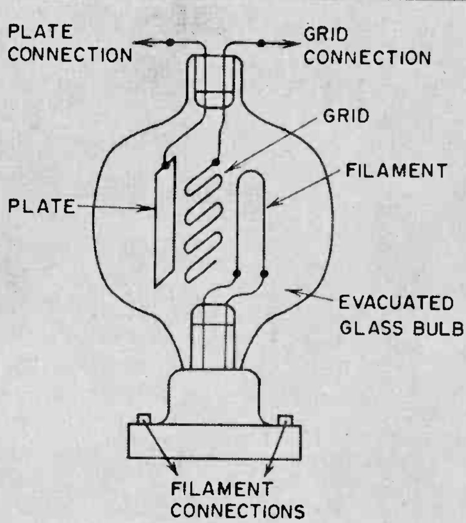
THE TELEGRAPH RELAY ; SUITABLE FOR "AMPLIFYING" ON-OFF SIGNALS, BUT NOT FOR VOICE CURRENTS.



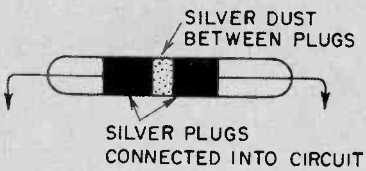
AN EARLY FORM OF TELEPHONY RELAY, OR "REPEATER" ; NEVER SUCCESSFUL IN PRACTICE



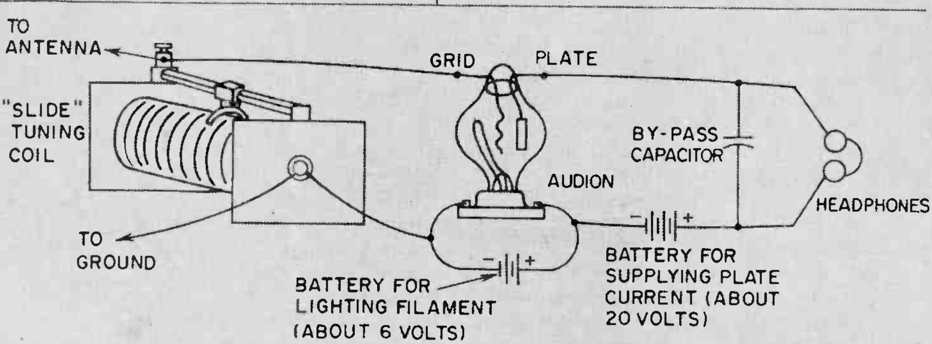
THE FLEMING VALVE ; FORERUNNER OF THE THREE-ELEMENT VACUUM TUBE.



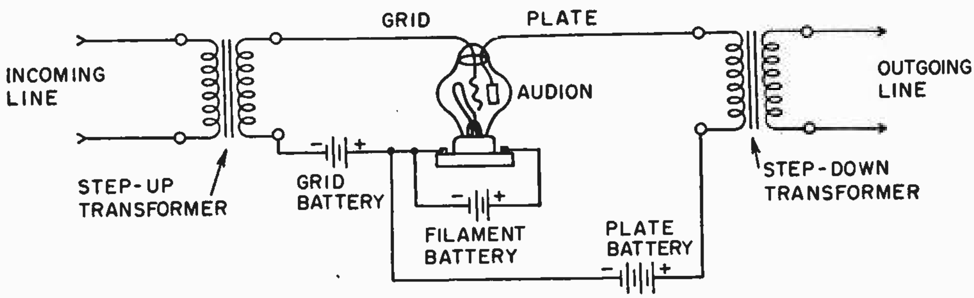
THE AUDION, DR. De FOREST'S FIRST AMPLIFYING VACUUM TUBE



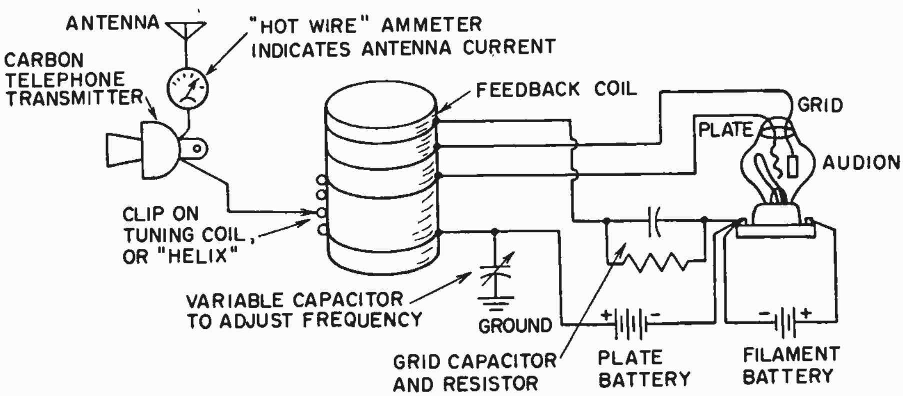
THE COHERER ; WIDELY USED FOR DETECTING WIRELESS SIGNALS AROUND 1900.



CIRCUIT SUCH AS USED BY DR. DeFOREST IN EARLY AUDION WIRELESS RECEIVER, AROUND 1905



HOW THE AUDION WAS FIRST USED AS A SUCCESSFUL TELEPHONE REPEATER AMPLIFIER



AN EARLY AUDION RADIOTELEPHONE TRANSMITTER
(WARNING: DO NOT USE THIS CIRCUIT TODAY, - IT'S ILLEGAL NOW!)

cases. Usually the cathode is heated by a suitable current; often from a specially-provided winding on the main power supply transformer.

All of the Working Parts of a vacuum tube are enclosed within a suitable glass or metal vessel from which all gases are removed as completely as possible. A vacuum then is "a lot of nuthin'." But a very important "nuthin'" it is. The slightest amount of gas has a bad effect upon the tube's characteristics and may prevent its operation entirely. It is impossible to *keep* a tube gas-free, if the air is merely pumped-out and it is sealed off. The very operation of the cathode itself, for instance, releases gases which must be constantly removed as the tube operates. To accomplish this, a *getter* is used in modern tubes. While the tube is connected to the vacuum pump, a small piece of a chemically-active metal, such as magnesium or barium, is vaporized within it, so that the metal condenses in a thin film within the bulb. You may see this clearly by examining any modern glass tube. Then after the tube is sealed off any gas molecules released during its normal operation are attracted to and 'stuck-onto' the surface of this metallic film. Thus the tube is normally kept nearly gas-free. Sometimes the getter film gets completely coated and the tube becomes gassy, or "goes-soft," as they say in the trade. It then must be replaced.

The Simplest Type of vacuum tube now in use contains only two active parts or elements: a *cathode* and a *plate*. (The heater is considered a part of the cathode, not a separate element.) Such a tube is called a *diode*, or two-element tube.

Most diode tubes are built with the cathode in the center surrounded by the plate, which is generally either round or elliptical in sectional shape. The cathode is brought to a red heat, whereupon it boils off a large number of electrons. These swarm about the cathode's surface and is called the *space charge*. The space charge cloud remains constant unless a large number are drawn away to a nearby electrode.

In normal operation the plate of every vacuum tube tends to remain relatively cool, so that it emits no electrons itself. Such plate emission would spoil the operation of the tube.

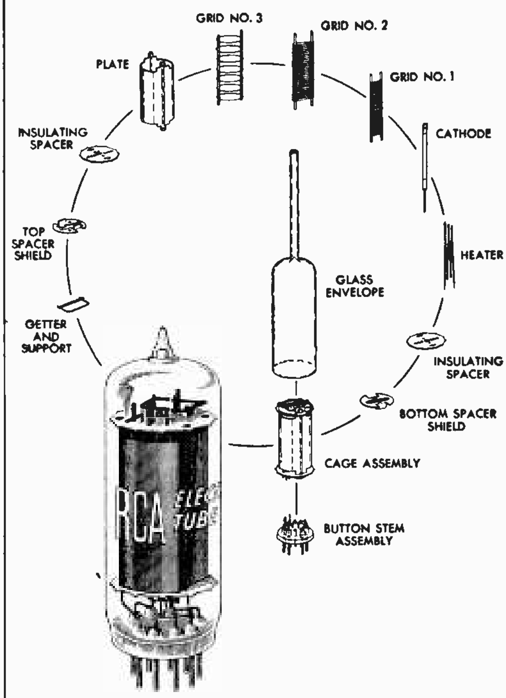
Let us connect a diode tube to a source of variable voltage, providing a voltmeter and ammeter to measure the electrical conditions within the cathode-plate circuit. We then observe that, so long as the plate is negative with respect to the cathode, the electron current flowing between these is negligible. This is because the negative plate does not attract the negative electrons (like charges repel). As soon as the plate becomes appreciably positive (with respect to the cathode) a current immediately commences to flow. The electrons, being negative, are attracted by the positive plate. This is perhaps the most important property of the diode-tube, that is, it acts as an electrical check-valve. AN ELECTRON CURRENT READILY FLOWS FROM CATHODE TO PLATE, BUT NOT IN THE OPPOSITE DIRECTION. This property is also clear from the graph, which shows the general relationship between the plate-cathode voltage and the resulting interelectrode current. This graph, often called a *characteristic curve,* is of the utmost interest to those working with and planning new circuitry.

Diode tubes are principally used as *rectifiers,* that is, devices which permit electrical current to flow in but one direction. Such an arrangement converts an ac current into a series of unidirectional pulses. When passed through a network of inductors and capacitors called a filter, the energy in such a string of pulses may be recovered as nearly-unvarying direct current. Such an arrangement is most often used as a power source for amplifiers, radio receivers, and other electronic apparatus.

Aside from its simple 'one-way' action, the diode tube is of limited usefulness in modern electronics. But it is possible to add another element, the *grid,* and vastly increase its flexibility. It was the addition of the grid that probably began the era of modern electronics. This grid is usually a spiral of wire which is inserted between the cathode and the plate.

With the Addition of the Grid we now have the three-element tube, or *triode,* the first real electronic control device.

To understand the triode, one must remember that it is the *net* force upon electrons at the cathode which determines their behavior within the tube. Unless this force is greater than zero, electrons will never leave the space-charge. The net force upon these electrons arises from two sources, the attractive force of the positive plate and the repulsive force of the (usually) negative grid. Because the grid is closer to the cathode than the plate, its

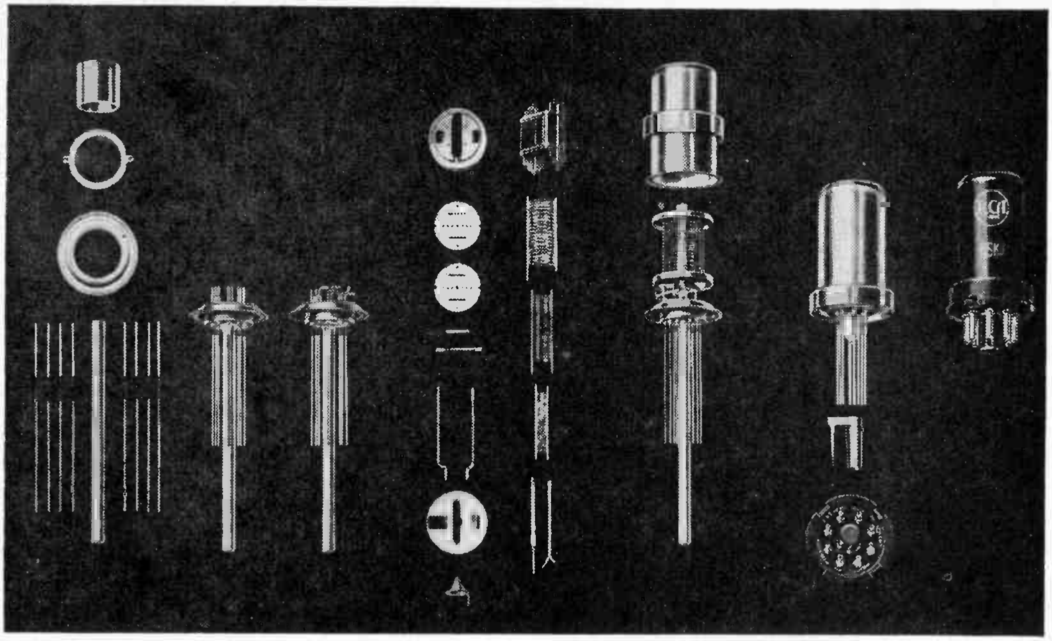


Parts of a Miniature Pentode

MINIATURE PENTODES offer a complete parts picture in the tube set-up. While more parts are used for dual-purpose, less are used for simpler tubes. Whole story is here.

field exerts greater force upon the electrons at the cathode than does the more distant plate. For instance, in one common triode, a negative voltage of 10 volts upon the grid will cancel the effect of 100 positive volts upon the plate, as far as electron attraction is concerned. How do we know that this cancellation has occurred? When the attractive force upon the electrons becomes zero, they have no tendency to leave the cathode. Then no current flows in the cathode-plate circuit.

Let us connect a triode tube in an experimental circuit. When the potentiometer arm is in the uppermost position, the grid is at its greatest negative potential (always with respect to the cathode, of course). When the grid is so strongly negative, its repulsive effect upon the negative electrons completely overcomes the attractive effect of the positive plate. No electrons leave the cathode; thus the cathode-plate current (henceforth called merely the plate current) will remain at zero, as indicated by the ammeter. This condition is



STUDY PENTODE PARTS again, and then see how many of the above pictured pieces you can identify by comparing. Tubes are different types, but both are pentodes. Don't let yourself be confused by separators!

called plate current cutoff in the trade. Now, as the potentiometer arm is gradually moved downward, making the grid less negative, a point is reached where plate current just barely begins to flow. The negative grid voltage which just exactly holds back the flow of electrons to the plate is one of the operating limits of the triode. It is called the cutoff-voltage, and depends both upon the construction of the tube and upon the positive plate voltage applied.

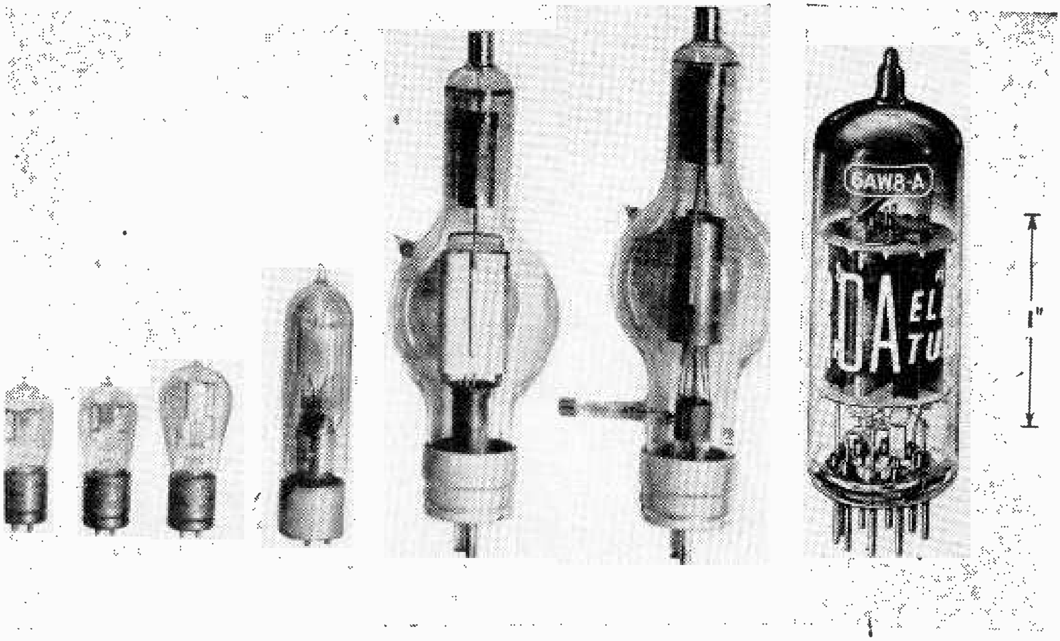
As the Grid Becomes Less Negative, its repulsive effect becomes less, and more and more electrons are attracted to the plate. The plate current therefore increases as the potentiometer arm is moved downward (as the grid is made less negative).

These ideas are most clearly illustrated in the graph. This graph indicates the relationship between the voltage in the grid circuit and the current in the plate circuit and is called a grid-voltage/plate current, or mutual characteristic curve. This curve is vital to our understanding of triode applications.

It will be observed that, as far as the plate circuit is concerned, nothing unusual happens when the grid voltage becomes zero, except that the plate current reaches a relatively high value. If we reverse the battery connections, so as to make the grid positive, with respect to the cathode, the plate current will increase with increasing grid voltage. This trend will continue until the electrons are drawn-away from the space-charge just as fast as they are emitted; the emission capacity of the cathode has been reached. No matter how much more positive the grid is made, the plate current cannot then increase. We have "sucked the well dry," so to speak. We refer to this maximum plate current value as the *saturation current*, in the trade. We never operate a tube at saturation current for long; such operation would strip the barium-strontium oxides from the cathode, and ruin it in short order.

Meanwhile, as the potentiometer arm is moved, what happens within the grid circuit? We find that, as long as the grid of most triodes is kept negative, the current flowing from it is negligible. A negative grid, for most practical purposes, acts as an open circuit. As soon as it becomes the slightest bit positive, the grid starts to behave as a diode plate, and attracts the negative electrons. For this reason we usually operate the triode tube with the grid negative, since it then draws no current from the circuit to which it is connected.

Let us consider that portion of the grid voltage/plate current curve between points A and B. Within this range, the plate current varies nearly in direct proportion to the grid voltage. This particular voltage/current range, known as the *linear portion* (linear meaning straight line), represents perhaps the most important operating conditions for the triode tube, generally speaking. For, if the tube did not have such properties, high-quality amplification of music, speech and video (picture) signals would not be possible.



HOW'S THIS FOR PROGRESS? Early vacuum tubes were big and bulky. Filaments were so bright you could read by their light, and they weren't very efficient either. They were assembled one at a time, cost was outrageous.

We have observed that, even though we hold the plate voltage constant, we may control the plate current by varying the grid voltage. Thus the grid voltage actually varies the internal resistance of the tube between the cathode and plate. The triode vacuum tube is in principle then, *a voltage-operated variable resistor*. Whereas the resistance of the ordinary variable resistor is adjusted by turning a knob, the resistance of the vacuum tube is controlled by making its grid more or less negative with respect to the cathode. Unlike the ordinary variable resistor, however, the only moving parts within the vacuum tube are the electrons, and these are extremely light. Thus a vacuum tube can control the current in an electrical circuit thousands of times more rapidly than any mechanical device, but it is still just a variable resistor. The same electrical laws continue to apply whether or not a vacuum tube is used in a circuit. There is no witchcraft in electronics.

Although we did not include such in our test circuit, it is customary to operate the vacuum tube with some kind of a *load* in its plate circuit. This load may be a resistor, transformer, inductor, loudspeaker, antenna coupling system (in the case of a radio transmitter) or any other device across which an electrical voltage may be developed. In this discussion, we will assume that the load is a simple resistor, unless otherwise stated. Similar operating principles will apply for other types of load, however.

The purpose of the load is to permit the plate voltage to change when the grid voltage changes, for it is the change in voltage from plate to cathode which is the useful output voltage of the tube.

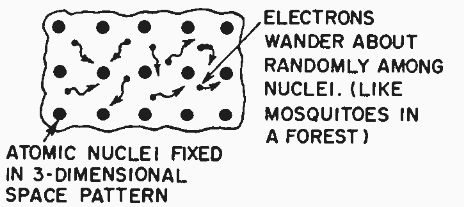
Let us examine the diagram of the triode tube with a load in the plate circuit. When the grid is made more negative (voltmeter in grid circuit reads higher value) the attractive force of the plate is partially cancelled. Thus the plate current, as indicated by the ammeter, decreases. Since the load voltage, E_l, is the product of the load resistance times the plate curent I_b, the load voltage must decrease. This means that the voltage from plate to cathode of the tube Eb, must increase. The load voltage plus the plate to cathode voltage of the tube must always add up to the plate supply voltage value. This is in accord with *Kirchoff's* voltage law, which tells us that the sum of all voltage-drops around any circuit must equal the supply voltage. When the grid voltage becomes less-negative (voltmeter in grid circuit decreases its reading) the plate current increases. This increases the voltage drop across the load, thus leaving less voltage across the tube. Thus the grid-cathode and the plate-cathode voltage always vary in opposite directions; when the grid becomes more negative the plate becomes more positive, and vice-versa.

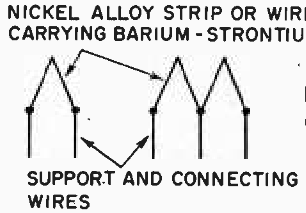
Of course, we must remember that in practical operation the plate is always positive with respect to the cathode in an absolute sense. But the plate voltage often does change in a negative direction (One must be careful never to confuse a voltage value with a change in a voltage value).

In addition to such mundane things as heater voltage rating and the ability of the tube to handle power, each triode tube has three important characteristics, by which we may judge its effectiveness. These are:

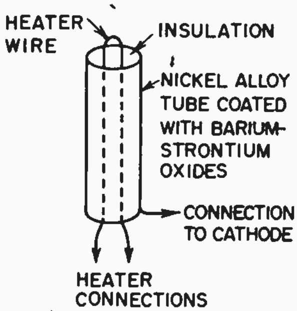
a. The *voltage amplification factor*, or mu. This expresses the ratio between the change in plate voltage necessary to cause a definite small change in plate current, and the change in grid voltage necessary to cause the same small current change.

b. The *mutual conductance*, or transconductance. This quantity describes the

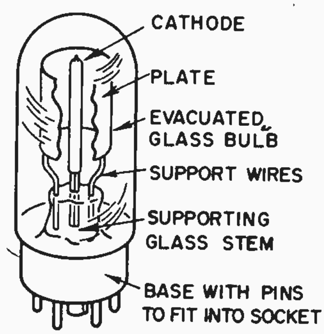




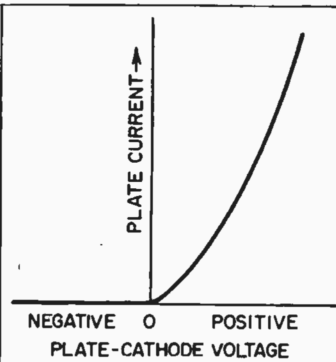
DIRECTLY-HEATED CATHODE



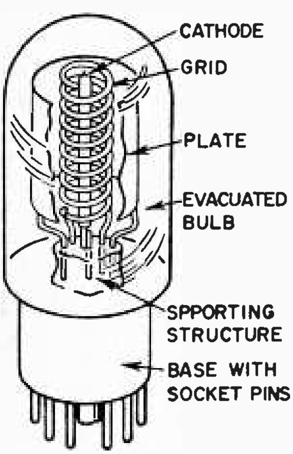
INDIRECTLY-HEATED CATHODE



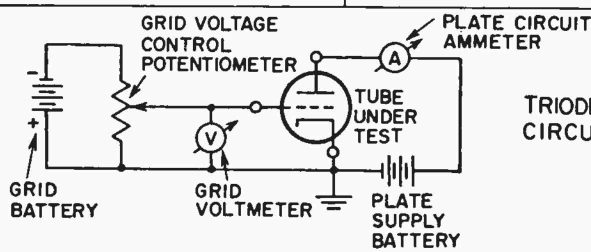
DIODE TUBE
PLATE CUTAWAY SHOWING HOW CATHODE IS ARRANGED



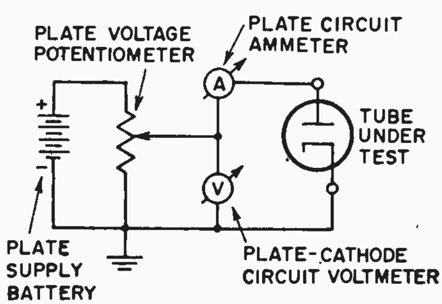
DIODE CHARACTERISTIC CURVE



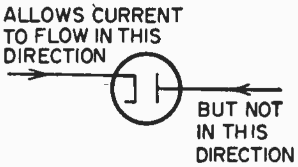
CUTAWAY VIEW OF TRIODE TUBE



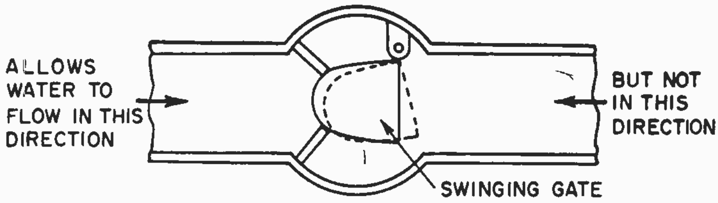
TRIODE TEST CIRCUIT



DIODE TEST CIRCUIT



THE DIODE TUBE,
AN ELECTRICAL CHECK VALVE



CHECK-VALVE IN WATER LINE

change in plate current which results when the grid voltage is changed by one volt. The plate voltage is held constant during this change.

c. The *dynamic or ac plate resistance.* This expresses the plate voltage change necessary to increase the plate current a given amount while the grid voltage remains constant. It also represents the internal resistance of the tube, as seen by the signal current.

These quantities may be found in the tube manufacturer's literature, or may be measured with apparatus such as we have described.

It is a mark of merit for a tube if the first two quantities, amplification factor and mutual conductance, are as high as practicable. These tell us how effective the grid is in controlling the plate current of the tube. On the other hand a low dynamic plate resistance is preferred, since the tube is then more conveniently coupled to a practically-sized load resistance.

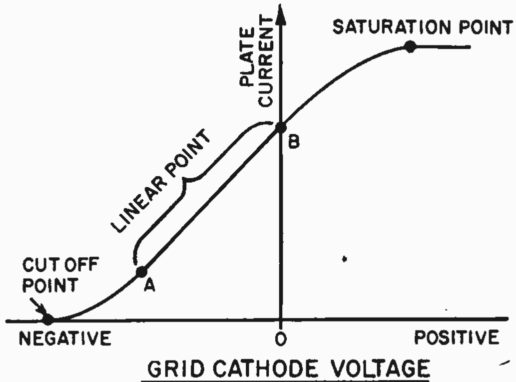
Until now we have been speaking of what might be called the dc properties of the triode; the relationships between relatively steady voltages and currents within the circuit. But these are not of the greatest interest to us; they are merely necessary evils. Rather we are much more interested in the signal handling properties of the tube.

What Is a Signal? This is the information-carrying electrical quantity, be it voltage, current or power. We will consider the signal to originate in a sine-wave ac voltage generator. This generator may be a microphone, antenna, industrial sensing-device or anything which generates an ac voltage. It is the ability to handle information that makes the vacuum tube so useful. We consider a sine-wave ac signal because it is the simplest from the circuit-analysis standpoint.

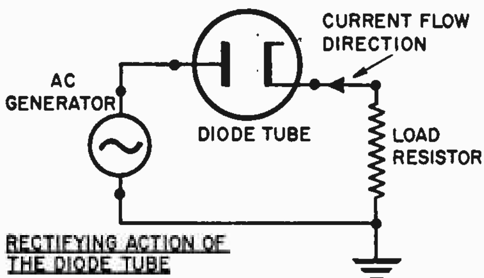
In order that the tube may respond properly to the variations in the signal voltage, it is necessary that the dc voltages between plate and cathode and grid and cathode be pre-adjusted to the correct values beforehand. The dc voltage between plate and cathode, determined by the plate voltage supply source and the load resistance in series with the plate circuit, is called the resting, or no-signal plate voltage. The plate is, of course, always positive with respect to the cathode. The dc voltage between grid and cathode (the grid is almost always negative with respect to the cathode) is called the grid bias. With a given value of plate supply voltage, it is the grid bias which is most effective in setting the operating conditions for the tube. In our diagrams here, we will represent the plate supply and grid bias voltage as being supplied from batteries, for simplicity (actually, these are most often obtained from a rectifier-filter power supply receiving energy from the commercial ac power mains).

Just where we set the operating point for our tube depends upon how we wish to use the output signal. For example, if we wish the output signal merely to operate a solenoid magnet coil in an industrial control circuit, we do not much care how much the signal waveform is distorted during the control process. On the other hand, if we deal with music, speech or video signals we must take care not to distort the signal waveform. We must then adjust the grid bias carefully or the juice will ferment, and the signal gets groggy!

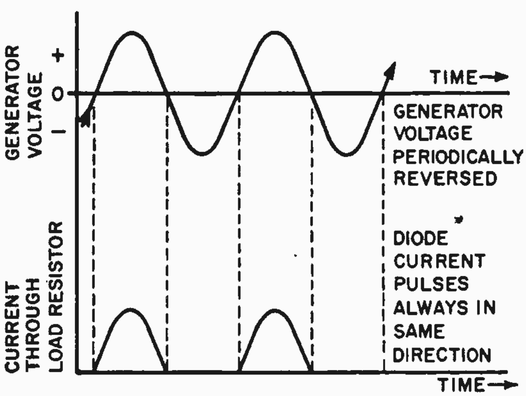
Two possible circuit conditions are shown in the accompanying illustrations. The first of these represents a case where distortion of the signal waveform is not detrimental to system behavior. On the left side we see how the signal waveform, riding upon the grid bias voltage line as its axis, is projected upon the grid/voltage/plate current characteristic curve of the tube, and how the plate current follows the grid voltage variations. Note that the grid bias voltage has a relatively large negative value; this means that the resting plate current is relatively low. This heats the tube plate but little, and thus results in efficient operation. But observe the rather serious distortion of the signal plate current which results. The curves at the right illustrate the relationship between grid voltage and output plate signal voltage. Notice that the output voltage waveform has higher amplitude than the input signal voltage, showing that magnification or amplification has resulted. But ob-



GRID VOLTAGE/PLATE CURRENT CHARACTERISTIC CURVE FOR TRIODE TUBE



RECTIFYING ACTION OF THE DIODE TUBE



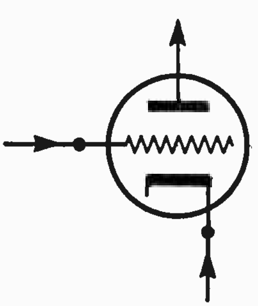
serve that the output voltage waveform, like the plate current waveform, is rather badly distorted. Complex speech or music signals put through such an amplifier would come out sounding like the wrath of heaven through a tin-horn phonograph!

The Second Case represents those conditions which should exist when the output voltage and current waveforms must closely resemble the input signal voltage waveform. Note that the grid bias has a smaller negative value and that it is adjusted to the center (or nearly so) of the straight line (linear) portion of the characteristic curve. As a result the plate current waveform is substantially undistorted. The right-hand curves show that the output signal wave is likewise quite free from distortion. Considerable voltage amplification may also be obtained under these conditions.

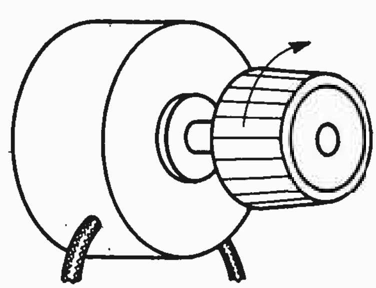
We do pay a price for distortionless amplification in a simple circuit like this. Because we cannot make the grid bias as negative, the resting, steady dc plate current is considerably greater. This causes the plate of the tube to become much hotter, and puts a greater stress upon the electron-emitting capabilities of the cathode. Not only this, but more power must be supplied from the dc plate power source; the amplifier is not nearly as efficient in its use of supply power. However, complex signals, such as speech or music, would be very well-reproduced under these conditions. Other modes of operation are possible too, and one discussed in advanced books.

These diagrams also illustrate a number of interesting points of vacuum tube operation for the observant reader. For instance, one clearly sees that while the plate current varies in step with the grid signal voltage, the plate signal voltage varies in exactly the opposite direction. One also notes that when the plate current is at its greatest amplitude, the plate voltage is at its lowest. This means that, for an amplifier of the distortionless type, the tube actually runs cooler when it is amplifying a signal than it does when no signal is supplied

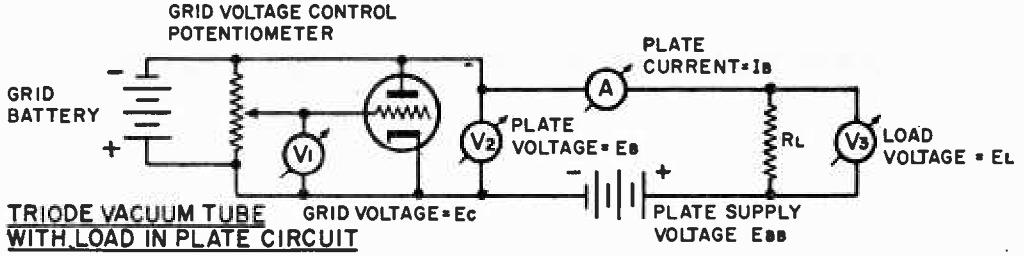
THE VACUUM TUBE IS A VOLTAGE OPERATED VARIABLE RESISTOR



THE RESISTANCE OF THE TRIODE VACUUM TUBE IS VARIED BY CONTROLLING THE GRID VOLTAGE



THE RESISTANCE OF THE ORDINARY VARIABLE RESISTOR IS VARIED BY TURNING A KNOB



TRIODE VACUUM TUBE WITH LOAD IN PLATE CIRCUIT

SUMMARY OF VOLTAGE-CURRENT RELATIONSHIP IN THE TRIODE TUBE CIRCUIT: —

WHEN THE READING OF V_1 INCREASES (GRID BECOMES MORE NEGATIVE) THEN READING OF A WILL DECREASE, V_2 WILL INCREASE, AND V_3 WILL DECREASE.

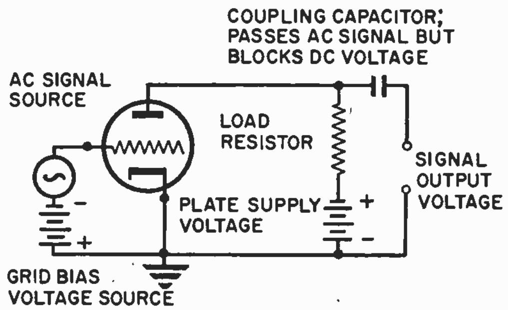
THE READING OF V_3 AND A WILL INCREASE AND DECREASE TOGETHER SINCE $V_3 = I_B \times R_L$,

THE READING OF V_2 AND V_3 WILL CHANGE OPPOSITELY SINCE $E_B + E_L = E_{BB}$, AND E_{BB} IS CONSTANT

to the grid. This is because, although the average dc power consumed by the tube is the same in both cases, some of this is delivered to the output, as signal power. Thus the plate does not have to radiate as much heat when the amplifier is in full operation. (Is this an adequate excuse for turning-up the radio or hi-fi set to full volume? We'll let you decide.)

