PRICE $5.00

BASIC TRANSISTORS

E

HEATHKIT

EDUCATIONAL SERIES

MODEL EK-3

595-315

HEATH COMPANY BENTON HARBOR, MICHIGAN

RESISTOR AND CAPACITOR COLOR CODES

RESISTORS

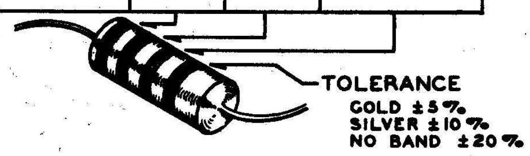
The colored bands around the body of a color coded resistor represent its value in ohms. These colored bands are grouped toward one end of the resistor body. Starting with this end of the resistor, the first band represents the first digit of the resistance value; the second band represents the second digit; the third band represents the number by which the first two digits are multiplied. A fourth band of gold or silver represents a tolerance of ±5% or ±10% respectively. The absence of a fourth band indicates a tolerance of ±20%.

The physical size of a composition resistor is related to its wattage rating. Size increases progressively as the wattage rating is increased. The diameters of 1/2 watt, 1 watt and 2 watt resistors are approximately 1/8", 1/4" and 5/16", respectively.

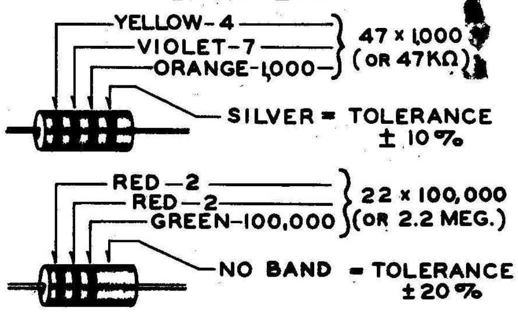
The color code chart and examples which follow provide the information required to identify color coded resistors.

CODE

COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER
BLACK	0	0	1
BROWN	1	1	10
RED	2	2	100
ORANGE	3	3	1,000
YELLOW	4	4	10,000
GREEN	5	5	100,000
BLUE	6	6	1,000,000
VIOLET	7	7	10,000,000
GRAY	8	8	100,000,000
WHITE	9	9	1,000,000,000
GOLD	-	-	.1
SILVER	-	-	.01



EXAMPLES



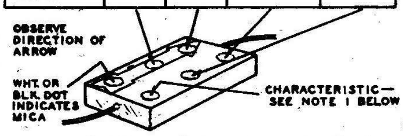
CAPACITORS

Generally, only mica and tubular ceramic capacitors, used in modern equipment, are color coded. The color codes differ somewhat among capacitor manufacturers, however the codes shown below apply to practically all of the mica and tubular ceramic capacitors that are in common use. These codes comply with EIA (Electronics Industries Association) Standards.

MICA

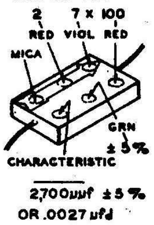
CODE

COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLER.%
BLACK	0	0	1	±20
BROWN	1	1	10	—
RED	2	2	100	± 2
ORANGE	3	3	1000	± 3
YELLOW	4	4	10,000	—
GREEN	5	5	—	± 5
BLUE	6	6	—	—
VIOLET	7	7	—	—
GRAY	8	8	—	—
WHITE	9	9	—	—
GOLD	-	-	.1	—
SILVER	-	-	.01	± 10



(VALUE IN µµf—SEE NOTE 3 BELOW)

EXAMPLE

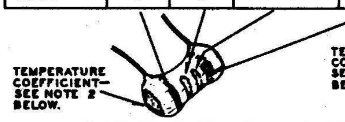


TUBULAR CERAMIC

Place the group of rings or dots to the left and read from left to right.

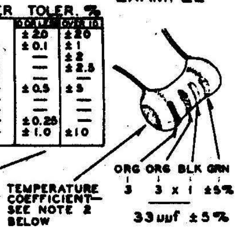
CODE

COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLER. % [illegible]	TOLER. % OVER 10
BLACK	0	0	1	±20	±20
BROWN	1	1	10	±0.1	±1
RED	2	2	100	—	±2
ORANGE	3	3	1,000	—	±2.5
YELLOW	4	4	10,000	—	—
GREEN	5	5	—	±0.5	±5
BLUE	6	6	—	—	—
VIOLET	7	7	—	—	—
GRAY	8	8	—	±0.25	—
WHITE	9	9	—	±1.0	±10



(VALUE IN µµf—SEE NOTE 3 BELOW)

EXAMPLE



NOTES:

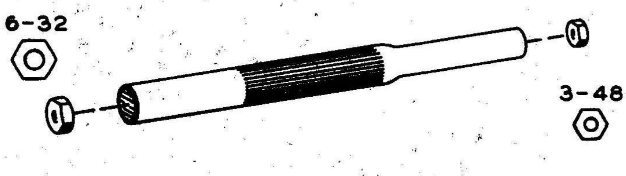
1. The characteristic of a mica capacitor is the temperature coefficient, drift capacitance and insulation resistance. This information is not usually needed to identify a capacitor but, if desired, it can be obtained by referring to EIA Standard, RS-153 (a Standard of Electronic Industries Association.)

2. The temperature coefficient of a capacitor is the predictable change in capacitance with temperature change and is expressed in parts per million per degree centigrade. Refer to EIA Standard, RS-198 (a Standard of Electronic Industries Association.)

3. The farad is the basic unit of capacitance, however capacitor values are generally expressed in terms of µfd (microfarad, .000001 farad) and µµf (micro-micro-farad, .000001 µfd); therefore, 1,000 µµf = .001 µfd, 1,000,000 µµf = 1µfd. The designation pf is sometimes used for µµf.

USING A PLASTIC NUT STARTER

A plastic nut starter offers a convenient method of starting the most used sizes: 3/16" and 1/4" (3-48 and 6-32). When the correct end is pushed down over a nut, the pliable tool conforms to the shape of the nut and the nut is gently held while it is being picked up and started on the screw. The tool should only be used to start the nut.



BASIC TRANSISTORS

★ ★

One of a series of Learn-by-Doing
EDUCATIONAL KITS
prepared especially for
Individual Home Study
or
Group Classroom Instruction

★ ★

HEATH COMPANY
Benton Harbor, Michigan

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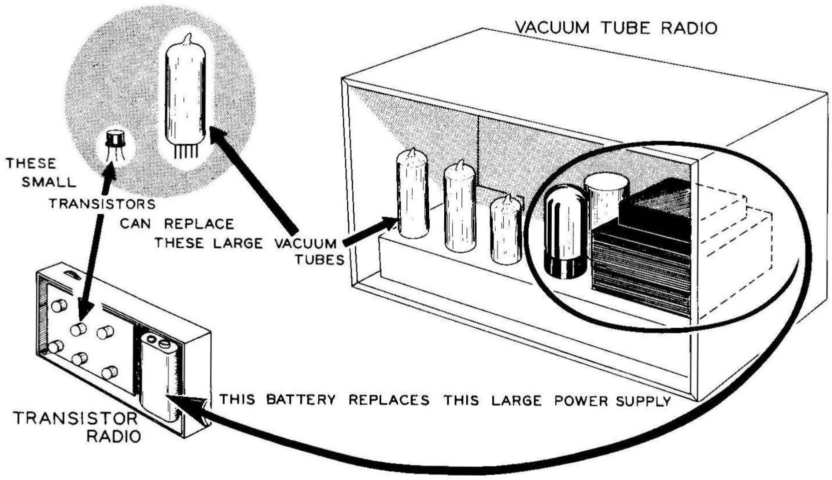
INTRODUCTION



The development of the transistor has opened up a whole new area in both the consumer and military fields of electronics. Studying the theory and practical applications of transistors in this "Basic Transistor" course will allow you to become familiar with this fascinating new field.

Among the advantages that transistors have over vacuum tubes are the following: They are very small in size, only a fraction of the size of a vacuum tube. In most cases they have very low power drain, thus they eliminate the need for a large power transformer and power supply. They can operate at low voltages, thus they can use a small battery to supply power, this makes them exceedingly handy for all types of portable electronic devices.

In the consumer products field, transistors are used widely in portable radios, miniature transmitters and receivers, car radios, and in many other applications. Military uses are too numerous to mention, but one of the most prominent places they are used is in guided missiles and in the space program.

While learning with this kit, do not be overly concerned if, during the first reading, your grasp of the ideas is vague or the topics seem to be of little importance. Unfamiliar concepts have a way of coming into focus after a second reading. During the second reading, however, be sure that you do have a solid grasp of each idea before proceeding to the next. Do not feel above reading the material a second time, or even more often, since a thorough knowledge of the basic principles is essential to getting the most from any course of studies.

The previous Heath Educational Kits, Basic Electricity, and Basic Radio, Parts I and II, provide you with an excellent background for the study of transistors. You will find it interesting to compare some of the transistor circuits of this kit to similar vacuum tube circuits in the Basic Radio course. Notice how much smaller the transistor circuits are.

In studying this text on Basic Transistors, you will do experiments that will demonstrate many practical transistor circuits. These circuits include an audio amplifier, a transistor radio, an audio oscillator, a broadcaster, and an intercom. Not only will you have the enjoyment of building and using each of these circuits, but you will also have the satisfaction of knowing how each of these practical transistor circuits operate, as well as finishing up with a fine transistor intercom when the course is completed.

TABLE OF CONTENTS

CONSTRUCTION NOTES

Refer to the "Kit Builders Guide" for complete information on unpacking, parts identification, tools, wiring, soldering, and step-by-step assembly procedures.

UNPACK THE KIT CAREFULLY AND CHECK EACH PART AGAINST THE PARTS LIST. In so doing, you will become acquainted with the parts. Refer to the information on the inside covers of the manual and in the Kit Builders Guide to help you identify the components. If some shortage or parts damage is found in checking the Parts List, please read the Replacement section and supply the information called for therein.

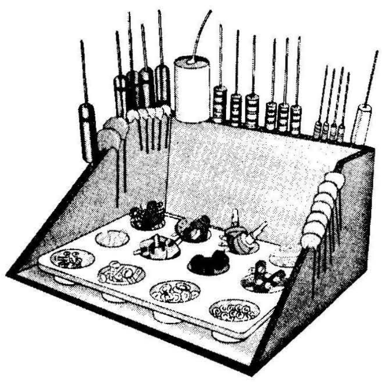
Resistors generally have a tolerance rating of 10% unless otherwise stated in the Parts List. Tolerances on capacitors are generally even greater. Limits of +100% and -20% are common for electrolytic capacitors.

We suggest that you do the following before work is started:

1. Lay out all parts so that they are readily available.

2. Provide yourself with good quality tools. Basic tool requirements consist of a screwdriver with a 1/4" blade; a small screwdriver with a 1/8" blade; long-nose pliers; wire cutters, preferably separate diagonal cutters; a pen knife or a tool for stripping insulation from wires; a soldering iron (or gun) and rosin core solder. A set of nut drivers and a nut starter, while not necessary, will aid extensively in construction of the kit.

Most kit builders find it helpful to separate the various parts into convenient categories. Muffin tins or molded egg cartons make convenient trays for small parts. Resistors and capacitors may be placed with their lead ends inserted in the edge of a piece of corrugated cardboard until they are needed. Values can be written on the cardboard next to each component. The illustration shows one method that may be used.



PARTS LIST

Resistors

	PART No.	PARTS Per Kit	DESCRIPTION
1	1-41	1	10 Ω (brown-black-black)
	1-42	1	270 Ω (red-violet-brown)
	1-9	1	1000 Ω (brown-black-red)
	1-11	1	1500 Ω (brown-green-red)
	1-73	1	8200 Ω (gray-red-red)
	1-20	1	10 KΩ (brown-black-orange)
	1-22	1	22 KΩ (red-red-orange)
	1-25	1	47 KΩ (yellow-violet-orange)
	1-60	1	68 KΩ (blue-gray-orange)
	1-26	1	100 KΩ (brown-black-yellow)
	1-35	1	1 megohm (brown-black-green)

1


Controls-Switches

	PART No.	PARTS Per Kit	DESCRIPTION
2	10-111	1	100 KΩ control
	10-116	1	5000 Ω control
3	60-14	1	Single-pole-single-throw (SPST) switch (two terminals)
	60-15	1	Double-pole-double-throw (DPDT) switch (six terminals)

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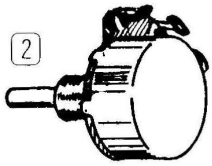

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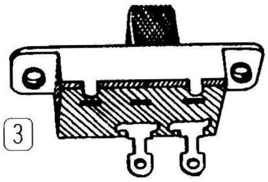

Capacitors-Coil

	PART No.	PARTS Per Kit	DESCRIPTION
4	20-105	1	180 $\mu\mu$f silver mica
5	21-46	1	.005 μfd disc
	21-47	1	.01 μfd disc
	21-48	1	.05 μfd disc
6	25-54	4	10 μfd electrolytic, 15 V
	25-56	2	100 μfd electrolytic, 15 V
7	AN-40-316	1	RF tuning coil

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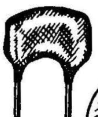

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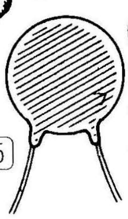

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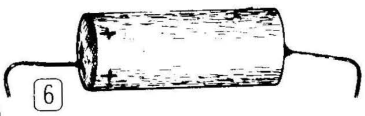

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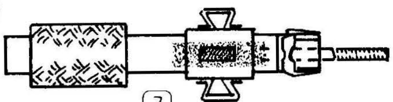

Hardware

	PART No.	PARTS Per Kit	DESCRIPTION
8	250-175	4	2-56 x 3/8" screw
9	250-52	24	4-40 x 1/4" screw
10	250-56	21	6-32 x 1/4" screw
11	250-89	1	6-32 x 3/8" screw
	250-26	3	6-32 x 5/8" screw
12	250-8	2	#6 x 3/8" sheet metal screw


8


9


10


11


12

	PART No.	PARTS Per Kit	DESCRIPTION
13	252-51	4	2-56 nut
14	252-2	8	4-40 nut
15	252-3	22	6-32 nut
16	252-7	1	Control nut


13


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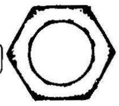

	PART No.	PARTS Per Kit	DESCRIPTION
17	252-50	20	4-40 speednut
18	252-22	2	6-32 speednut
19	253-1	2	Fiber flat washer, #6
20	253-2	2	Fiber shoulder washer, #6
21	253-10	1	Flat control washer


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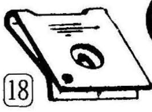
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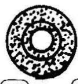
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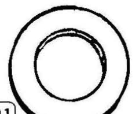
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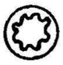
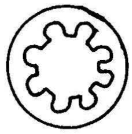
	PART No.	PARTS Per Kit	DESCRIPTION
22	254-9	8	#4 lockwasher
23	254-1	19	#6 lockwasher
24	254-4	1	Control lockwasher

22


23
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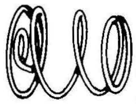
	PART No.	PARTS Per Kit	DESCRIPTION
25	255-49	3	Spacer
26	258-43	1	Battery contact spring
27	259-1	3	#6 solder lug


25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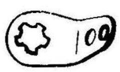
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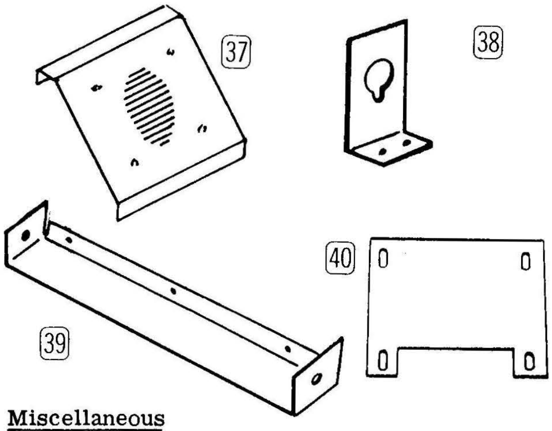
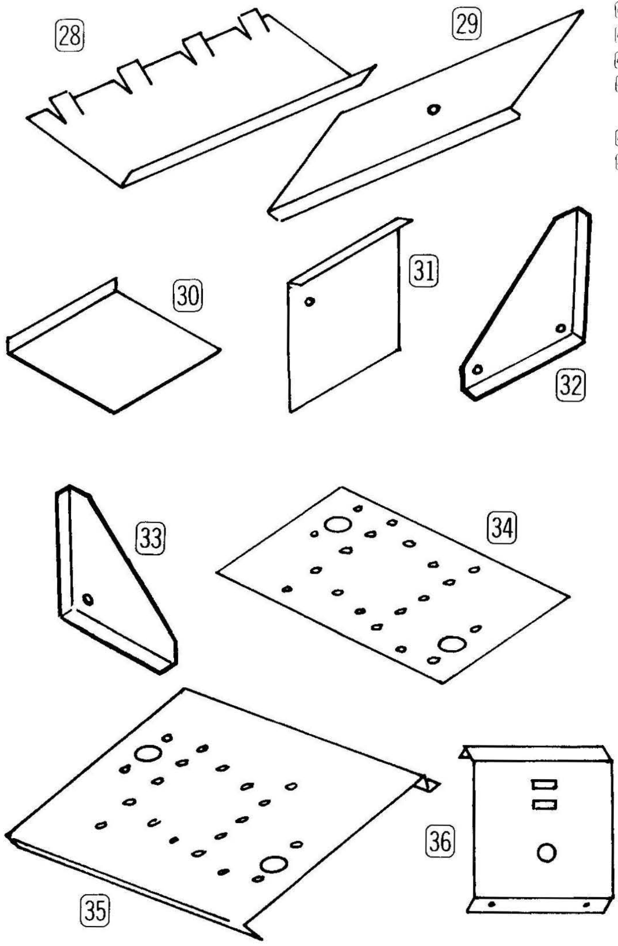
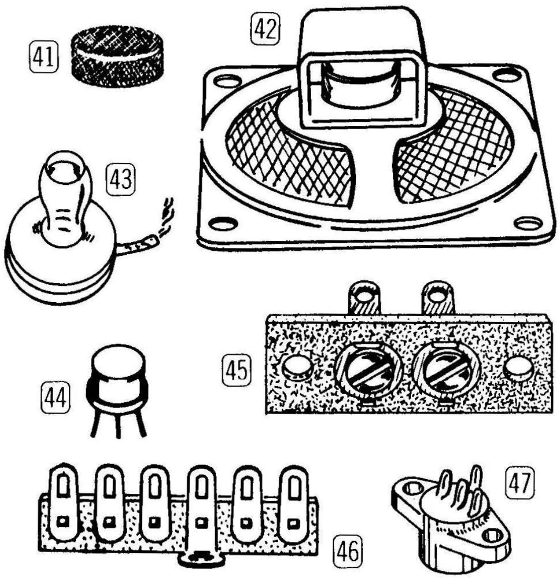
PART No.	PARTS Per Kit	DESCRIPTION
Metal Parts		
(28) 90-M208F	1	Master bottom plate
(29) 90-M209F	1	Master back plate
(30) 90-M210F	1	Remote bottom plate
(31) 90-M211F	1	Remote back plate
(32) 90-M212F	2	Left end panel
(33) 90-M213F	2	Right end panel
(34) 200-M337	1	Chassis plate
(35) 200-M338	1	Experimental chassis
(36) 203-M217F669	1	Left half front panel
(37) 203-M293F	2	Right half front panel
(38) 204-M316	1	Coil mounting bracket
(39) 204-M458	1	Battery retaining bracket
(40) 205-M267	1	Front panel support plate





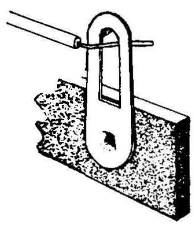
PART No.	PARTS Per Kit	DESCRIPTION
Miscellaneous		
(41) 263-7	8	Felt feet
344-59	1	Length hookup wire
(42) 401-35	2	Speaker
(43) 1401-36	1	Earphone
(44) 417-21	2	2N1274 transistor
(45) 431-6	1	2-lug terminal strip, screw-type
(46) 431-45	2	6-lug terminal strip
(47) 434-102	2	Transistor socket
462-113	1	Knob
331-6		Solder
595-515	1	Manual

NOTE: Four size "C" flashlight batteries should be purchased at this time for use when needed.

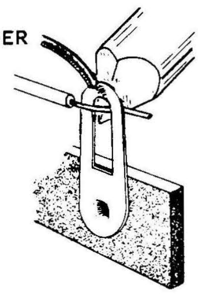


PROPER SOLDERING TECHNIQUES

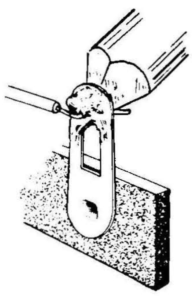
DO NOT PROCEED UNTIL YOU READ THESE



PLACE WIRE THROUGH OR AGAINST TERMINAL.