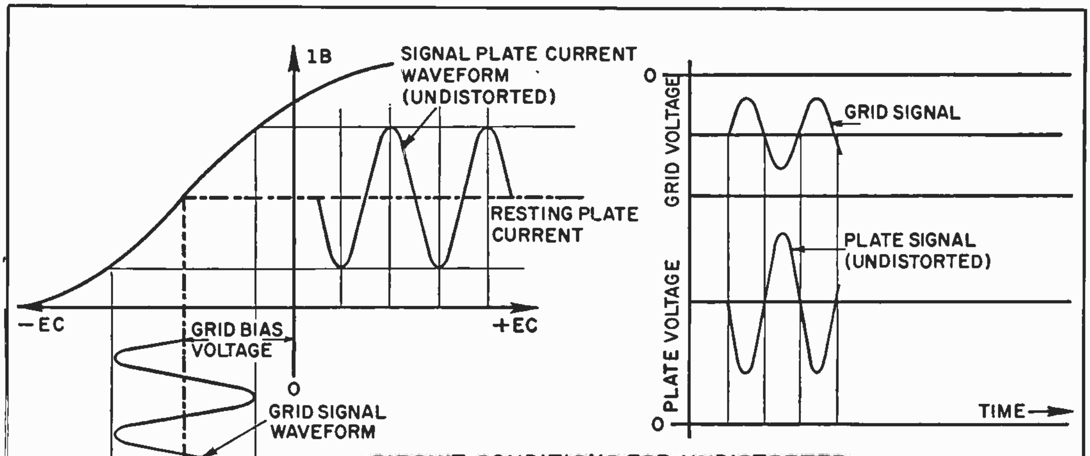
Vacuum tube signal amplifiers may be classified in many different ways; by end use, by the amount of grid bias used, by the frequency range over which they are to be used, or by the type of signal waveform they are designed to handle. We will leave these points to the more advanced books, however. It is important here to discuss two fundamental classifications; voltage amplifiers and power amplifiers.

A voltage amplifier is one which is designed to accept a signal of small amplitude, perhaps a few thousandths, or even millionths of a volt

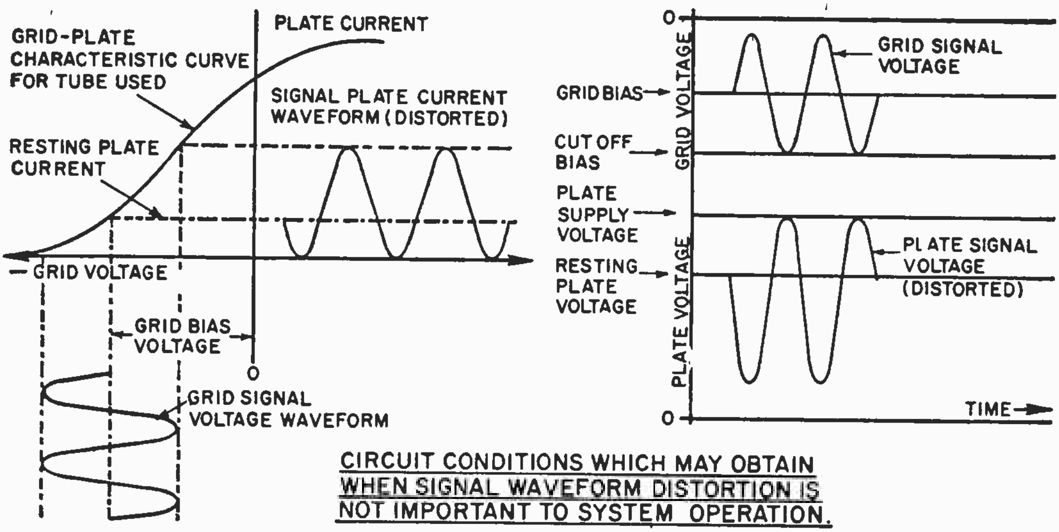


BASIC VACUUM TUBE AMPLIFIER CIRCUIT

and deliver it as a much larger signal voltage. The amount of power which it need supply may still be negligible, however (remember that while voltage is a component of electric power, one may have a relatively high voltage present without any power whatever being expended—consider a battery on open-circuit,



CIRCUIT CONDITIONS FOR UNDISTORTED SIGNAL AMPLIFICATION.



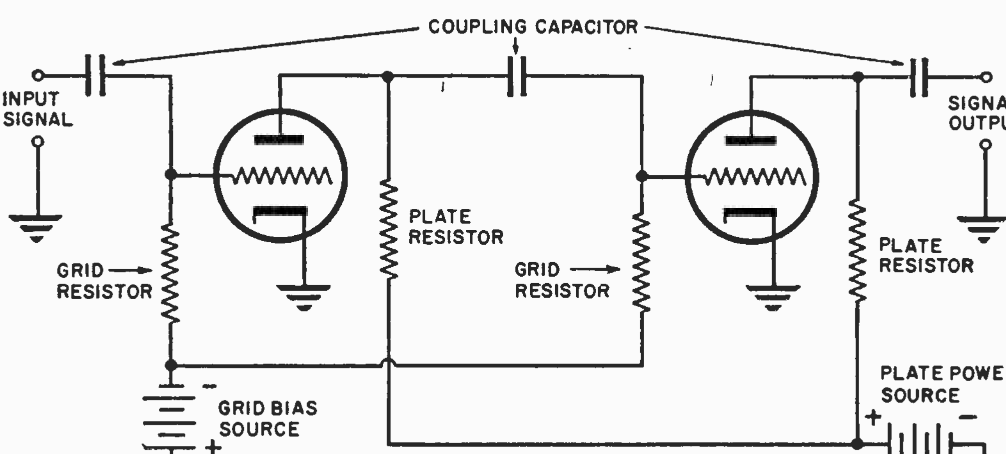
CIRCUIT CONDITIONS WHICH MAY OBTAIN WHEN SIGNAL WAVEFORM DISTORTION IS NOT IMPORTANT TO SYSTEM OPERATION.

for instance). Such amplifiers may take the minute signal voltages from a radio receiving antenna, a microphone, a phono-pickup or industrial sensing-device and magnify it sufficiently to drive a power amplifier. Small, sensitive tubes are used for a job like this.

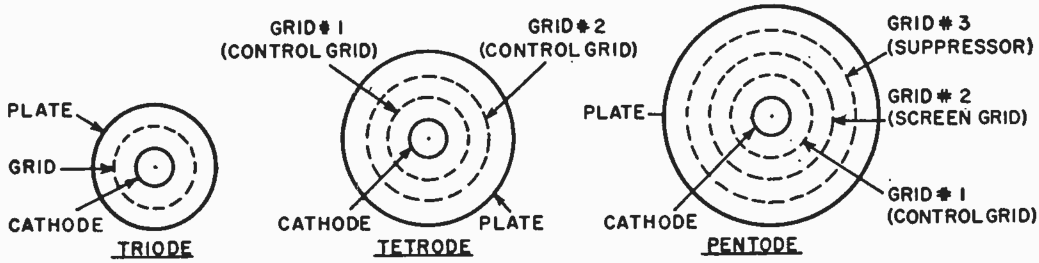
A Power Amplifier is expected to deliver real power to its load. This power may be used to drive a loudspeaker, operate a solenoid magnet or servo-motor in an industrial control system, or radiate radio signals from a transmitting antenna. In this application, larger and more powerful tubes are usually required.

It is only in the simplest situations that a single vacuum tube can provide sufficient amplification by itself. The more usual applications require that a number of tubes be used in cascade. This means that the signal output of one tube is fed into the grid circuit of the next in line. By this means, overall amplification of the order of millions may be readily achieved if a number of tubes are used.

Cascade operation thus implies that a coupling device be used to transfer the ac signal from one tube to the next. While this might become an involved topic, we will simplify it by considering only those systems operating in the so-called audio frequency-range; where the signal frequency is of the order of a few hundred to a few thousand cycles/second. Coupling systems for use at higher frequencies may be much more complicated, and may be read about in more advanced books. However,



A TWO-STAGE, RESISTANCE COUPLED VOLTAGE AMPLIFIER



TOP VIEW OF MULTIELEMENT TUBE ELECTRODES

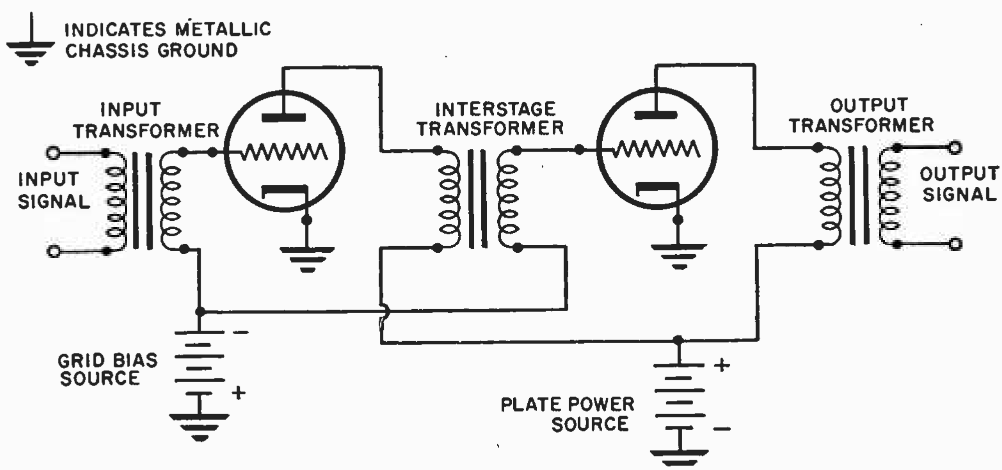
all coupling methods employ the same basic principles.

The first system of interstage coupling (One tube, with its associated circuit components, is called a "stage" of amplification.) is known as resistance-capacitor coupling, or resistance coupling, for short. Here the coupling capacitor serves to block the dc plate voltage of one stage from the grid circuit of the next, while readily passing the varying ac signal currents. Each tube develops its signal output voltage between plate and ground, the resistor in series with the plate makes this possible. The resistor in each grid circuit permits the signal voltage to build-up between grid and cathode, while yet transmitting dc bias voltage to each grid. Resistance coupling is generally used only in voltage amplifiers and usually where the signal voltage does not exceed a few tens of volts.

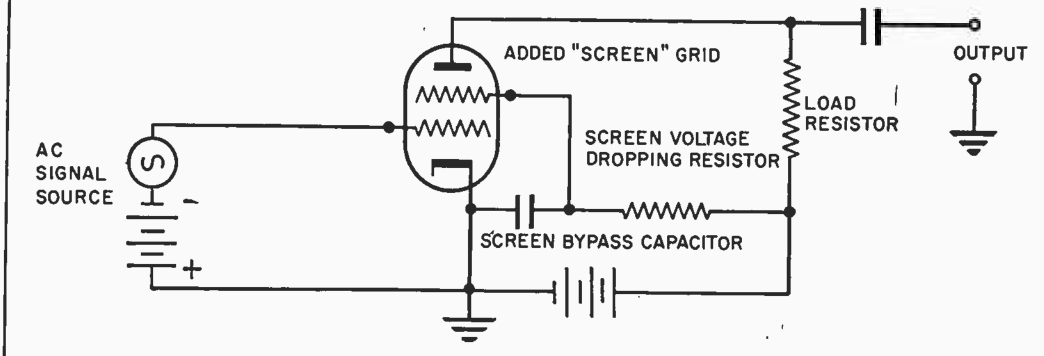
Transformer coupling may be used in either voltage or power amplifiers. The changing ac signal plate current creates a changing magnetic field within the primary coil of each transformer. This changing field cuts the turns of wire of the secondary coil and induces an ac voltage therein. When the secondary coil is in the grid circuit of a vacuum tube, this ac signal voltage becomes its input voltage. Since the only coupling between tubes is via the changing magnetic field, the dc plate voltage is blocked, but the ac signal voltage is passed.

Transformer coupling has the advantage of power and may also give some voltage step-up being able to transfer considerable signal or step-down of its own, as the situation requires. But transformers are relatively expensive, are more subject to failure and, if not carefully-shielded, may pick up excessive noise and hum from their surroundings.

In the circuits we have shown, batteries are used to provide grid bias and plate supply voltage. This is done purely in the interest of simplicity to avoid certain technical difficulties beyond the scope of this article. Actually, in practice, these voltages are supplied most often from rectifier-filter power supplies operated from the commercial ac power system.

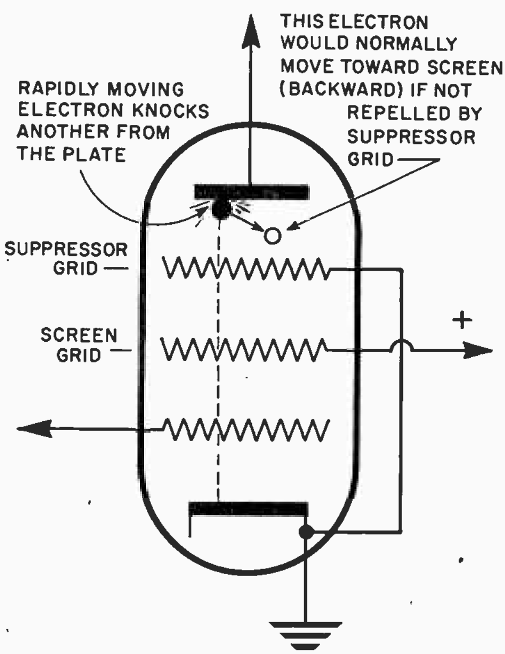


TWO STAGE TRANSFORMER COUPLED AMPLIFIER



HOW THE TETRODE IS CONNECTED

From what has been said, it might be inferred that the triode is the only kind of amplifying vacuum tube. This is by no means the case. In fact it might not even be the most-commonly used type today. In the late twenties it was discovered that the addition of a second grid, between the already-present grid number one and the plate, would give the tube superior amplifying properties. Thus the tetrode or four-element tube was born.



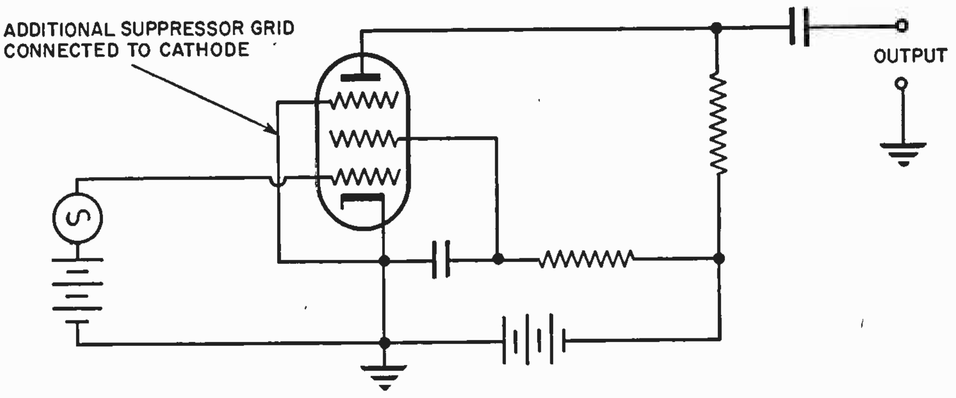
HOW THE SUPPRESSOR GRID SUPPRESSES REVERSE CURRENT WITHIN THE TUBE

In the tetrode, the cathode, grid and plate are connected just as they are with the triode. The additional grid number two, or "screen" grid, is connected to the positive plate supply voltage through a suitable voltage dropping resistor. The screen grid is often operated at from one-half to three-quarters of the plate voltage. The capacitor connected from the screen grid to cathode prevents the changing plate voltage from affecting the steady dc voltage from screen grid to cathode. In other words, it "by-passes" any ac signal voltage variations from screen grid to ground.

The Screen Grid performs two important functions within the tube. It serves as a "screen," or shield, between the plate and the grid of the tube, reducing feedback via this path, with its accompanying instability. Also, since it is positively-charged, it assists the plate in attracting electrons from the cathode.

The addition of the screen grid greatly improved the sensitivity and amplifying-properties of the tube. Both the amplification factor and the mutual conductance (previously mentioned) are markedly increased. A single properly operated tetrode might amplify a signal as much as would two or three triodes connected in a cascade.

But all is not joy. Experience with the tetrode reveals a serious defect. On strong plate current peaks the plate voltage often, for a brief instant, becomes less positive than the screen grid. Then any electrons "lounging" about the plate are attracted to the screen, resulting in a reverse current flow, which partially cancels the main stream. Where do these "lounging" electrons come from? When high speed electrons from the cathode hit the plate hard, as they do during a high current peak, they knock other electrons from the plate by main force, just like a fast ball down the alley will send the



HOW THE CATHODE IS CONNECTED

bowling pins flying. These electrons, lurking about the plate, are attracted toward the screen.

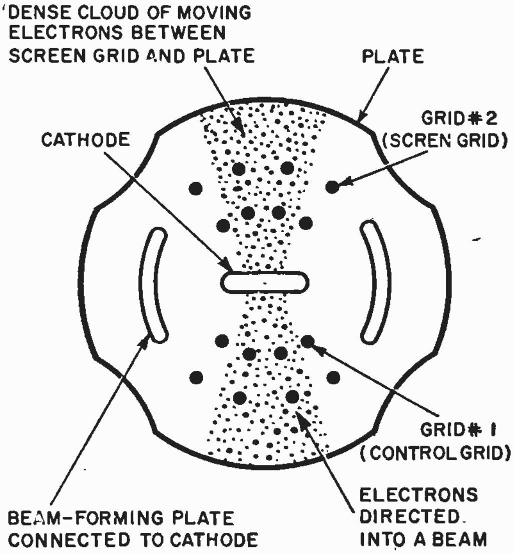
To remedy this defect, another grid was inserted between the screen grid and the plate. This number three grid, or "suppressor" grid, has little effect upon the fast electrons coming from the cathode. But it does repel any slower electrons trying to get from the plate to the screen grid. Thus the major defect of the tetrode was cured by making it into a pentode, or five element tube. The pentode retains all of the advantages of the tetrode while yet overcoming the back current effect. The pentode has become so successful that it is now the most popular amplifying tube. Ordinarily tetrodes as just described are no longer either made or used to any extent. Instead, the beam-power tetrode has gained favor.

As the name implies, the electron streams within the beam power tetrode are directed into dense beams by means of two negative, beam-forming plates on either side of the cathode. Not only this, but the wires within the screen grid are aligned to be within the "shadow" of the control grid wires. This further encourages the formation of dense electron beams. Observe, also, that the screen grid and plate are rather widely separated.

The Beam-Power Tetrode would suffer from the most serious defect of the ordinary tetrode, were it not for the presence of a large cloud of moving electrons between the screen grid and plate. This dense "cloud of negativity" effectively discourages any current flow from the plate backwards toward the screen grid. Thus, although a tetrode, the beam power tube has all of the advantages of the pentode, with a few of its own besides. These are high signal power sensitivity, lower screen grid current, and somewhat simpler construction techniques employed.

An amplifier schematic diagram employing a pentode voltage amplifier and a beam power tetrode is shown in the illustrations. This relatively simple, two tube circuit develops greater amplification, both voltage and power than would 4 or 5 triodes. The advantages of the multielement tube are thus obvious.

In addition to, or rather because of its amplifying ability, the triode (and its successors) may also serve as convenient sources of alternating current signals. To see how this may



THE BEAM POWER OF THE TETRODE

come about, consider the diagram. Here the primary of a variable-coupling transformer is inserted in series with the load resistance of an amplifier. The secondary, in turn, is connected in series with the signal generator at the input terminals. These connections are to be made such that the voltage induced into the transformer secondary will always add to (rather than subtract from) the voltage provided by the signal source. This last detail is vital.

Let us begin by decoupling the primary and secondary coils of the transformer so that no voltage is exchanged between these. Then let us start the signal generator, adjusting it to produce 10 volts of signal. Because the amplifier has a voltage gain (or amplification) of 10, the output voltage will be 100 volts. This is what we should expect.

Now let us increase the coupling within the transformer until the secondary induced voltage is 2 volts, meanwhile reducing the signal generator voltage to 8 volts. The amplifier goes on producing its usual 100 volts of output, just as before.

Then increase the coupling of the transformer to produce a secondary voltage of five, meanwhile reducing the signal generator output to 5 volts. Things in the amplifier go on as usual; it continues to produce 100 volts of signal output despite the fact that 50% of its input signal voltage is being developed by itself.

Finally, let us increase the coupling until the transformer secondary voltage is a full 10 volts, simultaneously reducing the signal generator voltage to zero. The voltage output of the amplifier continues to be the full 100 volts despite the fact that the amplifier is now entirely producing its own input signal voltage. It is apparently too stupid to know that the external signal input has been completely removed.

Such an amplifier, arranged to supply its own signal input, is called an oscillator in the trade. When in operation, an oscillator acts as a convenient source of alternating current signal energy, and these are widely used in this way. Unlike a mechanical rotating-coil alternator of the power-plant type, the oscillator has no moving parts (except electrons) and no bearings to lubricate. Furthermore, unlike the latter, it may generate voltages whose frequencies range from less than 1 cycle to billions of cycles per second and at power levels from microwatts to kilowatts.

Although we used an external signal generator to get this imaginary oscillator started, this is not necessary in practice. Properly designed oscillators are always self-starting, and cause no trouble in this respect.

What are the requirements for the generation of oscillations in an electronic circuit? First, we must have an amplifier, in this case a properly-connected and adjusted vacuum tube. Then we must have a means of feeding-back enough voltage, from output to input, to overcome the energy losses in the system. Finally this voltage fed back must be phased in such a way as to add to any signal voltage already present. (If this is not the case, then the oscillations will be cancelled-out instead of sustaining themselves.) It is important to note that, if these conditions exist within a circuit, oscillations will occur whether we want them to or not. Thus it often befalls that tyro radiomen, building what they hope will be an amplifier, find out that they have constructed an oscillator instead. Long leads and improper part placement provide unsuspected feedback paths, and the circuit goes into oscillation.

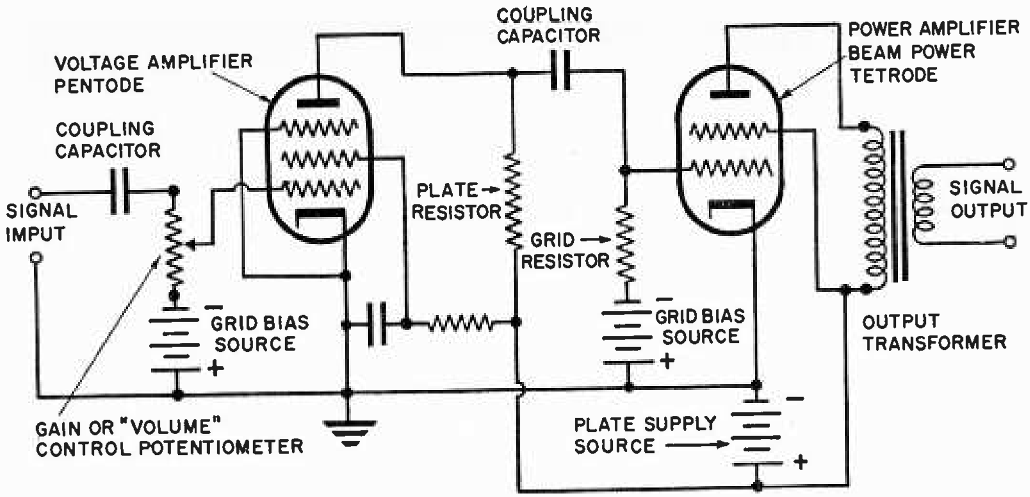
In addition to the essentials just mentioned, properly designed oscillators are provided with a frequency control circuit. This may be a coil and capacitor, designed to resonate at the designed frequency or it may be a tuning for or a specially ground slab of quartz, a piezoelectric crystal. Even the natural vibration frequencies of ammonia, or cesium molecules may be used as frequency control devices, as in the famous atomic clock of the United States Bureau of Standards.

In the oscillator circuit diagrammed, the frequency of oscillation is mainly determined by resonance in the capacitor and inductor combination, C and L. Feedback is provided by magnetic field coupling between the tuned circuit coil L, and the feedback coil. Proper phasing of the feedback voltage is assured by proper connections to the feedback coil. Any good triode will provide sufficient amplification if the feedback coil is properly proportioned.

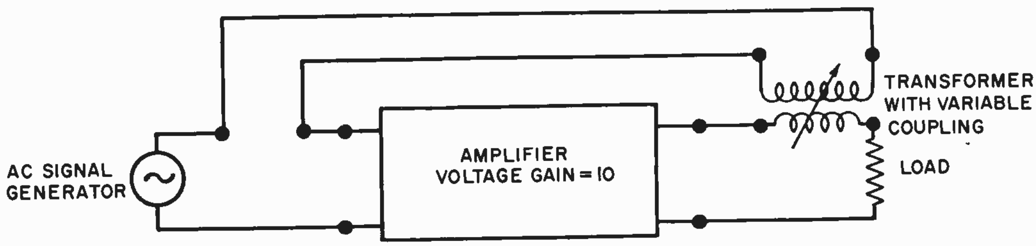
When properly set-up, oscillators such as this one will generate signal voltages at frequencies from ten cycles to one hundred million cycles per second. Design details of this and many other practical oscillator circuits may be found in those books devoted to electronic engineering.

Oscillators are used in carrier wire telephony, in radio and TV transmitters and receivers, in test equipment for these, and as high frequency power generators in industrial heat treating and plastic forming operations. These are also the basis for precision timing apparatus, such as the aforementioned atomic clock.

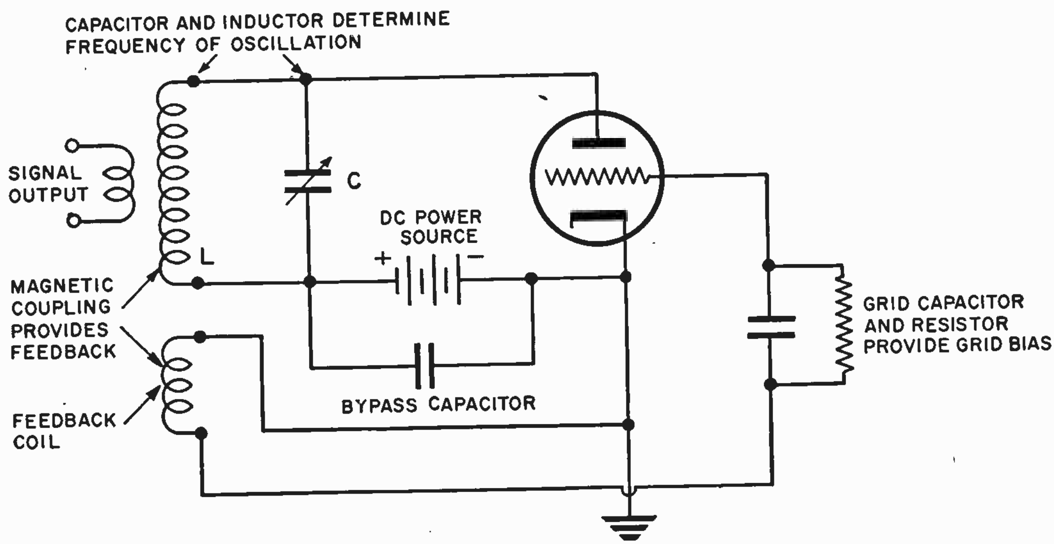
As rectifier, as amplifier and as generator of signals, the vacuum tube has earned an honored niche in the hall of history. Only the transistor challenges it as an immediate competitor in these fields. It will be a while before even this marvelous gadget completely catches up. The vacuum tube is well worth our efforts to understand it as completely as possible.



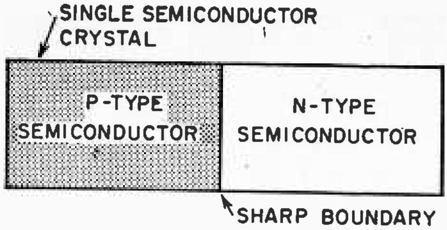
AMPLIFIER CIRCUIT EMPLOYING PENTODE AND BEAM POWER TETRODE
(FOR ILLUSTRATION ONLY — NOT A CONSTRUCTION PROJECT)



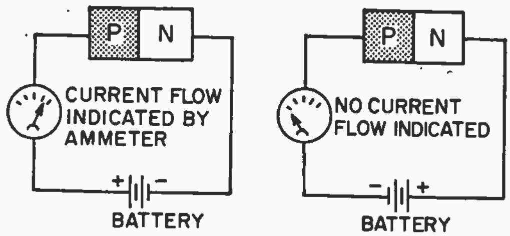
MAKING AN AMPLIFIER DRIVE ITSELF—
THE BASIS OF ELECTRONIC OSCILLATION



A COMMON PRACTICAL OSCILLATOR CIRCUIT WHICH MAY SERVE AS AN AC SIGNAL GENERATOR (FOR ILLUSTRATION ONLY)



A P-N JUNCTION

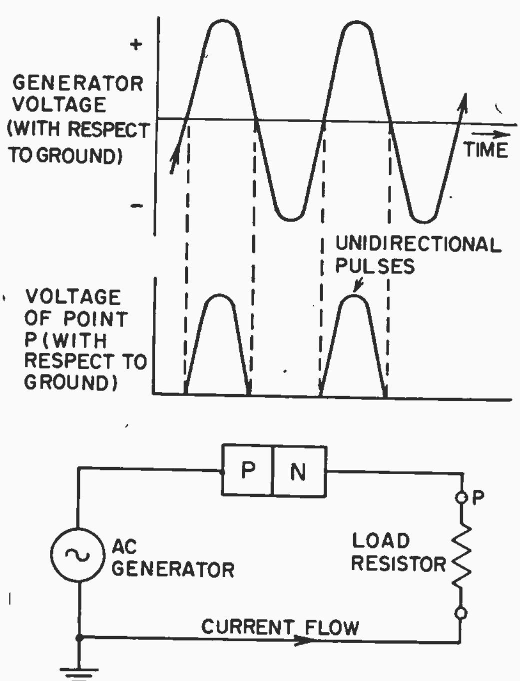


A FORWARD-BIASED JUNCTION

A REVERSE-BIASED JUNCTION

RULE FOR JUNCTION BIASING:
WHEN THE POSITIVE TERMINAL OF THE SOURCE IS CONNECTED TO THE P-MATERIAL AND THE NEGATIVE TO THE N-MATERIAL, THE JUNCTION IS FORWARD BIASED.

FORWARD AND REVERSE-BIASING OF A JUNCTION



RECTIFYING ACTION OF P-N JUNCTION

The Junction Transistor: How Does It Work?

By C. F. ROCKEY

THE transistor is best described as a solid-state amplifying device. Unlike the vacuum tube wherein the current carrying electrons fly through the empty space of a gas free jug, the transistor is a solid piece of matter that is harder than stone. As it operates, no familiar glow of filament or cathode meets the eye; everything happens in the mysterious darkness of an atomic crystalline lattice. Yet this little chunk of silvery stuff has challenged the king of amplifiers on his own home grounds; threatening to replace the vacuum tube completely in certain areas. How does this thing work? Let us see.

From the electrical point of view, there are three kinds of solid substances. The first of these are the insulators in which the internal electrons are tightly bound and cannot move when an electric field is applied. The second are the conductors. Here many electrons are relatively loose, and move readily in the presence of an electric field. Then there are the semiconductors which are intermediate between these.

Further, there are two types of semiçonductors. One of these conducts by means of free electrons, much as in ordinary conductors. The difference being in the lesser number of these free electrons per unit volume of material. Such materials are called N-type semiconductors. The other may be thought of as a conducting electric current by means of positively charged particles called holes, and are called P-type semiconductors. Actually, we know that electrons are the true conducting agents in P-type semiconductors also, but the mechanism of their action is somewhat different. We thus have found it easier to assume the existence of these holes.

The sub microscopic, structural reasons for the existence of these two types of semiconductors is in the realm of solid-state physics, and will not be considered further here.

But it is the existence of these two different types of semiconductor materials which makes the transistor possible. Unless stated otherwise, we will further assume that we may have ideally pure materials of each type at hand; materials which contain only the right kind of conducting particles. Obviously this is an oversimplification, but will make the reading much easier.

Let us imagine that we have a single semiconductor crystal of the same chemical substance, but consisting of equal parts of both P and N-type material. Furthermore, let's imagine that these two materials are separated by a sharp, planar boundary as shown in the illustration. Such a boundary between two different semiconductors in a single crystal is called a P-N junction.

What Are the Properties of a P-N junction? If we connect a small battery and a sensitive ammeter in series with the junction, we observe that it acts as a conductor in one direction but a (nearly) open circuit in the other.

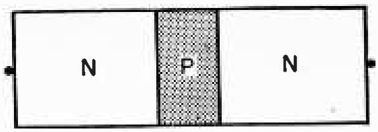
We will find that when we connect the positive terminal of the battery to the P-type material and the negative terminal to the N-type material, electrons flow from the N to the P material, holes in the opposite direction. Thus a considerable current will flow. In the trade we have come to call this the forward-biased condition for the junction. But when we connect the positive battery terminal to the N-type material and the negative to the P-type we find practically an open-circuit within the junction. This is the reverse-biased condition. The current-carrying particles are held, each in its own bailiwick, and no current can flow.

Thus a P-N junction, like a vacuum diode, is an electrical check-valve, allowing charge to move in just one direction. Like the vacuum diode, it may be used as a rectifier, for converting ac voltage into unidirection pulses, from which dc power may be recovered by filtering. The well known selenium rectifier is essentially a set of P-N junctions. (As are crystal diodes).

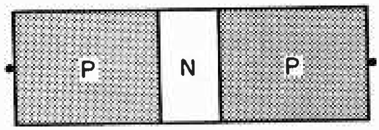
Although useful, the rectifying property of the P-N junction is of secondary interest to us here. Rather we are much more concerned with how these junctions may be combined together to form a transistor.

Transistors take many physical forms, but all those currently used operate upon the same principles. We will therefore discuss these in terms of the simplest device, the original junction transistor. The junction transistor may be thought of as a single crystal of a given semiconducting substance, usually germanium or silicon. But this single crystal is arranged to contain three different regions.

Since there are three different regions of semiconductivity, and two distinct kinds of semiconducting material, there are two different forms of junction transistor possible, the NPN and the PNP.