HEAT TERMINAL AND APPLY SOLDER.



ALLOW A SMALL AMOUNT OF SOLDER TO FLOW...... REMOVE SOLDER....THEN REMOVE IRON.

Correctly soldered connections are very important if you wish to obtain the proper operation from any circuit. A high percentage of the difficulties that cause faulty circuits are due to poor solder joints, especially among those who are relatively inexperienced in soldering. If you are a beginner with no previous experience in soldering, a half-hour's practice with some odd lengths of wire may be a worthwhile investment.

For most wiring a 30 to 100 watt iron, or its equivalent in a soldering gun, is satisfactory. A lower wattage iron than this may not heat the connection enough to allow the solder to flow smoothly over the joint. Keep the tip of the iron clean and bright by wiping it from time to time with a cloth.

CHASSIS WIRING AND SOLDERING

1. SOLDER ALL ELECTRICAL CONNECTIONS made in the experiments of this manual. Soldering instructions have been added to make the construction portions easier. The instruction given with each connection will be either to solder the connection (S) or not to solder the connection (NS). The instruction (S) will mean that no more connections will be made to this terminal at this time. The instruction (NS) will mean that more leads or wires will be connected to this lug.

2. To prepare a length of hookup wire, strip 1/4" of insulation from each end of the wire unless directed otherwise in the step. Be careful that bare resistor or capacitor wires do not cause short circuits by touching the chassis, or other lugs or wires they should not touch. Each wire should touch only the connecting point indicated in the directions.

3. When making connections, take advantage of gravity so the solder will flow down over the joint to be connected.

4. First, place the flat side of the tip of the soldering iron against the joint to be soldered. When the joint is hot enough to melt the solder, place the solder against the terminal and allow it to flow down over the joint. Use only enough solder to thoroughly wet the junction. It is not necessary to cover the entire area around the connection with solder.

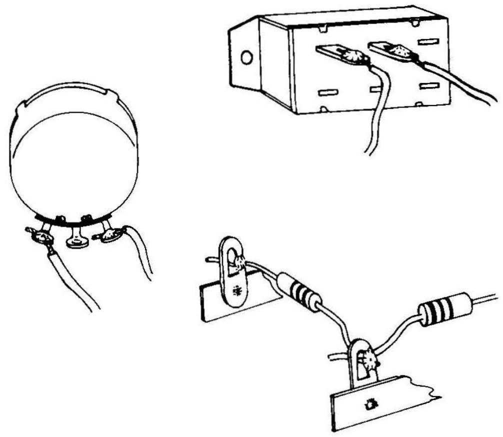
5. Next, remove the solder and remove the iron from the completed junction. Be careful not to move the leads until the solder is solid.

A poor or cold solder joint will usually look crystalline and have a grainy texture, or else the solder will stand up in a blob and will not adhere to the joint. Such joints should be reheated until the solder flows smoothly over the entire junction. In some cases, it may be necessary to add more solder to achieve a good, smooth solder joint.

TEMPORARY CONNECTIONS

Almost all of the soldering in the first nine lessons will be of a temporary nature. A temporary connection means that this part or wire will be removed again in another step or in the next experiment. When making temporary connections with resistors or capacitors, do not cut the leads.

A temporary connection should be one that can easily be removed at a later time. Some common examples of different types of temporary connections are shown in the following illustration. Usually the wires can be placed loosely through the hole in the terminal, but occasionally it may be necessary to put a loose bend around the terminal to hold the wire in place.

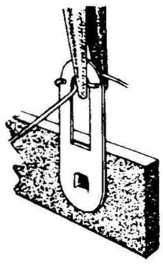


The following method is a handy way of quickly soldering a wire to a terminal, so it will not fall out of the hole. Quickly (so all of the rosin will not boil out of the solder), apply a small amount of solder to the end of the wire, just enough to wet the wire is sufficient. Apply a small amount of solder to the place where the wire is to be connected (sometimes, solder from a previous connection will work here). Now hold the wire and the tip of the soldering iron against the terminal until solder flows between the two. Hold the wire so that it does not move until the joint cools, and the connection is complete.

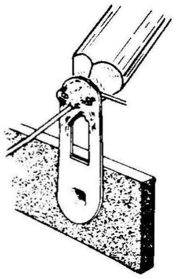
PERMANENT CONNECTIONS

Most of the permanent connections in this kit will appear in the last lesson. Since resistor and capacitor leads are usually much longer than they need to be, when a permanent connection is made, they should be cut to the proper length before the part is wired to the chassis. In general, the leads should be just long enough to reach and fasten to their terminating points.

When a wire or lead is connected to a terminal to form a permanent connection, it should be bent around the terminal as shown in the illustration. This will form a good joint that will not rely on solder for physical strength.



CRIMP WIRES

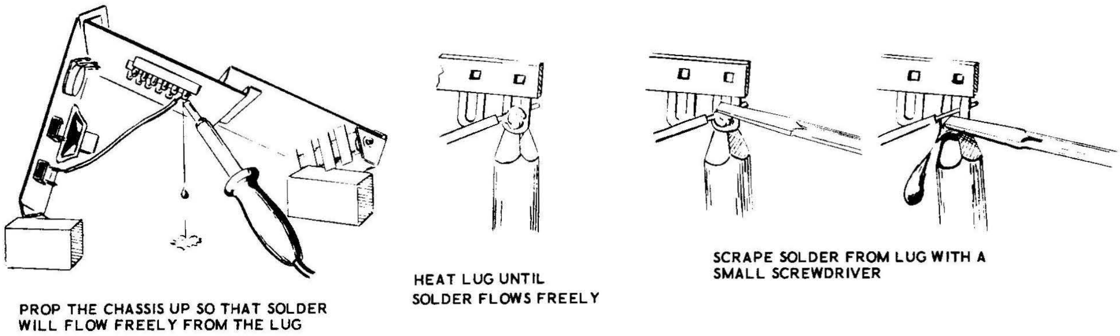


SOLDER WIRES TO TERMINAL

CLEANING OFF EXCESS SOLDER

You will find it necessary from time to time to remove the excess solder from a lug. The best method for doing this is shown in the following illustration. Be sure to place the heated lug in such a position so that the solder will fall from it by force of gravity. Use a small screwdriver to scrape the solder from the lug, and from the holes in the lug.

REMOVING EXCESS SOLDER FROM LUGS



ROSIN CORE SOLDER HAS BEEN SUPPLIED WITH THIS KIT. THIS TYPE OF SOLDER MUST BE USED FOR ALL SOLDERING IN THIS KIT. ALL GUARANTEES ARE VOIDED AND WE WILL NOT REPAIR OR SERVICE EQUIPMENT IN WHICH ACID CORE SOLDER OR PASTE FLUXES HAVE BEEN USED. IF ADDITIONAL SOLDER IS NEEDED, BE SURE TO PURCHASE ROSIN CORE (60:40 or 50:50 TIN-LEAD CONTENT) RADIO TYPE SOLDER.

LESSON I

WHAT ARE CONDUCTORS- SEMICONDUCTORS-RESISTORS-INSULATORS?

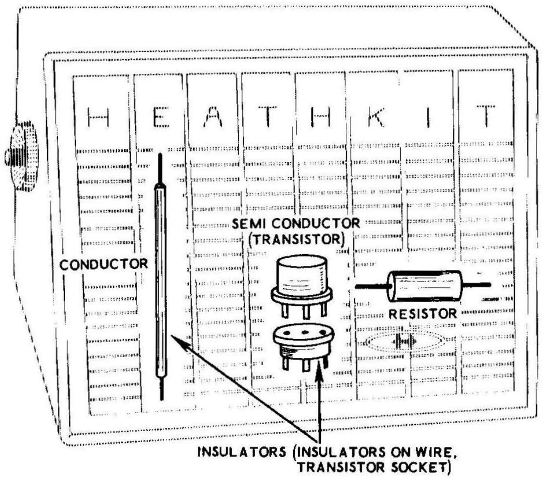


Figure 1A

Each part in the circuit of any radio is used because of the way electric currents either flow or do not flow through it. The same is true of all other electronic devices. The basic elements in each of these parts are divided into the following general categories, according to the way they react when an electric current tries to pass through them:

"Conductors," through which current passes very easily;

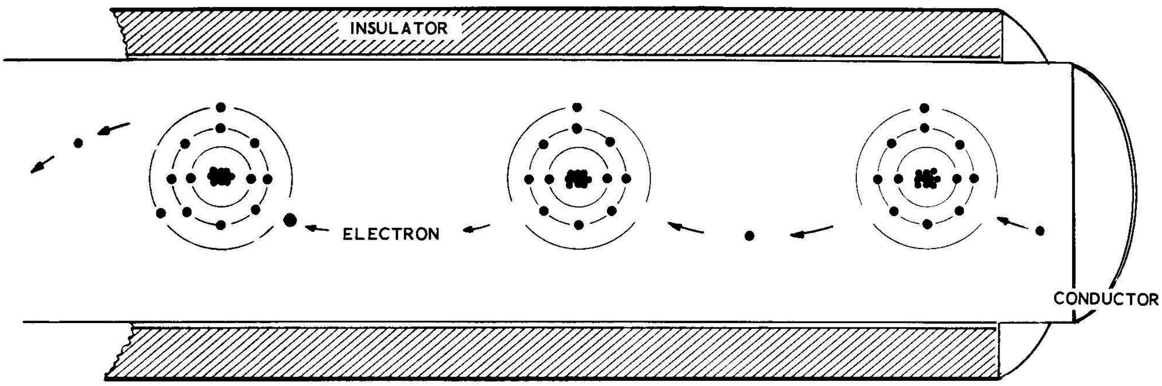
"semiconductors," which only partially conduct electric currents;

"resistors," which tend to hold back the flow of electric current;

"insulators," which block current flow almost completely.

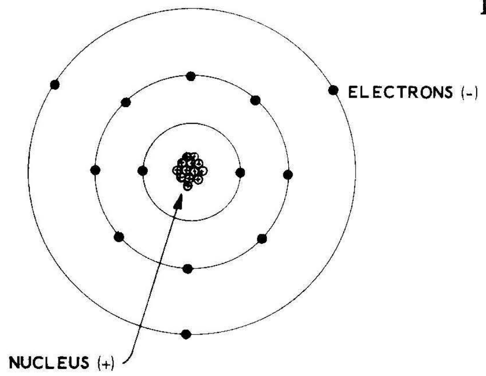
In this lesson you will receive an overall view showing how these different categories of material are used.

If you completed the Basic Electricity, and Basic Radio courses, a review of the basic principles given in these kits will be helpful before starting this kit. While it is not necessary to have completed these three previous educational kits in order to understand this kit, the background they provide is quite valuable.



A GREATLY ENLARGED VIEW OF THE ELECTRONS FLOWING FROM ATOM TO ATOM IN A LENGTH OF WIRE

Figure 1B
Part 2



THE ALUMINUM ATOM

Figure 1B
Part 1

HOW CURRENT FLOWS

All matter is made of atoms. Figure 1B, Part 1, shows what an atom might look like, if it were magnified one hundred million times.

At the center of the atom is a "nucleus" which contains a number of positively charged (+) particles and neutrally charged particles. Revolving about this nucleus, much like planets in orbit, are negatively charged (-) particles, called "electrons." These electrons are held to the nucleus by a force much like the force of gravity. There is a positively charged particle in the nucleus for each negatively charged electron in orbit around the nucleus.

All atoms of every kind of substance are constructed in the same manner, and only the number of electrons and the number of particles in the nucleus are different. The electrons orbit around the nucleus in a series of rings, with each ring wider than the previous ring. Atoms with larger numbers of electrons have more rings, and atoms with smaller numbers of electrons have less rings.

Electrons in the outer ring of some substances, such as aluminum and copper, are held in orbit quite loosely by the nucleus. These loosely held electrons will flow quite easily from the outer ring of one atom to the outer ring of another. A battery voltage, connected across the length of one of these substances, pushes a steady stream of electrons from atom to atom through the substance as shown in part 2 of Figure 1B. This stream of electrons flowing through the substance is called an electric current.

This stream of electrons, or electric current, is measured in "amperes" or "amps," just like the flow of water is measured in gallons per minute. One ampere is equal to the flow of a very great number of electrons (the number 6,250 with fifteen more zeros behind it) in a circuit in one second.

Usually, quite a bit less than one ampere of current flows in most electronic circuits. For this reason, the milliampere (ma), which is 1/1000 of an ampere, is used extensively. To state this in another way would be to say 1000 ma = 1 ampere, or .01 ampere = 10 milliamperes of current.

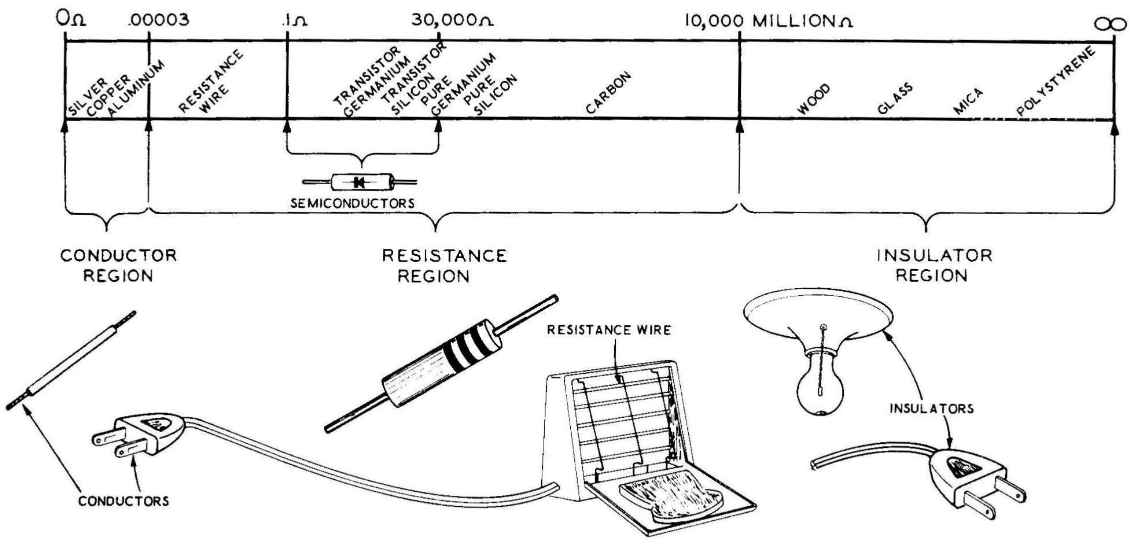


Figure 1C

The number of amperes or milliamperes of electric current that can flow in a substance is determined by how tightly held or how free the electrons are that are in the outer ring of each atom. If there are a large number of free electrons, the material does not resist the flow of current, and it is called a "conductor." If there are no free electrons, the material does not conduct an electric current at all, and it is called an "insulator." In between these extremes, conductors and insulators, lies a whole spectrum of materials that only partially resists the flow of electric currents. The chart of Figure 1C shows the difference in resistance between the various conductors, resistive materials, semiconductors, and insulators.

VOLTAGE

Voltage, the electrical pressure that pushes electrons through a circuit, is measured in volts. A larger number of volts would mean a larger amount of electrical pressure and a smaller number of volts would indicate a smaller amount of electrical pressure.

Electrical pressure works just like physical pressure does. For example: If you wish to get a dog into a bathtub you must apply pressure to him by pushing him in; he would not go by himself. Electrical pressure, or voltage, works in this same manner; if you wish to make electrons move through a conductor you must apply an electrical pressure, or voltage, to them to push them through the conductor.

RESISTORS

A resistor is a device that resists or impedes the flow of electric currents. The unit of resistance is an ohm (Ω). A resistor that offers a lot of resistance to currents will have a large number of ohms, and a resistor that only offers a small amount of resistance to currents will have a small number of ohms.

Generally, resistors are made from either a carbon compound or from a length of resistance wire made from metal alloys. Figure 1D shows how typical carbon resistors and typical wire-wound resistors are constructed.

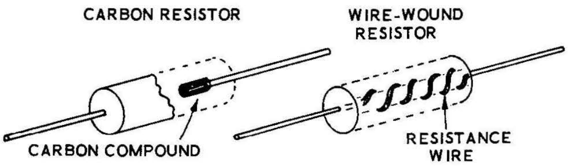


Figure 1D

To control how much resistance (how many ohms) a carbon resistor will present to electric currents, the carbon is mixed with a nonconducting material. By having more carbon and less of the other material, a small amount of resistance is created. By having a small amount of carbon and a large amount of the other substance, a large amount of resistance is created. The amount of resistance, or the number of ohms in a resistor is determined then, by the mixture of the carbon compound and not by the physical size of the resistor.

The amount of resistance in a wire-wound resistor is determined by the length of the wire and by the types of metal the wire is made from. This type of wire is called resistance wire and the longer the wire the larger the resistance.

The amount of current a resistor can pass depends on its physical size. Too much current would overheat a resistor and destroy its resistance elements. The larger a resistor is physically, the more heat it will dissipate, allowing more current to pass through it safely. High power resistors, therefore, are quite large and low power resistors are rather small. This power rating is independent of the resistor value in ohms. For example, a 100 ohm resistor rated at 2 watts could easily be much larger physically than a 500 ohm resistor rated at only 1/2 watt.

SEMICONDUCTOR MATERIALS

Semiconductors are a group of materials that are in the center of the resistance spectrum shown in Figure 1C. These materials have special characteristics caused by the type of crystal structure the material is composed of.

Pure semiconductor materials have a rather high resistance to the flow of electric current. When impurities are added to the semiconductor material (the amounts and types of these impurity materials are carefully controlled), the material has much less resistance to the flow of electric current. When one type of impurity is added, it causes a semiconductor material to have many excess (loosely held) electrons; this

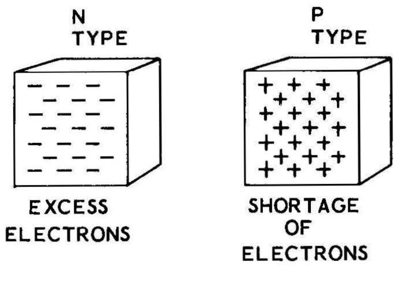
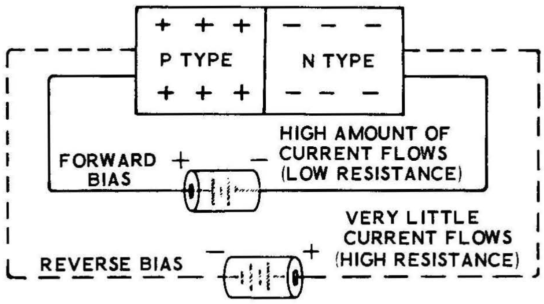


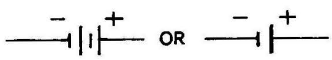
Figure 1E

type of semiconductor crystal, shown in Figure 1E, is called "N" type (negative).

When another type of impurity is added to the semiconductor material, it causes a shortage of electrons in a semiconductor material; this type of semiconductor crystal, also shown in Figure 1E, is called "P" type (positive).

When N type and P type semiconductor crystals are joined together in a crystal diode, as shown in Figure 1F, an unusual and very important phenomenon occurs at the "junction" where the two crystals are joined. When the plus terminal of the battery is connected to the N type crystal and the negative terminal of the battery is connected to the P type crystal, the junction appears like a very high resistance (almost like an insulator) and only the tiniest trickle of current is able to flow. A PN crystal, connected in this manner, so that almost no current flows, is said to have reverse bias applied to it.





ELECTRICAL SYMBOLS FOR A BATTERY

Figure 1F

When the battery is reversed, with the negative terminal connected to the N type crystal and the positive terminal connected to the P type crystal, current flows easily and the PN crystal acts like a small resistor (almost like a conductor). A PN crystal, connected in this manner (so that the current flows through it) is said to have forward bias applied to it.

A PN crystal junction, therefore, acts like a very large resistor when current tries to flow through it in one direction, and acts like a very small resistor when current flows through it in the other direction. This makes semiconducting material different from ordinary resistance materials.

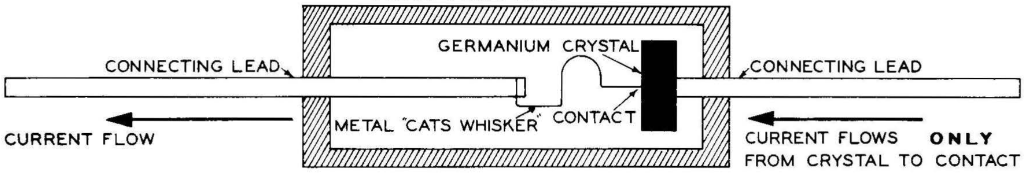


Figure 1G

The same type of one-way current effect also occurs in a different type of crystal diode, called the "point contact" diode. The point contact diode is shown in Figure 1G. The behavior of this point contact diode is essentially the same as the behavior of the PN junction diode; in one direction it presents a very high resistance to electric current and in the other direction, it presents a very low resistance to electric current.