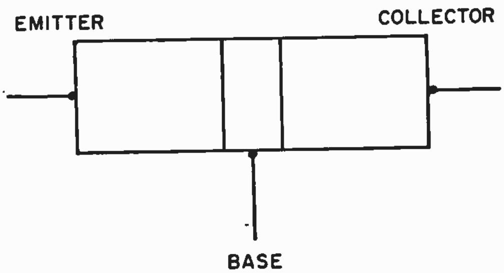


AN NPN TRANSISTOR

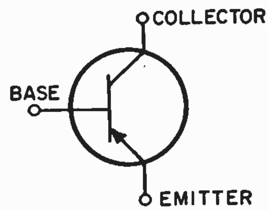


A PNP TRANSISTOR

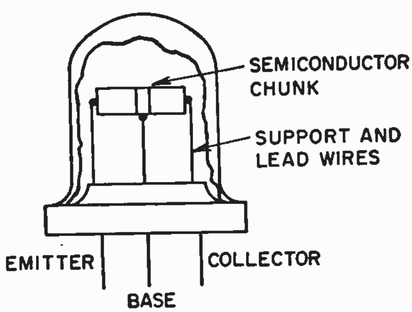
TYPES OF JUNCTION TRANSISTORS



CONNECTING-POINTS, OR "ELEMENTS" OF THE TRANSISTOR. (THESE ARE THE SAME FOR BOTH NPN AND PNP UNITS)



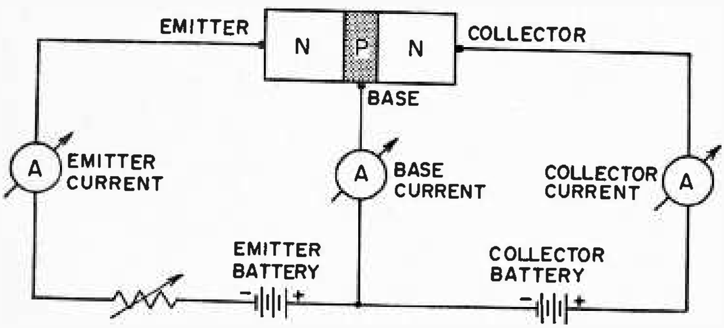
ONE SYMBOL USED FOR THE TRANSISTOR IN SCHEMATIC DIAGRAMS



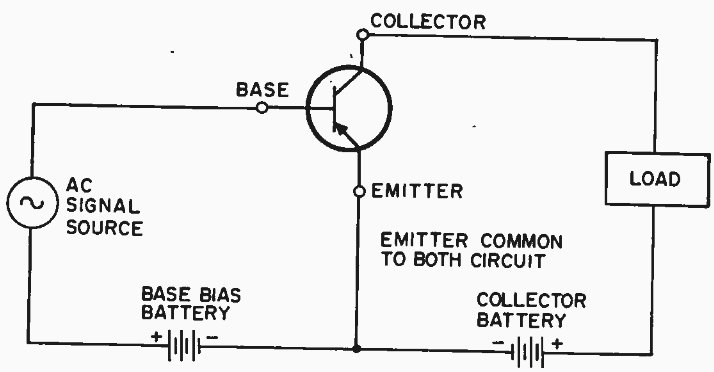
CUTAWAY VIEW OF ONE TYPE OF TRANSISTOR

Actually a transistor is a semiconductor sandwich. The NPN transistor consists of two regions of N-type semiconductor, as the bread of the sandwich, and a very thin region of P-type semiconductor as the meat. In the PNP transistor the bread is P-type semiconductor and the meat is N-type. The central meat section must be very thin, not over a few thousandths of an inch thick, if the device is to operate properly.

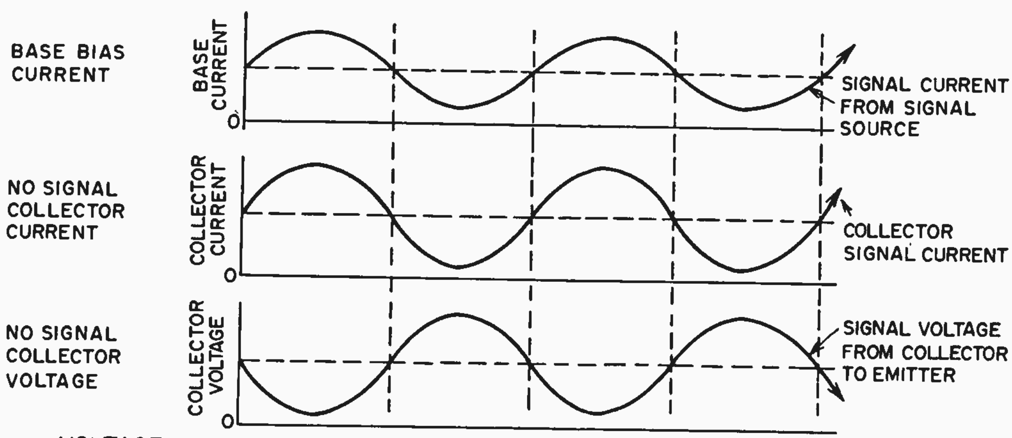
As we shall see, both PNP and NPN types are in current use. Both operate in the same basic manner and each has its specific advantages and disadvantages.



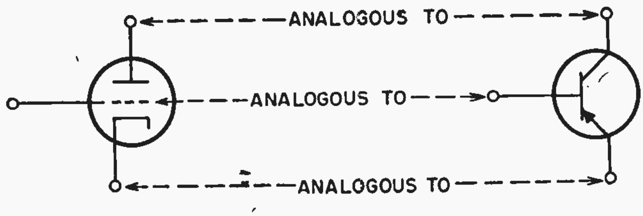
BASIC CIRCUIT FOR NPN JUNCTION TRANSISTOR (FOR PNP UNIT, REVERSE BATTERY POLARITIES



BASIC COMMON-EMITTER AMPLIFIER USING NPN TRANSISTOR



VOLTAGE AND CURRENT RELATIONSHIPS IN NPN COMMON EMITTER CIRCUIT



ANALOGIES BETWEEN THE VACUUM TUBE AND THE TRANSISTOR

At present it would seem that PNP transistors are somewhat cheaper to manufacture, but NPN units will operate at higher frequencies. There are a number of exceptions to these rules, however.

Being a block of solid material, the transistor has no elements in the sense that the vacuum tube does. But there are points upon the block that fulfill certain functions, as far as circuit connection and operation are concerned. We therefore think of these as being analogous to the element connections of the vacuum tube. These connections are called the *emitter, base,* and *collector,* respectively.

This terminology is difficult to justify in the light of the modern transistor; it was originated for use with the now obsolete point contact transistor, and made good sense when these were in use. But tradition dies hard, and so the old words remain in use despite their obscurity.

The thin middle section of either type of transistor is always called the base, as is the connection made to it. The connection to one of the outermost sections is called the emitter, the other, the collector. In many transistors it makes no difference which end is which, in others it definitely does. It is always best to follow the published data and markings on any particular unit, to be on the safe side.

The particles within the body of the semiconductor, whose motion through the material represents the current flow, are called the carriers. For now we will consider that only majority carriers, the right kind for that particular kind of material are the only ones present. Actually, of course, a few of the wrong kind, called minority carriers, are also present in all practical transistors. We shall not refer to these further.

Let Us Consider the NPN junction transistor; here the carriers are primarily electrons, and thus the discussion will be most easily followed by those with a vacuum tube background. The same principles apply to PNP units, the difference being that holes instead of electrons carry the current. The battery polarities are also reversed.

Examine the illustration showing the basic circuit. Here we observe in application what might be considered to be the first law of transistor circuits, that is, the emitter-base junction is always forward-biased, while the collector-base junction is always reverse-biased. This is a most important practical principle, and should be fixed firmly in mind. Otherwise one may seriously damage a transistor.

Suppose we start with the emitter resistor set to its open circuit position. Then the emitter current and the base current will both be zero, since they are both part of the same series circuit, and the current throughout a single series loop is everywhere the same. The collector current will also be zero, since the base-collector junction is reverse biased, making the junction an open circuit.

Now let us gradually reduce the resistance value of the emitter resistor. As we do so the emitter current and base current both increase. This is to be expected. But what we might not expect is that the collector current also increases. Why should this be? What is happening is that the positive charge on the base region is attracting current carrying particles from the emitter region. When these reach the base, they are further attracted to the even higher attractive potential within the collector region. Because it is so thin, these carriers go right through the base region and into the emitter region, or rather, most of them do. They then flow out of the collector connection and into the collector battery. Thus we say that the forward biased emitter base junction acts as a particle gun. It injects, or shoots carriers into the collector region. Of course, once these get into the collector region, they are immediately attracted to the collector terminal, resulting in a flow of collector current.

Please observe that it is only these injected carriers which result in collector current, for as soon as the emitter current becomes zero, so does the collector current. This is because the collector junction is reverse-biased. No carriers normally flow through it. Thus, because it directly controls the number of injected particles, the emitter current controls the collector current.

But what happens within the base region? As we have said, most of the particles entering it from the emitter region pass on through to the collector. But a few do not. These few flow out of the base connection, forming the base current. The base current is normally from about one to five percent of the emitter current; the other ninety-five to ninety-nine percent flows on as collector current.

A Reverse-Biased Junction acts as an open circuit, there may be a considerable voltage, several tens of volts, between the collector and the base. But the resistance of the forward-biased emitter-base junction is small, very little voltage may exist across it, not over a few tenths of a volt in practice. Thus it is most reasonable to speak in terms of the emitter junction current, rather than the voltage. Unlike the vacuum tube, then, where the output circuit current is controlled by the input circuit voltage, the transistor is a current-controlled, rather than a voltage device. This important fact must be kept in mind when using transistors. It also makes it impractical to substitute transistors directly into vacuum tube circuits without first making important changes.

As we have seen, most of the current entering the emitter leaves at the collector. Only a small amount emerges from the base. We may control the collector current by changing either the emitter or the base current. The base current tends to be a constant fraction of the emitter current. Therefore, a much smaller change need be made in the base than in the emitter current to cause the same change in collector current. This condition is reflected in two of the most important transistor characteristics, alpha and beta. These are defined as follows:

$$\text{Alpha} = \frac{\text{(Change in collector current)}}{\text{(Change in emitter current)}}$$

and

$$\text{Beta} = \frac{\text{(Change in collector current)}}{\text{(Change in base current)}}$$

In the typical junction transistor available today, alpha has a value of from 0.90 to 0.99 while beta ranges from about 10. to 100. Thus the base current is from ten to one hundred times more effective in controlling collector current than is the emitter current.

For this reason, the most widely-used transistor circuit today is the common-emitter circuit. The load, which the transistor supplies signal output voltage or power, is connected in series with the collector circuit. This may be a loudspeaker, industrial control solenoid or similar device. The signal input source is connected in the base circuit. The output power comes from the collector circuit battery, while the correct operating conditions are established by means of a bias battery in the base circuit.

As with the vacuum tube, we will assume that the signal to be amplified is a sine-wave ac voltage or current which may come from a microphone, radio receiving antenna, industrial sensing device, or similar signal source.

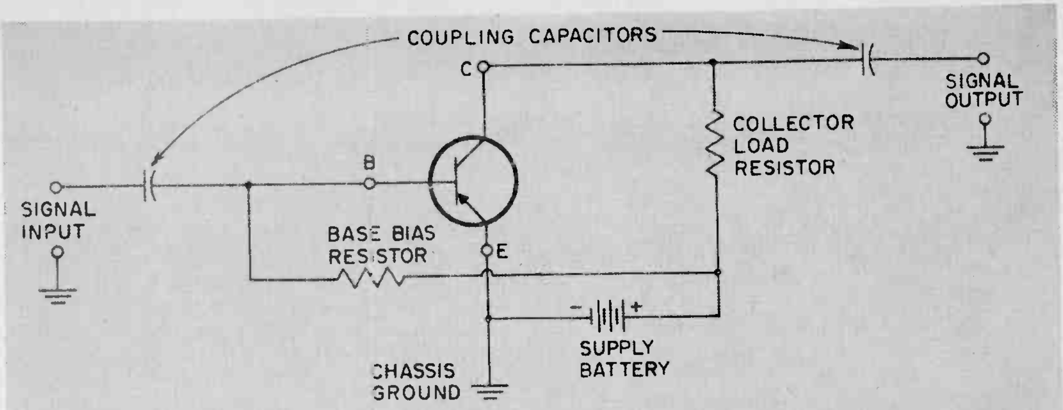
As the signal current alternates, it adds to and subtracts from the base bias battery current. As a result a greater or lesser number of current carriers are injected into the collector region, and the collector current through the load varies accordingly. Because the change in base current involved is so much smaller than the change in collector current, considerable current and power amplification is possible.

The illustration shows the current and voltage relationships in the common emitter transistor amplifier circuit. The base and collector currents vary in step with each other, while the voltage from collector to emitter (the collector signal voltage) varies in the opposite direction.

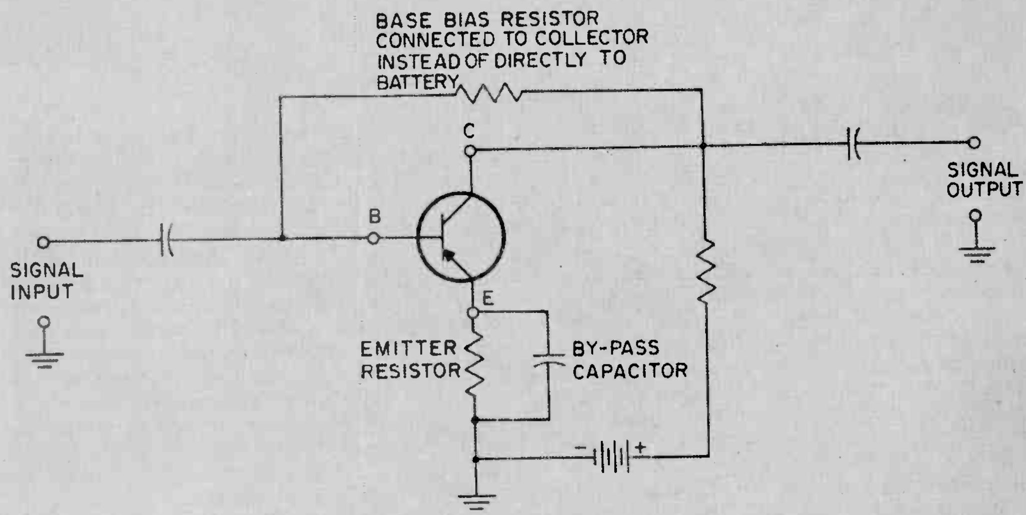
The similarities and differences between the operation of the vacuum tube and the transistor are now apparent. Whereas the vacuum tube is a voltage-controlled variable resistor, the transistor is a current-controlled one. The base current, in the common emitter circuit acts in the same manner as the grid voltage in the tube. In the vacuum tube, electrons travel through space from the cathode to the plate; in the transistor the current carriers (they may be either electrons or positive holes) migrate through the crystal from emitter to collector. Thus, from a purely external point of view, the emitter of the transistor may be considered analogous to the vacuum tube cathode, the base of the grid and the collector to the plate.

It is interesting to compare the effect of the base bias current of the transistor with the grid bias voltage in the vacuum tube. While the grid bias voltage tends to hold back the flow of plate current within the vacuum tube, preventing it from reaching excessively high values, an increase in the base bias current in the transistor causes more collector current to flow. To cut off the plate current of a vacuum tube, one makes the negative grid bias voltage large. But to cut off the collector current in a transistor, one removes the base bias entirely. Then the collector current drops to a negligible small value. Bias seems to have an opposite effect in these two devices.

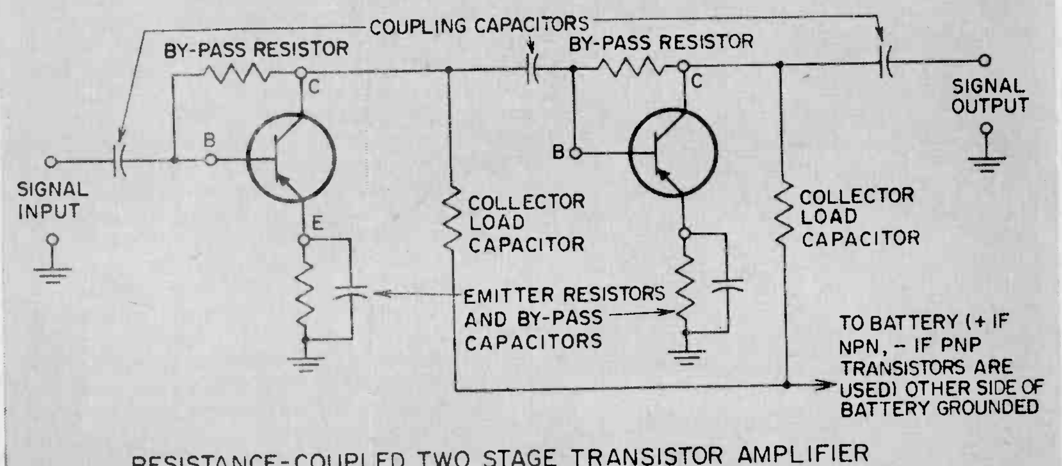
When we use the transistor in a practical common-emitter circuit for ac signal amplification, it is possible to eliminate the separate base bias battery. Since the base and the collector have the same polarity with respect to the emitter, one may supply base current by merely connecting a suitably sized resis-



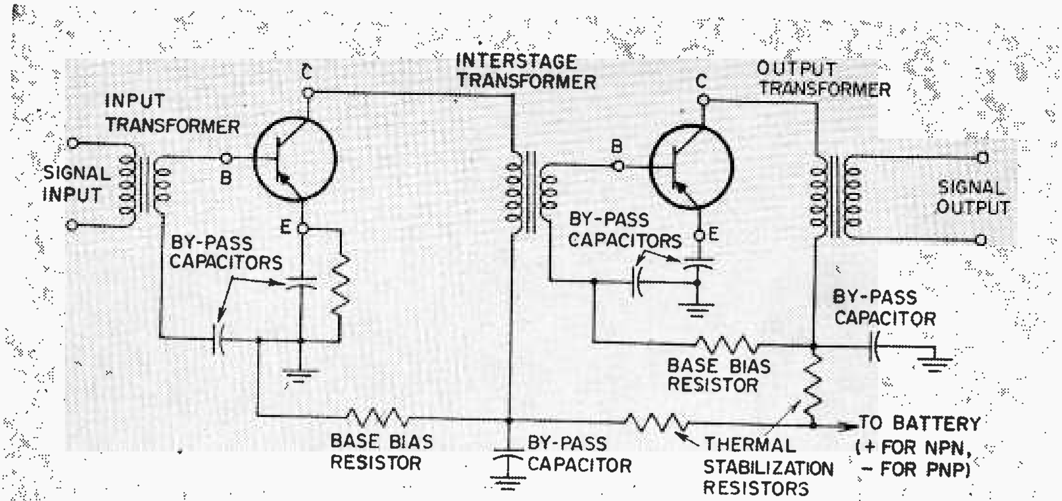
SIMPLE AC SIGNAL AMPLIFIER STAGE USING NPN TRANSISTOR
(FOR PNP TRANSISTOR, REVERSE BATTERY POLARITY)



AC AMPLIFIER STAGE DESIGNED TO MINIMIZE "THERMAL RUNAWAY"
(NPN TRANSISTOR)



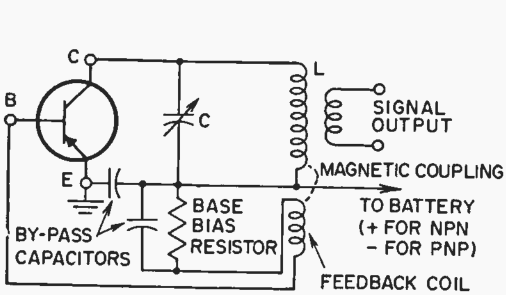
RESISTANCE-COUPLED TWO STAGE TRANSISTOR AMPLIFIER
DESIGNED TO MINIMIZE THERMAL RUNAWAY



TRANSFORMER-COUPLED TWO STAGE TRANSISTOR AMPLIFIER, DESIGNED TO MINIMIZE THERMAL RUNAWAY

tor from the ungrounded supply battery terminal to the base. Thus only one battery will be needed. The coupling capacitors in series with the input and output circuits serve the same purpose in the transistor circuit as they do with the vacuum tube. These block any flow of dc current while yet allowing ac signal currents to flow with ease.

At room temperatures and below transistors cause little trouble. But when the temperature rises, as it might in a higher-powered unit, or in apparatus exposed to the sun, extra current-carrying particles break loose within the crystal. As the number of these increases, the internal resistance of the transistor decreases, causing excess current to flow through the junctions. The increasing current raises the temperature, breaking loose more carriers and raising the current still higher. This vicious circle continues until the transistor is destroyed. We call this effect thermal runaway.

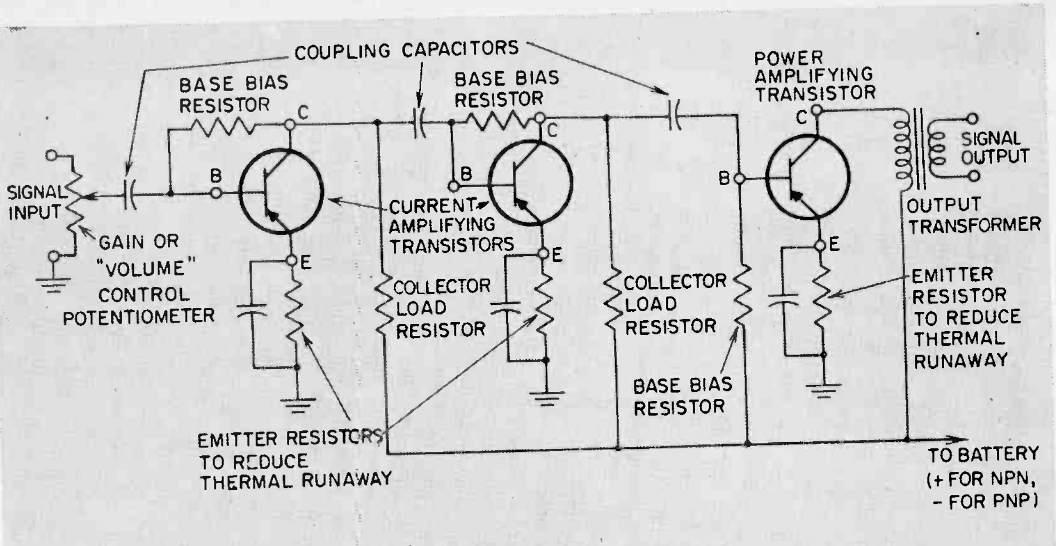


ONE TYPE OF TRANSISTOR OSCILLATOR

We may prevent thermal runaway by redesigning the circuit somewhat. For instance, we connect a resistor, the emitter resistor, in series with the emitter circuit. Normally there is about ten percent of the supply voltage dropped across this resistor. But when thermal runaway begins, the voltage drop across this resistor increases, reducing the voltage that is active between base and emitter. This cuts down the current and slows the avalanche. In order to reduce signal voltage loss in this resistor, we connect a large by-pass capacitor across it. The ac signal current flows through this, then, rather than through the resistor. But the dc must flow through the resistor.

We may also minimize thermal runaway by connecting the base bias resistor to the collector instead of to the battery. When current increases due to thermal runaway, the voltage drop across the load resistor increases. This decreases the collector voltage and, simultaneously, the base current. This holds the rising current in check. Of course, there is an undesirable feedback of ac signal current through the base resistor also, which reduces the amplification of the stage somewhat. But with proper design this loss need be but slight, and is more than compensated by the freedom from thermal runaway difficulties. Other techniques are also used, and are described in more advanced books.

Transistors may be connected in cascade, just as are vacuum tubes. This is done when one transistor alone will not provide sufficient amplification. The same principles are involved, but with an important difference. Whereas with the vacuum tube the incoming



A TRANSISTORIZED A.F. AMPLIFIER

signal 'looks into' practically an open circuit, the base-emitter resistance of the transistor is quite low, of the order of a few hundred ohms. This means that the coupling capacitors in a resistance-coupled transistor amplifier must be very much larger in capacitance than those used with tubes (tens of microfarads, instead of hundredths).

Transistor transformer-coupled amplifiers are also useful; miniature transformers being made especially for this purpose. But again, due to the low input resistance of the transistor, these transformers must have a step-down turns ratio (fewer turns on secondary winding than on primary winding) when coupling from one transistor into another.

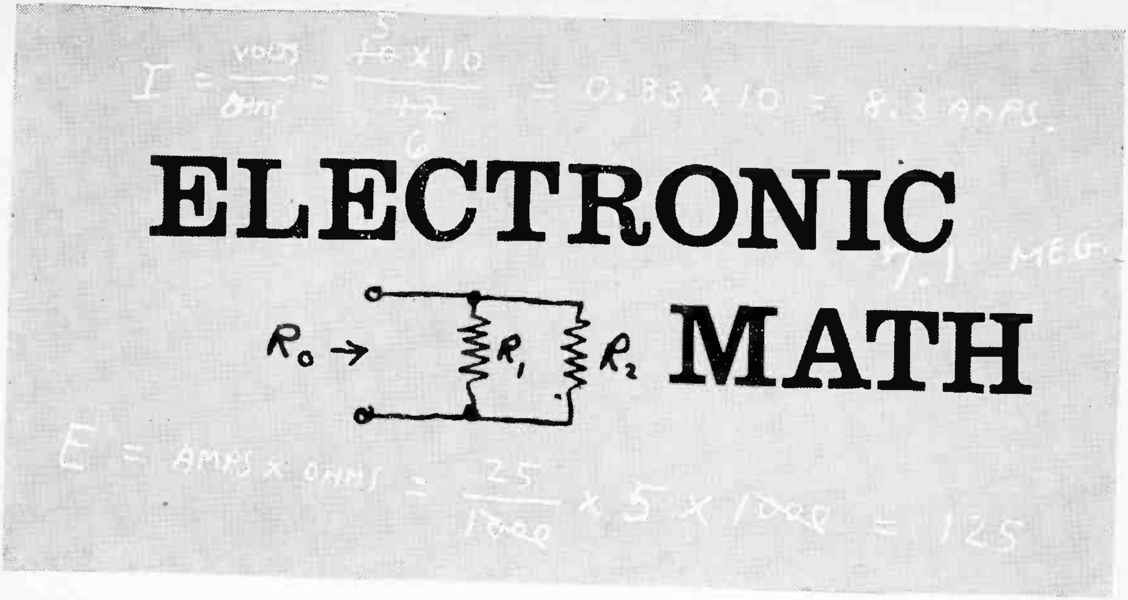
These amplifiers are designated for use with signals in the 'audio-frequency' range, that is, of the order of a few thousand cycles. Where higher frequency signals must be handled, more complex techniques are used, which are described in advanced books on transistor circuit design.

An oscillator is an amplifier arranged to supply its own input signal, and transistors, like vacuum tubes and all other amplifying devices, are also capable of oscillation. They then make most-useful signal generator for communications and industry. While high power transistors capable of more than a few watts output at the megacycle frequencies are not yet reasonable in price, they will be some day. Present transistors may deliver milliwatts of power at frequencies in the hundreds of megacycles, however, and are thus very useful. One type of simple transistor oscillator circuit is shown in the illustration. The parallel tuned L/C circuit determines the frequency of oscillation, and the coil in the base circuit, magnetically coupled to the tuned circuit coil, provides the feedback voltage. This circuit, when properly built and adjusted will serve as a signal generator at frequencies from 10 to about 10,000,000 cycles/second. The primary power and frequency limiting factor is the transistor itself.

The illustration shows a schematic diagram of an audio frequency amplifier using transistors. The first ten units are current amplifiers, and may together provide amplification of some ten thousand times. The power amplifier may provide a watt or two of signal power, sufficient to drive a small loudspeaker or industrial control device. This, of course, is a basic circuit . . . many refinements are possible and may be found discussed in books on circuit design details.

Present-day transistors are extremely durable mechanically, have a practically unlimited life span, are electrically efficient, and require no cathode-heating power. On the other hand, they tend to be much more expensive than vacuum tubes of equivalent quality, are easily damaged by heat, and are more subject to electrical damage in the hands of an inexperienced constructor. They also require relatively more power-supply current at much lower voltage than do most vacuum tubes. This makes them ideally suited to battery-powered apparatus, but somewhat inconvenient for equipment to be powered from the commercial ac power mains. But transistors have revolutionized the electronic industry, have well earned their place, and are probably here to stay.

ELECTRONIC MATH



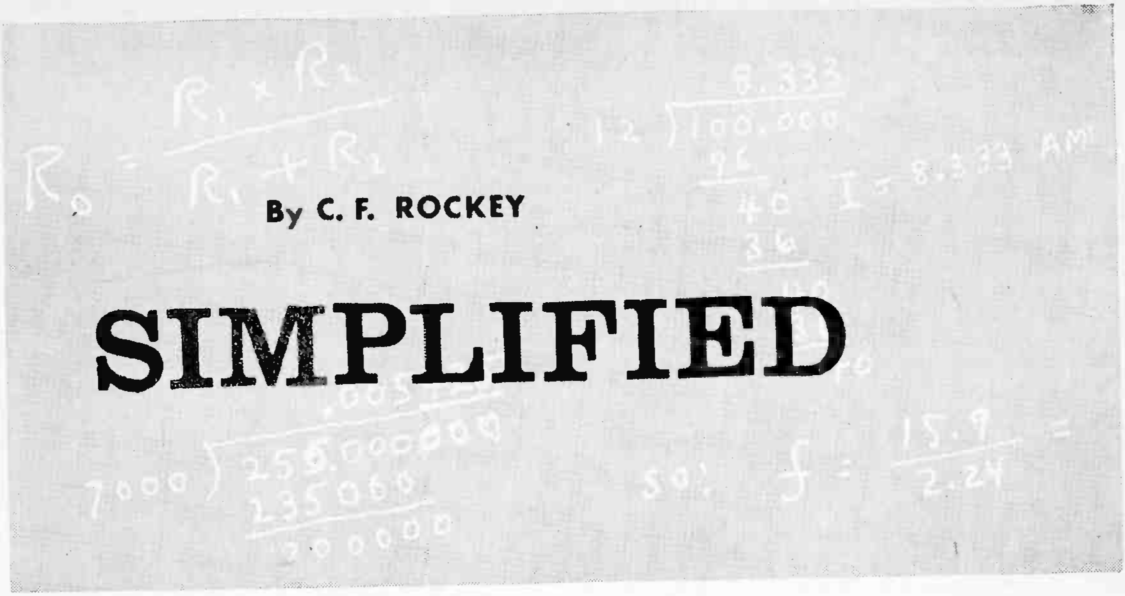
ELECTRONICS is a branch of applied physics. Physics is a mathematical science. If you want to get anywhere in electronics, either professionally or with your own conscience, you've got to face up to the figures. Ah, there's the rub! Mention mathematics to most people and they picture a dingy schoolroom with a dismal schoolmarm; the very image of dullness and despair. Or, they think of a dreamy-eyed egghead, with one foot in infinity and the other on a banana peel. But it needn't be so.

Trouble is, mathematics gets hung-up with tedium. When you were in school, your teacher nourished the faint hope that someone in your class might be a genius. So she set the class standards to keep him busy. The writer knows that you're not a genius, and neither is he. (Otherwise you wouldn't be reading this book.) He knows, from bitter experience, how tough this stuff is if one wants to make it so. But, rather, let's see how *easy* this math *may be*. We're going to learn to *get answers*, and not mess around.

Accuracy: First of all, there's this elusive business of accuracy. Sure, mathematics is accurate, it's made that way. But that's not why we're interested in it. We're interested in it as a *tool,* a way to handle the facts of electronics. And these, my friend, are seldom accurate. Most ordinary radio or electronic parts are seldom specified to within closer than ten percent of their true value; many no closer than twenty percent. Why fight city hall? For instance, why carry along figures like 235.0783 volts when the voltmeter you'd use to measure it might give you a reading anywhere between 230 and 240 volts? Why "sweat out" those extra figures? Don't you know that *you can't calculate accuracy into a situation;* that the overall accuracy is limited to that of the *least* accurate piece of information you're using? And with anything but the best laboratory data, this is not likely to ever be better than about 10%! So let's state our first operating rule: *"Be only as accurate as it pays you to be."* This, in itself, should relieve about half of the tedium from electronic calculations.

Secondly, let's get out of the "hoss 'n' buggy" days and use some *modern* methods. Old-fashioned "long multiplication" and "long division" were designed by people who had little to do and all day to get it done. Furthermore, these were designed for business calculations, like bookkeepers make, and not scientific calculations. So, let's find some "cheap 'n' dirty" techniques that will get the job done in half the time, and make it easier, too. Here we'll learn a system that's been in use by engineers for decades, that's guaranteed not only to be much easier, but to effectively eliminate those darned decimal-point worries also. Stick around, what have you to lose?

If you can possibly do so, hie yourself down to your neighborhood engineering supplies or stationery store, and latch onto a cheap slide rule. Believe us, mathematically-speaking, the slide rule is the great emancipator. Now you might once have associated slide rules with calculus, logarithms, and all that egghead stuff, but put that out of your mind. (Sure, eggheads use 'em, but that's because they're smart enough to do things the easy way. That's how they have time to be eggheads.) Anybody (and we mean anybody) who can read a fever thermometer, speedometer, steam-pressure gauge, or a volt-



By C. F. ROCKEY

SIMPLIFIED

meter can learn to multiply and divide on this simple gadget and thereby save three-quarters of his figuring time. You can get one that will serve you for years for less than two dollars. A book that shows you how is usually included.

Take the time to thoroughly understand what you're trying to do before you begin. Some people try to figure when they haven't the foggiest idea of what they're really trying to find. Naturally they have trouble.

A great help in solving any electronic problem is to *draw a neat, clear diagram first.* Then label it completely. Sometimes just the act of drawing the diagram will clean the carbon from the brain-cells, and make the whole thing clear as beer. Try it.

Finally, DON'T GET SCARED. No marks on a piece of paper, no formulas, not even the biggest numbers, can possibly hurt you. (If that formula looks scary, make an ugly face back at it and scare it first.) Remember here, you don't have a fussy teacher to satisfy or an exam to pass. How well you do is strictly up to your own conscience. Go to it, you have nothing to lose, and everything to gain.

Ohms Law: Let's begin with our old friend, *Ohm's law,* which relates the current flowing in an electrical circuit to the driving voltage and the resistance. This is commonly expressed by the formula:

$$I = \frac{E}{R}$$

Here I represents, the current, in amperes; E the voltage; and R the resistance, in ohms. To show how this works, let's make up a little problem. Suppose that a twelve ohm resistor is connected across a one hundred volt battery. How many amperes will flow?

First, we will draw a circuit diagram; not that we really need to with such a straightforward situation, but rather just to get into the habit (Fig. 1). Then we see that, to find the current, we must divide the voltage by the number of ohms. Now, this is the way most people would probably do it:

```
     8.333
12 | 100.000    I = 8.333 amps.
     96
     --
      40
      36
      --
       40
       36
       --
       40
```

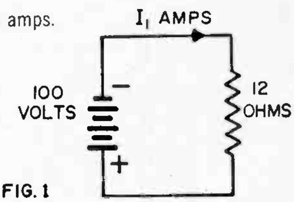


FIG. 1

But this is a lot of monkey-business. In the first place, how do we know that the voltage of the battery is exactly 100 volts, or the resistor exactly twelve ohms? After all, a *brand new* voltmeter, right out of its packing-box, is only expected to read within about two percent of the true value. This means that the battery may be developing anything from 98 to 102 volts when the meter reads 100 volts. Things get much worse as the meter grows older. The ohmmeters commonly used in electronic shops are notoriously inaccurate, especially when their internal batteries run down. Actually, although the resistor measures 12 ohms, its true resistance might easily be anything from 9 to 15 ohms. An answer of 8.333 amperes implies an accuracy of one part in one hundred thousand! Is such an answer justified? Why then the fuss?

Now, let's set this problem up in *modern* style:

$$I = \frac{\text{volts}}{\text{ohms}} \doteq \frac{\overset{5}{10} \times 10}{\underset{6}{12}} = 0.83 \times 10 = 8.3 \text{ amps.}$$

See how much easier this not only looks, but is. What did we do? First we "factored" the numerator into the product of ten times ten which, after all, still equals one hundred. Then we divided both numerator and denominator ("top" and "bottom" of fraction) by two. Finally, we can either divide five by six with short-division, or we can look up the decimal equivalent of 5/6 in any technical handbook. Also observe that we brutally dropped all but two digits from the answer. Even this "inaccurate" answer implies that we know the voltage and resistance to within one percent; perhaps even now it is a more accurate answer than we deserve.

Where this method really begins to pay off is when we must find the current in milliamperes, that is, thousandths of an ampere; as usually do in vacuum tube or transistor circuits. For example, let's suppose we want to find the current that flows through a 47,000 ohm resistor when connected across a 250-volt battery. If we set this up as grandfather would have done it:

```
            .005425
      ____________
47000 | 255.000 000     I = 0:005425 amps
        235 000
        -------         or: .005 425 x 1000 = 5.425 milliamps.
        235 000
        -------
         20 0000
         18 8000
         -------
         12 0000
          9 4000
         -------
          2 600 00
          2 350 00
         --------
```

Not hard, admittedly. But look at all those zeros, and the chances for making a decimal point error. Not only that, but think of all the trouble of finding "trial divisors" at each step. What a waste of time!

Now let's set it up in modern style. First, we remember that the typical resistor that is sold for electronic circuitry has a value which is within plus or minus 10% of that marked upon it. Thus we'd be completely justified in calling the resistor value 50,000 ohms, to make our work easier. And since 5 volts is somewhat less than 2% of 255 volts, we may round this off to 250 volts also, and still be within the 2% meter accuracy previously mentioned. Thus:

$$I = \frac{\text{volts}}{\text{amps}} \doteq \frac{\overset{5}{25} \times 10 \times 1000}{5 \times 10 \times 1000} = 5. \text{ milliamps.}$$

See how easy it is? You can do this directly in your head and, what's even more important, the decimal point places itself. When you consider that at least half of the errors made by amateur calculators are decimal point errors, the benefits are even greater.

How did we do it? First, we broke up 250 into its "factors," 25 and 10. Then we separated 50,000 into 5 x 10 x 1,000. Finally, remembering that 1 ampere contains one thousand milliamperes, we put this thousand into the numerator, or "top number." That's all there is to it.

Of course, if you're an arithmetic whiz, or you enjoy the tedium of long division, you wonder wherein the advantage lies. But, chances are, if you were one of these, you wouldn't have stayed with us this long. Let's move on.

Another common problem which arises in electronic work is that of finding the *voltage-drop* across a given resistor, when the current and resistance are both known. An example will illustrate. Suppose 25 milliamperes flow through a 5000 ohm resistor. What is the voltage "dropped," or developed across the resistor?

To work this problem, we remember to use the form of Ohm's law that gives voltage when current and resistance are known, that it:

$$E = I \times R.$$

The symbols and units are the same as we have been using.

Remembering that one ampere is equal to one thousand milliamperes, let's set up the problem as follows:

$$E = \text{amps} \times \text{ohms} = \frac{25}{1000} \times 5 \times 1000 = 125 \text{ volts.}$$

See how simple it is? When you 'dig' the modern method, the problems almost work themselves. No more "doodle-up and carrying one," no counting-off of zeros, no more worrying as to whether you've got the decimal point where it belongs. Who says Ohm's law is "hard?" (And can you imagine that thousands of candidates for F.C.C. radio operator's licenses fail their exams each year because they can't work Ohm's law?)

What happens when you know the voltage and the current, but would like to find the resistance? This is easy, too. First, let's use Ohm's law in the form:

$$R = \frac{E}{I}$$

with the symbols the same as before.

Now for an example: What is the resistance of a resistor that develops a voltage drop of 400 volts when 30 milliamperes flow through it? All right, let's set it up:

$$R = \frac{\text{volts}}{\text{amps}} \quad \frac{4\text{x}10}{\frac{3\text{x}10}{\underset{100}{1000}}} \quad \frac{4\text{x}10\text{x}100}{3} = 1.3 \times 1000 = 1300 \text{ ohms}$$

(Of course you remembered that ¾ is equal to about 1.3, didn't you?)

Try this one? How many volts flow through a 10000-ohm resistor when the current is 50 milliamperes? Did you get 500 hundred? Well, you're *wrong!* No, it's not your mathematics this time, my friend but rather your basic concepts. Now think; can voltage "flow?" Of course not! The only electrical quantity in a circuit that flows is *current.* Voltage exists, or develops between two points of a circuit but it never flows anywhere. (Despite the newspaper account of a man who was electrocuited when, "220 volts 'flowed through' his body.") There's a moral to this story: Make sure you understand the nature of the quantities you're working-with, before making calculations.

Joule's Law: Let's work out a couple of electrical power problems. To do this, we'll use what is sometimes called Joule's law. This important relationship comes in three forms:

1) $P = E \times I$
2) $P = I^2 \times R$
3) $P = \frac{E^2}{R}$

In all these, P stands for power, in watts; E for the voltage; I for the current, in amperes; and R for the resistance, in ohms.

Here are some examples, set up in modern form:

1) A radio transmitting tube draws 60 milliamperes at 300 volts. How much power is it consuming?

This calculation is perfectly straight-forward, once the setup has been properly made.

2) A resistor has a resistance of five thousand ohms and is passing a current of forty milliamperes. How many watts is it dissipating?

We remember that to "square" a number, we multiply it by itself. So:

$$P = (amps)^2 \times ohms = \frac{4\times10}{1000} \times \frac{4\times10}{1000} \times 5 \times 1000 = \frac{4\times4\times5}{12}$$

10   2

$$P = \frac{16}{2} = 8 \text{ watts.}$$

3) A lamp has an operating resistance of 200 ohms and operates across a 220-volt line. How many watts does it consume?

$$P = \frac{(volts)^2}{ohms} = \frac{2.2\times100\times2.2\times100}{2\times100.} =$$

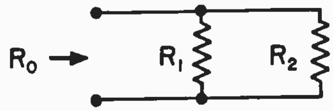
$$1.1 \times 2.2 \times 100 = 240 \text{ watts.}$$

Note carefully that the principle involved in each case is to break all large numbers up into smaller parts, or "factors." Very often these factors may then be divided-out or "canceled," leaving only small numbers to arithmetize. This is possible because most scientific calculations involve primarily multiplication and division. Ordinary, old-fashioned arithmetic, on the other hand, is built around business calculations, which emphasize addition and subtraction. By making use of the approach which best fits the work to be done, we may often make things considerably simpler as we have already shown. Rounding off excess figures is also a big help.

Sometimes, however, we run into a problem wherein both addition, multiplication, and division are involved in the same formula. Such is the case when we wish to *find the overall resistance of a pair of parallel resistors.* Here we may use the same methods we have been using, but we must observe a precaution. Whenever we have numbers with plus or minus signs between them, and we wish to simplify these by "factoring," as we have done, we must remove the *same factor* or factors from *all* numbers alike. Otherwise we will get into serious trouble.

An example will clarify this. But first, let us see the formula we will use:

$$R_0 = \frac{R_1 \times R_2}{R_1 + R_2}$$



Here R_0 is the overall resistance of the parallel circuit, R_1 and R_2 are the resistance values of the units to be paralleled. All are in ohms, of course.

For the example, let's assume that we have a 20000- and a 30000-ohm resistor connected in parallel. What will be the resistance of the combination? To set this up, let us "factor out" 10000 from each value, as we substitute it into the formula:

$$R_0 = \frac{2\times10000\times3\times10000}{(2\times10000) + (3\times10000)} = 10000 \; \frac{2\times3}{2+3} =$$

$$10000 \left\{ \frac{6}{5} \right\} = 1.2 \times 10000$$

So —R_0 = 1 000 ohms.

Or take another case, where the resistors to be paralleled are not of the same order of magnitude, say 2500 ohms and 30000 ohms. Although we cannot conveniently take 10000 out of each of these, we can take out a 1000. then:

$$R_0 = \frac{2.5\times10000\times30\times1000}{(2.5\times10000) + (30\times1000)} =$$

$$1000 \left\{ \frac{2.5 \times 30}{2.5 + 30} \right\} = 1000 \left\{ \frac{7}{32.5} \right\}$$

$R_0 = 2.3 \times 1000 = 2300$ ohms.

Inductive Reactance: So far we have been concerned with some of those general calculations which apply to both dc and ac circuits, where resistance is present. But there are a number of specific ac calculations which appear often enough in practical electronics to be worth our attention. The calculation of inductive reactance is one of these. Inductive reactance is the impedance offered by an inductor coil to the flow of an ac current. The formula for inductive reactance is:

$X_L = 6.28fL$, (or $X_L = 2\pi fL$)

Where X_L is the inductive reactance, in ohms; f is the frequency of the ac current, in cycles per second, and L is the inductance of the coil, in henrys. For some calculations, whether either the inductance of the coil or the frequency is not know accurately, 6.3, or just plain 6 may be used intead of 6.28.

To show the use of this formula, let us find the reactance of a two-henry inductor coil at 60 cycles/sec.:

$X_L = 6.3 \times 6 \times 10 \times 2 = 13 \times 6 \times 10 = 78 \times 10 = 780$ ohms.

Here we round off 6.28 to 6.3, and are therefore justified in calling 12.6 approximately 13. By so doing, we accrue an error of about three percent. This is usually well within the tolerance limits of most mass-production iron core inductor coils, so we do not become disturbed.

If we wish to use this formula at the higher frequencies, it works equally well if we let L be given in *microhenry's* (millionths of a henry), as high-frenquency tuning coils and R.F. chokes often are, and if we let f be given in *megacycles*. For instance, let's find the reactance of a 10 microhenry coil at a frequency of 7 *mc*:

$X_L = 6.3\,fL. = 6.3 \times 7 \times 10 = 44 \times 10 = 440$ ohms.

Capacitive Reactance: Like inductors, capacitors also have reactance, they also tend to oppose the flow of ac current through them. And the formula for *capacitive reactance* is:

$$X_C = \frac{15.9 \times 10000}{fC}$$

Where X_C is the capacitive reactance, in ohms; f is the frequency, in cycles per second; and C is the capacitance of the capacitor, in microfarads. In some calculations, 15.9 may be called 16 without to much error. Let's find the reactance of a two microfarad capacitor at 60 cycles, just to show how this goes:

$$X_C = \frac{15.9 \times 10000}{6 \times 10 \times 2} \quad \frac{15.9}{12} \times 1000 = 1330 \text{ ohms.}$$

As with the inductive reactance formula, this one also works if one uses micro-microfarads and megacycles, instead of microfarads and cycles. Since the technique of solving it is the same, we'll not bother with an example this time.

Resonant Frequency: Finally, a problem which always seems to bother begining electronics experimenters is the calculation of the *resonant frequency* of an inductor-capacitor capacitor tuned circuit, that frequency which is either strongly accepted or rejected by the circuit. This is not because such calculations are hard. They're not, *if* you know how to go about them. For one thing, many experimenters try to use the original, theoretical formula for making this calculation. Since this involves the unwieldy units (usually), of farads, henrys, and cycles, a drastic decimalpoint error nearly always results. Let's dodge that trouble right away by using a formula that's designed to *produce answers.* This formula is:

$$f = \frac{159}{\sqrt{LC}}$$

where f is the resonant frequency, in megacycles/second; L is the inductance of the coil, in microhenrys; and C is the capacitance, in micro-microfarads. Unfortunately, no matter how hard we try, we cannot get rid of that square root sign in the denominator; it's built into the system, it seems. But almost any engineering or mathematics handbook has a table of squares and square roots in it, or (even better) you can get a square root from the cheapest slide rule in a second or two. So there's no need to review that obsolescent nightmare of finding square root by the "long method," you despised so much back in school. Let that rest in peace.

Assuming that slide rule of a table is at hand, let us solve a typical resonant frequency problém, and see how easy it goes. Suppose we have a 10 micro-henry coil and a 50 micro-microfarad capacitor. At what frequency will such a combination be resonant? Let's set it up, and see:

$$f = \frac{159}{\sqrt{LC}} = \frac{159}{\sqrt{500}} = \frac{159}{\sqrt{5 \times 10}} = \frac{15.9}{\sqrt{5}}$$

From tables, or slide rule;

$\sqrt{5} = 2.24$

$$\text{So: } f = \frac{15.9}{2.24} = 7.1 \text{ megacycles/sec.}$$

Now that wasn't hard, was it? But you'd be surprised how many practical electronics men would rather take a beating than tackle a resonant frequency calculation. It's all in *knowing how,* my friend. Now *you* know how.

You've now found out how easy it is to make many of the common numerical calculations that elecyronics experimenters often would find convenient, but have previously shied-away from in pure animal fear. And there are many, many more practical and usable calculations which you can make by using the same basic techniques. All you need it a little ingenuity, and a little "heart."

Rectification, Filtering, and Detection

ALTERNATING current, usually used for commercial power, is bi-directional, yet most electronic equipment operates from direct current, which is uni-directional. The most common method of changing alternating current (ac) to direct current (dc) is by rectification.

It can be seen that, if we find a device that will only pass current in one direction, and feed ac into it, the output will be dc, since it will pass current only during the time the input current is moving in one direction. A diode tube is such a device, as are selenium and silicon rectifiers.

Electron Flow. If a diode tube is connected as in Fig. 1, electrons would flow from the heater to the plate, since the plate is positive in respect to the negative electrons (from the heater), and unlike charges attract. If we made the plate negative, no current would flow, since the negatively-charged electrons would be repelled by the like negative charge on the plate. The amount of electron flow (or current) would depend on the amount of positive plate voltage, as set by R. The more positive the plate is, the more current flows, as shown by the graph in Fig. 1.

At some point, however, the current stops increasing as the plate voltage increases. This is known as the *saturation point,* at which all electrons that leave the heater reach the plate. The current can then be increased only by increasing the amount of electrons available from the heater.

A Simple Form of Rectifier can be made by connecting a diode as in Fig. 2 (assuming the cathode is heated by a filament not shown). When, on the input side, point "A" is positive and "B" negative, the plate is positive in respect to the cathode, and electrons flow as indicated by the arrows.

On the next half-cycle however, point "A" is negative and "B" is positive. During this half-cycle the plate is negative in respect to the cathode, and no current flows. The output is then a fluctuating direct current that flows only on alternate half-cycles, as shown in Fig. 2, giving us a dc output from an ac input.

Since the rectifier in Fig. 2 passes current only on alternate half-cycles, or half of the

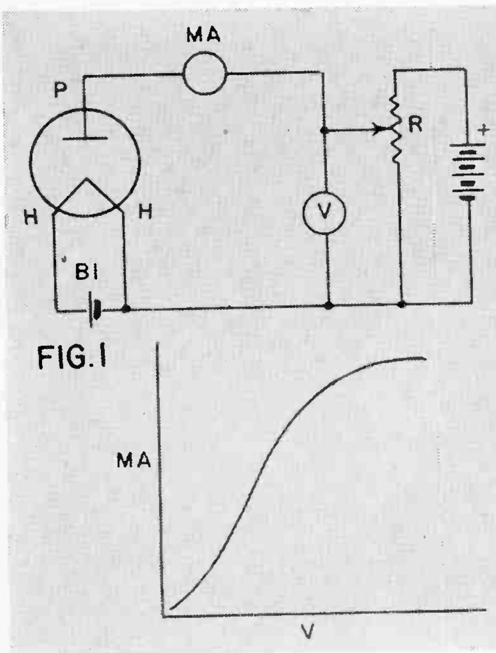


FIG. 1

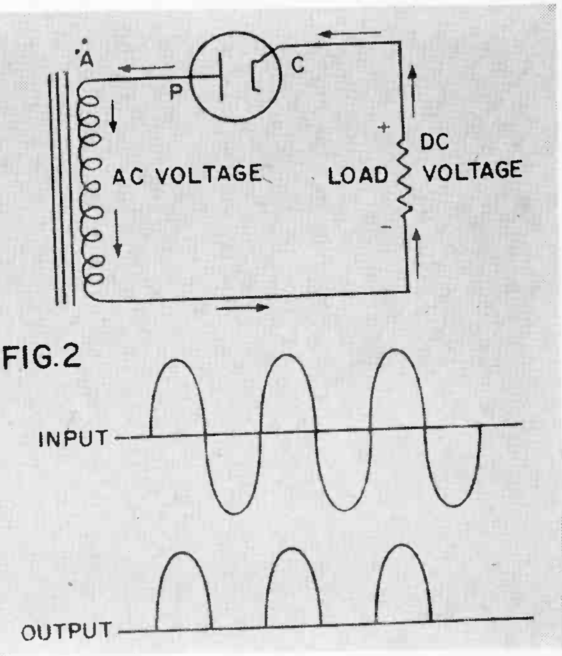
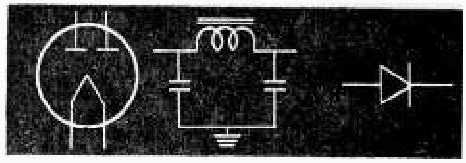


FIG. 2

Circuit Principles That Are Involved in Virtually All Electronic Circuits



time, it is called a *half-wave rectifier*. If a center-tapped input is available, two half-wave rectifiers can be connected in series, as shown in Fig. 3.

Half-Cycle Changes. In This Circuit, "A" is positive, and "C" is negative on half of the cycle. The midpoint of the input, "B" is negative in respect to "A," and positive in respect to "C." Since both tube cathodes are connected to the midpoint through the load, the plate of V_1 (connected to "A") will be positive to its cathode (connected to "B" through the load) one one half-cycle. Current will then flow from V_1 cathode to the plate, to "A," to "B," and through the load back to V_1 cathode (solid arrows). During this half-cycle, "C" (connected to V_2 plate) is negative in respect to its cathode, and current does not flow through V_2.

On the next half-cycle, however, the situation is reversed. "C" becomes positive in respect to "B," and current flows through V_2, from cathode to plate, to "C," to "B," and through the load back to V_2 cathode (dotted arrows). So one tube conducts during one half-cycle, and the other conducts during the other half-cycle. Since the system has current flowing during the entire cycle, it is called a *full-wave* rectifier. In practice, usually both plates are in one tube with a single cathode, called a full-wave rectifier tube.

Diode tubes, semi-conductor diodes, or chemical surfaces (selenium, copper oxide, etc.) which pass current in only one direction can be used for these rectifiers. Regardless of which is used, care must be taken in selecting the proper design for the voltage and current involved.

Peak Inverse Voltage. Figure 2 shows that the maximum voltage is across the tube when it is not conducting. At this point the cathode is at peak positive voltage in respect to the plate. This is called the *peak inverse voltage*, and is 1.41 times the "Root Mean Squared" (*rms*) input voltage (which is what most meters read, and how transformers are rated). The maximum allowable peak inverse voltage is included in rectifier specifications, and should not be exceeded.

In the full-wave rectifier (Fig. 3), the peak

FIG. 3

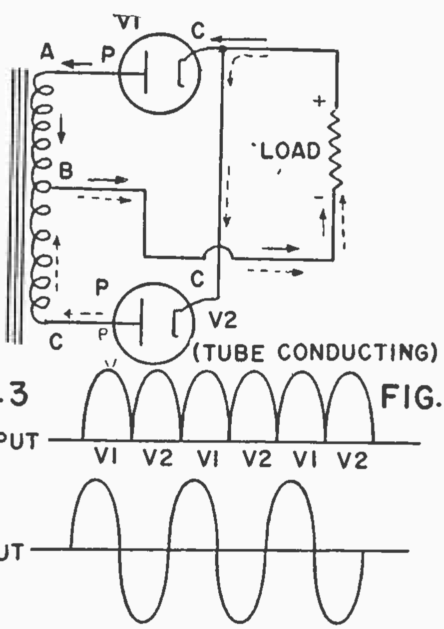
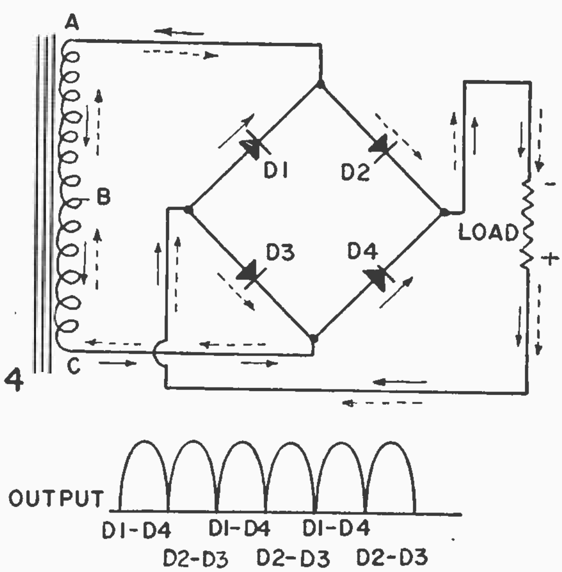
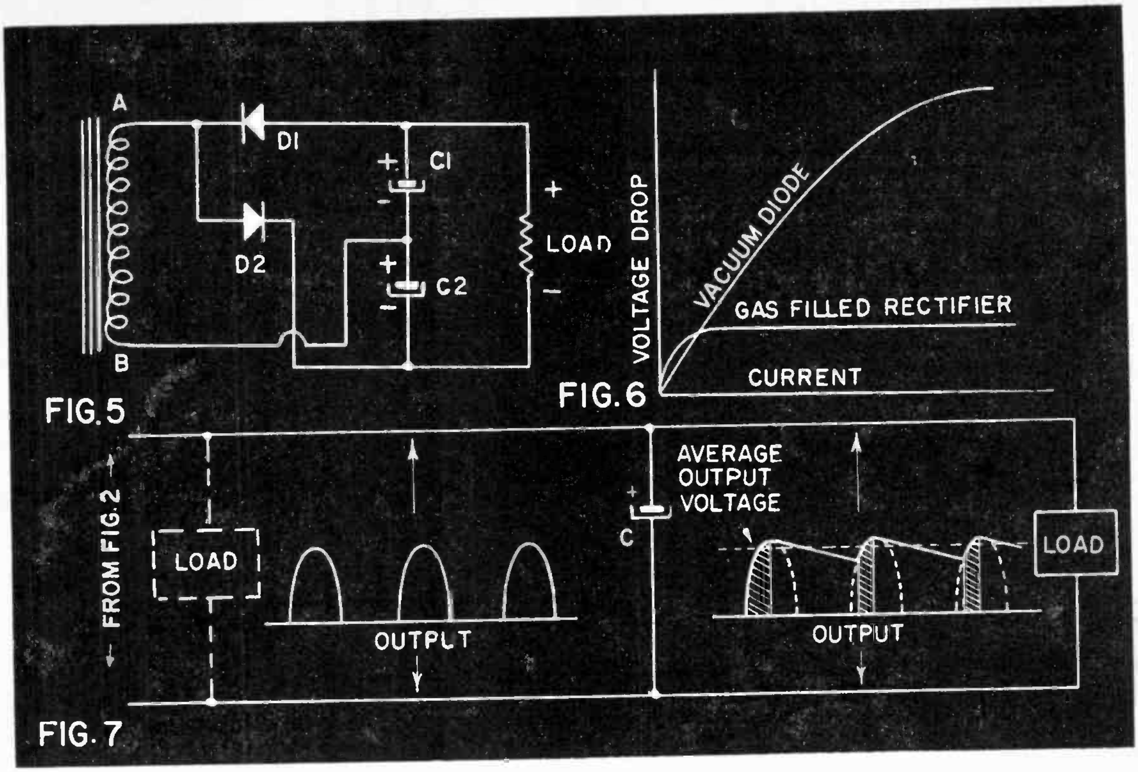


FIG. 4



(SHOWING DIODES CONDUCTING)



inverse voltage is related to the *rms* voltage on each side of the center-tap, since the circuit is essentially two half-wave rectifier circuits in series.

Rectifiers can also be placed in series or parallel to get greater current or voltage capacity. Tubes are often connected in parallel to increase current capacity. Fig. 4 shows how a series connection in bridge fashion can increase output voltage without increasing supply voltage or rectifier capacity. The diagram shows silicon diodes, but vacuum diodes could be used if there were separate filament supplies (one for D_1 and D_3, and one for D_2 and D_4). This is necessary due to the different potentials across the diodes at different times of the cycle.

In the Full-Wave Rectifier (Fig. 3), the voltage output was essentially equal to the voltage between "A" and "B," or "C" and "B," or half the transformer secondary voltage.

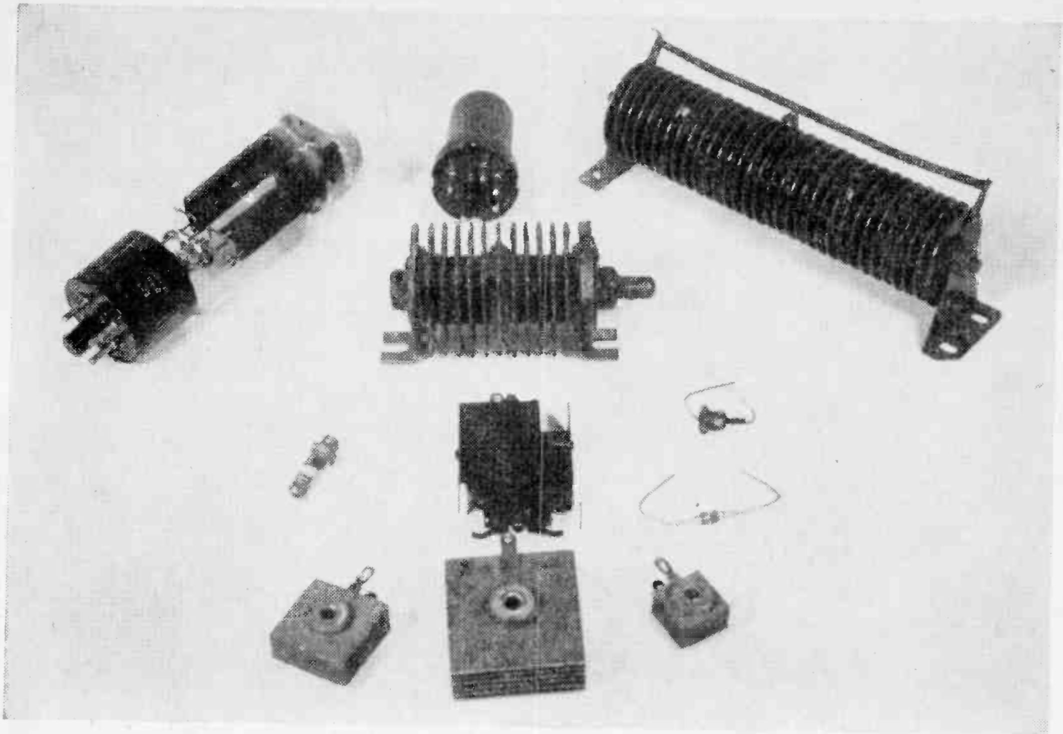
Suppose we use that same transformer in the *full-wave bridge rectifier* circuit shown in Fig. 4? When "A" is positive, current would flow through D_1 to "A," through the transformer to "C," through D_4, through the load and back to D_1 (solid arrows). On the other half-cycle, when "C" was positive, current would flow through D_3 to "C," through the transformer to "A," through D_2, through the load and back to D_3 (dotted arrows).

We would then have current flowing during both half-cycles, and the output voltage would be essentially equal to the full transformer voltage, between "A" and "C." At the same time, the peak inverse ratings of the rectifiers need be no higher than the ones used in the full-wave circuit (Fig. 3), since the diodes are connected in series for each half-cycle.

Rectifiers are also used in voltage-multiplier circuits. In these, a rectifier and capacitor work together to change the voltage to dc and increase it in value. Fig. 5 shows a rectifier-doubler or *voltage doubler*.

When "A" is positive, D_1 will conduct, and charge C_1 to the peak value of the input voltage. When "B" is positive (and "A" is negative), D_2 will conduct, and charge capacitor C_2 to peak input voltage. Since the capacitors are each charged to the peak value of the input voltage, and since they are in series, the output voltage will be twice the peak value of the input voltage. However, since any current drawn by the load tends to discharge C_1 while C_2 is charging (and vice-versa), the output voltage drops rapidly under load. To minimize this, large capacity condensers (40 mfd. to 100 mfd.) are usually used in this type of circuit.

Obviously, the peak inverse voltage rating



Common rectifiers include vacuum and gas tube types as well as solid state and chemically coated devices.

of rectifiers used in doublers must be high. When one diode is not conducting, the reverse voltage impressed across it is the peak supply voltage, plus the voltage to which one capacitor has been charged. The safe peak inverse value to use is therefore 2.82 times the rms supply voltage.

Voltage Multipliers. By placing two or more of these circuits in series, or combining one of them with a standard half- or full-wave rectifier, various amounts of voltage multiplication can be secured. There are tripler, quadrupler, etc., circuits, even up to eight times the input voltage.

In vacuum tube and selenium rectifiers, output voltage under load is reduced by the voltage drop in the tube or rectifier. This voltage drop increases as the current increases, since these rectifiers can be considered as fixed resistances. This loss can be overcome by using a gas-filled rectifier tube, or silicon rectifier, both of which have a relatively constant voltage drop, regardless of current. Fig. 6 shows the comparative voltage drop, related to current, between a vacuum rectifier tube (such as a 5U4), and a gas rectifier (such as an 83).

Gas-filled rectifiers usually contain mercury vapor. When the electrons within the tube reach a sufficient speed (as current starts to flow), they tear other electrons off the mercury atoms as they hit them. The gas then becomes "ionized," and furnishes additional electrons, which tends to reduce the resistance of the tube. As more current flows, there are more collisions and more additional electrons furnished. The result is that the tube resistance tends to decrease as current increases, causing a fairly constant voltage drop in the tube.

The nature of silicon rectifiers is somewhat similar in that the voltage drop is relatively constant. To date, however, silicon rectifiers with high voltage and high current capabilities are somewhat expensive.

Up to now all of the dc voltages we have seen have been fluctuating. This *ripple,* or ac component, must be removed, or there would be hum in the output. This is done by *filtering.* In Fig. 7, we have taken the output of the Fig. 2 circuit, and inserted a large capacitor across it, between the rectifier and the load.

The original output consisted of half-cycles of voltage which rose from zero to peak and back to zero, followed by a non-conducting half-cycle. With the capacitor in the circuit, however, the voltage does not drop to zero, but tends to level off.