SUMMARY

An electric current consists of the flow of free electrons through a substance. How much current flows is determined by the kind of material the current is flowing through. If the material has many free electrons, current flows through it easily. If the material has few or no free electrons, current does not flow easily through it.

A material through which current flows easily is called a "conductor," and a material through which current does not flow easily is called an "insulator." In between conductors and insulators are all the different ranges of materials that only partially resist the flow of current.

A "resistor" is made from a mixture of conductor and insulator types of materials to hold back the flow of electric current a certain amount. The larger the conductor content of the material, the smaller the resistance, and the less the resistor will hold back the flow of current. The larger the insulator content of the material, the more the resistor will hold back the flow of current, and the larger the resistance will be.

The amount of current that can be passed through a resistor without overheating it depends on the physical size of the resistor.

Semiconductor materials are resistive materials that have special characteristics caused by their crystal structure. When impurities are added to these semiconductor materials it causes either excess electrons in the semiconductor material (N type) or causes a shortage of electrons in the semiconductor material (P type).

Combining an N type and a P type crystal results in a rather unusual effect across the junction where the two crystals join; when an electric current goes through this PN crystal in one direction, the crystal appears to have a very low resistance. When an electric current trys to go through this PN crystal in the other direction, the crystal appears to have a very high resistance. This unusual effect is put to practical use in crystal diodes and in transistors.

HOW TO DETERMINE THE RESISTANCE OF SOME COMMON MATERIALS

To show how much various conductors, resistors, insulators, and semiconductors resist the flow of electric current.

PARTS REQUIRED

10 Ω resistor (brown-black-black)
270 Ω resistor (red-violet-brown)
1000 Ω resistor (brown-black-red)
22 KΩ resistor (red-red-orange)
2N1274 transistor
One water glass (about 8 oz.)
Table salt
One volt-ohm milliammeter (Tester from Basic Electricity course, or equivalent).

NOTE: Having the tester from the Basic Electricity course (or its equivalent) would enhance the experimental work in this kit by permitting you to make all the measurements and tests suggested in the text. However, if you do not have the tester from the Basic Electricity course, you will probably want to borrow a volt-ohm-milliameter or "VOM" in order to get the most out of your Basic Transistor experiments. An instrument of this type may be available on loan from a school, from a local amateur radio operator or hi-fi hobbyist, or from an acquaintance in the radio-TV repair business.

Although a meter is desirable, it is not absolutely essential to perform the experiments in the Experiment sections of the EK-3 lessons. No meter is used in many of the later lessons. When an experiment requires the use of a meter, if one is not available, read the experiment over carefully so as to have a clear understanding of how the meter would be used in the experiment.

The experiments in these lessons are not intended to introduce new material in a lesson. Their purpose is to take the knowledge learned in the theory section and to commit it more firmly to your memory by having you use it in a practical application. For this reason, the lack of a meter should not cause you undue concern; by diligent study, the Experiment section of each lesson will still be a valuable aid to your understanding of the practical applications of the theory given earlier in the lesson.

EXPERIMENT 1

To show the resistance of various conductors, resistors, and insulators.

NOTE: Each of the following resistance values (except for the resistors) is the amount of resistance that would be measured across a one foot length of the substance, with the overall dimensions shown in Figure 1H.

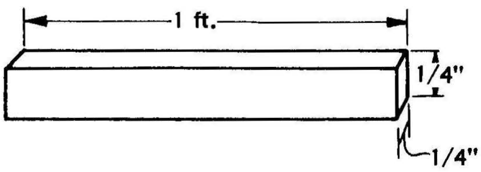


Figure 1H

CONDUCTORS

Silver wire - .000157 Ω
Copper wire - .000163 Ω
Gold - .000235 Ω
Aluminum - .000272 Ω
Zinc - .000575 Ω
Iron - .000944 Ω
Platinum - .000960 Ω
Nickel - .001 Ω
Tin - .0011 Ω
Brass - .0017 Ω
Lead - .002 Ω
Nichrome resistance wire - .0104 Ω

Resistors: Measure each of the following resistors and fill in the resistance sizes in the blanks provided on the chart below.

Determine the value of each resistor from its color code (refer to the chart on the inside of the front cover) and record the values in the blanks provided above. Now check the measured readings against the color coded resistor values as listed in the parts list. Compare the measured value of each resistor with its color coded value.

Place the resistors back with the rest of the parts; they will be used again in later lessons.

Insulators have so much resistance that each of

		MEASURED VALUE	COLOR CODED VALUE
Resistor 1-41	(brown-black-black)	________	________
Resistor 1-42	(red-violet-brown)	________	________
Resistor 1-9	(brown-black-red)	________	________
Resistor 1-22	(red-red-orange)	________	________

the following readings were divided by one million to make the values easier to read. To determine the actual value of resistance for each material (when dry) multiply the figure given by one million.

Wood	2,900,000 million ohms
Plastic	4,800,000 million ohms
Paper	19,000,000 million ohms
Glass	1,900,000,000 million ohms
Porcelain	29,000,000,000 million ohms

EXPERIMENT 2

To show how mixing materials changes the resistance values.

( ) Clip each one of the test leads of your ohmmeter to each side of an empty water glass as shown in Figure 1J and note the resistance indication. This indicates the resistance of the glass, which is too high to read on an ordinary ohmmeter.

( ) Fill the glass with water high enough so that the ohmmeter clips are wet. Note the resistance reading; it should read between 10 KΩ and 25 KΩ, depending on the mineral content of the water.

Record ____________________

( ) Add 2 teaspoons of salt to the water, one at a time. Stir the mixture and mark down the resistance reading after adding each teaspoonful.

Record ____________ Ω (1 tsp)

____________ Ω (2 tsp)

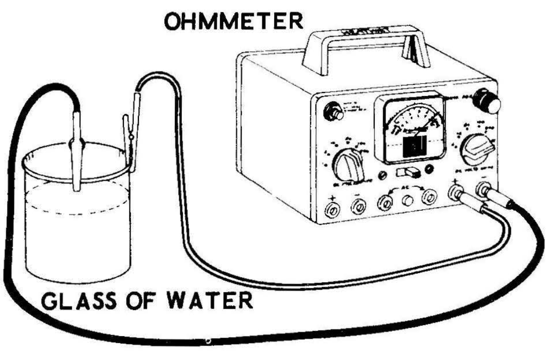


Figure 1J

EXPERIMENT 3

To show two different resistance readings across the PN junction. Since there are two PN junctions in the 2N1274 transistor, one of these junctions will be used for this experiment in place of a diode.

SPECIAL NOTE: If you are using an ohmmeter other than the test set from the Basic Electricity kit, you may find that your meter indicates in the wrong direction in the tests given below. This would only mean that the internal connections of the tester you are using are reversed from the internal connections of the Basic Electricity test set. Merely reversing your test leads should solve the problem.

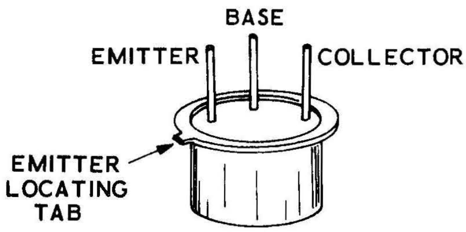


Figure 1K

( ) Connect the black lead to the base wire and connect the red lead of the ohmmeter to collector wire of one of the transistors (see Figure 1K). Note the resistance reading; it should read about 500,000 Ω (too high a resistance to be read on the EK-1 meter).

Record ____________________

( ) Now reverse the leads. Connect the red lead to the base connection and connect the black lead to the collector wire. Check the resistance reading on two different low ranges; note that although both readings are low in value, between 50 Ω and 300 Ω, they indicate different amounts of resistance. These two different readings for the same connection occur because the resistance of the PN junction changes when the current passing through it (from the ohmmeter) changes.

Range #1 ____________________

Range #2 ____________________

DISCUSSION

These experiments were arranged to give you a practical demonstration of how various materials react to the flow of electric currents. The list of conductors and insulators in Experiment 1 show that conductors have an exceedingly small amount of resistance and insulators have an exceedingly large amount of resistance. Resistors and transistors fall between these two extremes.

Measuring the resistors should have helped you to understand that even though these resistors are the same size physically, their electrical size depends on the amounts of the different types of materials that are mixed in them.

Experiment 2 not only showed the resistance of some materials but it also showed how the resistance of a substance can be changed by mixing different material in with it. Different values of resistance are obtained in resistors by mixing different types of materials together in this same manner.

Experiment 3 showed that the resistance read across a PN junction depends upon which way the current is flowing through the junction. Measuring the resistance from one direction, the current passes through easily, and the resistance is quite low. Measuring the resistance in the other direction, the current does not pass through the junction and the resistance measures very high.

LESSON 1

QUESTIONS *

1. All matter is made up of ______________.
2. At the center of each atom is the __________.
3. Orbiting about the center of the atom are negative particles called ______________.
4. The atoms of different materials differ only in the ______________ of negative and positive particles.
5. A resistor is a device that ______________ the flow of electric current.
6. What determines the amount of resistance a carbon resistor will present to an electric current?

____

____

7. The amount of current a resistor can pass depends on its ______________.
8. (True or False) Semiconductor materials have special characteristics caused by their crystal structure.
9. When impurities are added to semiconductor material, the material has (less, more) resistance to the flow of electric current.
10. The place where the N type and P type crystals are joined together is called the ______________.
11. When the plus terminal of a battery is connected to the N crystal and the minus terminal of the battery is connected to the P crystal, the junction appears like a very ______________ resistance.
12. A diode that uses a piece of semiconductor crystal and a metal contact is called a ______________ ______________ diode.

*NOTE: The answers to these questions will be found on Page 103.

LESSON II

HOW DO RESISTANCES IN SERIES AND PARALLEL CIRCUITS AFFECT CURRENT FLOW?

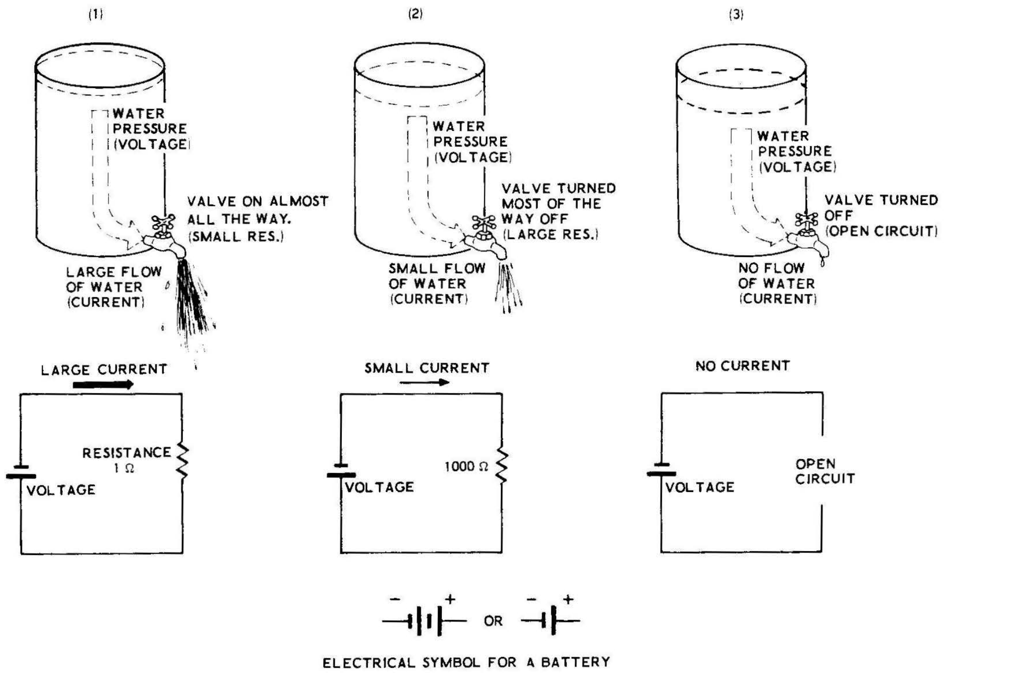


Figure 2A

The amount of current that flows in a resistor depends on how much resistance (how many ohms) the resistor has, and how much voltage or electrical pressure is applied across the resistor. The three water tanks of Figure 2A can be used to demonstrate the principles of how voltage and resistance affect current flow.

The water tank, with the flow pipe and valve at the bottom, is shown in three different conditions: with the valve all the way open, with the valve turned most of the way off, and with the valve turned all the way off. The pressure of the water at the bottom of the tank pushing into the pipe acts the same way as voltage does in an electrical circuit (voltage is the electrical pressure that pushes the flow of electrons through a circuit). The flow of water from the pipe acts like the flow of current in an electrical circuit; as the water pressure becomes higher, more water flows.

The valve in the pipe acts like a resistor does in an electric circuit. In part 1 of Figure 2A the full-open valve offers very little resistance to the flow of the water, thus it acts like a very small resistor. In part 2 of Figure 2A the valve has been turned most of the way off. Only a small amount of water can now flow, thus the valve acts like a large resistor.

In part 3 of Figure 2A the valve has been turned off completely. This makes the valve appear like a disconnected, or open circuit, and no water (current) can flow at all. Notice that with this valve position the water pressure (voltage) is still present even though no water (current) is flowing in the circuit.

THE CIRCUIT - A DEFINITION

An electrical circuit is any arrangement of electrical parts which allows for the flow of

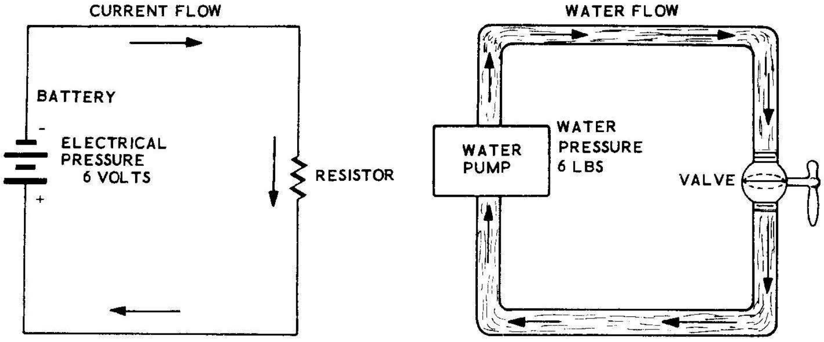


Figure 2B

current. For a circuit to be complete, the current must flow from one terminal of the power source, or battery, through the wires and parts, and back to the other terminal.

Figure 2B shows two complete circuits, one using a pump and a flow of water, and the other an electrical circuit using a battery and a flow of current. The battery and the pump perform the same functions, they supply pressure. The resistor and valve resist (or impede) the current (or water) flow. In both of these cases the circuit must have a complete path from one side of the battery (or pump) to the other side for proper operation.

An "open circuit" is a circuit in which there is no complete path from one side of the battery to the other. See Figure 2C for an example. No current can flow when an open circuit occurs; this puts the circuit in a "turned off" state.

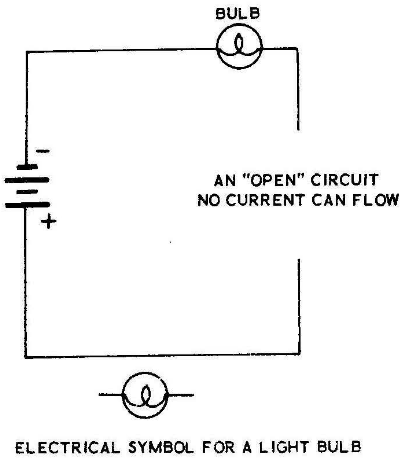


Figure 2C

A "short circuit." The bulb and resistor are shorted out by the screwdriver, causing too much current to flow, with the result that the battery burns out.

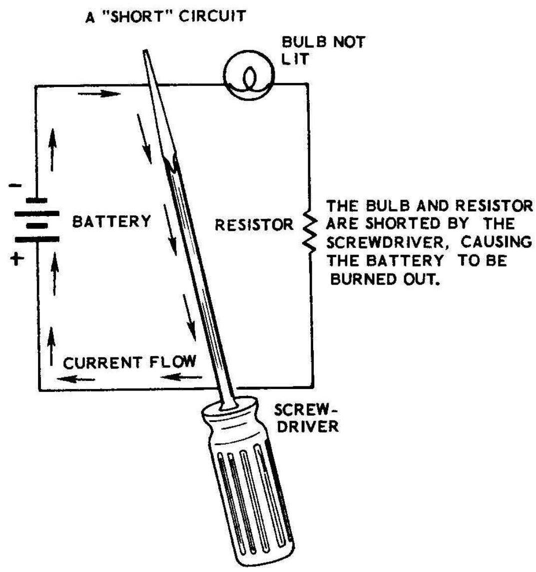


Figure 2D

A "short circuit" is a circuit where a low resistance connection has been made (usually accidentally) directly across the battery or power source (or on the wires to the power source) so that too much current flows. Short circuits generally result in ruined batteries, burned out fuses, or burned out wires and parts, depending on the type of circuit the "short" occurs in.

SERIES CIRCUITS

A series circuit is one in which the current has only one possible path to follow as it travels through the circuit. See the three examples shown in Figure 2E. Since there is only one path to follow, the same amount of current flows through all the parts of the circuit.

The total amount of current flowing in a circuit depends on two things: the resistance in the circuit, and the source voltage connected across the circuit. The amount of current can be calculated mathematically if the voltage and resistance are known by using Ohm's Law, which is

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

That is, the amount of current flowing in a circuit I is equal to the voltage across the circuit E divided by the resistance of the circuit R. (The abbreviation for voltage can be either E or V. Usually the letter E is used when dealing with Ohm's Law.)

The source voltage in a series circuit, as shown in Figure 2E, is divided among the series resistors proportionally according to the amount of resistance in each resistor. A large resistor will have a large amount of voltage across it and a small resistor will have a small amount of voltage across it. The sum of the voltages across the resistors is equal to the source voltage.

Part 1 of Figure 2E shows only one resistor connected across the battery. In this case all of the battery voltage is applied across this one resistor.

Part 2 of Figure 2E shows two resistors of equal value connected across the battery. Note that since these resistors are of equal value, the battery voltage divides evenly between the two resistors.

Part 3 of Figure 2E shows two resistors of different values connected in series across the battery. Resistor R2 is twice as large as resistor R1, for this reason resistor R2 has twice as much voltage across it as resistor R1. When three volts are applied from the battery, one volt appears across resistor R1 and two volts appear across resistor R2. The sum of the two voltages equals the source voltage, 3 volts.

The voltage across any of the resistors in a series circuit can be calculated by using simple algebra to solve Ohm's Law for E (voltage), as long as the circuit current and the resistance values of the resistors are known. In this case $I = \frac{E}{R}$ becomes $E = IR$.

PARALLEL CIRCUITS

A parallel circuit is a circuit where the resistors are connected across the battery in such a way that there are two or more current

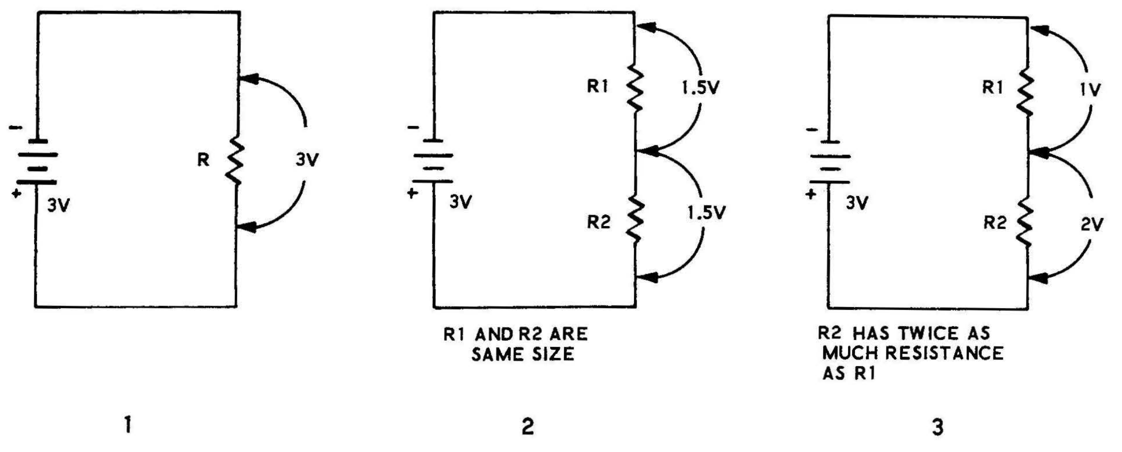


Figure 2E

paths around a circuit. See the parallel circuit of Figure 2F. The amount of current flowing in each one of the paths depends, as before, on the amount of resistance in each path. The same amount of voltage will appear across all the resistors in the parallel circuit since they are each connected directly to the battery.