On the conducting half-cycle, the capacitor first charges up to peak voltage, and then, as the supply voltage begins to decline, the ca-

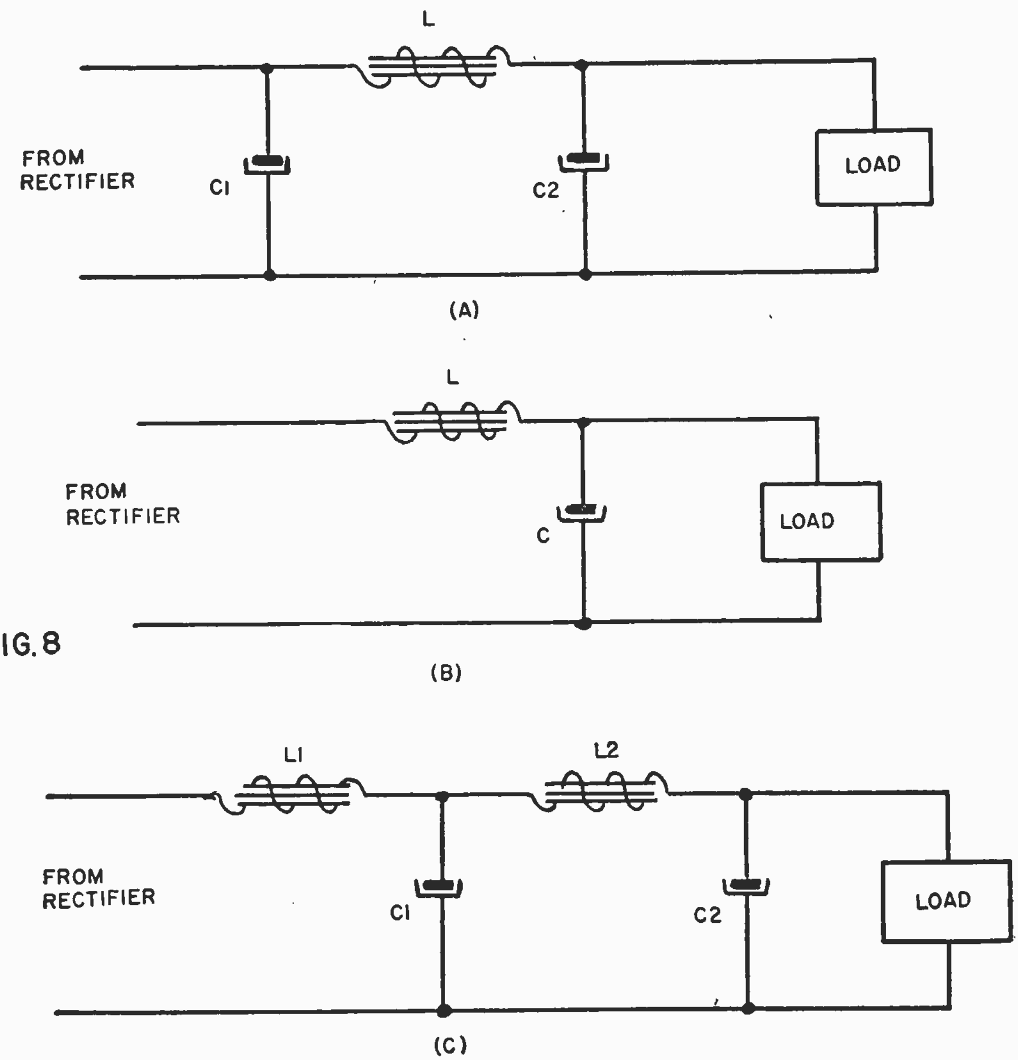

L
FROM RECTIFIER
C1
C2
LOAD
(A)
L
FROM RECTIFIER
C
LOAD
(B)
L1
L2
FROM RECTIFIER
C1
C2
LOAD
(C)

FIG. 8

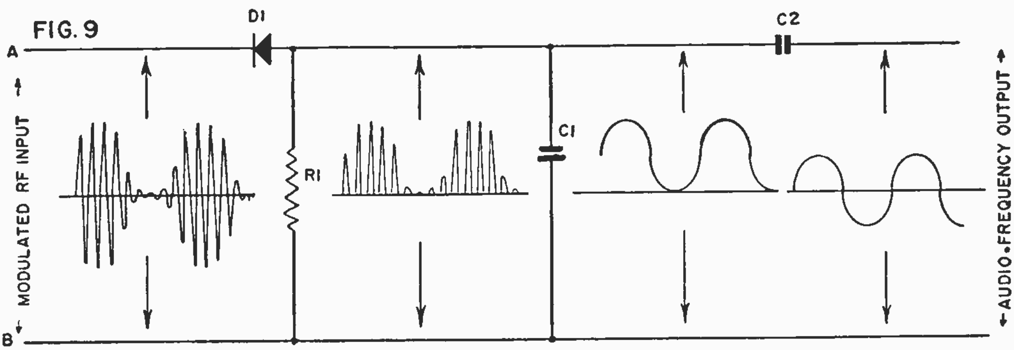

D1
C2
A
B
MODULATED RF INPUT
R1
C1
AUDIO-FREQUENCY OUTPUT

FIG. 9

pacitor starts discharging. It continues to discharge through the non-conducting half-cycle, but cannot completely discharge before the start of the next conducting half-cycle. On this half-cycle, it again charges to peak voltage, and the procedure is repeated. This results in the more constant voltage output shown at the right of Fig. 7. The shaded areas indicate the charging time of the capacitor, and the dotted line indicates the average output voltage, as related to the peak condenser voltage and the lowest voltage to which it can discharge.

A large capacitor must be used. It cannot completely discharge during the second half of the conducting cycle, and all through the non-conducting cycle. It also is apparent that, with a given size capacitor, filtering action would be better in a full-wave rectifier (Figs. 3 and 4), since there would be less time for the capacitor to discharge.

In actual practice, filter circuits usually take the form shown in Fig. 8. The most common circuit, a *capacitor input filter,* is shown in Fig. 8A. Here C_1 removes most of the ripple, as outlined above. The choke L_1 has a high inductance to ac and it, with capacitor C_2, smooths the output even more.

Fig. 8B and C are one- and two-section *choke input filters.* Here the choke greatly reduces the amount of ripple that gets to capacitor C_1, minimizing the compensation required of it during discharge time. In Fig. 8C, an additional choke (L_2) and condenser (C_2) further smooth out the ripple. They act essentially as L_1 and C_2 in Fig. 8A.

If the load current is high, it can be seen that the capacitor in Fig. 7 (or 8A) would discharge very rapidly, and the average voltage output would fall. For this reason, the voltage regulation of capacitor input filters (Fig. 8A) is poor, with the output voltage decreasing as the load current increases. In the choke input filter (Figs. 8B and C), the ripple, or fluctuation across the first capacitor is fairly slight, and the voltage can fall less during the discharge cycle. High load currents therefore have less effect on output voltage, and regulation is better. Due to this improved regulation, choke input filters are usually used where there is to be a wide variation in load current.

Rectification Principles are used for circuits other than power supplies in electronic work. Perhaps the most common circuit is in *detection.* This is the process of separating two alternating voltages, one at radio frequency and one at audio frequency.

In Fig. 9, our input is a modulated RF wave, and when "A" is positive, the input is rectified by D_1, similar to the half-wave rectification in Fig. 2. A rectified half-wave output then appears across the load resistor, R_1, and capacitor C_1 then removes the "ripple" from this output. In this case, the size of C_1 is selected so that it can discharge very little at the very high radio frequency rate, but can easily charge and discharge at the relatively low audio frequency rate. The voltage across in then filters out the radio frequency variations, but follows the audio frequency variations.

This output (shown at right of C_1) is still dc, always being positive. Placing C_2 in series with the output corrects this. As long as the voltage across C_1 is increasing, C_2 is charging. But the instant that the voltage across C_1 starts to decrease, C_2 starts discharging, the two actions resulting in the ac waveform shown below C_2. This ac voltage is then amplified for earphones or loud speaker.

Detection can also be done by triode tubes. In this case, the grid is biased so the tube is cut off and cannot conduct during negative half-cycles, giving the same output as diode D_1. Another method which gives similar results is to utilize the non-linear part of the tube's characteristic curve.

Detection is also used in listening to code, or CW. Here information is sent by breaking the radio frequency signal, which is above audible range. To enable operators to hear the breaks in the R.F. signal, *hetrodyne detection* is used. A constant internal R.F. signal is "beat" against the interrupted R.F. code signal.

Suppose a station is sending code by breaking its 1000-kilocycle signal. If we have a 1001 *kc* oscillator in our receiver, and mix it with the incoming 1000 *kc* signal, we will get a "beat" note of 1000 cycles, or the difference between the two. This "beat" note can be heard readily.

The "beat" note will only exist when the station has the key depressed, and sending a signal. When the key is open, and the station is not transmitting, our 1001 *kc* oscillator is still working, but has nothing to beat against, and we hear nothing. When the key is pressed, and the station sends out its 1000 *kc* signal, the "beat" note is produced, and we can hear the dots and dashes.

While there are certainly other circuits which are used in electronic equipment, these circuits are equally important certainly. However, the principles of rectification, filtering and detection are fundamental. Stress is always applied to amplifiers and oscillators, while these basic circuits outlined here go begging.

As you can see, rectifiers, filters and detectors are closely related to each other, and to a great extent are inter-dependent. These basic circuits are the root of many electronic equipment that we know as part of our everyday lives. . . . Perhaps now we can understand and appreciate the design considerations that went into bringing these benefits.

Learn By Doodling

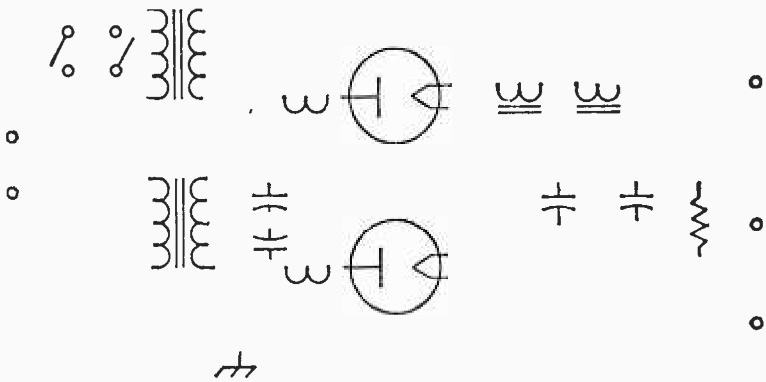
By ROBERT W. LUEBKE

HERE'S an easy way to test your knowledge of amateur radio circuits. The six circuits given on these two pages are some of those you'll find it essential to know about when working toward an Amateur Radio Operator's General Class license. We publish them by special permission of The American Radio Relay League, publishers of the *Radio Amateur's License Manual.*

The connecting wires have been removed, but all the components are shown. Cover the outlines on these pages with onion-skin or any other translucent paper and "doodle" in the missing connecting lines. Check your doodling for errors by comparing with the complete circuit diagrams on page 94.

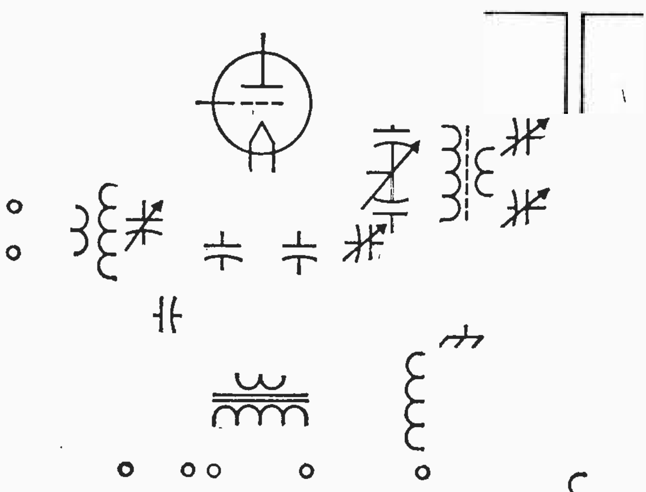
If you find your first doodle in error, study the circuit carefully and try again. Use a new sheet of paper each time rather than doodling directly on these pages. Soon you will be able to draw the entire circuit without using the outline at all.

1. Draw a schematic diagram of a full-wave single-phase power supply using a center-tapped high-voltage secondary with a filter circuit for best regulation, showing a bleeder resistor providing two different output voltages and a method of suppressing "hash" interference from the mercury-vapor rectifier tubes. Give the names of the component parts and approximate values of filter components suitable for either amateur radiotelephone or radiotelegraph operation.



1

2. Draw a simple schematic diagram of a plate-neutralized final RF stage using a triode tube coupled to a Hertzian antenna, showing the antenna system and a Faraday screen to reduce harmonic radiation.



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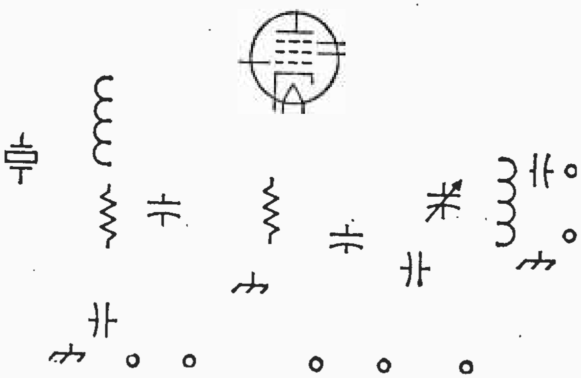
3. Draw a simple schematic diagram of a piezo-electric crystal-controlled oscillator using a pentode vacuum tube, indicating polarity of electrode supply voltages where externally connected.



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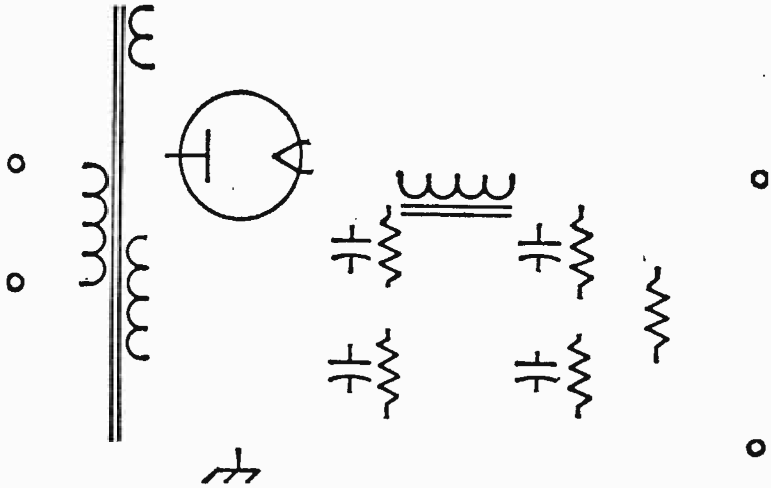
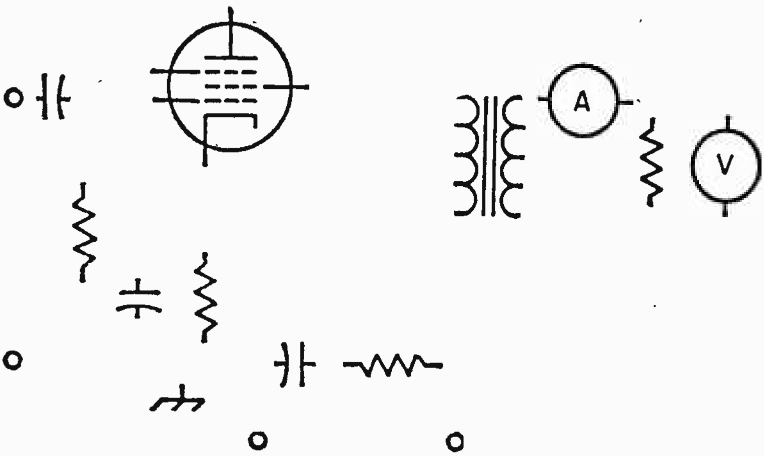
4. Draw a simple schematic diagram of a half-wave rectifier with a filter which will furnish pure dc at highest voltage output, showing filter capacitors of unequal capacitance connected in series, with provision for equalizing the dc drop across the different capacitors.

4



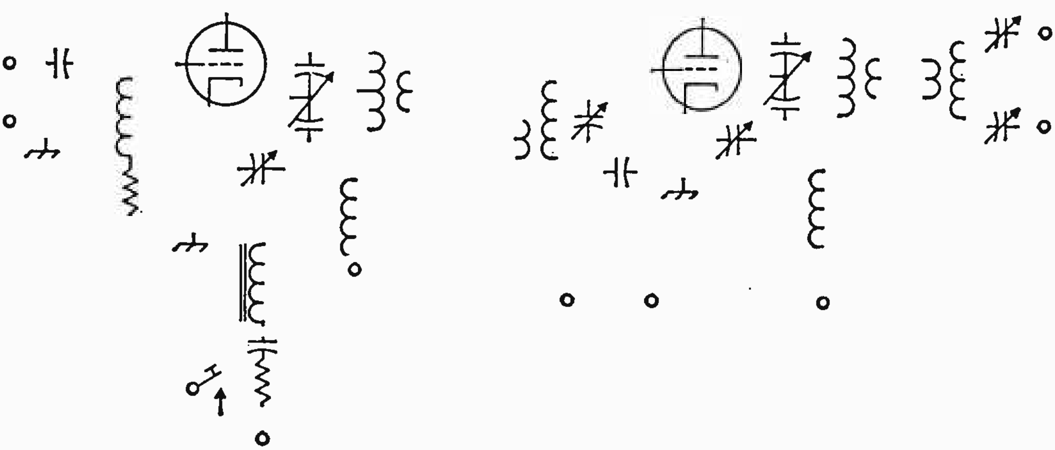
5. Draw a schematic diagram of a pentode audio power-amplifier stage with an output coupling transformer and load resistor, showing suitable instruments connected in the secondary for measurement of the audio-frequency voltage and current, and naming each component part.

5

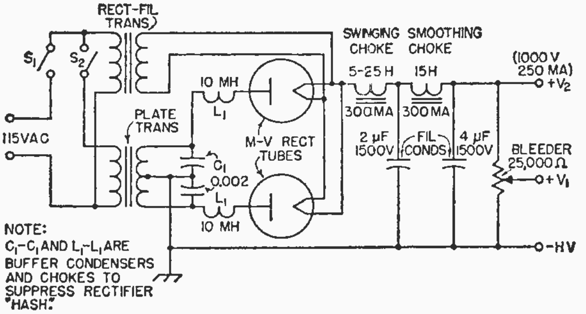


6. Draw a simple schematic diagram of two RF amplifier stages using triode tubes, showing the neutralizing circuits, link coupling between stages and between output and antenna system, and a keying connection in the negative high-voltage lead including a key-click filter.

6



Completed Circuit Diagrams



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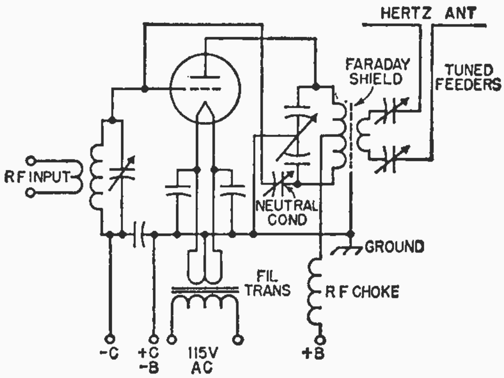

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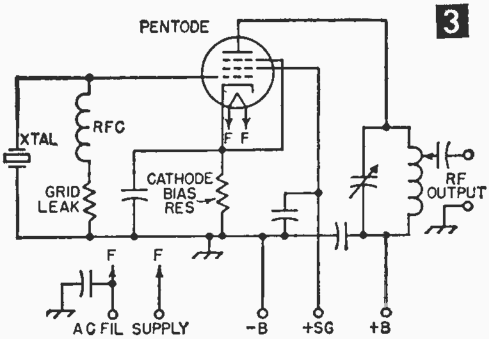

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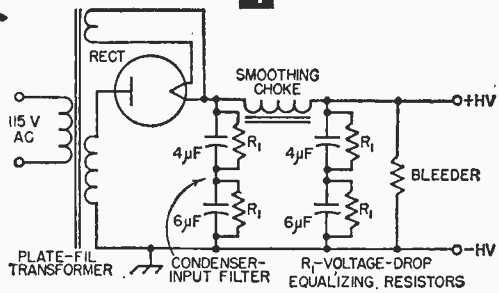

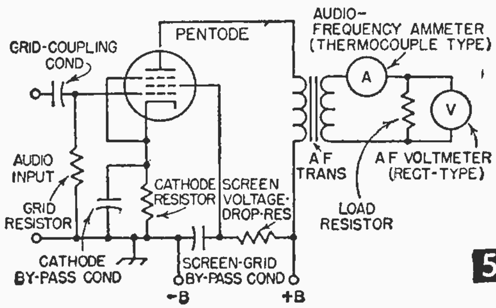

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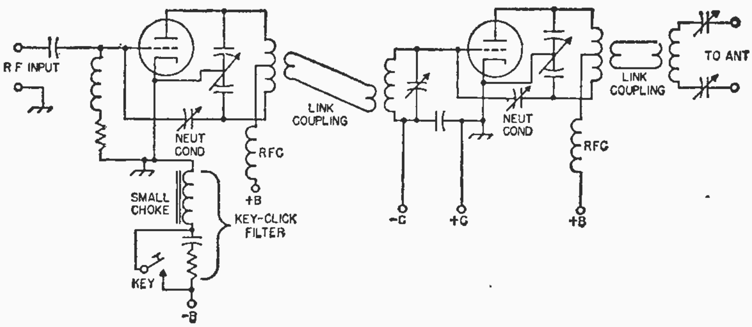


How Short Wave Works

By C. M. STANBURY, II

SHORT waves, unlike other radio signals, readily reach out to distant points. In fact when conditions are right, such a station can be heard around the world. Why?

With a dropping sunspot count, the range of usable frequencies will narrow but rare DX (distance) will improve. Again, why?

These are questions every SWL (short wave listener) should be able to answer. If you can't, keep reading.

The Ionosphere: All reception beyond 100 miles on frequencies below 30 *mc* depends upon the Ionosphere, that region of gasses between 50 and 200 miles above the Earth. The Ionosphere is bombarded by ultraviolet radiation from the Sun which produce ionized layers. Speaking loosely, these layers "reflect" radio signals back to, and around the curvature of the Earth. Actually the process is not reflection at all but, as shown in Fig. 2, refraction. When a wave encounters increased ion density at the layer's lower limit, it is bent. Bending increases as the signal travels further into the layer. If bent enough, it will be returned to Earth and give the appearance of reflection. If however our signal reaches the height of maximum ion density in this particular layer without being bent to Earth, the bending process is then reversed and it will emerge from the top of the layer travelling in approximately the direction as when it entered. So for all practical purposes that term reflection is satisfactory and we'll stick with it.

Now, as shown in Fig. 1, the ionosphere consists of four layers. The F2 layer is at the top and is most highly ionized. Ionization decreases with each descending layer. Needless to say, the greater the ionization the more a wave will be bent. Also (Fig. 1), the more obliquely it enters a layer, the less bending is required. Obliqueness, i.e. the angle of incidence, is dependent upon the hop length. The longer your hop, the lower your angle of incidence and the less bending required. Look at the diagram carefully and you'll see what we mean. And when you do, you'll understand why a nearby signal may pass through all the layers of the ionosphere while a station farther away is reflected and heard. Incidentally, maximum hop length is limited by the curvature of the Earth, height of layer and geometry. When this limit is exceeded, more than one hop is required (Wave B in Fig. 3).

At night our view of the Ionosphere changes, The D "Region" (which we'll discuss in a moment) disappears while the F1 and F2 layers combine.

Absorption and Frequency: Disappearance of the D Region is particularly fortunate for distant reception. Because of its low altitude and unusual shape, the D Region does not reflect radio signals but instead "Absorbs" them.

In each layer there is some collision between ions. If an ion carrying (propagating) a tiny portion of the radio signal collides with another ion, that bit of energy is lost and the overall signal weakened. This process is absorption. It increases with ionization and with atmospheric pressure thus is worst at low altitudes and almost nil in the rarified F layers. Incidentally, if it were not for this collisional process, layers would not disappear nor even diminish at night.

Up until now, we have discussed two factors which determine the effect of ionization upon a radio signal—height of layer and angle of incidence (obliqueness). But there is a third, even more important, frequency. The higher the frequency the less it is effected by ionization. If a frequency is high enough it will escape absorption but if it is too high, the radio signal will not be reflected back to Earth, not even by the F2 Layer. Between these two extremes lies a range of "Optimum Working Frequencies" (OWF), a range of channels best for reception from a given area.

Which brings us back to that first question —Why are short waves readily heard at distant points? Because no matter the amount of ionization, height of the reflecting layer or angle of incidence, the OWF always falls within the realm of short wave. Of course just where it falls between 3 and 30 *mc* does depend upon other factors.

Cycles, the Sun and Sunspots: As both reflection and absorption are controlled by Ionization, those forces of nature which regulate this process are very important to the listener. As we've already told you, ionization is produced by ultra violet radiation from the sun and is therefore greatest a little past

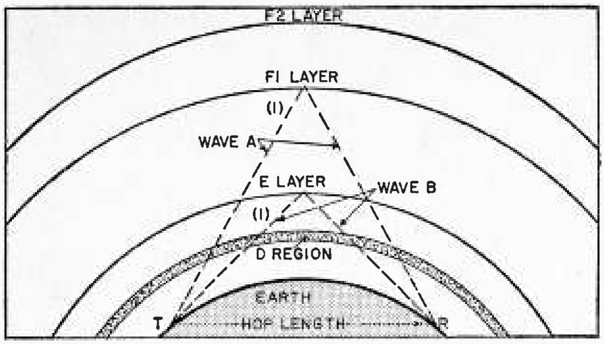


Fig. 1: Wave "A" requires too much bending to be returned to Earth by the E-Layer. The F-2 Layer, where ionization is greater, does the trick, effectively reflecting the signal. As wave "B" hits the E-Layer at a lower angle of incidence, it requires less bending and is therefore easily reflected by the E-Layer. (I=Angle of Incidence)

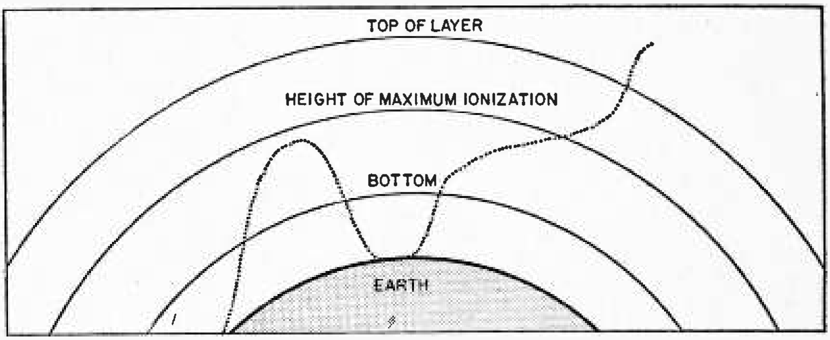


Fig. 2: Radio waves in an ionized layer.

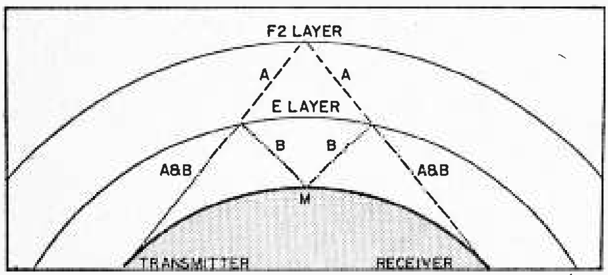


Fig. 3: This station is transmitting on two frequencies, A and B. A is the higher frequency which passes through the E-Layer where it is partially absorbed before being reflected back to Earth. Frequency B is reflected by the E-Layer and therefore suffers little in the way of absorption. It does suffer however, as it requires two hops. The strength of the received signals depends on what happens at point "M". SW Anyone?

midday and least just prior to sunrise. Logically it should also be at a higher level in summer than winter. This is true for all layers *except* the F2 which for some mysterious reason reaches a peak for brief periods around 1400 local time during winter.

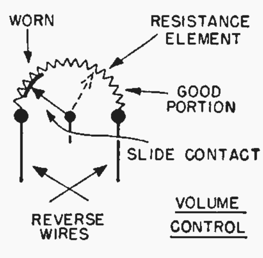
Ultra violet radiation also varies with the number of spots on the sun due probably not to the sunspots themselves but because of related phenomena on the solar surface. Sunspots follow a regular 11-year cycle. At its maximum, frequencies all the way up to 30 *mc* are reflected while channels below 7 *mc* are severely impaired by absorption even at night.

We are currently approaching a low in the cycle. Frequencies above 18 *mc* are now seldom useful but reception below 7 *mc* is tremendously improved. Generally speaking, the OWF range will be narrower resulting in crowding together of stations and a sharp rise in interference. But because the most revealing listening and rarest DX lies at the bottom of Short Wave, listening potential will be improved, especially on those nights when summer static is not too bad. Unfortunately, atmospheric static does not vary with the sunspot count.

We've answered that second question!

Salvaging Worn Radio-TV Control

• When a volume, tone, or other radio-TV variable resistance control becomes worn and gives spotty operation that can't be eliminated with control cleaner, try reversing the two outer wire connections (see sketch). This will put the operating range of the control on the least-used portion that is still serviceable and salvage the control for satisfactory use.—John A. Comstock.



PROJECTS SECTION

ALL of the radio schools recognize the value of actual laboratory practice. Knowing what soldering is and how it works is only half the story. The rest of the job is knowing how to solder. You can learn this only by actually using the tools and doing the job.

Here are some simple, interesting projects that you can build in your spare time to help familiarize you with laboratory practices. All you have to do is apply the knowledge gleaned from the foregoing pages, and in short order, you can assemble from parts, all of the devices shown. In addition to having the completed project for your own use, you will have gained a big extra . . . The practical knowledge of the use of tools, the familiarity and ease that marks the "pro," and more important, you will have assimilated a new knowledge. This will serve you very well when you read other technical publications, and help you to understand the workings and involvement of the familiar electronic equipment that surrounds you.

Surge Resistor

When a television or radio set quits, it's most probably a bad tube. The trouble with bad tubes is usually a filament

By HARRIS EDWARD DARK

MOST filament materials have a much higher conductivity when cold than when hot. The surge-strain on TV, hi-fi and radio tubes is greatest during the first few milliseconds following switch-on. For the same reason, old light bulbs usually burn out at the time they are turned on, rather than a few minutes later.

When your picture-tube filament goes, you're in for some real expense. Because there are so many other tubes in a TV, it's worthwhile to protect them all from that high initial surge.

Such protection is not only possible but easy to provide because of a very happy characteristic of carbon. This element's conductivity-temperature ratio is inverse to that of tungsten and most other metals: Carbon's resistance is greater when cold, less when hot.

A carbon conductor in the ac line makes a good surge resistor, one that can double or triple the life of tubes that must be switched on and off frequently. The positive electrode from an old dry cell is ideal for this application (Fig. 1).

Crush an old flashlight battery carefully with pliers or a vise. Remove the carbon. Make five or six cross-cuts with a hacksaw, each about three-fourths of the way through the carbon (to increase the carbon's resistance). To each end, attach a tube cap or other suitable clamping device (you can't solder to carbon).

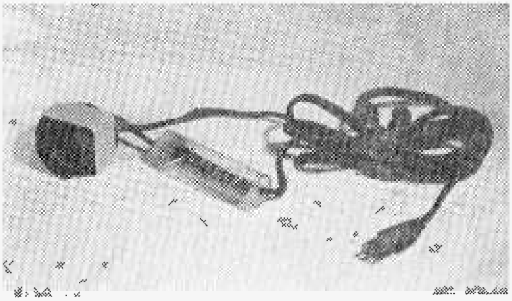


Fig. 1: The surge resistor takes the heavy current load caused by turning electronic gear on and off.

Housing: The carbon should be housed in a glass pill tube or something similar, rather than being merely wrapped with tape, because its temperature will rise 100 to 200 degrees in operation, depending on the TV's current draw.

Next, connect (preferably by soldering) the carbon into one side of the duplex line supplying the TV set, or insert it into one side of an extension cord (Fig. 2). Provide only one outlet, because if the carbon is already warmed by supplying another appliance, it will not have the desired surge resistance when a second power consumer is turned on.

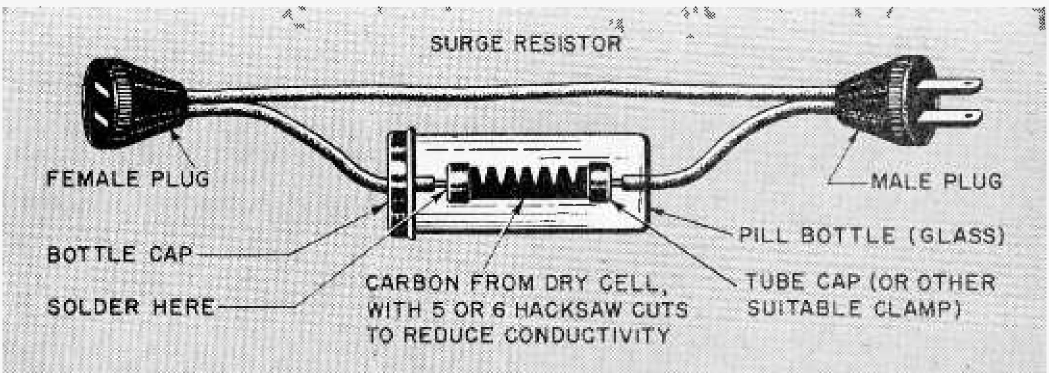
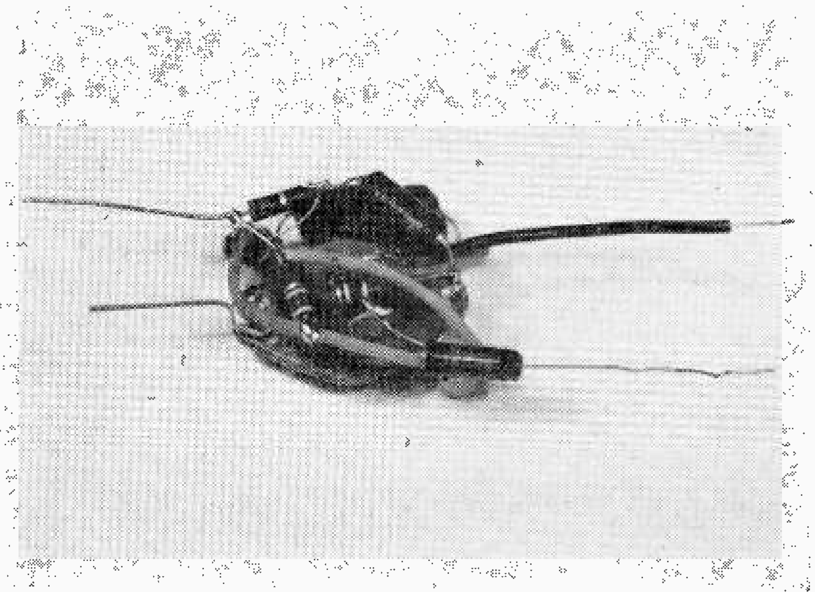


FIG. 2 – SCHEMATIC DIAGRAM



PARTS group right on the power transistor. This handy handful takes up little room, does big job.

Power Amplifier Module

Did you ever wish you had a small, inexpensive amplifier so you could try out those little signal circuits that need some boost?

By FRANK WOODS, JR.

THE power output capability here depends on the voltage supply, the amount of heat sink provided, and the value of resistor R4 (Fig. 2). The flexibility of the amplifier module becomes apparent later on.

Construction: Construct the amplifier on the output power transistor Q3. Make connections by twisting component pigtails together and soldering. Some of the pigtails are insulated with spaghetti.

Wire Q2, R4, and Q3 together as a first step. Connect end of R4 to the case of Q3 with a nut and bolt. Connect the other end of R4 temporarily so that you can change to another value later if necessary. Proceed with the remainder of the soldering and wiring, using Figures 1 through 3 for guidance. Go easy with the soldering heat on transistor connections.

Punch two holes in each end of the case with a hot ice pick. Place the amplifier in the plastic case.

The variables: The amplifier is ready to use with a 6-volt power supply and an 8-ohm speaker or a 3-volt power supply and a 3.2-Ohm speaker in the connection arrangement. The arrangement with a 6-volt power supply may also be used without changing the value of R4. The power output capability is around 1/4 watt with these arrangements.