Figure 2F shows a simple parallel circuit in which R2 is twice as big as R1 and R3 is ten times as big as R1. Ten volts (10 V) is applied across each resistor from the same 10 volt source. Notice that the current in each path is proportional to the amount of resistance. R1, which is a small resistor, has a large current flowing through it; R3, which is a large resistor, has a small current flowing through it.

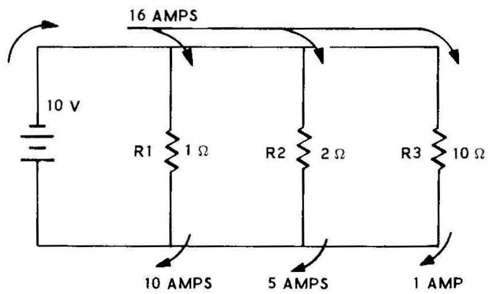


Figure 2F

If the total or overall resistance for the parallel circuit were calculated it would be equal to a single resistor that would allow the same total amount of current to flow through it alone as now flows from the battery through all three current paths. This total resistance for a parallel circuit can be calculated using the formula $\frac{1}{R\ TOTAL} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

See the example shown in Figure 2G.

The overall or equivalent resistance of a circuit can also be calculated with Ohm's Law by using the total circuit current and the total voltage.

$$R\ equivalent = \frac{E\ total}{I\ total\ (sum\ of\ all\ currents)}$$

SUMMARY

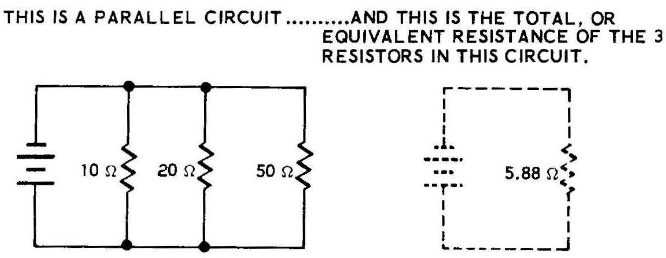
The amount of current that flows through a resistor depends on how much resistance (how many ohms) the resistor has, and how much voltage or electrical pressure is applied across the resistor. The current that flows in the resistor can be calculated with the formula

$$I = \frac{E}{R} \quad \text{or} \quad current = \frac{voltage}{resistance}.$$

I = current in "amps"
E = voltage in "volts"
R = resistance in "ohms"

A series circuit is a circuit where the current has only one path to follow around the circuit. The voltage in a series circuit is divided between the different resistors proportionally, according to how much resistance there is in each resistor. Larger resistances will have larger voltages across them and smaller resistances will have smaller voltages across them.

A parallel circuit is a circuit where there are two or more paths for current to follow through the circuit. The amount of current in each path depends on the amount of resistance in that path. The same voltage appears across each of the resistances (each current path) in a parallel circuit.



$$\frac{1}{R} = \frac{1}{10} + \frac{1}{20} + \frac{1}{50} = \frac{10}{100} + \frac{5}{100} + \frac{2}{100} = \frac{17}{100}$$

$$\frac{1}{R} = \frac{17}{100} \qquad 17R = 100 \qquad R = 5.88\ \Omega$$

Figure 2G

HOW TO PROVE OHM'S LAW

To show by experiments that $I = \frac{E}{R}$

PARTS REQUIRED

1 Master bottom plate
1 Experimental chassis
1 Battery retaining bracket
4 2-56 x 3/8" screw
3 4-40 x 1/4" screw
5 6-32 x 1/4" screw
1 6-32 x 3/8" screw
4 2-56 nut
4 6-32 nut
5 4-40 speednut
2 6-32 speednut
2 #6 solder lug
4 #6 lockwasher
2 #6 fiber flat washer
2 #6 shoulder washer
1 Battery contact spring
2 6-lug terminal strip
2 Transistor socket
1 Length hookup wire
2 2N1274 transistor
1 1000 Ω resistor (brown-black-red)
1 1500 Ω resistor (brown-green-red)
1 Volt-ohm-milliammeter
Hookup wire

PREPARING THE EXPERIMENTAL CHASSIS

Refer to Figure 2H for the following steps.

( ) Fasten the two 6-lug terminal strips to the experimental chassis as they are shown in Figure 2H, using 6-32 x 1/4" screws, #6 lockwashers, and 6-32 nuts. Be sure the chassis faces in the direction shown in Figure 2H.

( ) Install transistor sockets Q1 and Q2 from above the chassis, using 2-56 x 3/8" screws and 2-56 nuts. Be sure that the lugs of each transistor socket face as shown in Figure 2H.

( ) Cut a length of wire about 6 feet long from the roll of hookup wire you received with this kit. Put the rest of the wire (about 50 feet) to one side, it will be used later when longer lengths of wire will be needed.

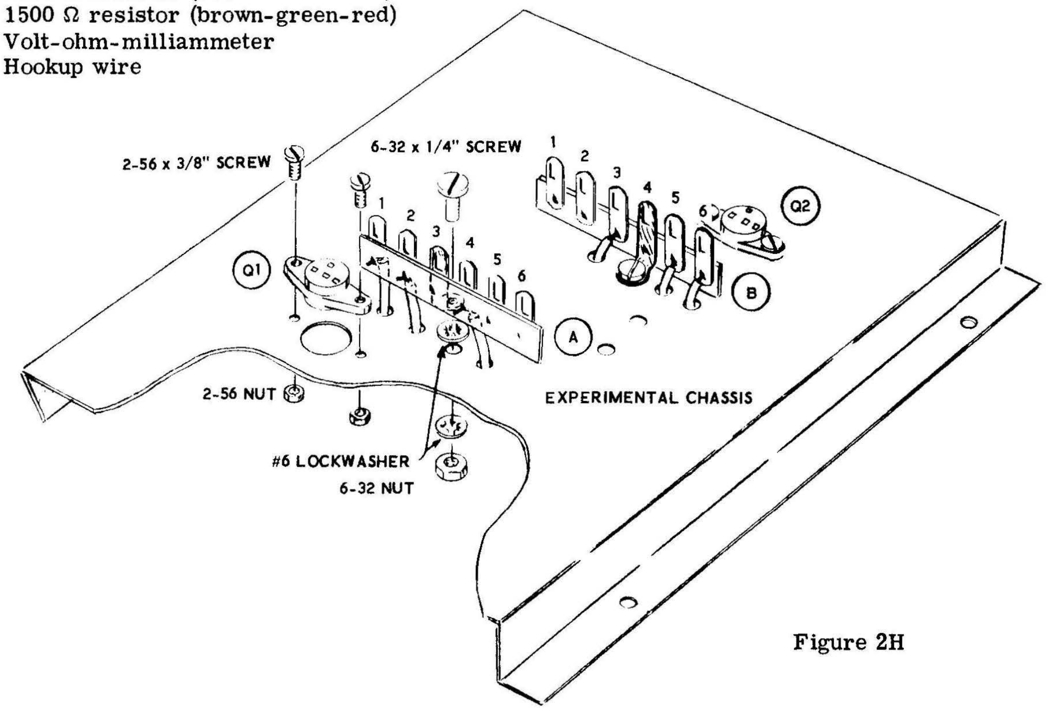


Figure 2H

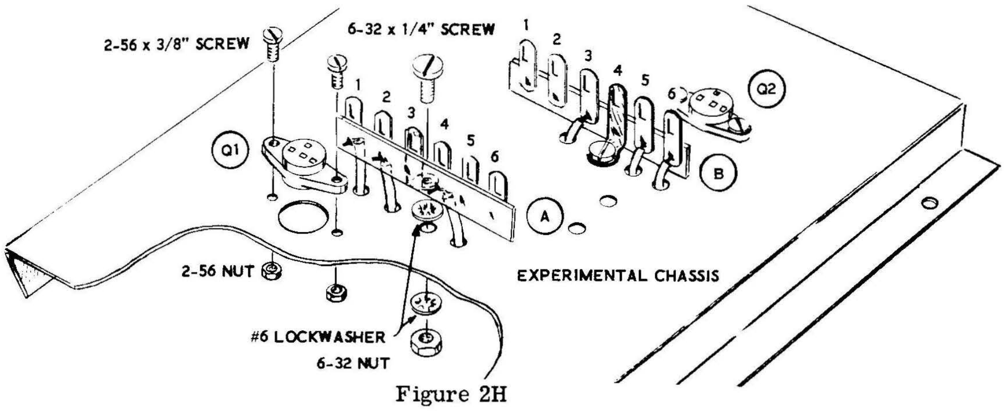


Figure 2H

When you need wires to make connections on the experimental chassis, use pieces cut from this 6 foot length. Many of these pieces of wire can be used a number of times in different experiments. If you find the 6 foot length is not enough, cut an additional 2 or 3 feet (as needed) from the longer length.

( ) Cut four 1-1/2" lengths of hookup wire and strip 1/4" of insulation from both ends of each wire.

Unless directed otherwise, all connections made during these experiments are temporary connections and will be removed or changed after short periods of time. Use temporary solder connections like those indicated in the Proper Soldering Techniques during the experiments in these lessons.

( ) Insert one end of one of these wires through the chassis hole near lug 1 of terminal strip A. Connect the other end of the wire to the lower hole in lug 1 of terminal strip A (S).

( ) Insert one end of a 1-1/2" wire through the chassis hole near lug 2 of terminal strip A. Solder the other end of the wire to the lower hole in lug 2 of terminal strip A (S).

( ) Insert one end of a 1-1/2" wire through the chassis hole near lug 5 of terminal strip B. Solder the other end of the wire to the lower hole in lug 5 of terminal strip B (S).

( ) Insert one end of the remaining 1-1/2" wire through the chassis hole near lug 6 of terminal strip B. Solder the other end of the wire to the lower hole in lug 6 of terminal strip B (S).

( ) Cut two 1-3/4" lengths of hookup wire and strip 1/4" of insulation from both ends of each wire.

( ) Insert one end of one of these 1-3/4" wires through the chassis hole near lug 4 of terminal strip A. Solder the other end of the wire to the lower hole in lug 4 of terminal strip A (S).

( ) Insert one end of the other 1-3/4" wire through the chassis hole near lug 3 of terminal strip B. Solder the other end of the wire to the lower hole in lug 3 of terminal strip B (S).

Refer to Figure 2J for the following steps.

( ) Install the three 4-40 speednuts in position as they are shown on the master bottom plate with the flat sides facing the bottom (painted) side of the master bottom plate.

( ) Install a 6-32 x 1/4" screw through a fiber shoulder washer (from the flat side). Install this screw and the shoulder of the fiber washer through the hole at the left end (with the bracket facing as shown in Figure 2J) of the battery retaining bracket. Fasten the assembly in place by placing a fiber flat washer, a #6 solder lug, and a 6-32 nut on the screw on the outside of the retaining bracket.

( ) Install a 6-32 x 3/8" screw through the small hole at one end of the battery contact spring (from the inside of the spring). Place a fiber shoulder washer over this screw, and install the shoulder of this washer through the large fiber washer. Now insert this screw through the hole in the right end of the battery retaining bracket.

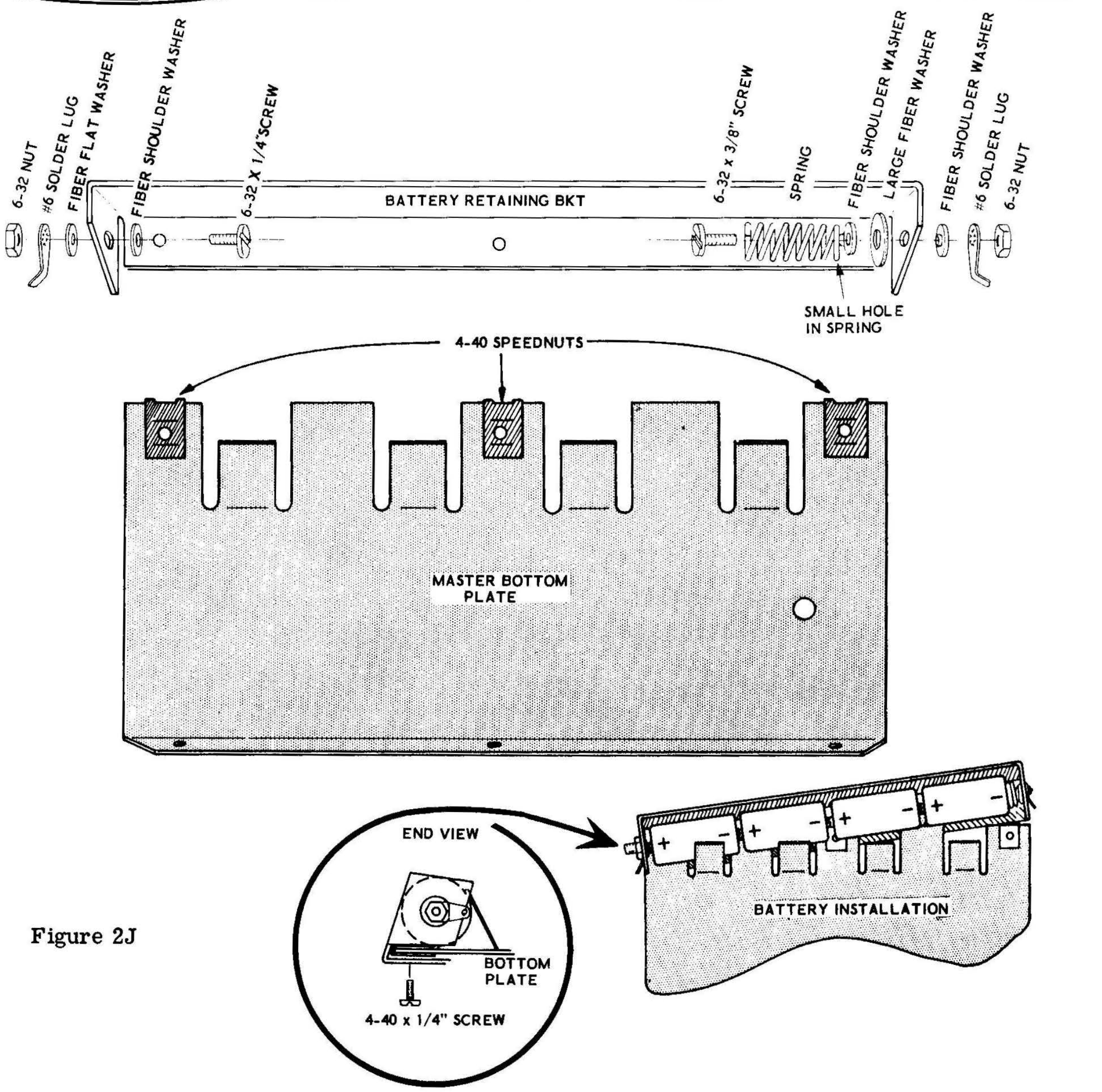


Figure 2J

( ) Install another fiber shoulder washer over this screw on the other side of the bracket. Put the shoulder of the washer in the hole in the bracket, and fasten the assembly in place with a #6 solder lug and a 6-32 nut. Place the solder lug as it is shown in Figure 2J.

( ) Fasten one end of the battery retaining bracket to the master bottom plate as it is shown in the inset drawing of Figure 2J. Use a 4-40 x 1/4" screw through from the bottom of the retaining bracket into the 4-40 speednut on the bottom plate.

( ) Install the four size C cells with the flat end of each battery facing toward the end of the bracket which has the spring attached to it.

( ) Finish installing the battery retaining bracket on the master bottom plate by pressing it in position and installing the two remaining 4-40 x 1/4" screws through the battery retaining bracket into the 4-40 speednuts on the master bottom plate.

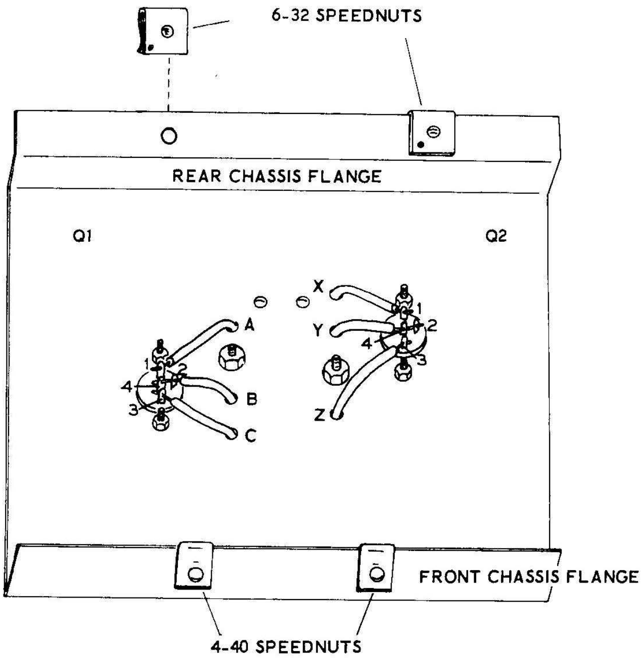


Figure 2K

Refer to Figure 2K for the following steps.

( ) Solder the wire coming through hole A to lug 1 of transistor socket Q1.

( ) Insert the wire coming from hole B through lug 2 to lug 4 of transistor socket Q1. Now solder the wire to both lugs.

( ) Solder the wire coming from hole C to lug 3 of transistor socket Q1.

( ) Solder the wire coming from hole X to lug 1 of transistor socket Q2.

( ) Insert the end of the wire coming from hole Y through lug 4 to lug 2 of transistor socket Q2. Now solder the wire to both lugs.

( ) Solder the wire coming from hole Z to lug 3 of transistor socket Q2.

( ) Install two 6-32 speednuts over the holes on the rear chassis flange. Install two 4-40 speednuts over the holes on the front chassis flange. Be sure the flat surface of the speednuts face as they are shown in Figure 2K.

EXPERIMENT 1

To demonstrate Ohm's Law in series circuits.

Refer to Figure 2L for the following steps.

( ) Connect the experimental chassis to the master bottom plate as it is shown in Figure 2L by inserting two 6-32 x 1/4" screws up through the master bottom plate into the 6-32 speednuts on the rear flange of the experimental chassis.

NOTE: Do not cut any wire from resistor or capacitor leads since these parts will all be used several times.

For most connections you will find it best to strip about 1/4" of insulation from both ends of the hookup wires before connecting them to the lugs. Occasionally, 1/2" to 3/4" of insulation can be removed when you are connecting one end of a wire to two adjacent lugs, or under the screw of a screw-type terminal strip.

( ) Connect a 6-1/2" hookup wire from the -6 volt solder lug (S) to lug 3 of terminal strip A (NS).

( ) Connect a 1000 Ω (brown-black-red) resistor from lug 3 (S) to lug 6 (NS) of terminal strip A.

( ) Compute the amount of current that should flow through this resistor when the circuit is completed using Ohm's Law $I = \frac{E}{R}$

$I = \frac{6}{1000} =$ ____ Amperes = ____ Milliamperes.

Remember, one milliampere is equal to one-one thousandth (.001) of an ampere. Example: 9 milliamperes = .009 amperes.

9 ma = .009 Amps

( ) Switch the meter to the 10 or 15 milliampere range. Connect the negative lead of the meter to lug 6 of terminal strip A and connect the positive lead of the meter to the +6 volt solder lug. The meter itself now completes this simple series circuit.

( ) The meter should now indicate the actual current flowing in circuit #1 of Figure 2L. Mark down the computed current and the measured current in the blank spaces below circuit diagram #1 in Figure 2L. Very likely you will find these two measurements slightly different; this will be due mainly to the minor variations in value in meters and resistors.

( ) Disconnect the meter from the circuit.

( ) Connect a 1500 Ω (brown-green-red) resistor from lug 6 of terminal strip A (S) to lug 6 of terminal strip B (NS).

( ) Connect a 7" length of hookup wire from lug 6 of terminal strip B (S) to the +6 volt solder lug (S). The two resistors are now connected in a series circuit as shown in Schematic #2 of Figure 2L.

Do not leave the circuit connected in this manner for a long period of time after the next four steps are done. This could cause the batteries to become run down.

( ) Measure the voltage across each resistor and mark it down in the proper blanks below Schematic #2 of Figure 2L. Disconnect and remove the wire from lug 6 of terminal strip B to the +6 volt solder lug.