To use an 8-ohm speaker in the direct connection with 3 volts or any speaker with the transformer connection and 3 volts of power supply, you may have to lower the value of R4 to 390K. In any event, check the case temperature of Q3 with your finger. *If, after a few minutes of operation, the case becomes too hot to touch, the value of R4 should be increased.*

To operate the module at higher power out-

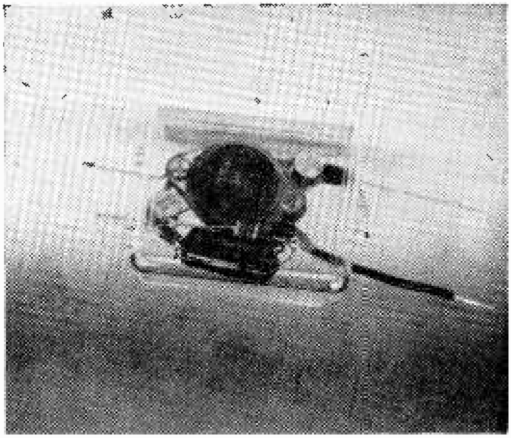


Fig. 1: Fitted into a miniature plastic case, the unit is insulated from other equipment, presents nice appearance.

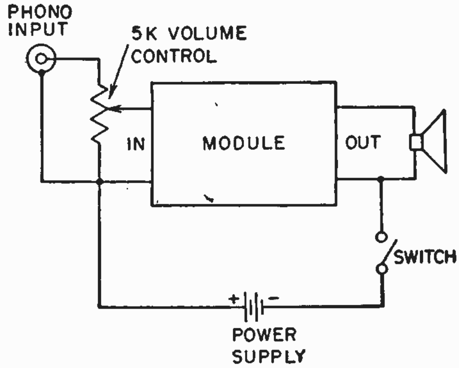
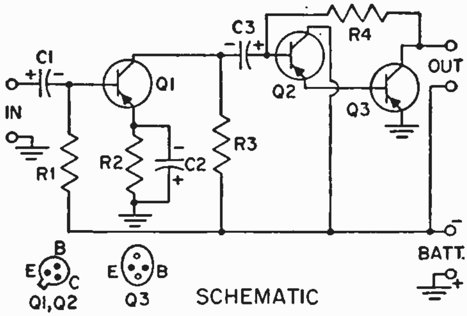


FIG. 3



SCHEMATIC

FIG. 2

MATERIALS LIST—POWER AMPLIFIER MODULE

Desig.	Size and Description
R2	470 Ohms, ½ Watt Resistor
R3	2.7 K, ½ Watt Resistor
R1, R4	470 K, ½ Watt Resistor (see text on R4)
C1, C3	8 mfd., 6 v. Ultraminiature Electrolytic Capacitor (Lafayette CF-102)
C2	100 mfd., 6 v. Ultraminiature Electrolytic Capacitor (Lafayette CF-106)
Q1, Q2	2N1381 Transistor (TI)
Q3	2N307 Transistor (Sylvania or RCA)
	1⅝ x 2⅛ x 1 inch Plastic Case (Lafayette MS-156)

Parts Source: Lafayette Radio
111 Jericho Turnpike, Syosset, L. I., N. Y.

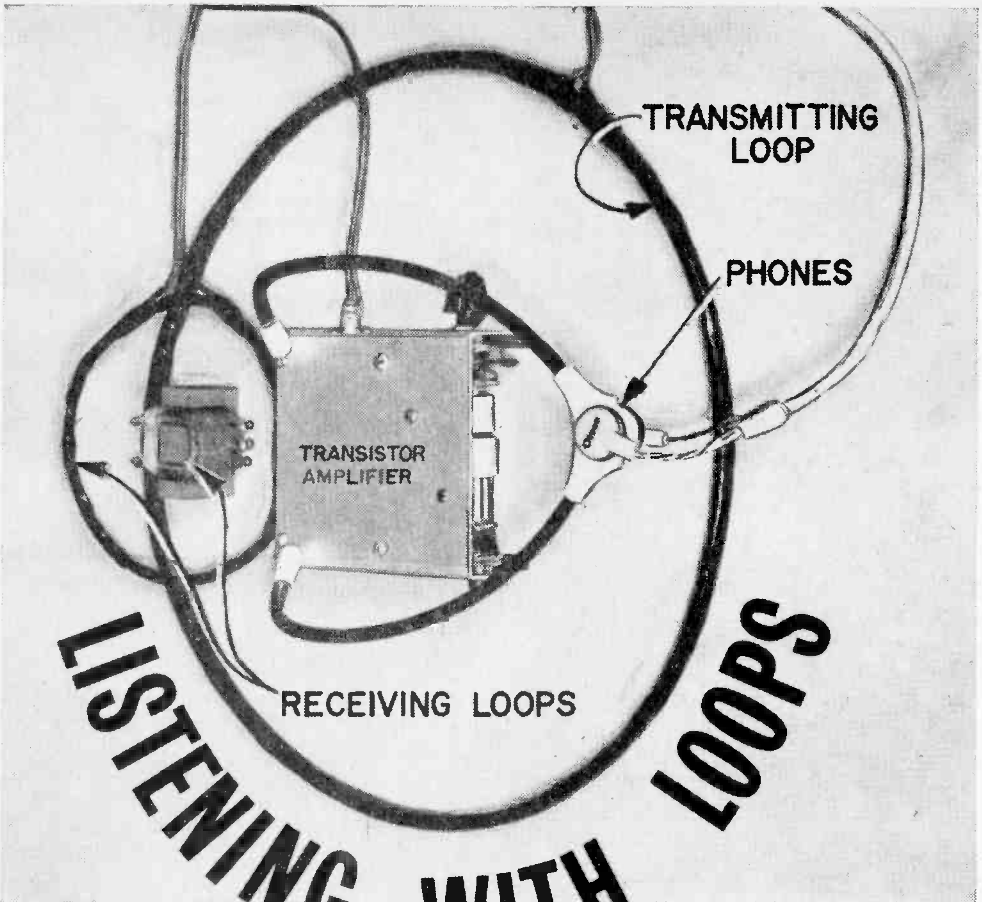
put capability, transistor Q3 requires heat sinking and ventilation, and the value of R4 must be lowered. Use a 6-volt power supply. One simple heat sink approach is to use long bolts through the mounting holes on Q3 and to fasten several nuts to each of the bolts. Another approach is to bolt radiating fins made of sheet metal to Q3. In any event, be careful not to short portions of the circuit with the heat sink attachments. Then, with a current meter connected in one of the battery supply leads, select a value of R4 that makes the current rise to about 0.4 ampere. Watch the current closely. If it tends to continue to rise after the connection is made, disconnect the power supply and increase the amount of heat sinking.

Use: Figure 3 shows the amplifier module hooked up with a volume control for general purpose use as a phono amplifier, PA amplifier, signal tracer, etc.. Another use for the amplifier is to raise the available power output from a transistor portable for picnic and beach party use.

If you use two amplifier modules and speakers, you can operate stereo. The volume controls may be ganged or separate as you wish.

This module can be used in any of the many applications for audio amplifiers. The power supply may be flashlight batteries, a 6-volt automobile battery, or an operated power supply with 6 volts output and a capability of supplying 250 ma. for the higher power output arrangements. If you use a battery power supply, connect a 160 mfd., 6V. electrolytic capacitor across the power leads with correct polarity.

You've probably thought of several applications where this handy unit would serve you, so don't procrastinate . . . start soldering!



LISTENING WITH LOOPS

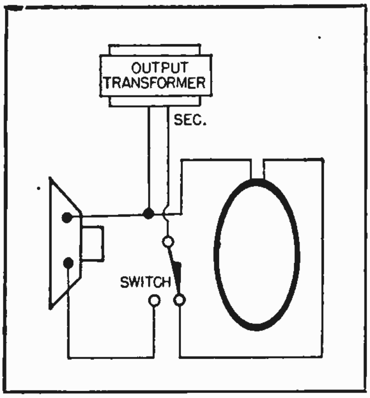
Did you ever attend a "silent" dancing party? The dancers wear earphones and only they hear the music. The effect is eerie...

By JOHN POTTER SHIELDS

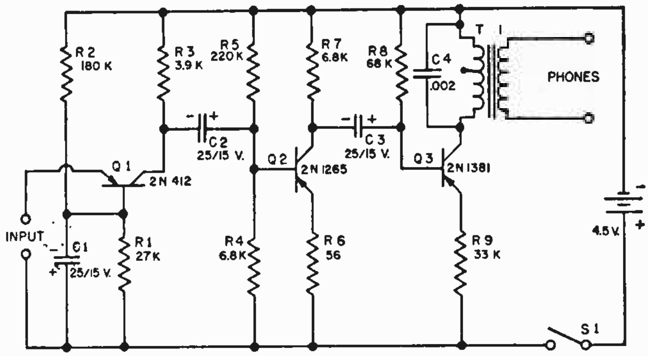
YES, you can hear loud and clear with no physical connection between your earphones and radio or hi-fi. What's more, you can hear when others cannot. The loop system is great for getting the sound from your television without interrupting grandma's nap. With loop listening a housewife can keep up with her chores while hearing her favorite programs without trailing wires and without having the radio or hi-fi blasting through the house. Here's how your loop system works and how to build it.

In Operation, as the signals flow through the transmitting coil, they generate a magnetic field around the coil which varies in proportion with the currents. The field produced by the transmitting coil induces currents in the receiving coil which are a facsimile of the signals applied to the transmitting coil. These currents in the receiving coil are applied directly to phones or an amplifier for further amplification. The action is exactly the same as a transformer.

For Maximum Range, the transmitting loop should be as large as possible and consist of many turns. To wind the coil, trace a



1. WIRE loop and speaker to select.



2. SCHEMATIC for transistor amplifier which boosts sound.

line conforming to the desired overall dimensions on your workbench. Drive 1-in. nails equal distances around the marking to form a coil form. When the winding is completed, remove the coil from the form and secure its turns in place with tape. Remove the insulation from the leads and attach them to a convenient length of ordinary "zip cord."

Due to its low impedance, the transmitting loop is connected to the transformer terminals of the particular amplifier being used. Due to the low impedance of the output transformer secondary, #20 or heavier wire should be used to wind the transmitting loop. The coil should not consist of more than 50 turns. If you like, a S.P.D.T. switch can be included in the setup so that either the loop or speaker is connected to the output transformer.

MATERIALS LIST—TRANSISTOR AMPLIFIER

R1	27K	(Olson #R-50, ½ watt)
R2	180K	
R3	3.9K	
R4	6.8K	
R5	220K	
R6	56 ohm	
R7	6.8K	
R8	68K	
R9	33 ohm	
C1	25 mfd 15 volt miniature elec. cap. (Olson #C-872)	
C4	.002 cap. (Olson #C-307)	
T1	500 ohm pri., 3.2 ohm sec. output transformer	
Q1	2N412 transistor	
Q2	2N1265 transistor	
Q3	2N1381 transistor	
1	S.P.S.T. rotary switch (Allied #34-B-080)	
1	battery holder and 3 pen-lite cells	
1	1 x 3¾ x 4⅛" miniature aluminum chassis	
1 pc.	2⅜ x 2²³⁄₃₂" un-clad peg board	
1	bag push-in terminals (Olson #HW-5)	
1	phone jack (Allied #41-H-642)	
1	phono jack (Allied #46-H-214)	
1 pr.	headphones (Olson #PH-55) (4 ohms) or PH-10 (4,000 ohms)	
1	½ lb. #20 enamel covered magnet wire (for transmitting loop)	
1	¼ lb. #30 enamel covered magnet wire (for receiving loop)	

The Receiving Loop should be as large in diameter as possible. Since the receiving loop will normally work into medium to high impedance inputs, it should have as many turns as are practical as this will increase both its sensitivity and impedance match. As mentioned earlier, the receiving loop can be connected directly to a pair of phones for short range operation. The phones should have an impedance of between 500 and 2,000 ohms.

A self-contained amplifier can be used to considerably boost the operating range. With the transistor amplifier between the receiving loop and phones, the operating range was extended to about 20 feet. A five inch coil wound with 100 turns of #30 wire yielded an operating range of about 15 feet.

The transistorized amplifier is straightforward with the exception that a common base input stage is used rather than the more conventional common emitter configuration. This provides a better impedance match between the receiving coil and the amplifier's input. The output transformer shown in the schematic matches the last transistor to the four ohm stereo phones.

Placement of the receiving coil need not be a problem if a reasonably small loop is used.

As Much Power As Possible should be used to drive the transmitting loop in order that the amount of amplification between the receiving loop and phones can be kept to a minimum. Excessive amplification at the receiving end can cause an objectional amount of hum and spurious noise. The ratio of the energy emitted to the surrounding radiation should be as high as possible.

One-Transistor Experimental Tuner

By WALTER TEMCOR

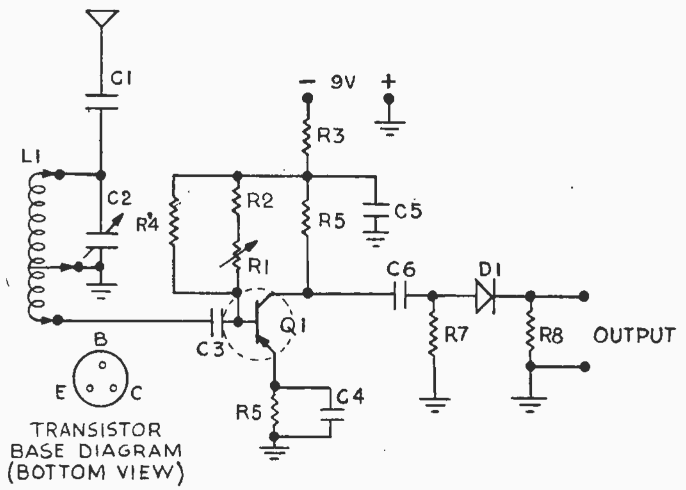


FIGURE 1 SCHEMATIC

Our experimental one-transistor tuner picks up short wave broadcasts. With a broadcast coil it is red hot. Parts cost about $5

WANT to experiment with transistor tuners? Here's a good starter. It's a superb performer on broadcast and will pick up short wave. Performance on short wave is limited, but it will get the high-powered Voice of America broadcasts, and on occasion you may pick up Moscow or London. The tuner is presented as a breadboard project that makes experimentation easy and keeps the cost down. The circuit is shown in Fig. 1. The unit is assembled on a miniature perforated board. Figures 2 and 3 show top and bottom views. The clip leads connect to the coil, not shown. The two home-made short wave coils are shown in Fig. 4. The broadcast coil is a store-bought type. You can use any kind of amplifier that you have available in place of the amplifier shown in Fig. 5.

Construction: Use Figs. 1, 2, and 3 for guidance in construction. Most of the connections are made with the component pigtails on the bottom of the perforated board. Note that the frame of tuning capacitor C2 connects to ground. The ground symbol in Fig. 1 refers to common connection to the ground bus and is used to maintain simplicity in the diagram.

R1 is held in place by its connection in the circuit. This is a sensitivity control, and you simply adjust it for best performance. The setting may vary slightly with frequency, but in general it won't have to be readjusted very often.

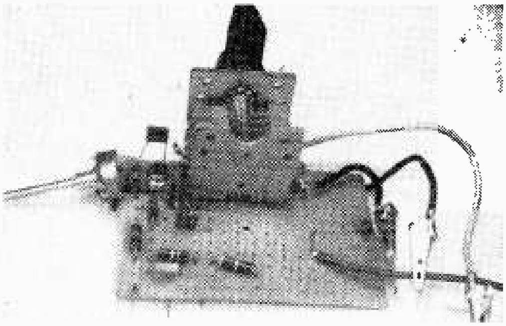


Fig. 2: Top view of the tuner. Note that the potentiometer is supported to the mounting board only by its connections.

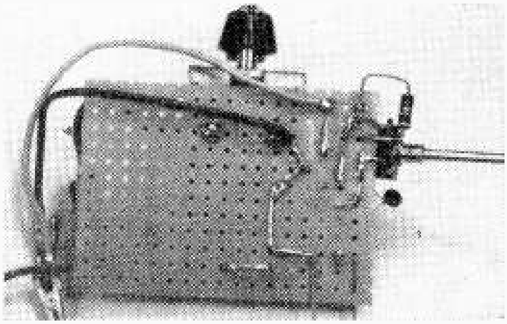


Fig. 3: The under-chassis view shows the clip leads for coil connections. Using clip leads facilitates coil changing.

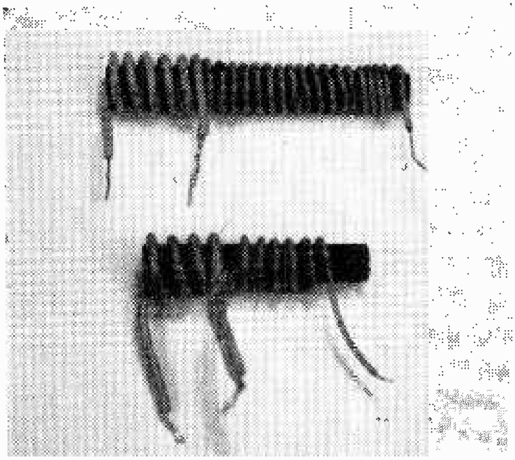


Fig. 4: The coils, wound on ferrite with insulated wire.

The coils are constructed on pieces of ferrite rod. Use Fig. 4 and the data in the parts list for guidance. To break the ferrite rod clean, measure off the required length, scribe the break point with a shallow hack saw cut on one side, and break the rod at this point, using both hands with one thumb held opposite the saw mark. The length of the ferrite cores is not critical.

You may want to add battery and amplifier input lead extensions to the basic tuner board. The author made these connections directly to the amplifier and picked up battery power from the amplifier which uses a 9-volt battery. It should be emphasized that any audio amplifier may be used. You can even use the audio amplifier from a table model radio.

Comments: The transistor is a 99 cent-er. The tuning circuit and biasing arrangement is conventional. The tuning circuit consisting of L1 and C2 receives the signal from the antenna through C1. The coil connected to the clip leads and the setting of C2 determine the frequency which the tuner will receive. The signal passes through C3 to the base of Q1. C3 isolates the dc bias on the base of Q1 from the tuning circuit ground. Base bias is provided via the resistor combination of R1, R2, and R4. R2 limits the bias to safe ranges, regardless of R1 setting. R5 provides collector bias and is part of the Q1 load. R6 stabilizes Q1 and C4 provides a bypass path for RF. R1 and C5 decouple the tuner from the auxiliary amplifier if you pull power from it, as the author did.

The signal at the collector of Q1 is RF. This signal is fed through C6 to the detector diode D1 and the associated resistors R7 and R8. The diode output is audio. The usual bypass capacitor across the output, is omitted because amplifier input capacitance generally provides the required bypassing like for free.

The antenna requirement is 3 to 10 ft. for broadcast and about 50 ft. for short wave. You'll also need a ground for short wave.

The amount of experimentation that can be performed is unlimited. You can try various feedback schemes to improve sensitivity. You can experiment with the effects of the value of the collector load resistor R5 if you wish, and you can even try a coil as a load. The setting of R1 for best performance will vary somewhat with the value of R5.

You can change different types of transistors (stick to pnp) to determine effects on performance. You can try lower battery voltages. Again, the setting of R1 will be different.

Experiment with the coils, too. You can decrease turns at top and bottom of the coils, or move turns closer together. You can try the circuit without the cores in the coils, and you can experiment with permeability tuning by moving the cores in and out of the coils.

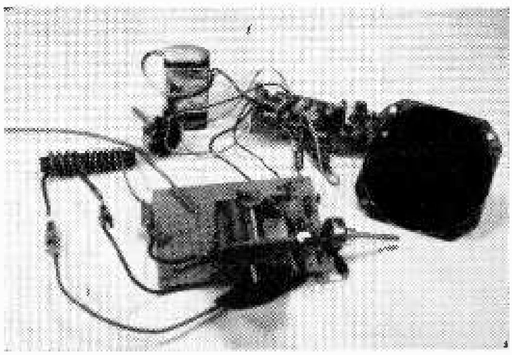
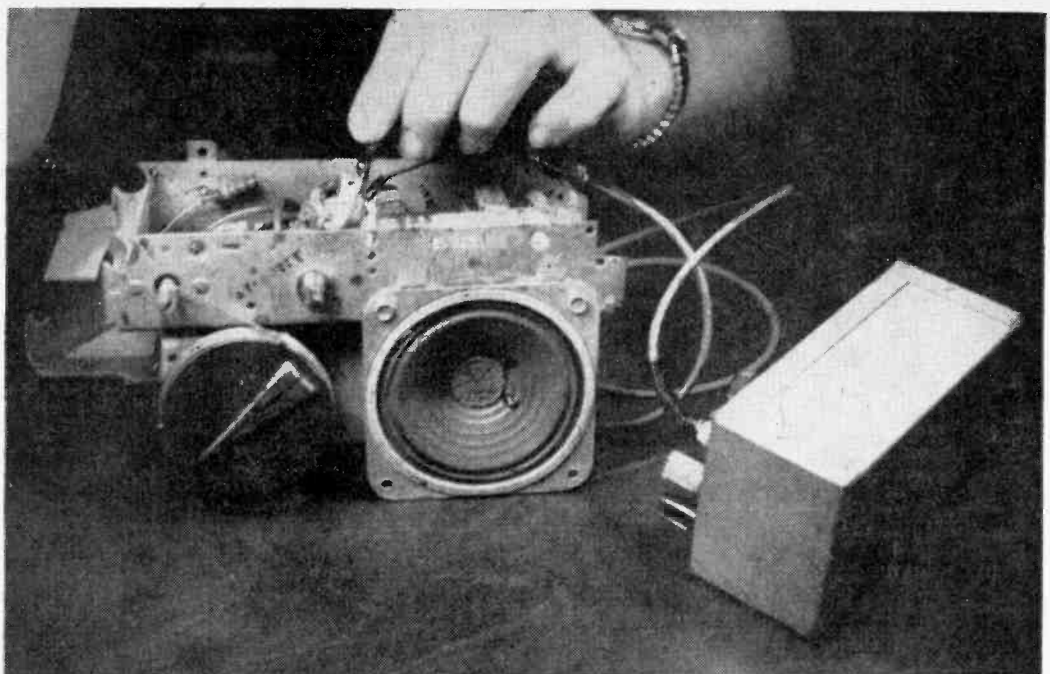


Fig. 5: The finished unit looks unfinished, but is actually shown hooked up with an amplifier and speaker. Battery serves both.

MATERIALS LIST—ONE-TRANSISTOR EXPERIMENTAL TUNER

Desig.	Size and Description
	½-w carbon resistors (10% Tolerance)
R3, R6	1 k
R5	2.7 k
R8	4.7 k
R7	10 k
R2	47 k
R4	220 k
R1	1 megohm miniature potentiometer (Lafayette VC-38)
C1, C6	100 mmf 75-v miniature ceramic capacitor
C3, C4, C5	.01 mfd 75-v miniature ceramic capacitor
C2	365 mmf variable capacitor (Lafayette MS-214)
Q1	T2163 transistor (Philco)
D1	1N60 germanium diode (Raytheon)
	2 7/16 x 3⅜ miniature perforated board
	pointer knob (Lafayette KN-40)
	minigator clips (Mueller 30), 3 required
L1	(A) broadcast (Lafayette CO-89)
	(B) 2—7 mc—23 turns (tapped at 6th turn) of #22 insulated hook-up wire on 2⅞" length of .33" diameter ferrite rod.
	(C) 5.5—15 mc—10 turns (tapped at 4th turn) of #22 insulated hook-up wire on 2" length of .33" diameter ferrite rod.
	(Lafayette MS-332 is .33 dia. x 7½" long ferrite rod)
B1	9-v battery (Lafayette BA-2)
	Amplifier shown in the figures is PK-522 with VC-27 volume control and switch and SK-66 loudspeaker
	Parts for this project were obtained from: Lafayette Radio, 111 Jericho Turnpike, Syosset, L. I., N. Y.



THE TRANS BOX

This compact two-transistor unit triples as an AF-RF signal tracer, utility amplifier, and transistor circuit power supply

By FORREST H. FRANTZ Sr.

THIS unit and an audio or RF signal generator are all that are required to signal trace broadcast and short wave receivers and audio amplifiers of all kinds.

Power for external transistor circuits is available from the tracer at 1.5, 3, 4, 5, or 6 volts at the flick of a switch. It does extra duty as a utility amplifier for general lab use. A self-contained loudspeaker makes the unit convenient without the inconvenience of an earphone.

Mount the Battery Holder on the perforated board as in Figs. 2 and 4. Mount the output transformer on this board with a piece of solid wire passing through the holes and around the underside.

Drill the holes for the battery terminals, input jack, volume control, switch and speaker. Cut the volume control shaft to a length of ⅜-in. Mount these parts. Be careful to avoid shorting of the battery terminals to the case. Wire the front panel. Fasten the circuit board to the speaker with solid wire. Interconnect the board and the front panel circuitry (Fig. 4). Connect leads from the batteries to the switch (Fig. 6).

The First Switch Position is "off." Other switch positions turn the signal tracer-amplifier on. In addition, section B of S1 selects the battery voltage which will appear across the battery output terminals for powering an external circuit with current requirements of 25 milliamps or less. This feature will prove invaluable for checking out transistor tuners, amplifiers and other circuits and for performing circuit experiments requiring small currents.

For Audio Testing and signal tracing, use a shielded lead with a miniature phone plug termination on one end and extended leads with minigator clips on the other end. To signal trace in tube circuits connect a 47K resistor in series with the center lead of the shielded input cable. This minimizes circuit

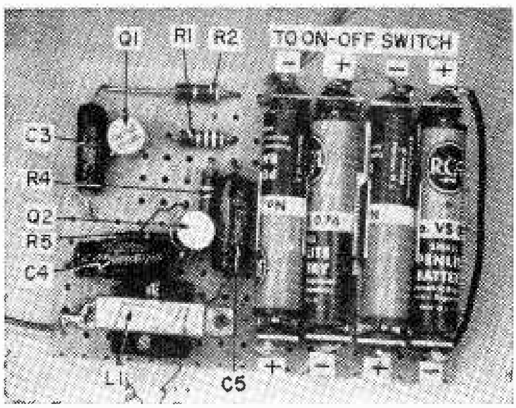


FIG. 1: Looking down on the circuit board, the parts are easily located. Wiring isn't critical, but try to keep leads as short and as neat as possible.

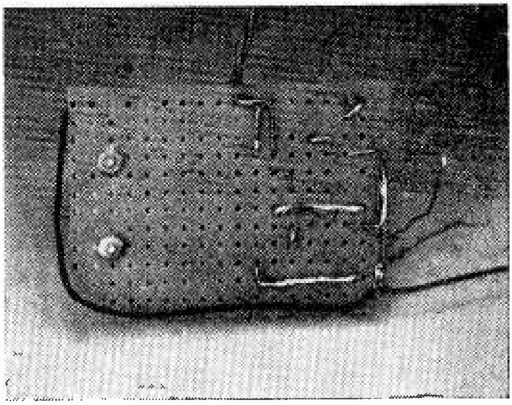


FIG. 2: Wiring is brought through the holes to the underside of the circuit board. Note that no components mount underneath for ease of servicing.

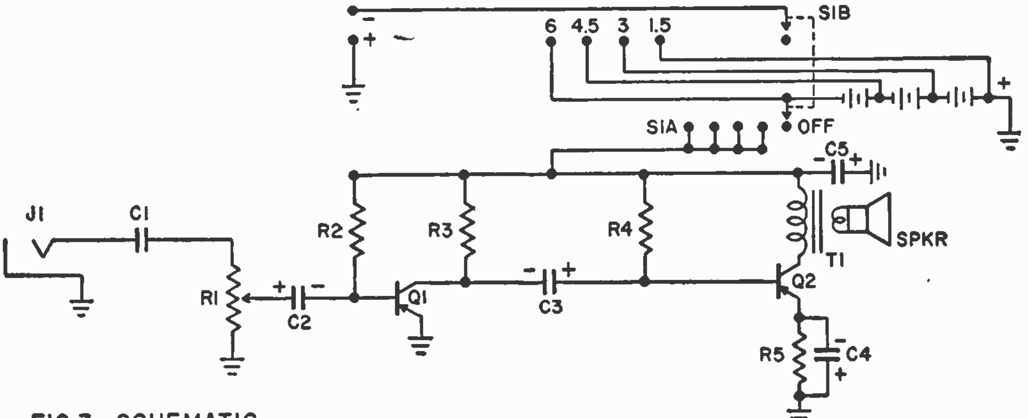


FIG.3- SCHEMATIC

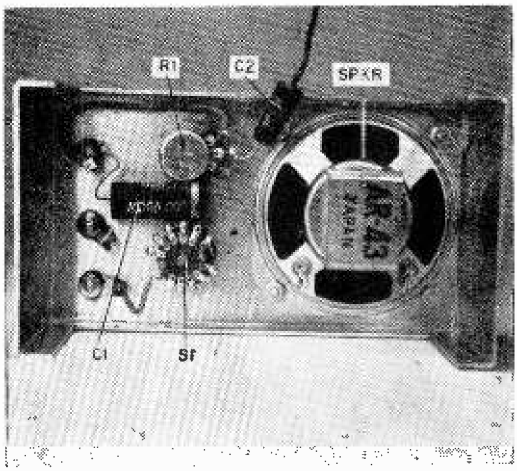


FIG. 4: Chassis-mounted parts inside the box cover include the speaker, switch, potentiometer, jacks and two capacitors. Wire these in place separately.

loading during testing operations.

If you have difficulty, check the battery holder for good contact to the batteries. You may have to fill the contact eyelets with solder. Check the circuit against the wiring diagram. With the audio signal tracing lead in the input jack, you should be able to hear the speaker hum when you touch the center input lead (volume all the way up).

Heart of the Signal Tracer is the high gain, two-stage transistor, audio amplifier on the perforated board. The signal under test enters the tracer through jack J1 and is applied to gain control R1 through isolation capacitor C1. C1 is rated at 600 volts and keeps dc from getting through, but permits audio to pass. The gain control feeds the signal to the amplifier.

Resistors R2, R3, and R4 provide operating biases for Q1 and Q2. Capacitors C2 and C3 provide isolation between dc potentials, but pass ac signals. Resistor R5 stabilizes the

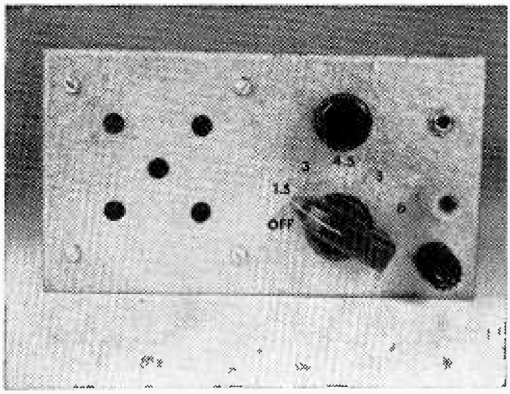


FIG. 5: Looking head-on at the front panel, the unit presents an uncluttered, business like appearance. Finish the panel with decal lettering and lacquer.

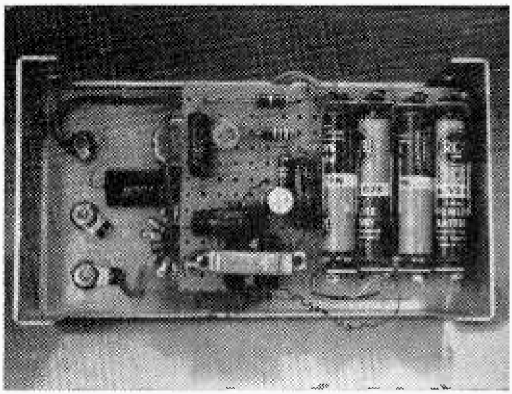


FIG. 6: Inside the box with the circuit board installed in place. Box and circuit board are wired separately, after installation, hooked up together.

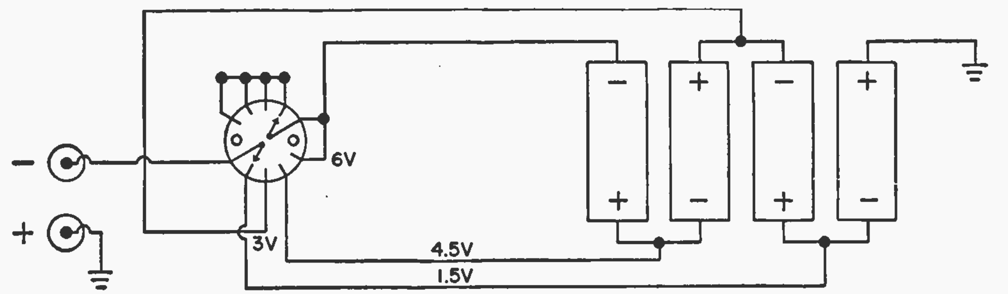


FIG.7- BATTERY SWITCH WIRING

operating point of Q2, C4 is a bypass around R5, and C5 bypasses (effectively shorts) the ac signal around the battery to prevent degeneration due to internal battery resistance.

Transformer T1 couples the output of transistor Q2 to the loudspeaker with the proper impedance match. Section A of switch S1 provides one "off" position, but applies voltage to the amplifier on the other four positions. Section B of S1 switches 0, 1.5, 3, 4.5, or 6 volts to the battery output terminals.

This provides a convenient source for obtaining those much-needed, often hard to find test voltages to power transistorized equipment on the workbench. You can also use these voltages to substitute for batteries that are suspect, in equipment under test.

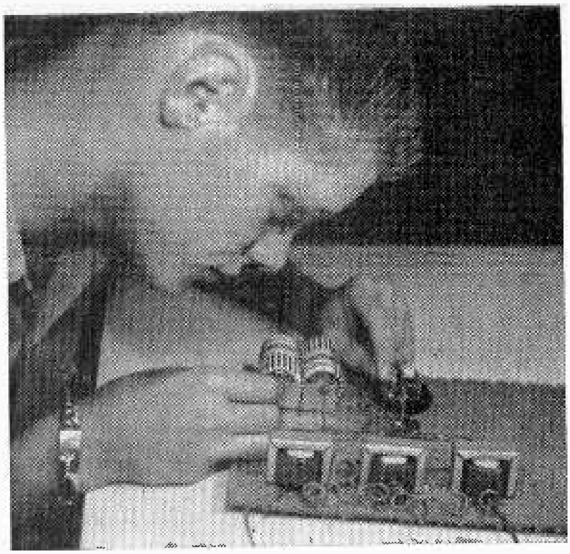
Amplify Phone Bell

• Before going down in the basement or out in the backyard, set your telephone on a cake pan or baking tin placed upside down. The added resonant surface picks up and amplifies the bell sound.