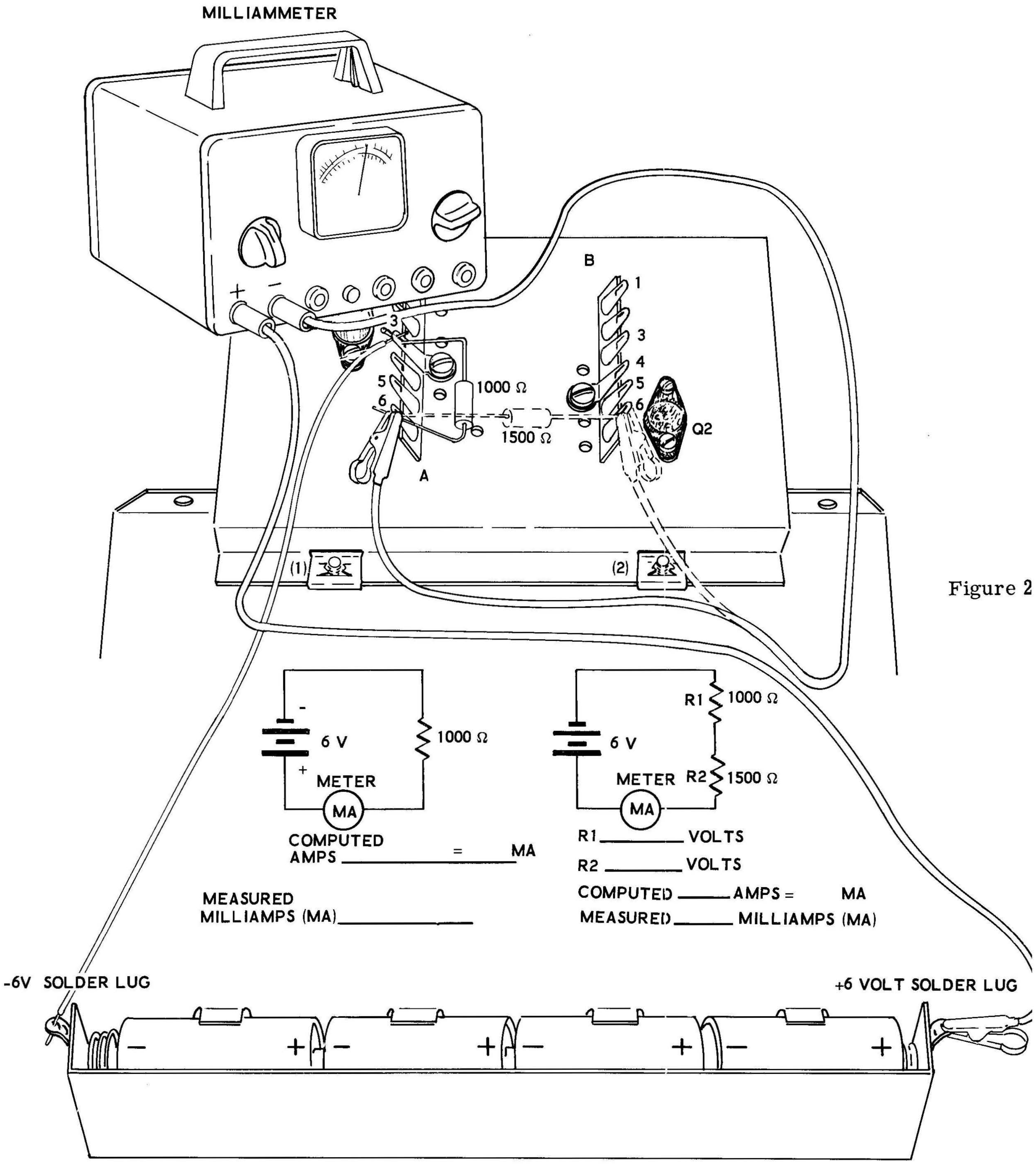
( ) Compute the current flowing in one of (or both) the resistors using Ohm's Law,

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

and insert it in the proper blank in Figure 2L.

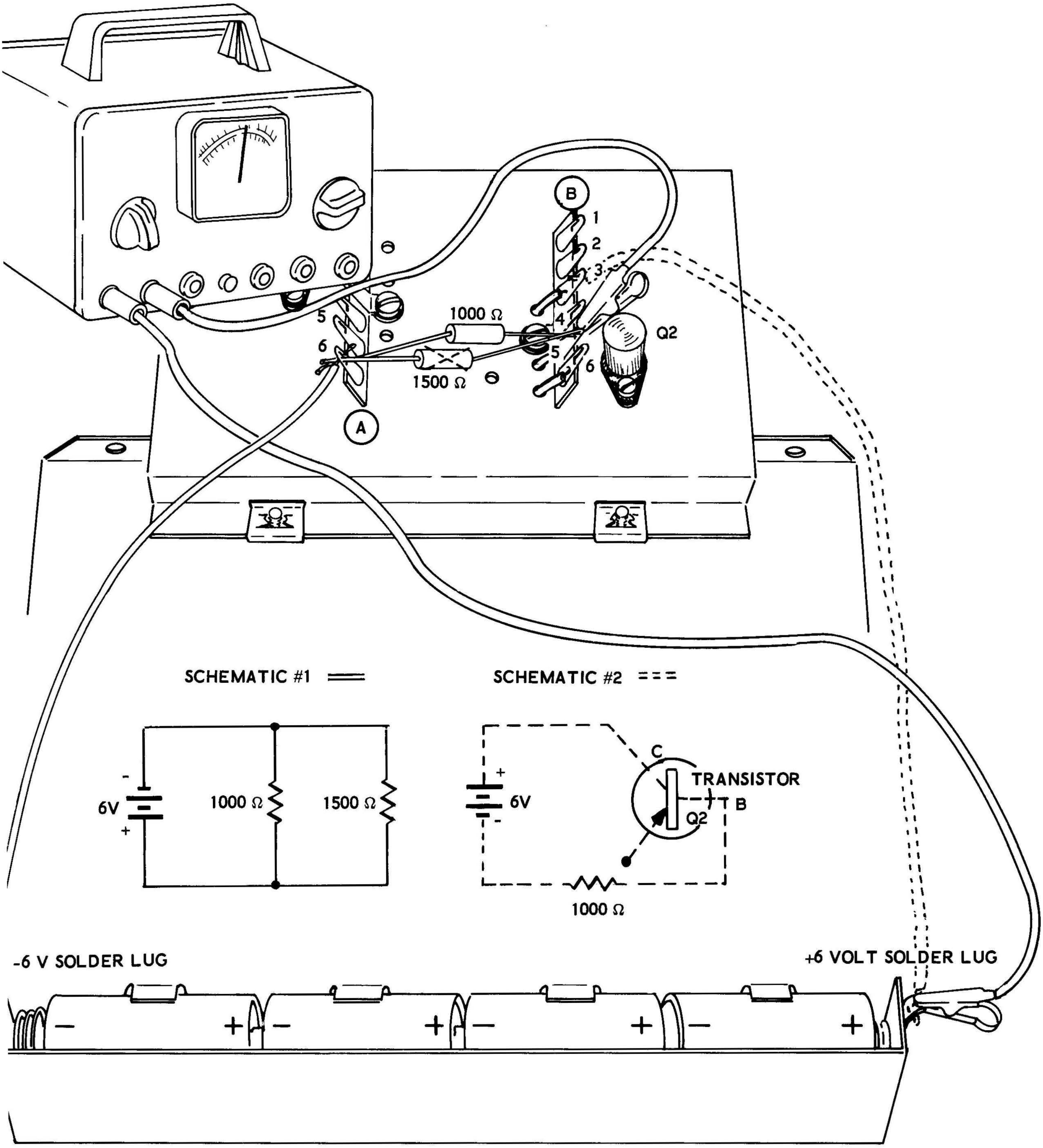
( ) Turn your meter to the 5 or 10 milliampere scale; connect the negative lead to lug 6 of terminal strip B and connect the positive lead to the +6 volt solder lug.

( ) The meter now reads the measured current flowing in the circuit. Mark this current down in the correct blank of Schematic #2 in Figure 2L, and then disconnect the meter leads.



MILLIAMMETER
+
−
B
1
3
4
5
6
3
5
6
1000 Ω
1500 Ω
Q2
A
(1)
(2)
-
6 V
+
1000 Ω
METER
MA
COMPUTED
AMPS ______________ = ______ MA
MEASURED
MILLIAMPS (MA)____________
R1
1000 Ω
6 V
METER
R2
1500 Ω
MA
R1 __________ VOLTS
R2 __________ VOLTS
COMPUTED ______ AMPS = MA
MEASURED ______ MILLIAMPS (MA)
-6V SOLDER LUG
+6 VOLT SOLDER LUG

Figure 2



B
1
2
3
4
5
6
Q2
1000 Ω
1500 Ω
5
6
A
SCHEMATIC #1
SCHEMATIC #2
6V
1000 Ω
1500 Ω
6V
C
TRANSISTOR
B
Q2
1000 Ω
-6 V SOLDER LUG
+6 VOLT SOLDER LUG

EXPERIMENT 2

To demonstrate Ohm's Law in parallel circuits and to demonstrate a PN junction acting as a resistor.

Refer to Figure 2M for the following steps.

( ) Unsolder and remove both resistors from the experimental chassis.

( ) Change the connection of the wire from the -6 volt solder lug as follows: unsolder the end of this wire from lug 3 and connect it instead to lug 6 of terminal strip A (NS).

( ) Connect the 1000 Ω resistor from lug 6 of terminal strip A (NS) to lug 5 of terminal strip B (NS).

( ) Connect the 1500 Ω resistor from lug 6 of terminal strip A (S) to lug 5 of terminal strip B (S).

The parallel circuit shown in Schematic #1 of Figure 2M is now hooked up on your experimental chassis, except for the final wire to the +6 volt solder lug. The following calculation should be completed before any further connections are made on the chassis.

( ) Compute the amount of current that should flow through each resistor when the circuit is completed, using Ohm's Law.

$I = \frac{E}{R} = \frac{6}{1000} =$ _____ A = __________ MA.

$I = \frac{E}{R} = \frac{6}{1500} =$ _____ A = __________ MA.

( ) Now add these two currents together to obtain the total current that will flow from the battery in this parallel circuit.

__________ MA

+ __________ MA

= __________ MA total current.

( ) Switch the meter to read current on a 10 or 20 milliampere range. Complete circuit 1 of Figure 2M with your meter. Connect the positive lead to the +6 volt solder lug and connect the negative lead to lug 5 of terminal strip B.

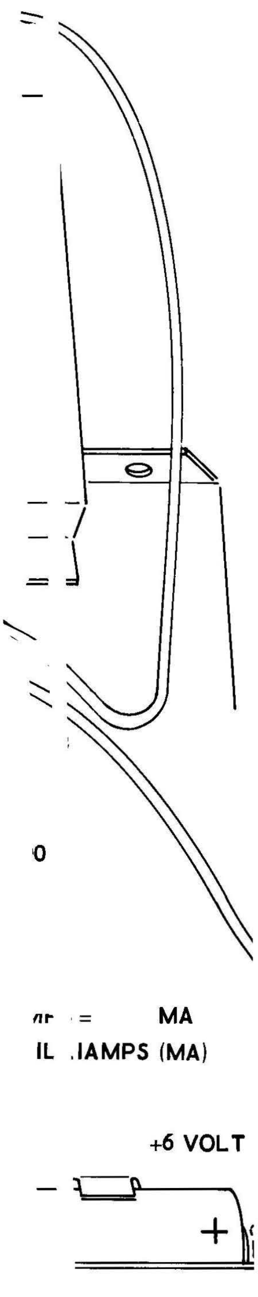
( ) The meter now indicates the total current flowing in the circuit. Record this current, and then disconnect the meter. __________ MA.

( ) Now compare this current just measured with the total current that you calculated a few steps earlier. You will probably find a small difference between the two readings, because of small differences between the actual value of the resistors and the color-coded values.

( ) Now compute the equivalent resistor (see Figure 2G) that would draw the same amount of current from the battery as these two resistors now do in parallel. First change the current from milliamperes to amperes as done in the example on Page 16.

$$\text{Total R} = \frac{\text{Total E}}{\text{Total I (in amperes)}}$$

$$\frac{\text{Total E}}{\text{Total I}} = \frac{\text{6 volts}}{\text{\_\_\_ Amps.}} = \text{\_\_\_\_\_\_}\ \Omega.$$



( ) Unsolder and remove the 1500 Ω resistor.

( ) Cut the leads of the two 2N1274 transistors to a length of 1/4". Plug one of the transistors in each of the transistor sockets. Be sure the three transistor leads are correctly aligned with the holes in each socket.

( ) Connect a wire from the +6 volt solder lug (S) to lug 3 of terminal strip B (S).

The circuit is now connected as shown in Schematic #2 of Figure 2M.

( ) Switch the meter to read voltage on the 5 volt range in order to measure the voltage across the transistor. Connect the negative lead to lug 5 (Base connection) and connect the positive lead to lug 3 (Collector connection) of terminal strip B. Record this voltage. ________V.

( ) Unsolder and remove the wire that connects from the +6 volt solder lug to lug 3 of terminal strip B.

( ) Switch the meter to read current on the 10 or 15 milliampere range. Connect the positive lead of the meter to the +6 volt solder lug and connect the negative lead to lug 3 of terminal strip B.

Your milliammeter now completes the circuit, and indicates the amount of current passing through the series circuit that consists of the 1000 ohm resistor and the PN junction of transistor Q2. Mark this current down and then disconnect the milliammeter. ________MA.

( ) Compute the resistance of the PN junction in the circuit. This can be computed by turning Ohm's Law around with basic algebra so that

$$R = \frac{E \text{ (measured voltage)}}{I \text{ (measured current in amperes)}}$$

R = ________ = ________ Ω.

DISCUSSION

Experiment 1 gave you a demonstration of the truth of Ohm's Law by allowing you to calculate and then measure the current in a simple series circuit. Although your computed and calculated current probably did not come out exactly the same, due to normal variations in size (tolerances) in the meter and resistors, they should have come out close enough to the same value of current to demonstrate that the law really works.

The first part of Experiment 2 directed you first to compute and then to measure the amount of current flowing in a simple parallel circuit. This demonstrated another proof of Ohm's Law and showed you that the amount of current that flows in each current path of a parallel circuit is proportional to the size of the resistor in that path. A large resistor will have a small amount of current, and a small resistor will have a large amount of current.

In the second part of Experiment 2 you calculated the resistance of a PN junction, with forward bias applied to it, in a simple series circuit. Your calculations showed you that it acts like a small resistance with forward bias applied. If the junction had been connected in the opposite direction, with reverse bias applied to it, it would have acted like a resistance so large that it would have appeared to be an open circuit.

LESSON 2

QUESTIONS

1. On what does the amount of current that flows in a resistor depend?

2. What is an electrical circuit?

3. What is an "open" circuit?

4. When a "short" circuit occurs (too much current, no current) flows in the circuit.

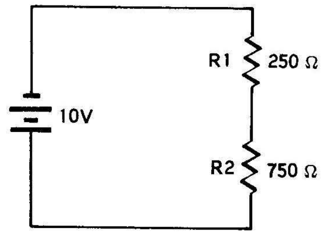
5. In a series circuit, the same amount of current flows through each resistor. (True, False)

6. In a series circuit, the full amount of the source voltage always appears across each resistor. (True, False)

7. In a parallel circuit there is more than one path for current to follow around the circuit. (True, False)

8. How do you determine the total current flowing in a parallel circuit?

9. Calculate the following values.



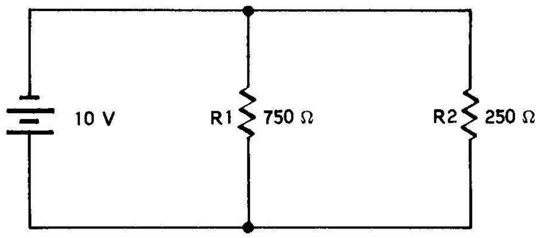
TOTAL RESISTANCE (R) = ______

TOTAL CURRENT (I) = ______ A = ______ MA

VOLTAGE ACROSS RESISTOR R1 (E) = ______

VOLTAGE ACROSS RESISTOR R2 (E) = ______

10. Calculate the following values.



TOTAL RESISTANCE (R) = ______

CURRENT IN R1 (I) = ______ A = ______ MA

CURRENT IN R2 (I) = ______ A = ______ MA

TOTAL CURRENT (I) = ______

LESSON III

HOW DOES A TRANSISTOR REACT IN A SERIES CIRCUIT?

In Lesson I you learned how current flows, and how different materials react to its flow. In Lesson II you learned how current flows in series and parallel circuits; that the source voltage divides proportionally over the resistances (or "load" resistors) in a series circuit; and that the voltage that appears across a resistor is proportional to its resistance, the larger the resistance, the larger the voltage that appears across it, and vice versa.

This lesson will show you that a transistor acts like a resistor; a resistor that can be adjusted in electrical size to have either a larger or a smaller number of ohms. By controlling the amount of resistance that this transistor presents to the circuit, the amount of current that flows through the circuit can be controlled.

A VARIABLE RESISTOR CHANGES CIRCUIT VOLTAGES AND CURRENT (SEE R1) BY TURNING THE SHAFT - A MECHANICAL CHANGE

A variable resistor, also called a potentiometer, or control, is a resistor whose electrical size (number of ohms) can be adjusted. Figure 3A shows how these variable resistors are generally constructed. A length of resistive material, such as carbon, or resistance wire, is connected in a horseshoe shape between two terminals. A metal tab, which is turned by the shaft, can contact any point along this resistive surface. This tab, which is also called the "arm" of the control, is connected to the center terminal. When the shaft is turned, the resistance between the center lug and both outside lugs changes. For this lesson, only two of the variable resistor terminals will be used, the center terminal, and either one of the other terminals.

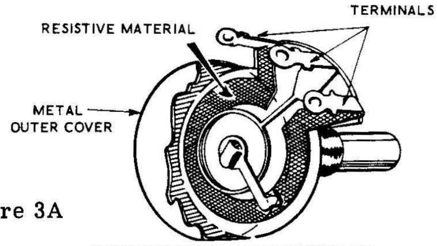
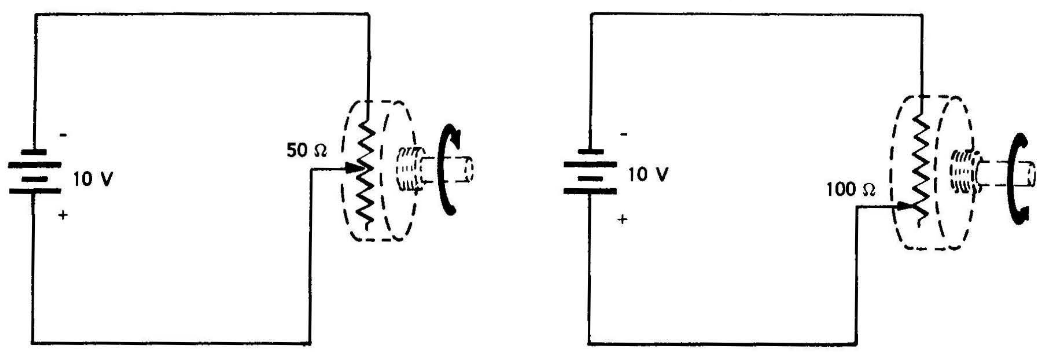


Figure 3A

CONSTRUCTION OF A POTENTIOMETER OR VARIABLE RESISTOR.

The first part of Figure 3B shows a variable resistor, which has been adjusted to 50 ohms resistance, connected across a 10 volt battery. By using Ohm's Law you can determine that the current flowing in this circuit would be .2 amperes or 200 milliamperes (200 ma).

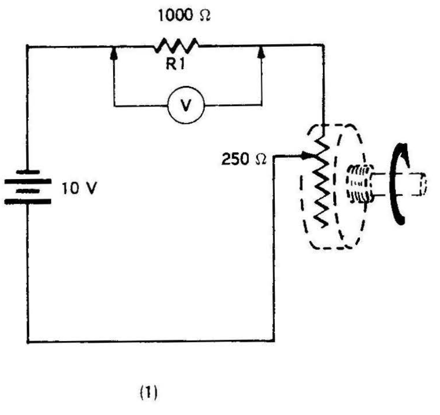
In Part 2 of Figure 3B, the shaft of the variable resistor has been turned so that it now has a resistance of 100 ohms. Now, when you figure the current in the circuit, you find it has decreased to 100 milliamperes (100 ma). This shows that by changing the resistance of a circuit, the current through the circuit is changed. Therefore, turning the shaft of the variable resistor controls the amount of current flowing in Figure 3B.

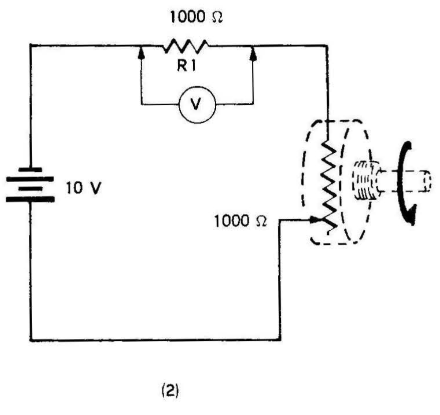


$I = \frac{E}{R} = \frac{10}{50} = .2$ AMPS = 200 MA.

$I = \frac{E}{R} = \frac{10}{100} = .1$ AMP = 100 MA.

Figure 3B





CIRCUIT CURRENT = $\frac{\text{TOTAL E}}{\text{TOTAL R}} = \frac{10}{1250}$ = 8 MA.