MATERIALS LIST—TRANS BOX

Desig.	Size and Description
R5	68 ohm, 1/2 watt carbon resistor
R3	4.7 k, 1/2 watt carbon resistor
R4	150 k, 1/2 watt carbon resistor
R2	390 k, 1/2 watt carbon resistor
R1	5 k miniature potentiometer (Lafayette VC-33)
C1	.1 mfd, 600 v paper tubular capacitor (Aerovox P8292ZN28)
C3	10 mfd 6v ultraminiature electrolytic capacitor (Lafayette CF-103)
C2	10 mfd 25 v ultraminiature electrolytic capacitor (Lafayette CF-142)
C4, C5	50 mfd 6 v ultraminiature electrolytic capacitor (Lafayette CF-105)
T1	10 k primary, 10 ohm secondary output transformer (Lafayette TR-93)
S1	5-position, 2-pole miniature rotary switch (Lafayette SW-78)
Q1, Q2	2N1380 transistor
B	1.5 penlight cells, four in series (RCA VS074)
J1	miniature phone jack (Lafayette MS-370 is jack and plug set)
	binding posts (Lafayette MS-566 is kit of 10; only 2 required for this project)
	4-cell battery holder (Lafayette MS-170)
	2 7/16 x 3 3/8" unclad miniature perforated board (Lafayette MS-304)
	miniature knob (Lafayette MS-185)
	pointer knob (Lafayette KN-43)
	2 1/8 x 3 x 5 1/4" gray hammertone aluminum miniature case (Lafayette MC-381)

Parts source: Lafayette Radio, 111 Jericho Turnpike, Syosset, N. Y.



Build This High Voltage Source

By FORREST H. FRANTZ SR.

ALTHOUGH high voltage and high cost may seem synonomous to the experimenter, this isn't always the case. You can construct a high voltage source for interesting electrical and physics experiments at relatively low cost. The high voltage source described in this article can be constructed for about $5. It will provide an ac voltage of from 600 to about 1500 volts depending on the characteristics of the individual components used and the adjustment of the buzzer which serves as a vibrator.

The basic supply of energy for the high voltage power source is interesting too. The energy to operate the unit is furnished by two ordinary flashlight batteries. The power source then converts 3 volts into 600 to 1500 volts. This is a voltage multiplication of 200 to 500!

The operation of the high voltage source is based on the conversion of a smooth dc voltage into a pulsating dc voltage, amplification of the associated current, followed by voltage step up through a transformer.

A frequently used technique for converting smooth dc to varying dc is to chop the dc with a vibrator. The scheme is shown in Figure 1. When a dc voltage is applied initially, current flows through the contacts and the coil. The core of the coil is magnetized and the armature which carries one of the contacts is attracted to the core. When this occurs, the current path is broken, the magnetic field collapses and spring tension on the armature pulls it and the attached contact up toward the other contact. Current flows again and the cycle is repeated.

The operation is similar to the operation of an electrical buzzer. The difference, of course, is that the buzzer is built to make sound while the vibrator is made to chop a voltage. Consequently, vibrators usually have heavier contacts and are placed in sound absorbing enclosures. The important point though, is that a buzzer may be used as a vibrator.

How do you obtain a pulsating voltage from the buzzer? The contact interruptions cause the pulsating dc waveform shown in Fig. 1 to appear across the coil. This voltage contains a dc and an ac component. If the reference is considered to be on the center of the waveform the voltage would in fact be an ac voltage. (A pulsating dc voltage changes value but never crosses the zero reference line. An ac voltage changes value and polarity.) A pulsating dc voltage applied to the primary of a transformer produces an ac voltage in the secondary.

The contacts of an inexpensive buzzer cannot handle very large currents without undergoing rapid destruction. However, a transistor may be used as a current amplifier. Fig. 2 shows a buzzer equipped with a transistor current amplifier. When the buzzer armature is up (contacts closed) base current flows. This causes a much larger emitter current to flow. The voltage between the emitter and positive battery terminal is almost equal to the base voltage.

The current amplification of the transistor (beta) is the ratio of output to contact current (exclusive of coil current). Thus, if the output current is 1 ampere and the beta of the transistor is 50, the contact current is 1/50 of an ampere or only 20 milliamperes.

The requirement for high current is imposed by the voltage step-up required. Al-

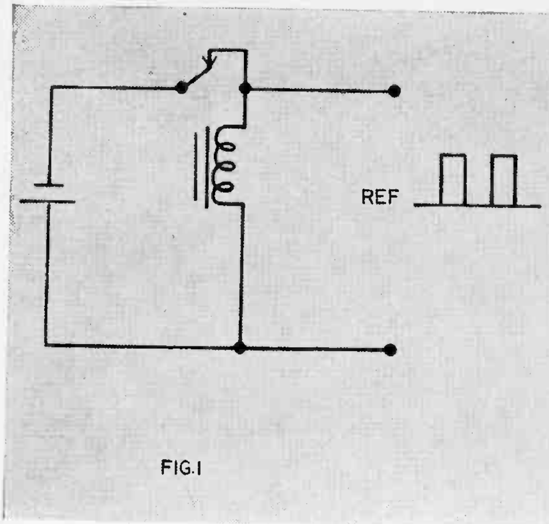


FIG. 1

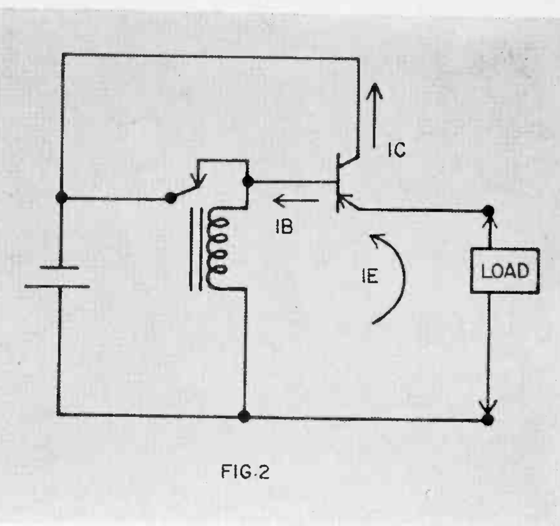


FIG. 2

though a voltage of only about 1 volt rms is available from the circuit arrangement of Fig. 2, the desired voltage output is 600 to 1500 volts. The power available at a transformer secondary is never more than the power into the primary. Therefore high current is required in the primary although the secondary current is small.

The final circuit of the high voltage power supply is shown in Fig. 3. The buzzer and transistor circuit is the same as that of Fig. 2 with one exception. The resistor R has been connected in series with the buzzer V to limit current through the buzzer coil.

The output circuit (which provides the voltage step-up) employs three inexpensive output transformers. The low impedance windings (ordinarily secondaries) are employed as primaries and are connected in parallel. The high impedance windings (usually primaries) are employed as secondaries. They're connected in series to provide three times as much voltage as a single winding.

Build the high voltage source on a perforated Masonite board. Use Fig. 4 as a guide for mounting components. Mount the transistor on a metal bracket (½-in. wide with 1½-in. sides) with a machine screw and nut. The bracket, in addition to supporting the transistor, acts as a heat sink. The transistor collector is connected to the shell and therefore connects to the bracket.

Connect the transistor base lead to the buzzer coil and contact junction with a lead soldered to the coil frame. Solder the base and emitter leads directly to the transistor

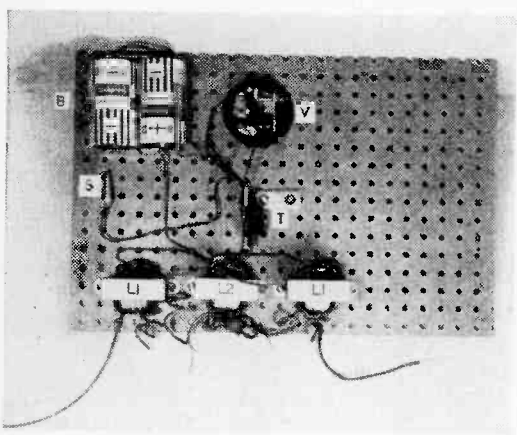


FIG. 4: Follow the parts placement indicated in the photograph above. Switch is a Mueller Minigator clip.

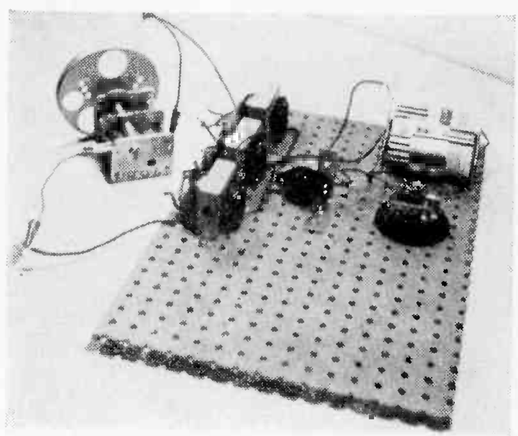
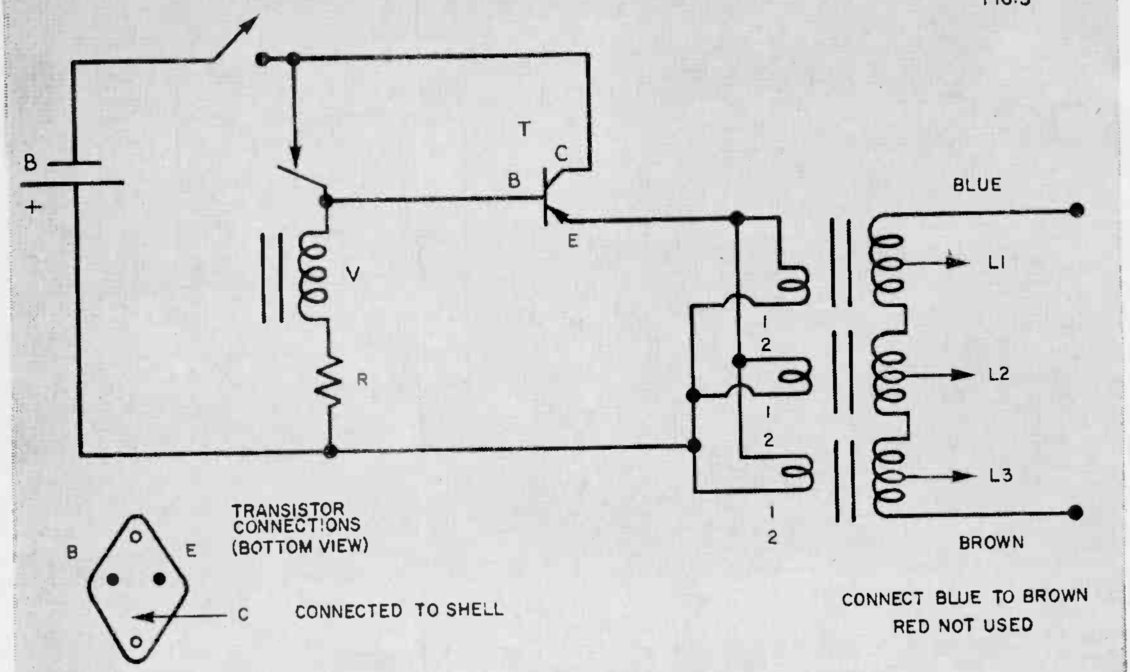


FIG. 5: The high voltage source can be used for effectively burning dust particles from capacitor plates.

FIG. 3



pins. Use a pair of needle nose pliers between soldering iron and transistor body to avoid heat damage.

Connect taps 1 and 2 of transformers L1, L2 and L3 in parallel in the transistor collector circuit. Connect the high impedance windings brown to blue (red unused) to form the high voltage output circuit.

The switch S is a *Mueller Minigator* clip. It is clipped to the negative battery terminal to turn the high voltage supply on. When the clip is disconnected, the high voltage source is off.

The adjustment of the buzzer is a major factor in determining the output of the power supply. To adjust the buzzer for maximum output from the high voltage source, connect a voltmeter set to a range in the neighborhood of 1000 to 2000 volts to the output leads of the power supply. Loosen the lock-nut slightly on the buzzer contact adjusting screw and adjust this screw for maximum voltage output. This adjustment is fairly critical and it's tricky. You may have to repeat it several times to get good results.

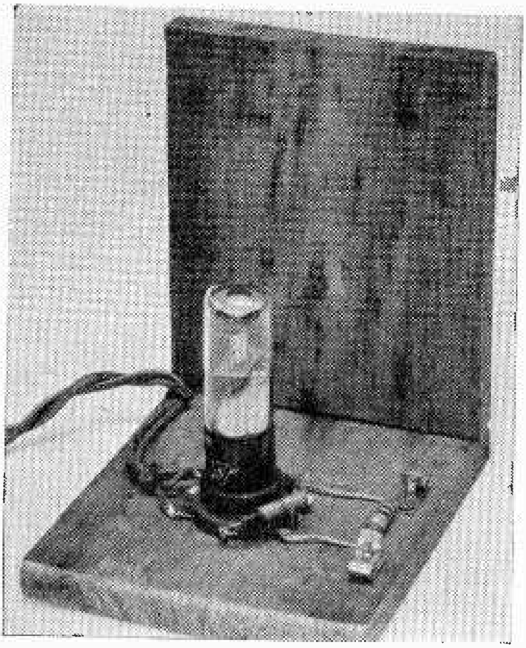
The voltage output may be increased by increasing the input voltage—*up to a point!* The input voltage should never exceed 6 volts. And the input voltage should never be increased to the point where heavy contact arcing begins. When heavy contact arcing occurs, the contact points burn out after a relatively short period of operation.

Use the high voltage source in electrical experiments that require high ac voltages. It may be used, with a rectifier and filter to supply high dc voltages, or in maintenance applications to burn small particles of dust out of capacitor plates (see Fig. 5). The experimenter will find the high voltage source interesting to construct and use. Since it operates from two regular flashlight batteries and generates a very high voltage, it has wide-eyed wonder appeal. It is also extremely portable.

MATERIALS LIST—HIGH VOLTAGE SOURCE

Desig.	Size and Description
R	10-ohm ½-w resistor
L1, L2, L3	TR-12 universal output transformer
T	CBS 2N255 or Sylvania 2N307 power transistor
V	1½-v high frequency buzzer (Lafayette MS-436)
B	two 1.5-v batteries series connected (Burgess #2)
S	minigator clip (Mueller 30)
	battery holder (Lafayette MS-176)
	⅛ x 7²⁷⁄₃₂ x 11²⁷⁄₃₂" perforated board (Lafayette ML-81)
	bracket (see text)

Components may be obtained from Lafayette Radio, 111 Jericho Turnpike, Syosset, L. I., N. Y.



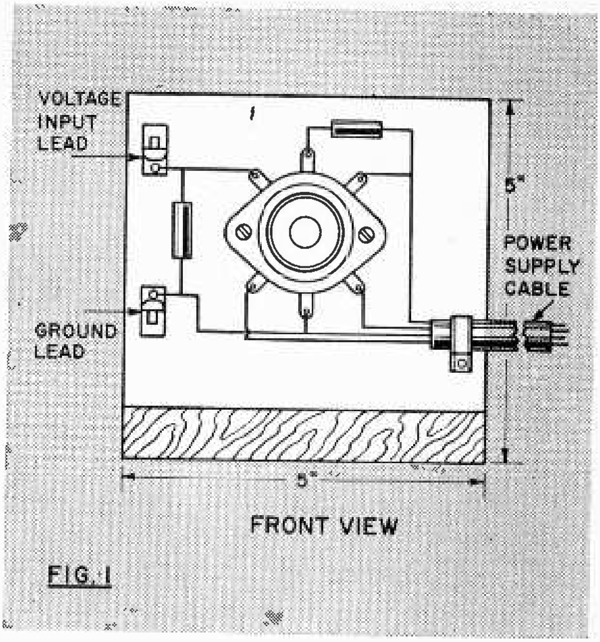


FIG. I

The Magic Eye

Sees much, tells plenty. A cheap and handy testing instrument

By C. F. ROCKEY

TIME was when every radio was equipped with a magic eye tuning indicator, which winked saucily as you tuned across the band. Although seen less often today, the 6E5 tube that fulfilled this function continues to be useful to the electronic trouble-shooter. For this is a combined vacuum-tube amplifier and cathode-ray indicator, both in the same envelope. Together, they form a dandy vacuum-tube voltmeter, at a cost of about two dollars.

All you need, basically, is a magic-eye tube, an Eby baseboard-mounting, six prong socket, and a few small parts. Of course, you also must have a power supply handy, but you can take the voltages necessary out of the piece of apparatus you're testing, if you have no other source. (100 to 300 volts dc at a couple of milliamperes, and 6.3 volts at 0.3 amp.)

The schematic diagram (Fig. 4) should be self-explanatory. None of the parts are critical, and may vary as much as 50% without serious difficulties being involved.

Two features make this instrument particularly handy:

1. It indicates, qualitatively at least, both dc and ac voltages, at frequencies well up into the high audio range.
2. It has a high internal resistance, disturbing the circuit being investigated very little. Only commercial vacuum-tube voltmeters, or very expensive volt-ohmmeters have as high an internal resistance as this simple gadget.

As it stands, the 6E5 is a 0 to 8 volt vacuum tube voltmeter. Its primary utility is as a qualitative voltage tester or signal indicator, and most of the applications to be described use it in this way. However, it may be broadly calibrated against a known dc voltage source, or by remembering that it requires eight volts between grid and cathode (grid negative) to exactly close the eye. Smaller closure angles are approximately proportional to voltages below eight volts.

Build the gadget on a simple little backboard and base of ¾-in. white pine (two pieces 5-in. square) as shown in Fig. 3.

Applications: *1. Signal tracing in a PA or amplifier.* Connect the *ground lead* to the chassis of the amplifier. Now, with a signal

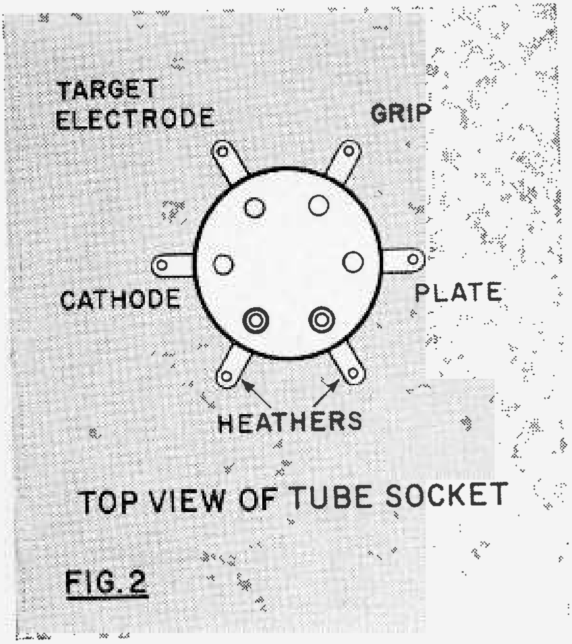


FIG. 2

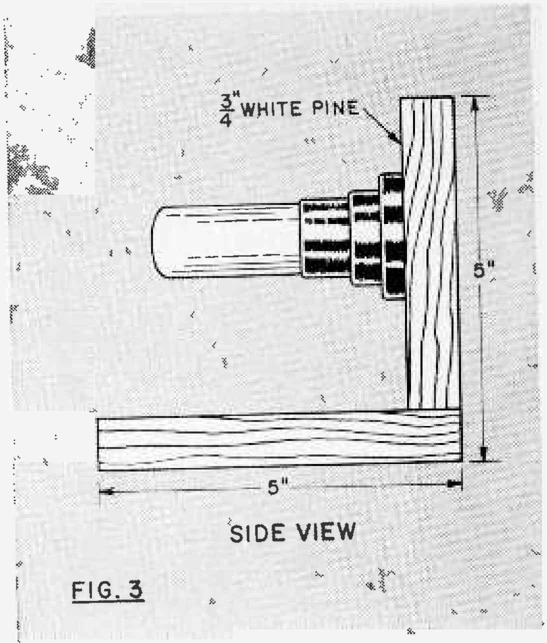


FIG. 3

being supplied to the input of the amplifier, from signal generator, record, or mike, touch the voltage input lead to each successive grid and plate, beginning near the input stages of the amplifier. If a signal is being transmitted this far, you will observe a continual flicker of the shadow, beyond that which occurs when you first touch the lead to the terminal. It is necessary to connect a capacitor (about 0.01 mfd, 400 W.V.) in series with the voltage input lead. With care and practice, a signal as small as 0.1 volt may be readily detected in this way.

2. *Checking the front-end performance of a radio.* Connect the ground lead to the chassis, or to the common ground bus of the receiver being tested. Connect the voltage input lead to the hot side of the audio volume control. Tuning the receiver across the band should cause the eye to close noticeably each time a signal is tuned in. To adjust the receiver for best performance, tune in a station at the high-frequency end (1400 KC, or higher) and carefully adjust each of the IF transformer trimmers for maximum closure of the eye. When the IF trimmers have been thus adjusted, then adjust the trimmers upon the tuning capacitor for maximum eye closure. When this has been done, you may be sure that your set has been adjusted for good performance. (Note: This procedure applies to a simple superheterodyne broadcast receiver only. Some large, expensive receivers, or communications receivers, require more equipment for proper alignment. Also, better try this on an older set first, for practice, before tackling your best radio.)

3. *Visual monitoring of Tape recorder.* Overloading of the tape, causing saturation of the magnetic oxide of the tape on a loud passage, is a frequent form of distortion in home recordings. Since many of the less-expensive tape recorders have inadequate level indicating indicators, if any at all, this overloading can easily occur.

Your 6E5 makes an effective visual monitoring device, or volume indicator. Connect it to your tape recorder as shown in the diagram below, which will apply to most of the home-recording machines. A schematic diagram of your particular machine, obtained at small cost from the manufacturer, will aid you in making these connections. Borrow an audio signal generator from a friend, or from your neighborhood service shop and, using a 1000 cycle signal, determine the overloading-level of your particular machine. Then adjust the potentiometer, so that the eye just closes. Now you can regulate the volume on recordings to keep the eye from completely closing on loud sound peaks. This will give your tapes lots of level without annoying distortion.

4. *Tuning and modulation indicator for the amateur transmitter.* Although the dc plate milliammeter employed in most amateur transmitters will tell you when your transmitter is running the correct power input, it can tell you nothing about the power output and little about the degree of modulation. If you use a coaxial cable to feed your antenna, you can use your magic eye to tune for the greatest signal output for a given power input; that is, for greatest efficiency. Refer-

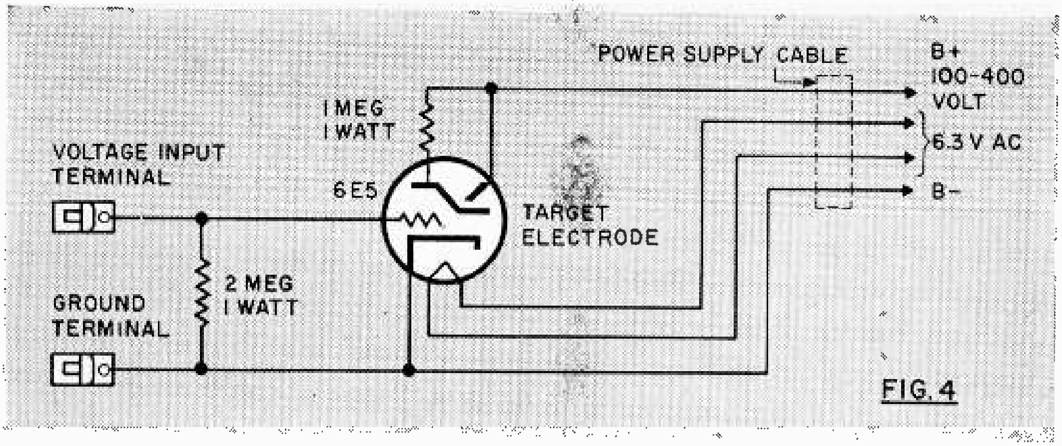


FIG. 4

ring to the diagram will show the connections, and it may be used with any amateur transmitter that employs coaxial cable output. The power consumed by this indicator is in the microwatts, and negligible by any ordinary standards, so it does not waste valuable RF watts. It also indicates relative degree of modulation.

If you have one of the more-powerful transmitters, and you find that the eye shadow "overlaps," try a 6G5 tube instead of the 6E5. All connections will remain the same.

These suggestions, drawn from a fairly wide range of applications, by no means limit the usefulness of this neat, widely-available little indicator. It's cheap, almost universal, and difficult to burn out.

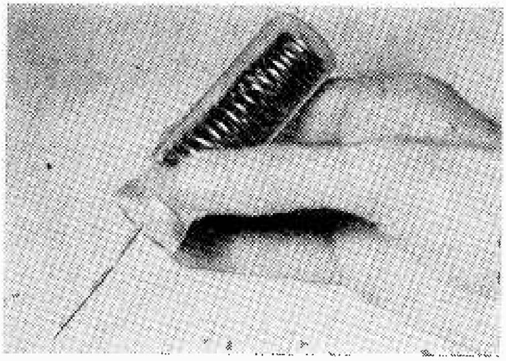
MATERIALS LIST—THE MAGIC EYE

Amt. Req.	Size and Description
1	6E5 tube.
1	Eby, or similar, base-mounting six-prong socket.
2	Fahnestock clips.
1	five foot length of cable, four wire. (May be shielded, but need not be.) May be two lengths of POSJ lamp cord twisted together.
1	2 megohm, 1 watt resistor.
1	1 megohm, 1 watt resistor.
2	pieces ¾ x 5 x 5" pine.
	Test leads.
	Wire screws, rosin-core solder, etc.
	Small piece of metal (from tin can) to clamp down cable. (Or you may use insulated staples.)

Power supply requirements:
Any small power supply providing anything between 100 and 400 volts, dc, and 6.3 volts ac will work. Or you may "steal" the power from any piece of radio-electronic gear using a transformer type power supply. The drain will be negligible.

Shockproof Solder Holder

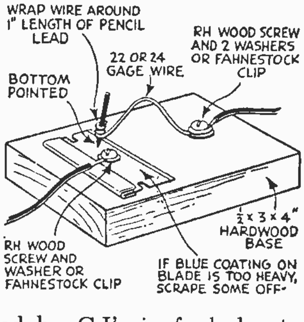
• Have you ever been shocked while soldering live wires in a "hot" circuit? This won't happen again if you wrap a length of solder



into a coil and place it in a plastic pill bottle (available at most drug stores). Punch a hole in the lid and thread one end of the coil through hole. Use this holder as you would a pen, pulling out more solder from the coil inside as needed.—John A. Comstock.

Improved Razor-Blade Detector

• Here is a more rugged version of the familiar fox-hole razor-blade "crystal" detector. The original was a piece of pencil lead bridged across the edges of two razor-blades



and sometimes used by G.I's in foxholes to pick up local broadcasting stations. This was fairly sensitive, but it was very difficult to hold an adjustment, as the least vibration or jar caused the lead to rock and roll on the blade edges, resulting in erratic and noisy reception. For the arrangement shown, blue steel single or double edge blades (such as *Pal* razors) seem to be the most sensitive, but many other blades also have sensitive spots on them. Use with a conventional circuit and a good antenna and ground.—Art Trauffer.

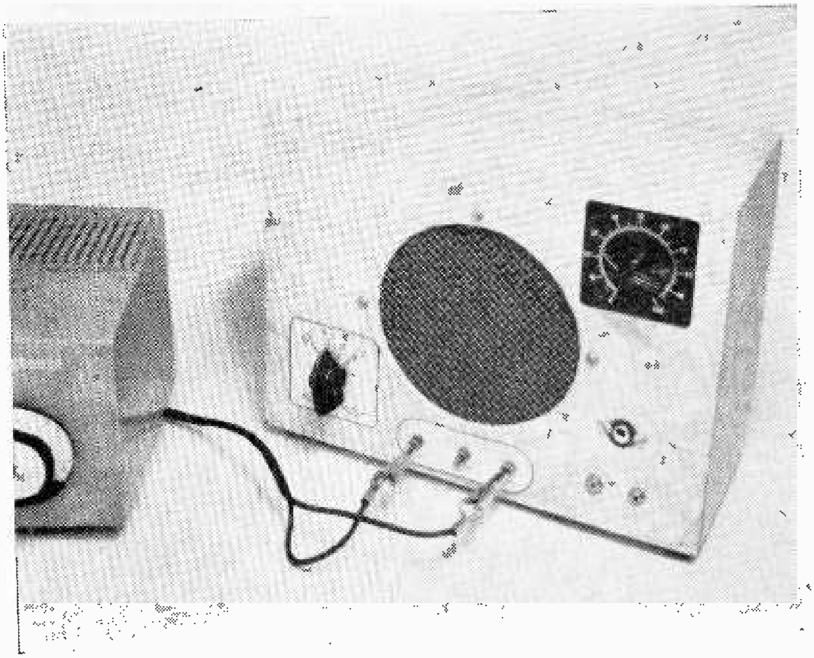


Fig. 1: The unit is a versatile test instrument for general use around the laboratory, as well as a supplementary speaker for audio use.

Speaker Box Does Everything

By ROY L. CLOUGH JR.

ONE of the handiest pieces of equipment, this little speaker box, performs an impressive list of chores.

It's a remote speaker with constant impedance volume control; It's an impedance match, speaker to plate, of any output impedance from 2000 to 10,000 ohms; It matches either single-ended or push-pull output; It's a phone patch box to any receiver with isolating capacitors that nullify shock hazard; It can be used as a dynamic mike with input matched to practically any PA or tape recorder and it can be used to test final audio stages where an output transformer is suspect and input stages where the mike is questioned.

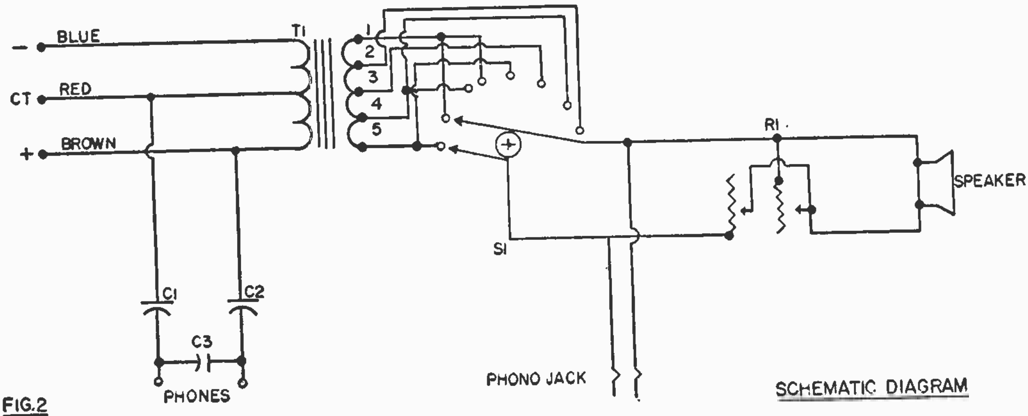


FIG.2

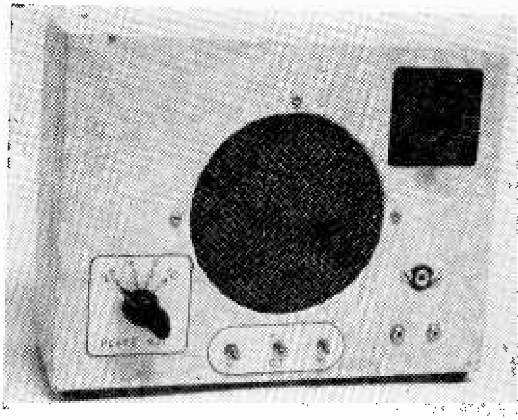


Fig. 5: The front of the unit presents a handsome appearance. The controls are easily accessible and all connections are provided on the front panel face.

You may locate most of the needed parts in the junk box. The rotary switch, for example, can be anything that will perform the required switching operations. We used a war surplus two-deck job. Any two-pole switch that will switch to four different positions will do the job.

A 5-in. permanent magnet speaker with a 3.2-ohm voice coil was used. Speaker size isn't too important if you don't mind re-dimensioning the box. You can also use an 8- or 16-ohm speaker; just check the spec sheet that comes with the transformer for the appropriate connections.

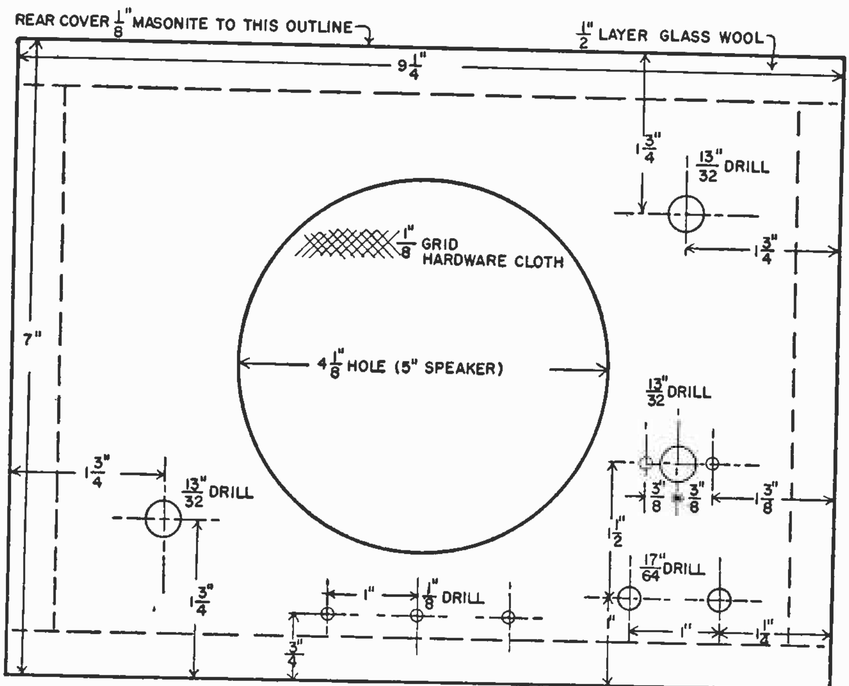
Make the box from ½-in. plywood sides. The front and back is ⅛-in. tempered hardboard. *Elmer's Glue-all* is entirely adequate to hold it together sans nails or other fasteners. Cover the box with *Contact* plastic covering material after cutting all the required holes.

The speaker grille is a scrap of ⅛-mesh hardware cloth or screening, held in place by the speaker rim when it is bolted in place.

Mount the "L" pad in the upper right hand corner, install the phono-jack and phone jacks in the appropriate holes. The transformer is bolted to the box behind the speaker. Wiring the switch will be easier if pigtails are attached before mounting the switch. The same is true for the connections to the 4-40 brass nuts and bolts which serve as outside terminals. Check the wiring diagram carefully before making the final connections and you'll have no trouble.