VOLTAGE ACROSS R1 E = IR = 8V

CIRCUIT CURRENT = $\frac{\text{TOTAL E}}{\text{TOTAL R}} = \frac{10}{2000}$ = 5 MA.

VOLTAGE ACROSS R1 E = IR = 5V.

Figure 3C

In Figure 3C a 1000 ohm resistor, R1, has been connected in series with the variable resistor. In Part 1 of Figure 3C the variable resistor has been adjusted to a resistance of 250 ohms. The Ohm's Law calculation shows that .008 amperes, or 8 milliamperes of current is flowing through the circuit. The lower calculation shows that 8 milliamperes of current flowing through R1 causes 8 volts to be measured across resistor R1. The remaining 2 volts appears across the variable resistor.

In the second part of Figure 3C the variable resistor has been adjusted to a resistance of 1000 ohms. Now, 5 milliamperes of current is flowing through the circuit. This 5 milliamperes of current flowing through resistor R1 causes a voltage of 5 volts to appear across R1. The remaining voltage, 5 volts, appears across the variable resistor.

Thus the voltage across the series resistor (R1) changed from 8 volts to 5 volts. This is demonstrated in the two schematics of Figure 3C which show that turning the shaft of the variable resistor controls the circuit current. Therefore, turning the shaft controls the voltage developed across series resistor R1. The amount that the voltage across R1 changes depends on how far the shaft is turned.

The following paragraphs will show you that a transistor can be connected in a circuit in place of the potentiometer and the same kind of results can be obtained; in this case the change in voltage across series resistor R1 will be caused by an electrical change in the transistor instead of by the turning of a shaft.

TRANSISTORS

Transistors are made by placing the two different types of semiconductor crystals together in the form of a sandwich (review Semiconductor Materials, Lesson I). Two crystals of one type are used for the "bread" parts of the sandwich, and one crystal of the other type is used in the "meat" position between the two others. A transistor is also like having two semiconductor diodes, made from only three pieces of crystal material.

Figure 3D shows how junction transistors are constructed, and their schematic symbols. At one end of the PNP transistor is a large "P" type semiconductor crystal called the Emitter. At the other end of the transistor is another large P type crystal called the Collector. In between these two P type crystals is a thin wafer of N type crystal material called the Base.

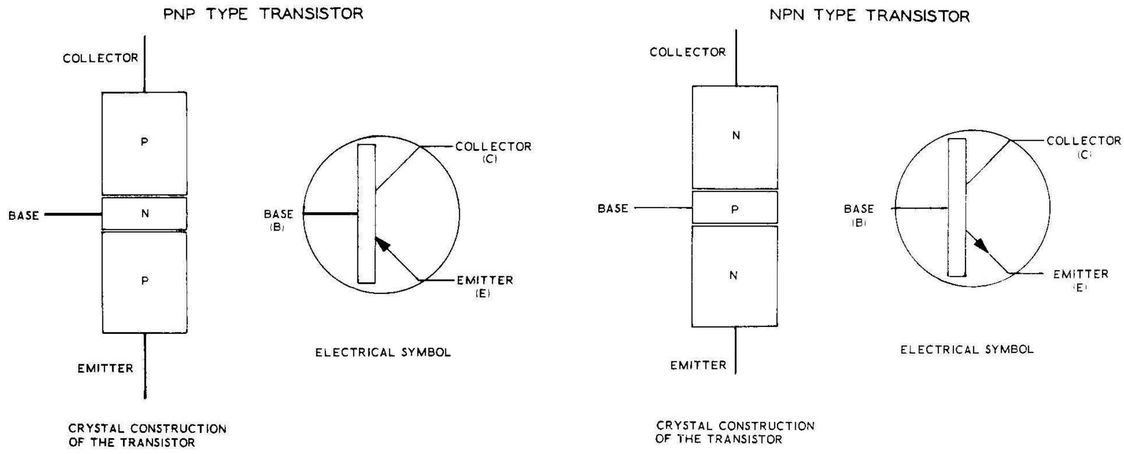


Figure 3D

The NPN transistors are constructed in exactly the same manner, except that the types of crystal material are reversed, two N type crystals are separated by a thin wafer of P type crystal. The schematic symbol for the NPN type transistor is the same, except that the arrow that indicates the emitter points in the opposite direction, away from the base. The first type of transistor, the PNP type, is used in the circuits that are constructed in this kit and are the most common type.

To make the operation of the transistors easier to understand, think of the Emitter as emitting current into the transistor. Think of the Collector as collecting current and sending it back through the rest of the circuit to the battery.

A TRANSISTOR CHANGES CIRCUIT VOLTAGES AND CURRENT (SEE R1) ELECTRICALLY BY CHANGING THE TRANSISTOR CONTROL VOLTAGE OF BATTERY #2.

Figure 3E shows a transistor replacing the variable resistor of Figure 3C. The values for current and resistance given in Figure 3E were selected to make the circuit action as clear as possible, and are not necessarily the amounts of current or resistance that you might find in an actual circuit.

In both parts of Figure 3E the battery voltage connected to the Base of the transistor does the same job as the shaft of the variable resistor; it causes the resistance of the transistor in the series circuit to be changed.

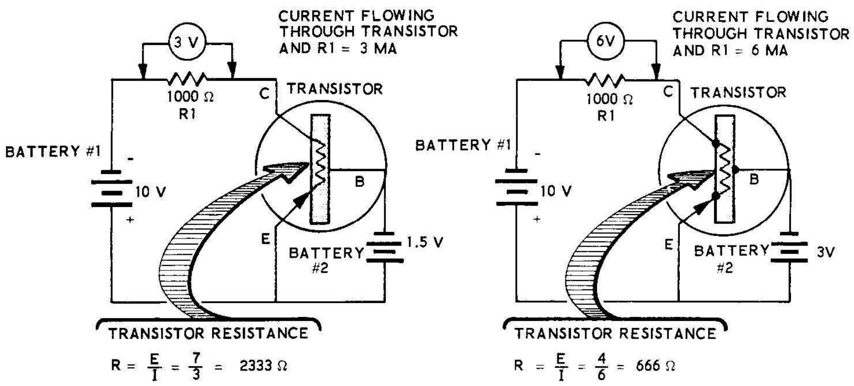


Figure 3E

In Part 1 of Figure 3E a 1.5 volt battery is connected between the Base and Emitter of the transistor, causing 3 milliamperes of current to flow in the circuit. The 3 milliamperes of current causes 3 volts to appear across 1000 ohm resistor R1. This leaves 7 volts appearing across the transistor. Calculating the resistance of the transistor with Ohm's Law shows that under these conditions the transistor acts just like a 2333 ohm resistance would in the circuit.

In Part 2 of Figure 3E, a 3 volt battery replaces the 1-1/2 volt battery that is connected between the Base and Emitter of the transistor. This voltage increase causes the resistance of the transistor to decrease, so that now 6 milliamperes of current flows in the circuit. Now, with the larger current, 6 volts appears across resistor R1. Using Ohm's Law to calculate the new resistance of the transistor in the circuit, shows that it has decreased to 666 ohms.

This change in resistance demonstrates that a transistor in a series circuit acts just like a variable resistor would. The change of resistance is performed mechanically in the variable resistor by turning the shaft, and it is performed electrically in the transistor by changing the voltage applied between the Base and the Emitter. The next lesson will explain how this electrically controlled resistance change is put to use in circuits.

SUMMARY

A transistor contains three semiconductor crystals put together in the form of a sandwich, with one type of crystal material in the center and a crystal of the other type on each side of it.

A variable resistor is a resistor in which the number of ohms can be adjusted mechanically, by turning a shaft. A transistor also has an adjustable number of ohms, only its resistance is adjusted electrically.

In a series circuit containing two resistances, one fixed and the other variable, the current can be increased or decreased by turning the shaft of the variable resistor. Changing the current in the circuit causes the voltage across both resistors to change, although the total voltage always stays the same as the source voltage (battery, etc.). Turning the shaft of the variable resistor, then, will cause the voltage appearing across the other (fixed) resistor to increase or decrease.

If the variable resistor is replaced by a transistor in the series circuit, the same type of current changes can still be made. Now, with the transistor, the resistance is changed electrically by changing the voltage applied between the Base and the Emitter. This changes the current flowing through both the transistor and the fixed resistor (resulting in a change in voltage across the fixed resistor). This shows that the transistor can be made to control current in a circuit, just like a variable resistor would.

HOW TO CONTROL CURRENT IN SERIES CIRCUITS

To show that a transistor and a variable resistor will both control current in a similar manner.

PARTS REQUIRED

1	EK-3 Experimental chassis w/bottom plate assembly
1	Left half front panel
1	Right half front panel
1	Front panel support plate
1	Speaker
1	1000 Ω resistor (brown-black-red) now wired on the chassis
1	47 KΩ resistor (yellow-violet-orange)
1	5000 Ω control (variable resistor)
1	SPST (Single Pole Single Throw) switch
1	DPDT (Double Pole Double Throw) switch
12	6-32 x 1/4" screw
2	4-40 x 1/4" screw
8	6-32 nut
1	Control nut
8	#6 lockwasher
1	Control lockwasher
1	Control flat washer
1	#6 solder lug
1	Screw-type 2-lug terminal strip
1	Knob
1	Volt-ohm-milliammeter

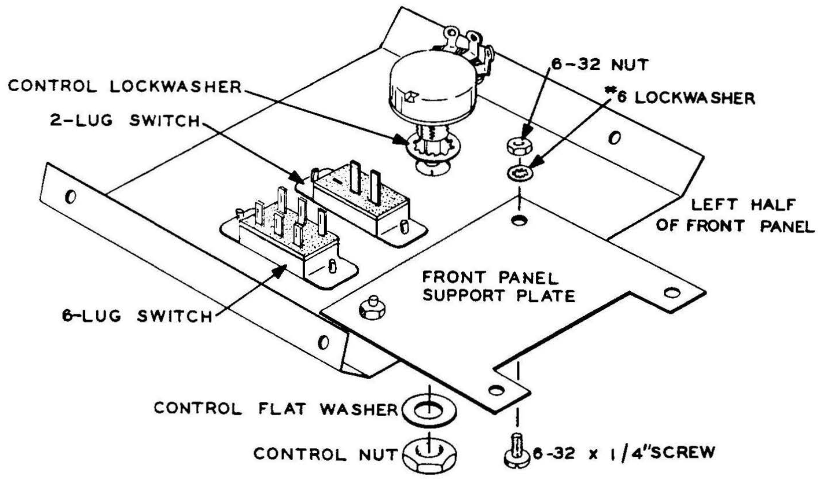


Figure 3F

PREPARING THE CHASSIS

Refer to Figures 3F and 3G for the following steps.

( ) Place the left half of the master front panel (with the large round hole and two rectangular holes) as it is shown in Figure 3F.

( ) Fasten the 5000 Ω control as shown in Figure 3F using a control lockwasher, control flat washer and a control nut.

( ) Fasten the 2-lug switch as it is shown in Figure 3F, using 6-32 x 1/4" screws. The two switch lugs should be positioned as shown.

( ) Fasten the 6-lug switch to the front panel using 6-32 x 1/4" screws.

( ) Fasten the front panel support plate to the front panel as shown in Figure 3F using 6-32 x 1/4" screws, #6 lockwashers, and 6-32 nuts. Do not tighten yet.

( ) Place the other half of the master front panel as shown in Figure 3G and fasten the screw-type terminal strip to it using 6-32 x 1/4" screws, #6 lockwashers, and 6-32 nuts.

( ) Mount the speaker on the right-hand front panel. Fasten the two front panels together at the same time, making sure speaker lugs are oriented as shown. Use 6-32 x 1/4" screws, #6 lockwashers, and 6-32 nuts. Now tighten all screws holding the front panel support.

( ) Fasten the assembled front panel to the front lip of the experimental chassis as it is in the inset in Figure 3K by installing two 4-40 screws into the 4-40 speednuts on the front flange of the experimental chassis.

( ) Install the knob on the shaft of the 5000 Ω control and tighten the setscrew.

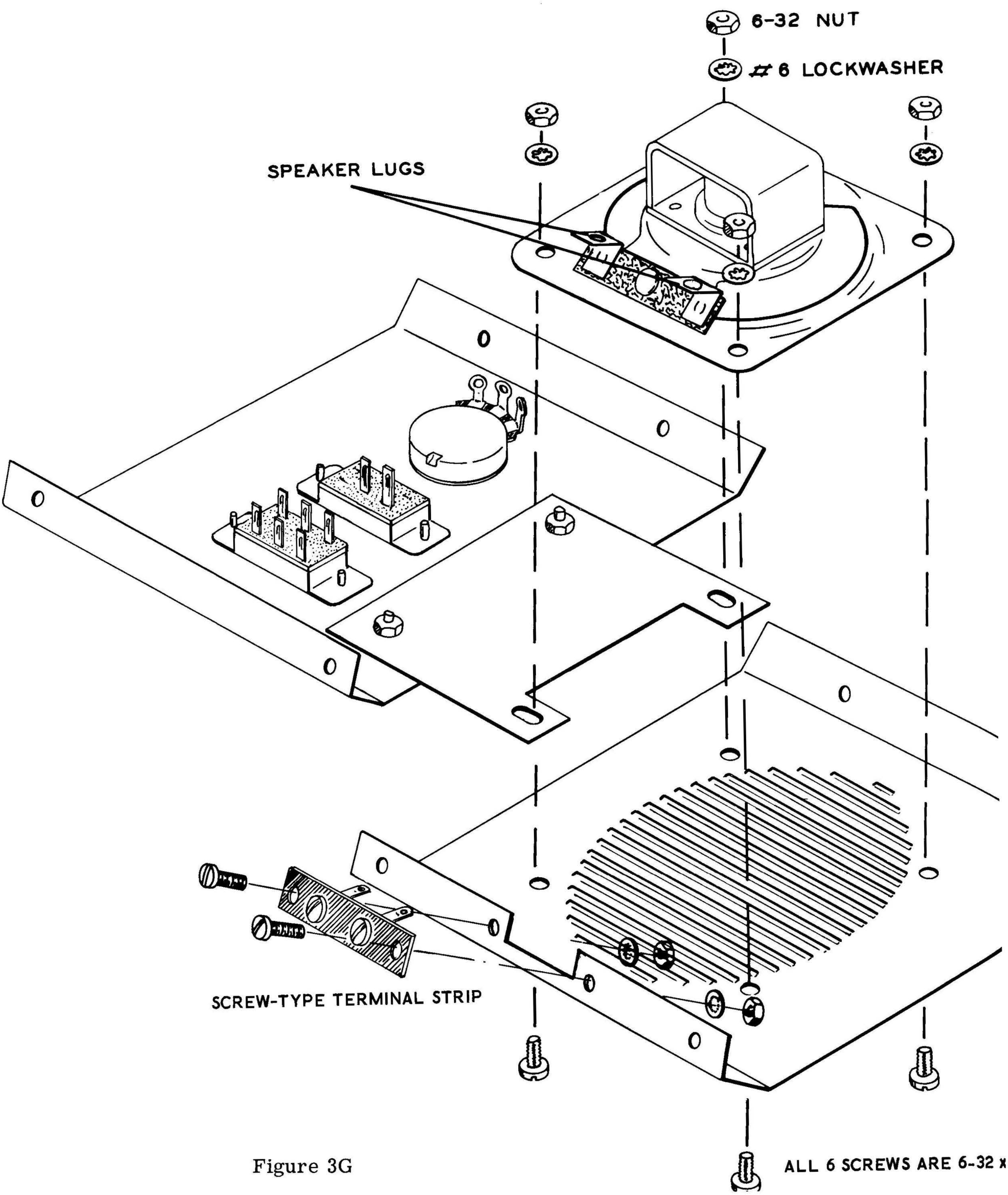

6-32 NUT
#6 LOCKWASHER
SPEAKER LUGS
SCREW-TYPE TERMINAL STRIP
ALL 6 SCREWS ARE 6-32 x

Figure 3G

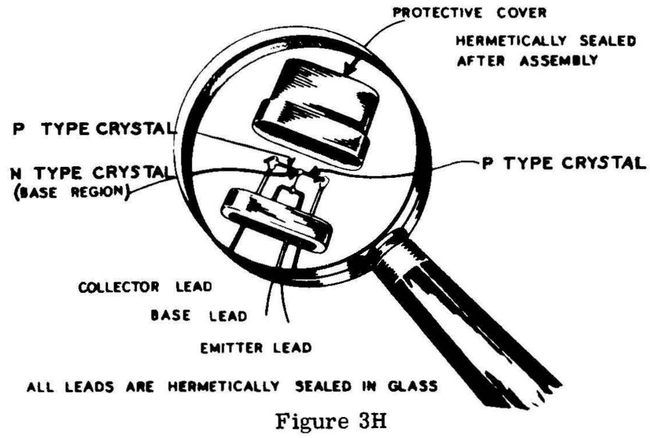


Figure 3H

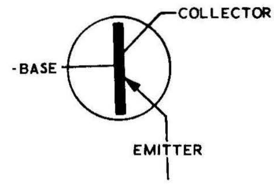


Figure 3J

BECOMING FAMILIAR WITH THE NEW PARTS

The construction of a typical junction transistor is shown in Figure 3H. Its schematic symbol is shown in Figure 3J. The transistor shown was made from germanium crystals, but transistors are also made from silicon crystals. The case or protective cover shown is oblong in shape, but it could just as easily have been made round like the transistors used in this kit.

Leads are brought out through the bottom of the transistor case from each of the three segments of the crystal material, the Emitter, Base, and Collector. The actual base region may be only 1/1000" thick, therefore this layer must be precisely located before other wires are attached.

The entire unit is assembled in areas that are as clean as a hospital operating room so that the amounts of impurities in the crystal can be carefully controlled. The assembly is then hermetically sealed in a protective case, often with an inner compound to assist in conducting heat away from the assembly.

EXPERIMENT 1

To show that by adjusting a variable resistor you can control current in a series circuit.

Refer to Figure 3K for the following steps.

( ) Unsolder and remove the 1000 Ω resistor and the wire from the -6 volt solder lug to lug 6 of terminal strip A.

( ) Place the ON-OFF switch in the OFF position.

( ) Connect a 12" length of hookup wire from the -6 volt solder lug (S) to lug 1 of the ON-OFF switch (S).

( ) Connect a 1000 Ω resistor from lug 2 of the ON-OFF switch (S) to lug 3 of the variable resistor (S).

( ) Connect an 8" length of hookup wire from lug 2 of the variable resistor (S) to the +6 volt solder lug (S).

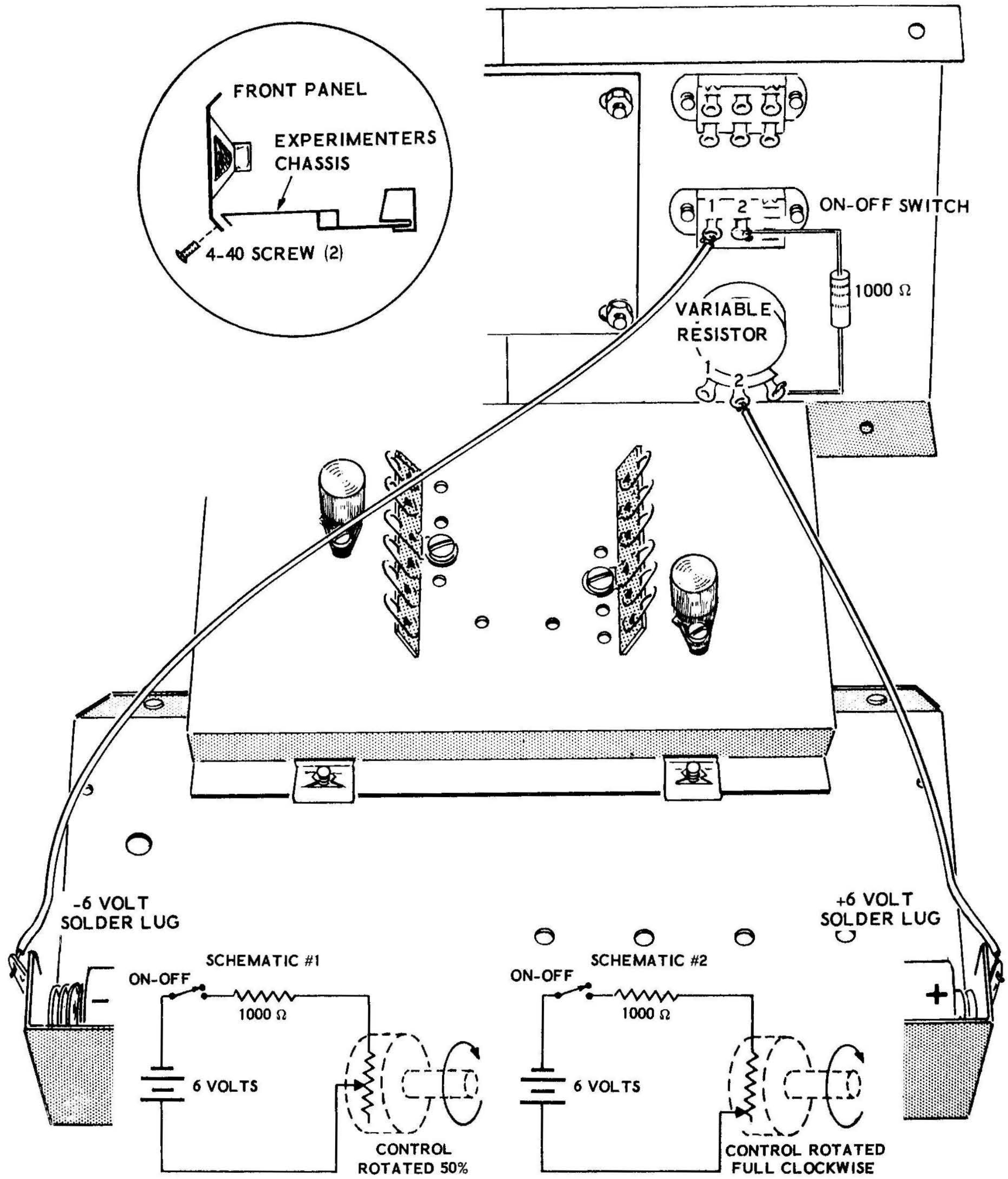
( ) Turn your meter to the ohms position. Connect one lead to lug 2, and connect the other lead to lug 3 of the variable resistor. Now adjust the variable resistor until the meter indicates 2000 Ω.

( ) Remove your meter leads from lugs 2 and 3 of the variable resistor. You have now adjusted the variable resistor to give you the circuit of Schematic #1 of Figure 3K.

( ) Adjust the meter so it will indicate current on the 5 milliampere range. Connect the negative lead of the meter to lug 1 and the positive lead to lug 2 of the ON-OFF switch.

( ) The meter has now completed the circuit by connecting across the ON-OFF switch. Note the amount of current indicated by the meter and mark it down in the correct blank below Schematic #1.

( ) Disconnect the meter leads from the ON-OFF switch and connect the EK-1 meter to read voltage on the 10 volt scale.



VARIABLE RESISTOR	= 2000 Ω	VARIABLE RESISTOR	= 5000 Ω
CIRCUIT CURRENT	= ______	CIRCUIT CURRENT	= ______
VOLTAGE ACROSS 1000 Ω RESISTOR	= ______	VOLTAGE ACROSS 1000 Ω RESISTOR	= ______

Figure 3K

( ) Connect the minus voltmeter lead to lug 2 of the ON-OFF switch and connect the positive voltmeter lead to lug 3 of the variable resistor. Turn the ON-OFF switch ON. Note the reading on the meter. This is the voltage across the 1000 Ω resistor, Mark it down in the correct blank below Schematic #1 of Figure 3K.

( ) Turn the ON-OFF switch to the OFF position and disconnect the meter leads from the lugs of the switch and variable resistor.

( ) Switch the EK-1 meter to read resistance again, connect one lead to lug 2 and the other lead to lug 3 of the variable resistor. Adjust the variable resistor so that the meter reads a resistance of 5000 Ω.

( ) Now switch the EK-1 meter to read current on the 5 milliampere range, and connect the leads as before; connect the negative lead to lug 1 and the positive lead to lug 2 of the ON-OFF switch.

( ) The circuit has now been adjusted so that your meter will read the current flowing in Schematic #2 of Figure 3K. Note the current reading on the meter and write it down in the proper blank below the schematic.

( ) Remove the meter leads from the ON-OFF switch and switch the meter to read voltage on the 10 volt scale. Turn the ON-OFF switch ON.

( ) Now connect the negative meter lead to lug 2 of the ON-OFF switch and connect the positive meter lead to lug 3 of the variable resistor. Note the voltage reading on the meter and insert it in the proper blank below Schematic #2 of Figure 3K.

( ) Turn the ON-OFF switch OFF and disconnect the meter leads.

EXPERIMENT 2

Showing that a transistor will control current in a series circuit by changing its resistance electrically.

Refer to Figure 3L for the following steps.

( ) Disconnect the 1000 Ω resistor lead from lug 3 of the variable resistor and connect it instead to lug 3 of terminal strip B (S).

( ) Disconnect the lead from lug 2 of the variable resistor and connect it instead to lug 6 of terminal strip B (S).

( ) Connect a 47 KΩ resistor from lug 6 of terminal strip A (NS) to lug 5 of terminal strip B (S).

( ) Connect a #6 solder lug to one end of a 6-1/2" hookup wire as shown in the inset drawing of Figure 3L (S). Squeeze the solder lug out flat with pliers before soldering the lead to it.

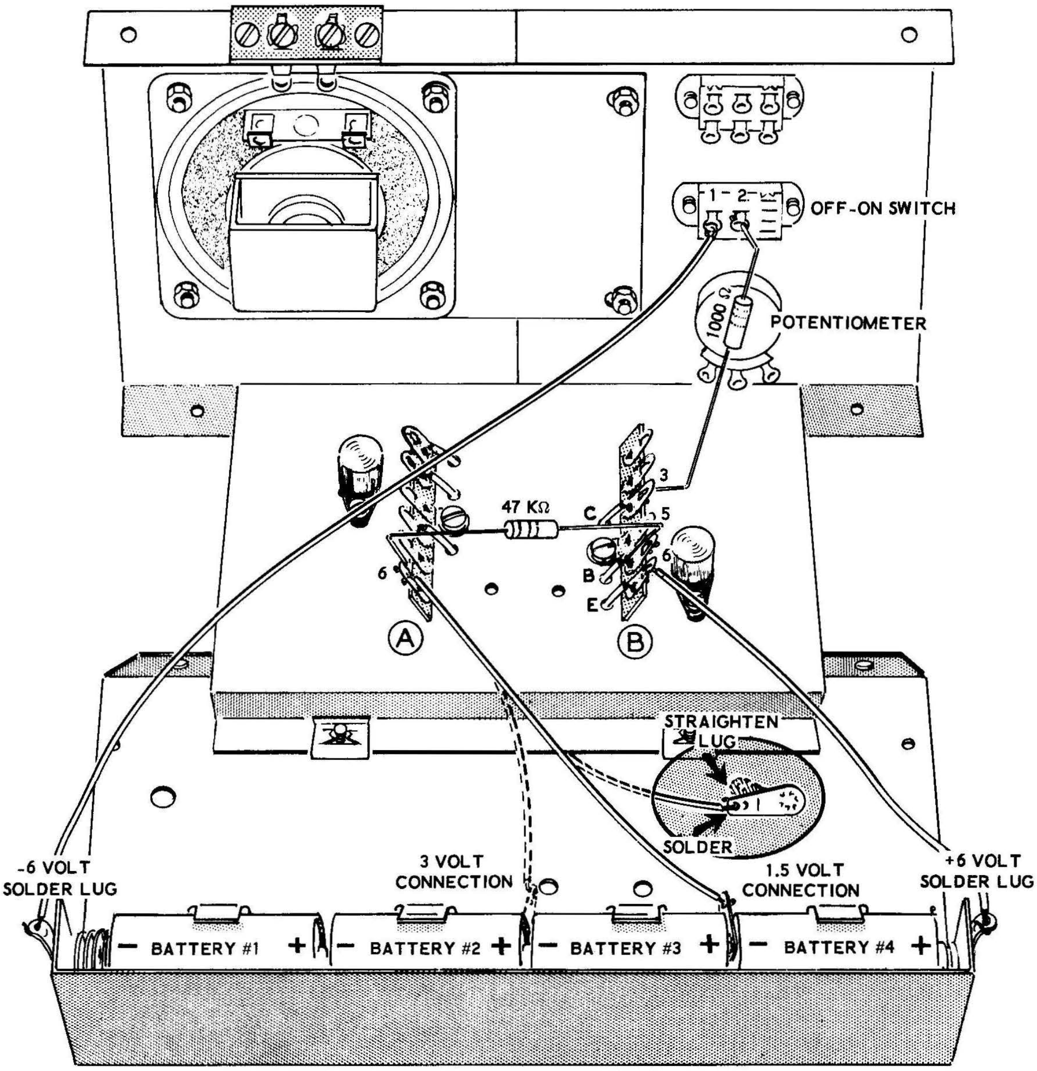

OFF-ON SWITCH
1
2
1000 Ω
POTENTIOMETER
3
47 KΩ
C
5
6
B
E
6
A
B
STRAIGHTEN LUG
SOLDER
-6 VOLT SOLDER LUG
3 VOLT CONNECTION
1.5 VOLT CONNECTION
+6 VOLT SOLDER LUG
— BATTERY #1 +
— BATTERY #2 +
— BATTERY #3 +
— BATTERY #4 +

Figure 3L

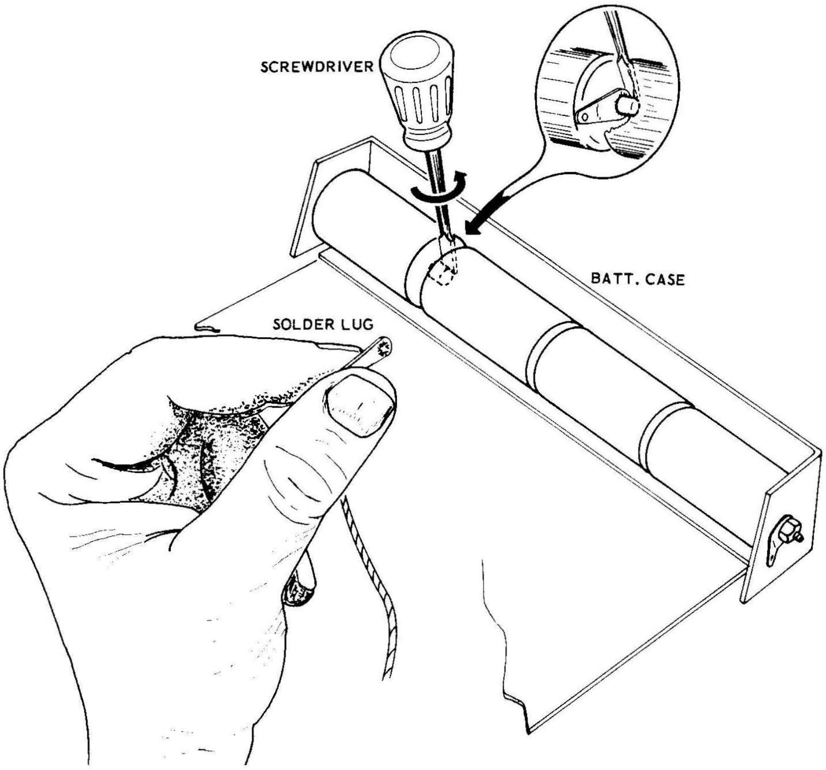


Figure 3M

( ) Connect the free end of this 5-1/2" wire to lug 6 of terminal strip A (S). Insert the #6 solder lug down between battery #3 and battery #4 in the manner indicated in Figure 3M. Be sure the solder lug is not touching any metal parts of the chassis.

NOTE: The experimental chassis is now wired with the circuit shown in schematic #1 of Figure 3L. To make the schematic diagram easier to follow, the battery which controls the current in the transistor is shown separately. Actually it is battery #4 that is used for this purpose, as well as its normal purpose of supplying power to the rest of the circuit (in series with the other three batteries). The 47 KΩ resistor is used only as a protective device (current limiter) in the circuit, and it should not be considered as an integral part of the experiment.

( ) Switch the meter so that it will read current on the 5 milliampere range. Connect the negative meter lead to lug 1 and the positive meter lead to lug 2 of the ON-OFF switch.

( ) The circuit of Schematic #1 is now completed since your meter bridges across the ON-OFF switch. Note the reading on the meter and mark it down in the blank for measured circuit current (I) on Schematic #1 of Figure 3L.

( ) Disconnect the meter leads and switch the meter to read voltage on the 10 volt range.

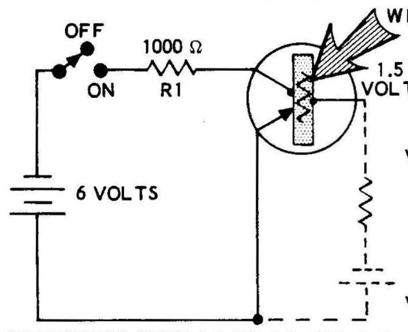
( ) Connect the negative lead of the meter to lug 2 of the ON-OFF switch and connect the positive lead of the meter to lug 3 of terminal strip B.

( ) Turn the ON-OFF switch to the ON position and note the reading on the meter. Mark this voltage reading down in the blank for the "measured voltage across R1," the 1000 Ω resistor at Schematic #1 on Figure 3L.

( ) Disconnect the meter leads, and turn the ON-OFF switch to the OFF position.

SCHEMATIC #1 OF FIGURE 3L

CALCULATING RESISTANCE OF THE TRANSISTOR ......
WITH 1.5 VOLTS APPLIED TO THE BASE.

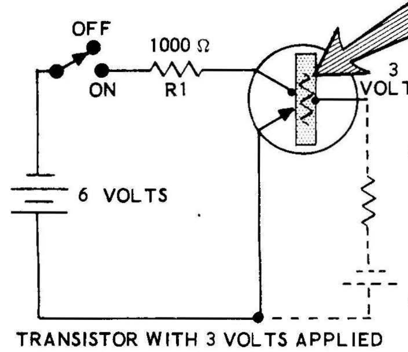


TRANSISTOR WITH 1.5 VOLTS APPLIED

I:	MEASURED CIRCUIT CURRENT	=	00066 A ______ MA
V1:	MEASURED VOLTAGE ACROSS R1	=	.5 V
	TOTAL VOLTAGE	=	6 VOLTS
	VOLTAGE ACROSS R1 (V1 - SAME AS ABOVE)	=	.5 V
V2:	VOLTAGE ACROSS TRANSISTOR = (6 VOLTS - V1)	=	5.2 V
	CALCULATED TRANSISTOR RESISTANCE = (V2) / I	=	______ OHMS 6,2[illegible]

SCHEMATIC #2 OF FIGURE 3L

CALCULATING THE RESISTANCE OF THE TRANSISTOR.....
WITH 3 VOLTS APPLIED TO THE BASE



TRANSISTOR WITH 3 VOLTS APPLIED

I:	MEASURED CIRCUIT CURRENT		______ MA
V1:	MEASURED VOLTAGE ACROSS R1	=	______ V
	TOTAL VOLTAGE	=	6 VOLTS
	VOLTAGE ACROSS R1 (V1 - SAME AS ABOVE)	=	______ V
V2:	VOLTAGE ACROSS TRANSISTOR = (6 VOLTS - V1)	=	______ V
	CALCULATED TRANSISTOR RESISTANCE = (V2) / I	=	______ OHMS

( ) Disconnect the 6-volt solder lug from between batteries #3 and #4 and insert it between batteries #2 and #3.

NOTE: The circuit of Schematic #2 is now connected on your experimental chassis.

( ) Switch the meter to read current on the 5 milliampere range. Connect the negative meter lead to lug 1 and the positive meter lead to lug 2 of the ON-OFF switch.

( ) Note the current indicated by the meter and mark it down in the blank for "measured Circuit Current" (I) at Schematic #2 of Figure 3L.

( ) Disconnect the leads from the ON-OFF switch and switch the meter to read voltage on the 10 volt range.

( ) Connect the negative lead of the meter to lug 2 of the ON-OFF switch and connect the positive lead of the meter to lug 3 of terminal strip B.

( ) Turn the ON-OFF switch ON and note the meter reading. Mark this voltage reading down in the blank for "measured voltage across R1" at Schematic #2 in Figure 3L.

( ) Turn the ON-OFF switch to the OFF position and disconnect the meter leads. Disconnect the solder lug from between batteries #2 and #3.

CALCULATING TRANSISTOR RESISTANCES

( ) Transistor resistance in Schematic #1. Determine V2, the voltage across the transistor, by subtracting the voltage across R1 from the total voltage, 6 volts.

( ) Now calculate the transistor resistance, using the total circuit current as the current through the transistor.

Transistor resistance,

$$R = \frac{E \text{ (voltage across transistor)}}{I \text{ (current through transistor)}} = \underline{\qquad\qquad}.$$

When you have calculated this resistance, mark it down in the correct blank at Schematic #1 of Figure 3L.

( ) Transistor resistance in Schematic #2. Determine the resistance of the transistor of Schematic #2 in the same manner. Subtract the voltage across R1 from the total voltage to determine the voltage across the transistor. Mark this voltage down for voltage V2.

( ) Now calculate the resistance of the transistor for Schematic #2.

Transistor resistance,

$$R = \frac{E \text{ (voltage across transistor)}}{I \text{ (current through transistor)}} = \underline{\qquad\qquad}.$$

( ) When this transistor resistance has been calculated, mark it in the proper blank at Schematic #2 of Figure 3L.

DISCUSSION

Experiment 1 (Figure 3K) showed how current can be controlled with a variable resistor. By changing the setting of the variable resistor, the current in the circuit changed and when the current changed, it changed the voltage across resistor R1. Experiment 2 (Figure 3L) showed that the same type of control can be accomplished using a transistor in place of the variable resistor. Notice that the voltage at R1 was changed by changing the voltage connected between the Base and the Emitter of the transistor. When this voltage at the Base of the transistor was changed, it changed the resistance of the transistor in the series circuit. When the resistance of the transistor changed, it changed the current flowing in the circuit just as the variable resistor did. The result of the current change was the same as the result obtained in Experiment 1, the voltage across R1 changed.

The last part of Experiment 2 showed you by your own calculations that the transistor acted like a resistor in the circuit. Notice the difference between the resistance of the transistor in Schematic #2 and the resistance of the transistor in Schematic #1. When the transistor acts like a large resistor, a small amount of current flows, and when the transistor acts like a small resistor, a large amount of current flows in the circuit.

LESSON III

QUESTIONS

1. What is a variable resistor?

2. Can the current in a series circuit be made adjustable by placing a variable resistor in the series circuit?

3. A transistor is made by placing (two types, three types) of semiconductor crystals together in the form of a sandwich.

4. What are the names of each of the three parts of a transistor?

5. In the schematic symbol for the NPN type transistor, the arrow for the Emitter points (toward, away from) the base of the transistor.

6. The resistance of a transistor can be changed by changing the voltage connected between the __________ and __________ of the transistor.

7. When you change the current flowing through a series circuit, the voltage across both resistors will change; will the total voltage change too?

LESSON IV

HOW TO CONTROL THE CURRENT FLOWING THROUGH A TRANSISTOR

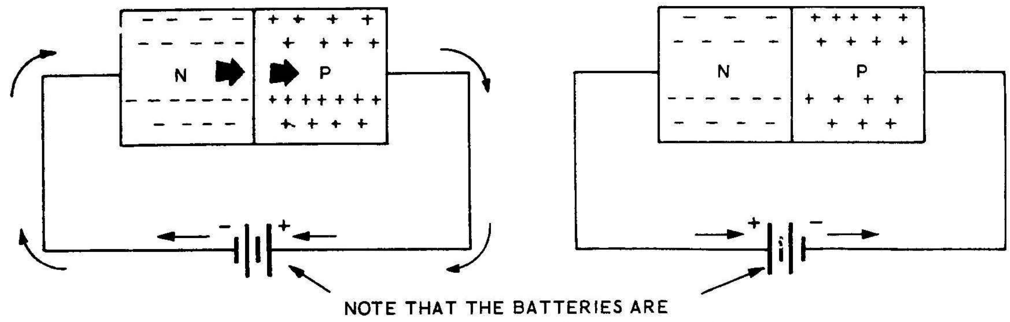


Figure 4A

Lesson III showed that a transistor acts like a variable resistor in a series circuit, a variable resistor whose size can be adjusted electrically. Lesson IV will show you how the resistance of a transistor is controlled: a small current flowing from the Emitter to the Base controls the amount of resistance in the transistor, and therefore determines whether a large or small current will flow through the transistor from Emitter to Collector.

In Lesson I you were first introduced to P type and N type semiconductor crystals. Remember that a diode was made by joining N type and P type crystals together, and that a diode may be connected to a battery in two ways. The area where the two crystals come together is referred to as a junction.

Useful amounts of current will only flow in one direction through a junction. When the battery is connected to the crystal in such a direction that current flows, the diode (or junction) is said to have "forward bias" applied to it. When the battery is connected so that practically no current flows, the diode (or junction) is said to have "reverse bias" connected to it. Semiconductor diodes that have forward bias and reverse bias applied to them are shown in Figure 4A.

Transistors usually contain two PN junctions. One of these junctions is between the Emitter crystal and the Base crystal, and the other is between the Base crystal and the Collector crystal. A NPN type transistor is shown in Figure 4B.