Draw the switching dial plate on a stiff white cardboard, with transparent plastic spray over markings and cement it with vinyl glue to the covering of the box.

How It Works: A 3.2-ohm speaker is mounted in a heavy, rigid box with a fibreglass lined back cover and rubber tacks under each corner isolate the speaker box from table or bench. The result is good tone



DRILL SPEAKER MOUNT HOLES AS REQUIRED   SIDES ½" PLY X 3⅞" DEEP—FRONT ⅛" MASONITE

FIG.4

MATERIALS LIST—SPEAKER BOX

No. Req.	Size and Description
1	Triad s-62-x universal output transformer (30 ma each side)
1	Clarostat CIL-4 "L" pad
2	.1 400 v paper capacitors
1	.006 400 v paper capacitor
1	phonograph jack
2	earphone jacks
1	rotary switch, 2 poles, four positions
3	¾" 4–40 brass fillister head bolts
6	4–40 brass nuts
1	5" speaker, PM with 3.2-ohm voice coil
2	pointer knobs
Misc.	assorted scraps of ½" plywood, hardboard scrap and vinyl contact type covering, 5" sq. of wire screen, ⅛ mesh, four rubber-headed tacks.

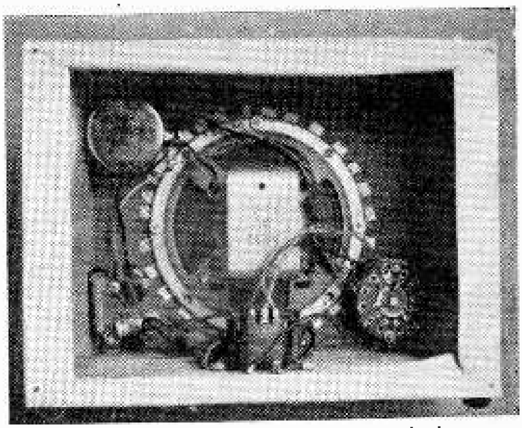


Fig. 3: Parts placement is easily seen with the rear cover removed. The hardware cloth grille screen is held in position by pressure from the speaker rim.

quality from a small speaker in a cheap enclosure. A universal output transformer is connected through a rotary switching arrangement that permits matching impedances from 2 to 10 K ohms. Between the voice coil and output transformer switch a 4-ohm "L" pad and a phono jack is inserted which permits constant impedance volume control of the speaker when used either as a 3.2-ohm remote speaker or when connected to the plate output.

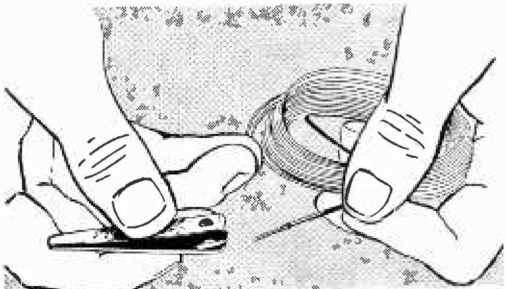
A capacitor network permits the attachment of phones (1500 ohms or higher) to any receiver with no shock hazard. The outside terminals are connected to the transformer in such fashion that either single-ended or push-pull output may be fed into the box.

By running a shielded microphone cable to the outside terminals the box can be used as a dynamic mike with any PA system or recorder. Switching the plate impedance control will permit matching inputs to practically all amplifiers. If attentuation is desired the "L" pad control can be cut in. A couple of alligator clip test prods plugged into the box terminals can be used to check audio final stages, if, for example, the output transformer of the set under test is suspect.

Still other uses will suggest themselves to the experimenter who will quickly be aware that the speaker box is a very nice thing to have around.

Nail Clipper Strips Wire

• A nail clipper makes an excellent tool for radio and TV hobbyists, to use for removing insulation from small-gage wiring. First, how-

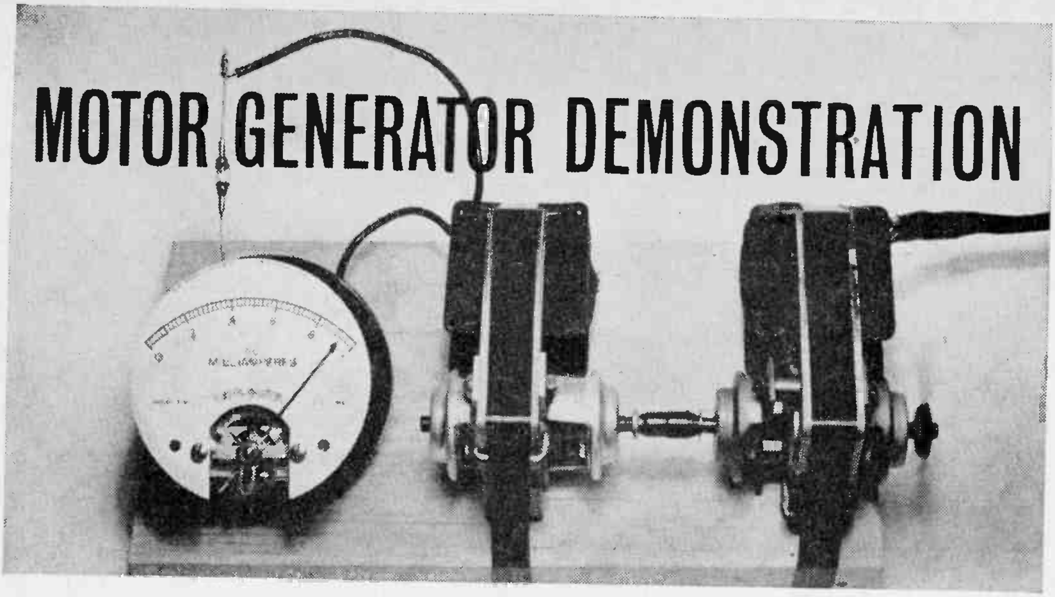


ever, remove the pressure-handle to avoid exerting too much force and cutting right through the wire.—R. J. DeCristoforo.

Easy Transistor Class Identification

• It's almost impossible to determine whether a transistor is of the NPN or PNP variety just by looking at it in a circuit. However, an easy clue to identification lies in the fact that the middle letter of the transistor class designation indicates which terminal of the battery is connected to the collector element. Thus, in the case of the PNP type, the *negative* terminal of the battery is connected to the collector; similarly, the *positive* terminal of a battery is connected to the collector element of a transistor of the NPN variety. Either by checking the polarity of the potential on the collector element, or by tracing out wires to the battery, it is a relatively simple matter to determine correctly the class of a given transistor.—John A. Comstock.

MOTOR GENERATOR DEMONSTRATION

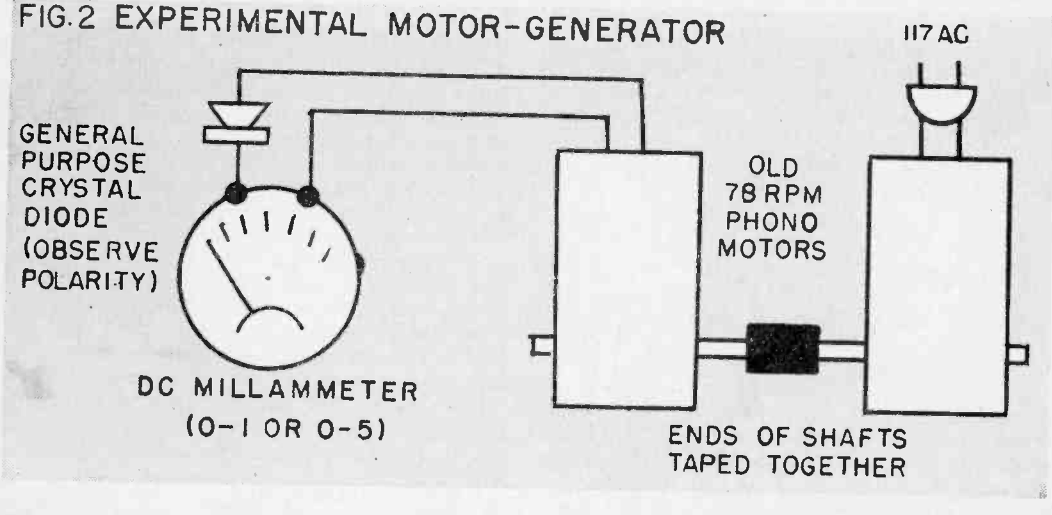


TWO old phono motors, salvaged from junked 78-*rpm* record players, can be used to demonstrate the fundamentals of a motor-generator set. Two motors are strapped to a piece of board, and the shafts are coupled with tape so that one motor drives the other. The captive motor generates a small ac current which is rectified to dc by a germanium diode and then registered on a dc milliammeter.

Ordinarily, a generator produces current by revolving a coil in a magnetic field, or by revolving a magnet within a coil. But in this experimental set-up there is very little magnetism in the captive motor because it is not connected to the ac lines, so it only generates a feeble current.

Figures 1 and 2 show the construction. The two motors are strapped on a ¾x3½x8-in. wood base using friction tape, and the two shafts are coupled with a few turns of plastic tape. If necessary, one of the motors can be blocked-up a little so that the shafts line up well. Connect a line cord and plug to the right hand motor, and tape the connections well to avoid shocks and shorts. Connect the two leads on the captive motor to the two posts on the rear of a 0-1 or 0-5 dc milliammeter. When you start the motor you will note that the meter needle barely moves and vibrates rapidly—that's because you are feeding ac current into a dc meter. Connect a common general-purpose germanium diode (1N34A, etc.) in one meter lead, as shown, then the ac will be rectified to dc because the current can only pass through the diode in one direction. Be sure to observe correct polarity—the cathode (plus) lead of the diode goes to the plus post on the meter. A soft sponge rubber pad under the meter protects it from motor vibrations. Other 110-volt motors could be used for this experiment.—ART TRAUFFER.

FIG. 2 EXPERIMENTAL MOTOR-GENERATOR



Experimenter's Chassis

Versatile, reusable chassis for experiments and circuit development

By W. F. GEPHART

WHEN working with experimental circuits the need for an experimenter's chassis becomes obvious. After experience with two home made and one commercial experimental chassis, the author decided to summarize his experience and design a chassis to meet these needs.

The following seemed to be important factors in considering design aspects:

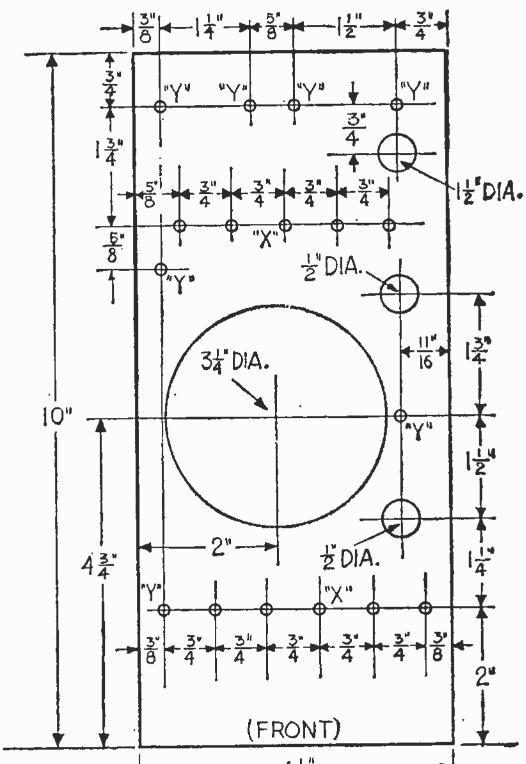
The unit should be able to handle any type of tube or transistor available now or in the future. It should be compact, without being crowded, yet be able to handle several stages if necessary. Connections should be quick and easy to make and be secure. In multiple stage work, there should be an option of making certain leads (ground, filaments, etc.) common if desired. The chassis should be able to handle panel parts and mounted parts (transformers, relays, etc.). The unit should be durable and long-lasting and low in cost.

The unit shown here meets these conditions. The basic chassis takes various inserts to handle different tubes or transistors, and permits adaptation to future designs. Connections are made by Fahnestock clips, both as connection points and to tube socket pins. To be compact, yet permit multiple stage work, each basic unit only handles one tube or power transistor (or two low-powered transistors), yet any number of basic units can be plugged together for multiple stage work. When units are plugged together, switches give the option of making ground, B plus and/or filament leads common between units.

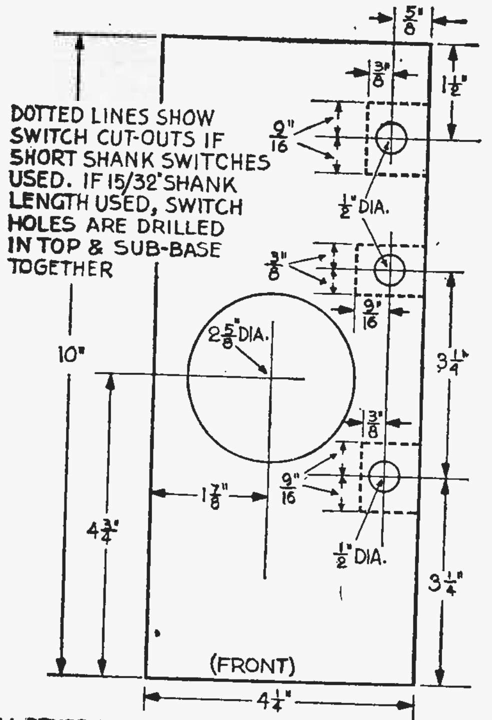
While each basic unit has a panel for mounting switches and potentiometers, space is not allocated for chassis-mounted parts. Instead, a special mounting adapter was made that fits above the basic unit to take transformers or relays when required. This saves having waste chassis space when not needed.

By using high quality clips, connections do not load with solder, can be made quickly, and will last indefinitely. Each basic unit costs about six dollars and each tube-transistor insert will run from about 60¢ to $1.20, depending on the socket and number of clips required. Basic units or inserts can be added in the future, in any reasonable number. Since each basic unit is only 4½ in. wide, a four-stage chassis would only be 18 in. wide, and a six-stage only 27 in. wide.

The parts list gives the material required for each basic unit. Since the drilling for the plugs and jacks in the side pieces is critical (so units will plug together properly),



ALL HOLES 8/64" UNLESS SHOWN OTHERWISE
FIGURE 1: HARDBOARD TOP



ALL OTHER HOLES IN TOP & SUB-BASE TOGETHER

FIGURE 2: PLYWOOD SUB-BASE

it is best to cut and drill side pieces together for the ultimate number required, and save the extras. For example, if you plan to build two basic units now, but feel that you might want two more later, cut and drill side pieces for all four units. The cost of the extra side pieces is trivial.

The following steps assume that more than one basic unit is being made, and reference to clamping pieces together refers to similar pieces for the multiple units.

First cut the hardboard top (Fig. 1), side pieces (Fig. 3), plywood sub-base (Fig. 2), and white pine end pieces to the size shown. Next, cut the notches for the switches in the plywood (required if switches with shanks of less than 15/32 in. are used; switches shown in parts list have 15/32-in. shanks).

Clamp the plywood sub-bases together, with ends and sides aligned, and drill a 1/16-in. hole through all pieces at the center of the large insert hole. Separate the pieces, and cut the insert hole in each.

Next, nail the front and back pine supports to the ends of the plywood sub-base. Set the sub-bases and ends on a flat surface, and check the hardboard side pieces to be sure they are flush with the top of the plywood. Clamp all side pieces together, and drill four 9/64-in. holes at points indicated. Before removing the clamps, mark the top and front edges with nail polish, to help keep the pieces in proper alignment during assembly.

Remove the clamps, and enlarge the holes in half of the side pieces to 1/4 in. and fasten them to the plywood and end pieces, properly aligned, using brads and glue. Use a side piece with 9/64-in. holes on the right side (looking from the front), and a piece with 1/4 in. holes on the left side.

Clamp the hardboard tops together, and drill all holes except the switch holes. Remove the clamps, hold the top in place on the plywood, and drill the holes marked "X". Temporarily fasten the top to the plywood with 5/8x6-32 screws and nuts in these holes, and then drill 9/64-in. holes through the plywood at holes marked "Y". Drill 1/2-in. holes through both hardboard and plywood for the switches.

Remove the top and apply decals and lines for common-connected terminals (Ground and B plus) as shown. These lines can be painted on, or put on with 1/16-in. colored graph tape, such as *Chart-Pak* available at drafting supply houses. It is best to then spray the panel with lacquer or varnish to

MATERIALS LIST—EXPERIMENTER'S DEVELOPMENTAL CHASSIS

Amt. req.	Size and Description
	For Each Basic Unit
1	1/8 x 4 1/2 x 10" hardboard (top)
2	1/8 x 1 1/2 x 10" hardboard (sides)
1	1/8 x 4 x 4 1/2" hardboard (panel)
1	1/4 x 4 1/4 x 10" plywood (sub-base)
2	1/2 x 1 1/2 x 4 1/4" white pine (ends)
	(Use tempered hardboard, two sides smooth)
17	#10 Fahnestock clips (Cat. #41 H 705)
4	G-C 33-034 banana plugs (Cat. #41 H 400)
4	G-C 33-192 banana jacks (Cat. #41 H 470)
9	soldering lugs
2	SPST toggle switch C-H 8280-K16 (Cat. #34 B 500)
1	DPST toggle C-H 8360-K7 (Cat. #34 B 502)
8	1/2" x #6 *rh* woodscrews
2	1/2" x #8 *rh* woodscrews
9	5/8" x 6-32 machine screws and nuts
	For Each Transformer-Relay Adapter
1	1/8 x 3 1/4" 4 1/2 hardboard
4	8-32 brass thread rod, 3 1/2" long
8	8-32 brass nuts
	For Each Low-Power Transistor Insert
1	1/8 x 3 1/4" diameter disk hardboard
2	transistor sockets, Elco 3304 (Cat. #41 H 093)
8	#10 Fahnestock clips (Cat. #41 H 705)
4	1/4" x 2-56 machines screws and nuts
8	1/4" x 6-32 machines screws and nuts
	For Each Octal-Transistor Adapter
1	1 1/4" dia. disk plastic, metal, etc.
2	transistor sockets, Elco 3304 (Cat. # 41 H 093)
4	1/4" x 2-56 machine screws and nuts
1	1 3/4" x 6-32 machine screw and nut
1	Octal tube base with all eight pins
	For Each Power Transistor Insert
1	2 1/2 x 3 1/4" piece 18-20 gauge aluminum with 1/2" flange on end
1	1/8 thick 3 1/4" dia. disc hardboard
3	#10 Fahnestock clips (Cat. #41 H 705)
3	soldering lugs
3	miniature alligator clips, Miller #30 (Cat. #41 H 142)
3	1/4" x 6-32 machine screws and nuts
	For Each Tube Insert
1	1/8 thick 3 1/4" dia. disk hardboard
1	tube socket as desired, with mounting screws and nuts
1	#10 Fahnestock clip, 1—1/4 x 6-32 screw and nut for each tube pin

Catalog numbers refer to Allied Radio, 100 N. Western Ave., Chicago 80, Ill.

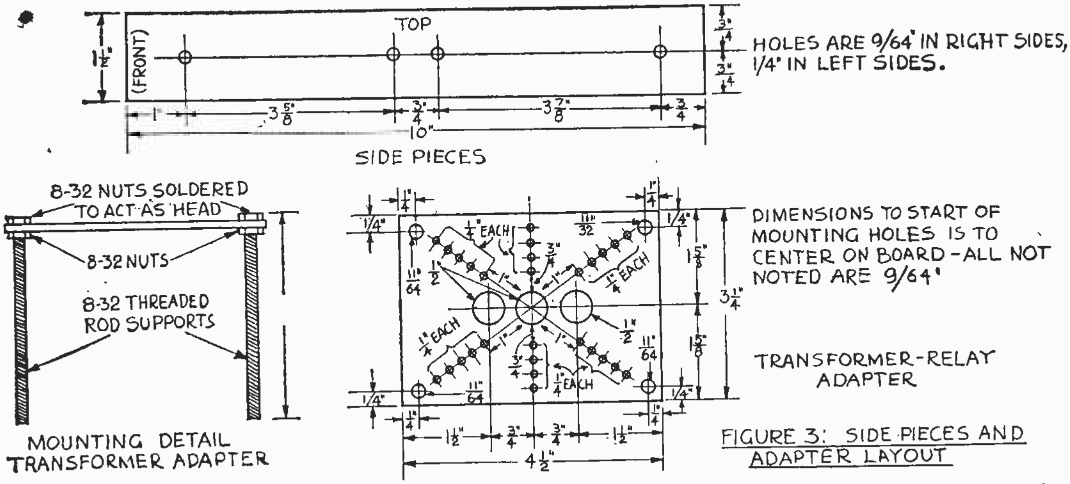
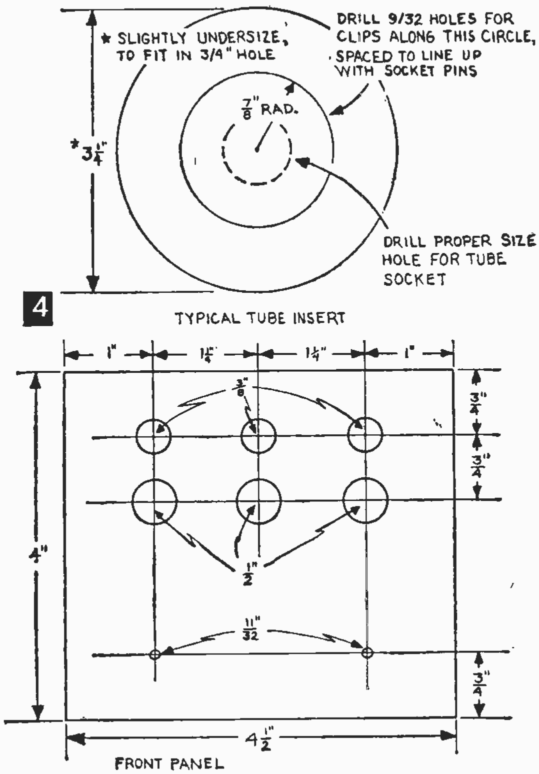


FIGURE 3: SIDE PIECES AND ADAPTER LAYOUT



between the nut and underside of the plywood. Then, using an awl or nail, start screw holes in the plywood for the other clips, and attach them, using ½x #6 RH woodscrews. Mount the switches, with the double pole switch in the center hole.

Mount four banana plugs (with solder lugs on the inside) on the right-hand side piece, and four banana jacks (with lugs on the inside) on the left-hand side piece. Cut and drill the front panel (Fig. 4), and fasten to the front support with two ½x #8 RH woodscrews. The top three holes are for protect the decals and lines.

Next, cut and drill at least one transformer-relay adapter plate (Fig. 3). Lay it on the hardboard top, with one long side flush with the front, and mark the position of the four 11⁄16-in. corner holes on the hardboard top. Drill four 3⁄16-in. holes at these points to hold the adapter supports.

Place the hardboard top back on the sub-base, and fasten in place by mounting clips in the "X" and "Y" holes. Use ⅝x6-32 screws and nuts, and include a solder lug

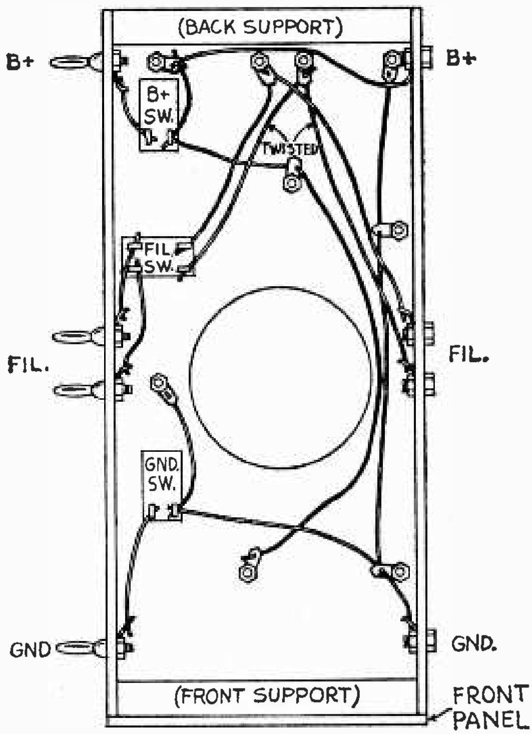


FIGURE 5: PICTORIAL WIRING

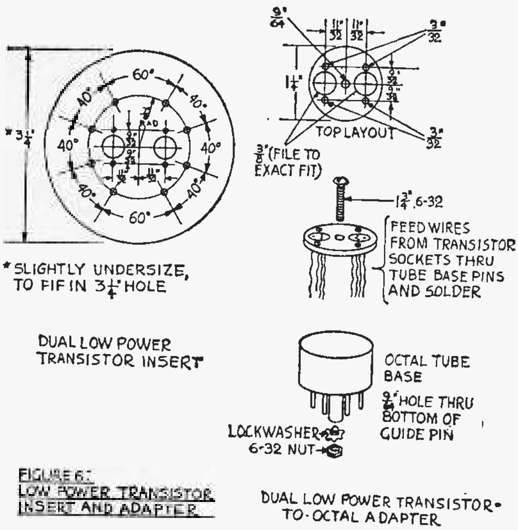


FIGURE 6: LOW POWER TRANSISTOR INSERT AND ADAPTER

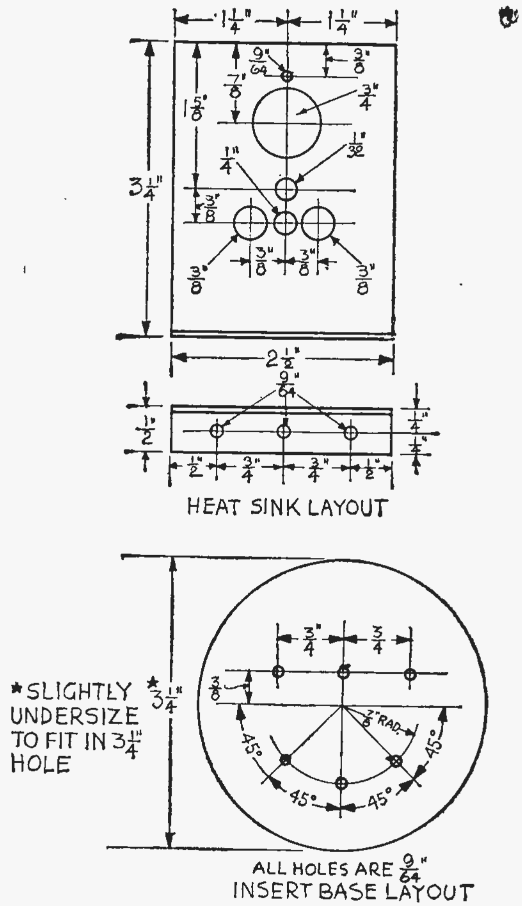


FIGURE 7: POWER TRANSISTOR INSERT

rotary switches and potentiometers, and the bottom three are for toggle switches, push buttons, and pilot lights.

The basic units should be wired underneath as shown in Fig. 5. Route all wiring around the insert hole, and be sure the filament wiring is consistent, the right hand clip always connected to the front jack and plug. This permits proper polarity on dc filaments when using several basic units with common heaters.

All inserts are slightly less than 3¼ in. diameter, to fit snugly in the insert holes in the top, and all have clip mounting holes on a ⅞-in. radius. They can be made of hardboard, Bakelite, plastic or any other insulating material that is not more than ⅛ in. thick. With the exception of the dual low-power transistor insert (Fig. 6), tube sockets are mounted in the center of the insert, with the clips arranged around the socket in line with the tube socket pins. For octal and other large sockets, it is best to use 1/16 in. stiff, hard plastic so retainer ring sockets can be used, to save the space required for mounting screws.

Since fewer parts are usually involved in transistor circuits, two sockets can be mounted on one insert (Fig. 6). For power transistors, where some sort of heat sink is usually desirable, a special insert (Fig. 7) is used. The holes in the aluminum plate will accommodate a number of different power transistors, and space is available for other configurations. In this case, leads and alligator clips are attached to the Fahnestock clips, and fastened to the transistor terminals after mounting.

Another means of using low-powered transistors is the adapter shown in Fig. 6. A base from an old octal tube has two transistor sockets mounted in it, and adapts the regular octal tube insert for transistor use. It saves making a special transistor insert, and saves a few Fahnestock clips. The four-pin transistor sockets will handle most low-powered transistors.

The transformer-relay adapter (Fig. 3) is supported by four 3½ in. sections of 8-32 threaded brass rod, and two 8-32 nuts, one being soldered to the top to form a head. Regular 8-32 screws are not available in this length, and at least 3½ in. is required to clear panel-mounted items.

In using the adapter, the component is fastened in at least one hole, and leads are run through one or more of the large holes. Panel-mounted items are wired to the chassis before the adapter is put in place. There is room under the adapter to connect the wires from the component to the proper clips when the adapter is in place.

In using the chassis, many items can be connected between clips (including tube socket clips), and short lengths of wires can be used to make connections between related clips. Soldering may be required for panel-

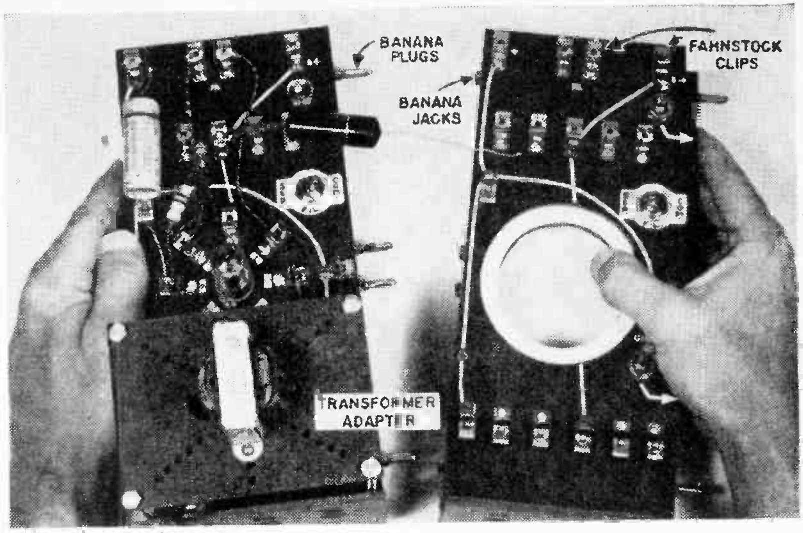


Fig. 8: With one stage complete on the left chassis, a second chassis is plugged in for development of next stage.

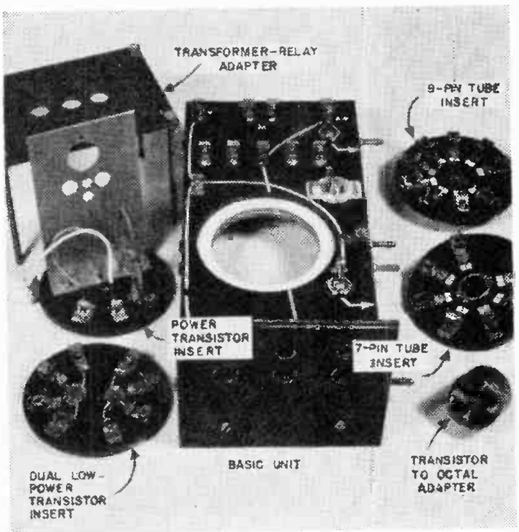


Fig. 9: The basic unit shown with some accessories. These fit the large center hole and permit breadboarding circuits.

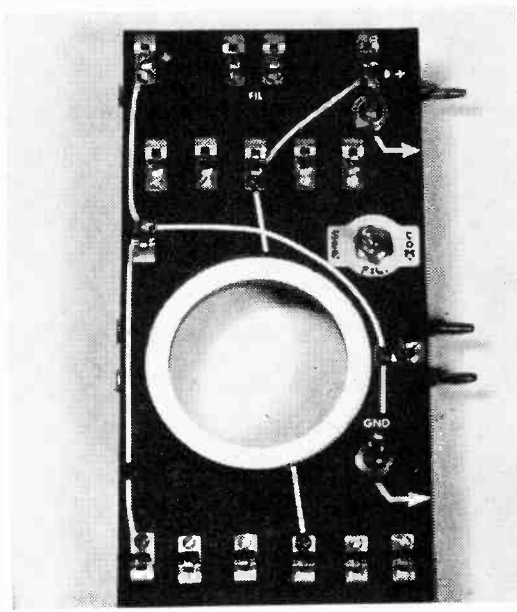


Fig. 10: Basic unit seen from the top with no insert. Lines indicate commonly-connected clips. Note plug and jack positions.

mounted items, but this can be avoided if a wire with an alligator clip on one end (to attach to potentiometer or switch lugs) is used.

When multiple chassis units are used, the switches permit interconnecting Ground, B plus, and filament leads if desired, so that only one set of leads and connections has to be made to the power supply. However, connections must be made between the tube insert filament clips and the regular filament clips on each basic unit.

Two cautions about using multiple units. First, when unplugging basic units, pry them apart *carefully* at the center (between the filament lead plugs), using a screw driver.

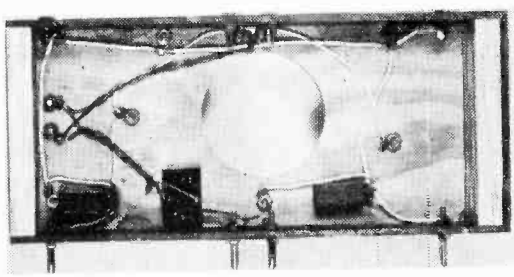


Fig. 11: Underside of basic chassis shows how wiring is dressed around center hole and filament leads are twisted for anti-hum.

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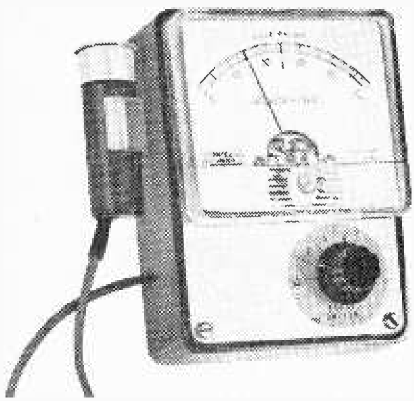

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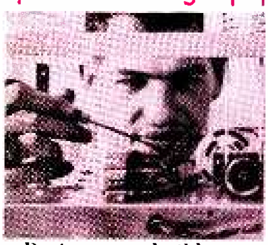

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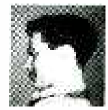

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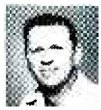

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