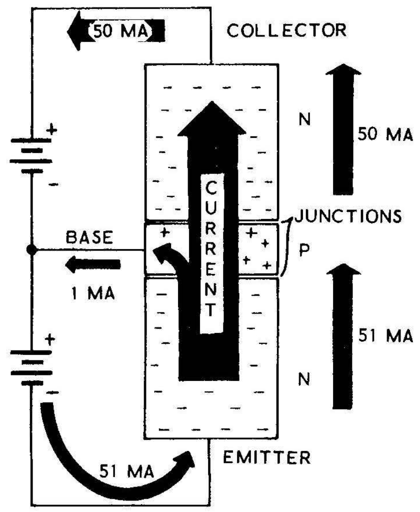


Figure 4B

To make the transistor operate properly, the batteries are connected so that the Emitter-to-Base junction has forward bias applied to it, and the Base-to-Collector junction has reverse bias applied to it. Because the Base crystal is actually constructed so that it is very thin (sometimes only about 1/1000 of an inch thick), most of the current leaves the Emitter, passes right through the thin Base region, and flows to the Collector. As a result, only a very small current flows from the Emitter to the Base, and a comparatively large current flows from the Emitter to the Collector. The currents shown in Figure 4B are representative of the relative sizes of currents in actual circuits. Notice that 50 milliamperes of current is flowing from the Emitter to the Collector and only 1 milliampere of current is flowing from the Emitter to the Base.

The small current that flows from the Emitter to the Base controls the large current that flows from the Emitter to the Collector. This smaller Emitter-to-Base current causes changes to take place in the PN junctions with the result that the transistor acts as if it were made up of the resistors shown in Figure 4C.

The junction between the Emitter and the Base acts like a small fixed resistor, and the junction between the Base and the Collector acts like a large variable resistor. This large variable resistor usually stays very large compared to the smaller resistor. This large variable resistance was the resistance you measured across the transistor in the Experiment section of Lesson 3.

Figure 4D and Figure 4E show how the Emitter-Base current affects the larger variable resistance that appears between the Base and Collector of the transistor. In Figure 4D a small voltage is connected between the Base and Emitter with the minus and plus terminals connected as shown. The small voltage causes a small amount of current to flow from the Emitter to the Base. This small Emitter-to-Base current causes the variable Base-to-Collector resistance to be quite large, and as a result, a smaller current flows through the transistor from the Emitter to the Collector.

In Figure 4E a larger voltage has been connected between the Base and Emitter of the transistor, causing a larger current to flow. The larger Emitter-to-Base current causes the variable Base-to-Collector resistance to become smaller, thus allowing a larger current to flow from the Emitter to the Collector in the transistor. Remember then, that a small Emitter-to-Base current results in a smaller Emitter-to-Collector current and that a larger Emitter-to-Base current causes a large current to flow from the Emitter to the Collector.

A small voltage, therefore, applied between the Base and Emitter of a transistor, will control the current flowing in a transistor almost as if it were opening and closing a gate for the current

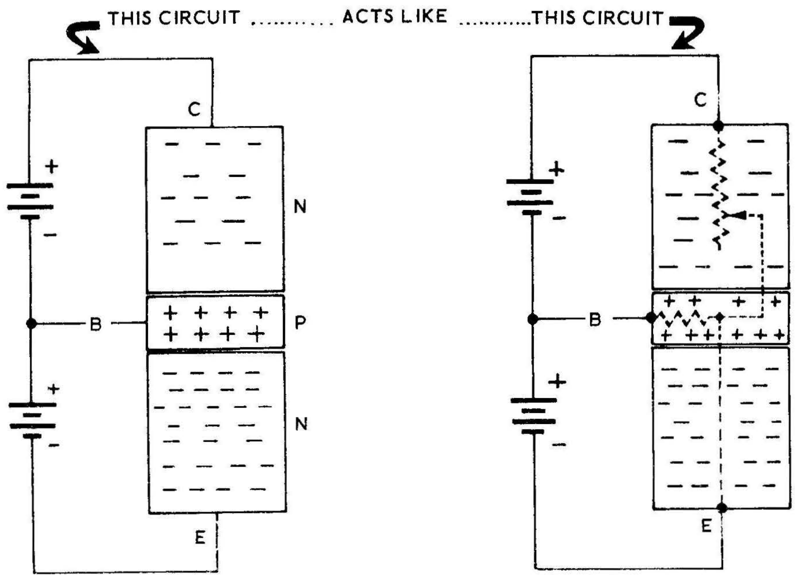


Figure 4C

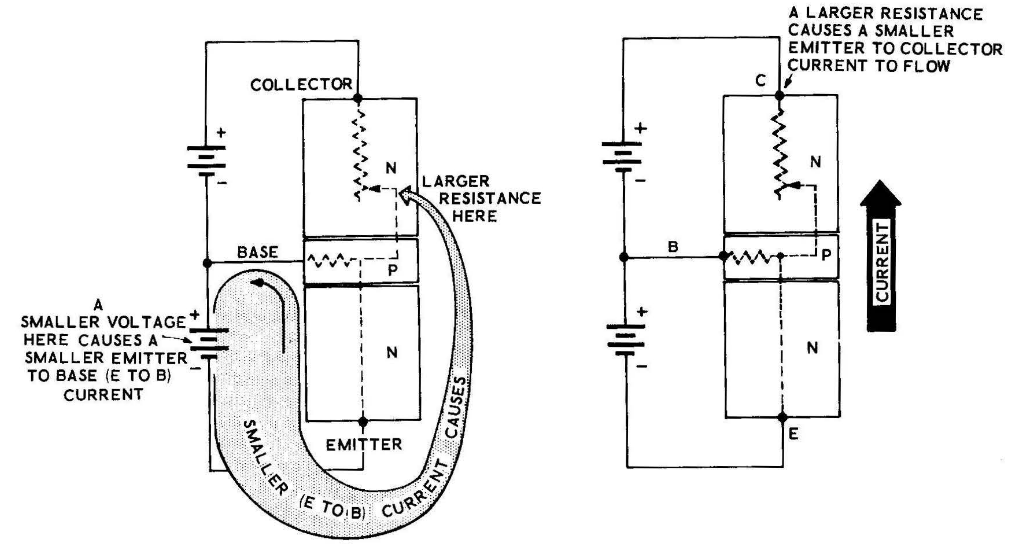


Figure 4D

to flow through. All practical transistor circuits work only because the current through the transistor can be carefully controlled in this manner. Lessons 5 through 10 will show you how these carefully controlled currents in the transistors are put to work in different types of electronic circuits.

PNP TRANSISTORS

There are two types of transistors, the NPN type and the PNP type. In the explanations of previous paragraphs NPN transistors have been used. In NPN transistors, the current emitted by the Emitter consists of a flow of electrons. These electrons are then collected by the Collector and sent back to the battery.

In the following paragraphs, as well as in the remaining lessons, all explanations will be made using PNP transistors, since transistors of this type, which are used more commonly, are supplied with this kit. PNP transistors work in exactly the same manner as the other type, ex-

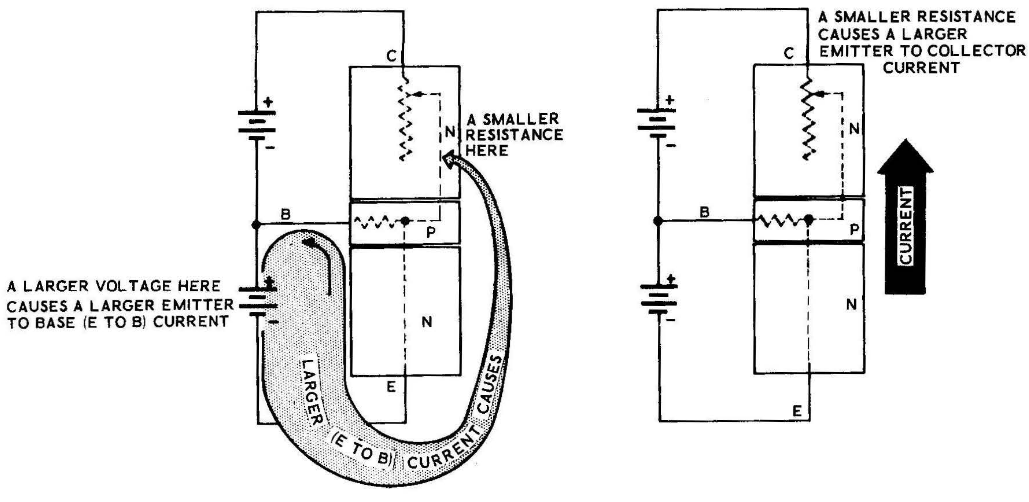
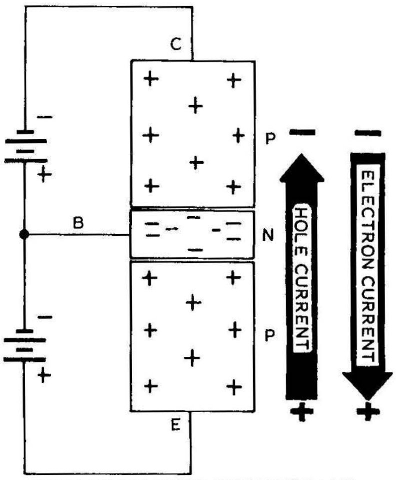


Figure 4E



HOLE CURRENT FLOWS FROM + TO -

Figure 4F

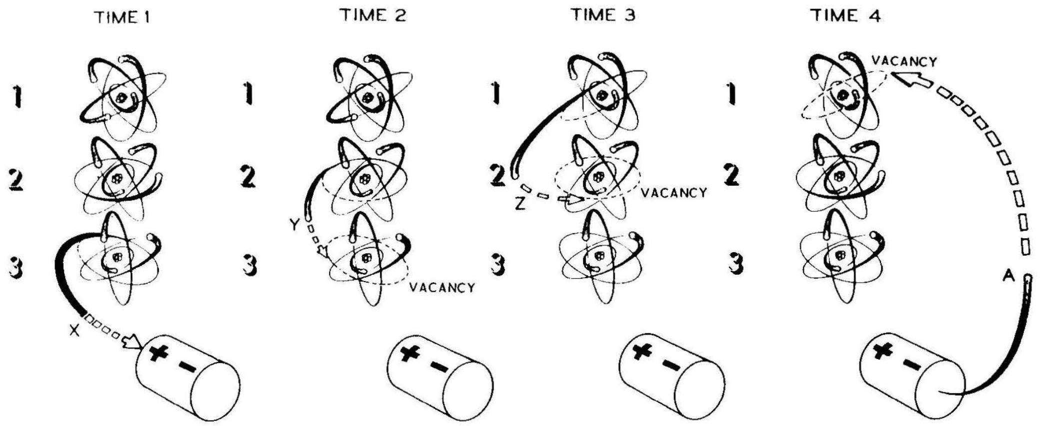
cept that the batteries are connected in the opposite direction. This means that all the electron streams will flow through PNP transistors in the opposite direction from the currents that were shown by the arrows in the circuits of the previous pages.

All the PNP circuits in the following pages could be explained by following the flow of electrons as you have done in previous lessons. They have not been explained this way because we believe it would be more confusing for you; as you follow the flow of electrons from the Collector to the Emitter, it would seem as if the current were flowing backwards in the transistor. In the type of explanation that will be used, the Emitter is still emitting the current into the transistor and the Collector still collects current as before. The following paragraphs will explain how and why this can be done.

HOLE CURRENT

Engineers and scientists explain the flow of current by either one of two theories; by the flow of electrons which flow from - to + in the circuit, or by the flow of holes (called "conventional current" or "hole current") which flow the other way, from + to -. These two types of current are shown in Figure 4F.

We will use this "hole current" to explain the PNP transistor circuits. The current emitted by the Emitter and collected by the Collector will be holes instead of electrons. The same + to - hole current will be used throughout all these circuits.



ELECTRON X LEAVES ATOM 3 TO GO TO THE POSITIVE TERMINAL OF THE BATTERY.

THIS LEAVES A VACANCY (OR "HOLE") IN ONE OF THE ORBITS OF ATOM 3.

ELECTRON Y LEAVES ITS ORBIT AROUND ATOM 2 AND FILLS THE VACANCY (OR HOLE) LEFT BY ELECTRON X.

THE VACANCY HAS NOW MOVED FROM ATOM 3 TO ATOM 2.

ELECTRON Z LEAVES ITS ORBIT AROUND ATOM 1 AND FILLS THE VACANCY (OR HOLE) LEFT BY ELECTRON Y.

THE VACANCY HAS NOW MOVED FROM ATOM 2 TO ATOM 1.

ELECTRON A LEAVES THE NEGATIVE TERMINAL OF THE BATTERY AND FILLS THE VACANCY LEFT BY ELECTRON Z IN ATOM 1.

Figure 4G

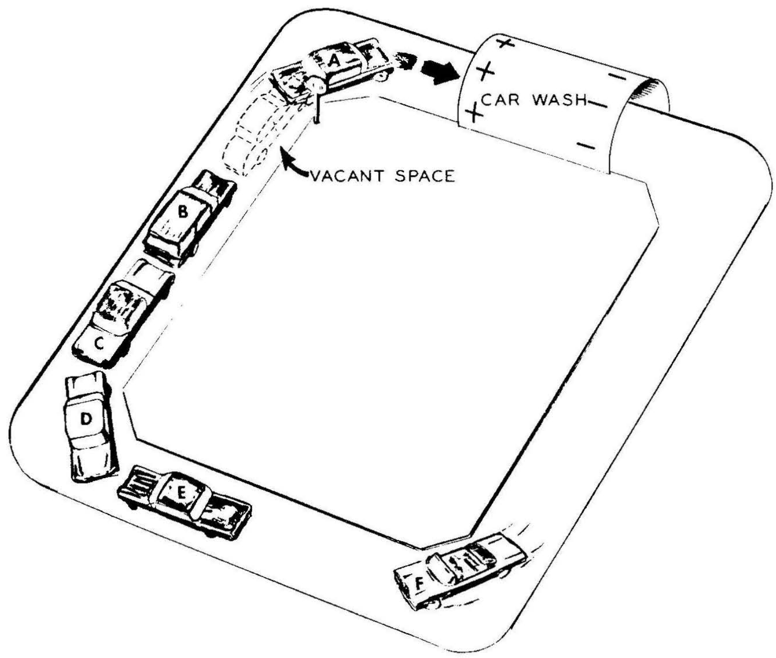


Figure 4H

If you wish to obtain a more advanced understanding of PNP circuits you can return to these lessons (Lessons IV through X) after you have finished Lesson X, and analize the circuits once again in terms of the electron currents flowing in them.

Hole current, which flows in the opposite direction from the flow of electrons, can be explained in the following manner. Figure 4G shows free electrons flowing from atom to atom through a conductor. When an electron flows from one atom to another, it leaves an empty space or "vacancy" in the outer shell of that atom that tries to attract another electron. To make this empty space easier to describe, it is generally called a "hole." As electrons move to the right, toward the positive voltage, the holes (left by the electrons) have the effect of moving in the opposite direction, toward the minus voltage.

How these holes, or vacant spaces, travel may be easier to see if you study Figure 4H. In Figure 4H, the car wash represents the battery, the cars represent electrons, and the vacant space between car A and car B represents a hole. Car A has just moved up toward the plus end of the car wash, leaving a hole (or vacant space) between it and car B. When car B moves up one position, the hole (vacant space) moves back to where car B is now shown. When car C moves up, the hole (vacant space) moves one more space back to where car C is now shown. Notice then, as the cars (electrons) move forward toward the plus (+) end of the car wash, the vacant space (or hole) gradually moves back and around the corner toward the negative (-) end of the car wash.

The flow of electrons and holes in a circuit works in the same manner. As the electrons move toward the plus voltage, the holes move toward the minus voltage.

NOTE: Since PNP transistors are used in the experiments of this kit, PNP transistors will also be used as examples for the theory sections of the lessons. For this reason, so they will be easier to understand, all of the transistor circuits will be explained in terms of hole current (sometimes called "conventional" current). Remember, hole current flows from plus (+) to minus (-), the opposite direction from electron current flow.

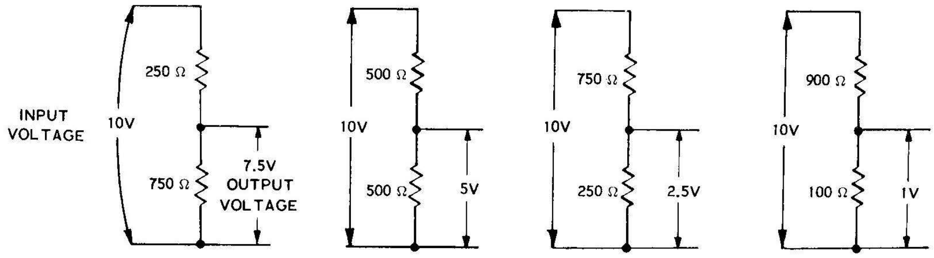


Figure 4J

POTENTIOMETER TYPE CONNECTIONS OF VARIABLE RESISTORS

A large voltage can be divided up into smaller voltages by placing resistors in series in the manner shown in Figure 4J. Since the source voltage divides across series resistors in proportion to their resistance values, the 10 volt source of Figure 4J will be divided between the two resistors according to their values. The total circuit resistance in all four voltage dividers is 1000 ohms. In the first divider, the 750 ohm resistor represents 3/4 of the total resistance, so 3/4 of the total voltage, 7.5 volts, is developed across it. In the second voltage divider the resistors are of equal values, so 1/2 of the total voltage, or 5 volts, is developed across each resistor. In the third divider the 250 ohm resistor represents 1/4 of the total resistance, so 1/4 of the total voltage, or 2.5 volts, is developed across it. In the last divider the 100 ohm resistor represents only 1/10 of the total resistance, so only 1 volt is developed across it.

Figure 4K shows how a variable resistor can be connected to act as an adjustable voltage divider. This type of use (the "potentiometer" connection) is one of the most common uses of a variable resistor.

The advantage of using a potentiometer voltage divider becomes quite obvious by observing Figure 4K. Not only can the same four voltages obtained from the dividers in Figure 4J be obtained, but now that the potentiometer has made the voltage divider completely variable, any voltage between zero and ten volts can be obtained by turning the shaft of the potentiometer. This potentiometer connection is often used as an easy method for obtaining a voltage whose size can easily be adjusted. A voltage divider of this type will be put to a practical use in the experiments of this lesson.

SUMMARY

A transistor contains three semiconductor crystals. A very thin wafer of one type of crystal is placed between two larger segments of the other type of crystal. Current flows into this transistor from the crystal at one end called the Emitter, passes through the thin center crystal called the Base, and is collected by a third crystal called the Collector. Only a small amount of the total current from the Emitter of the transistor flows from the Emitter to the Base, because the Base is so thin most of the current passes through it to the Collector.

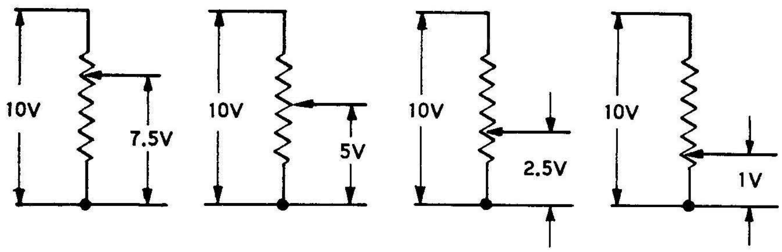


Figure 4K

The small current that flows from the Emitter to the Base of the transistor controls the large current that flows from Emitter to Collector. When the Emitter-to-Base current is smaller it acts as if it were closing a gate between the Emitter and Collector, which allows less current to flow through. When there is a larger Emitter-to-Base current it acts as if it were opening a gate between the Emitter and Collector, allowing a larger current to flow through.

In an NPN transistor a stream of electrons flows from the Emitter to the Collector. In a PNP transistor, a stream of holes (hole current) flows from the Emitter to the Collector. The hole current is actually the flow of vacant spaces that are created in the outer rings of the atoms when the electrons move away. Electrons always flow toward a positive voltage, holes always flow toward a negative voltage.

When a variable resistor is connected as a potentiometer, the voltage connected across the two outside terminals will be divided when an output is connected between the center terminal and either of the outside terminals. By adjusting the arm of the potentiometer the complete input voltage, or any fractional part of it, can be produced at the output connections.

HOW TO CONTROL THE CURRENT FLOWING THROUGH A TRANSISTOR

To show that the small Emitter-to-Base current controls the larger Emitter-to-Collector current. (To show that the resistance of a transistor is controlled electrically.)

PARTS REQUIRED

1 Experimental chassis, wired for Lesson 3.
1 22 KΩ resistor (red-red-orange)

EXPERIMENT 1

To show potentiometer action.

( ) Disconnect and remove the 1000 Ω resistor connected from lug 2 of the ON-OFF switch to lug 3 of terminal strip B.

( ) Disconnect and remove the 47 KΩ resistor connected from lug 6 of terminal strip A to lug 5 of terminal strip B.

( ) Disconnect and remove the wire from lug 6 of terminal strip A.

( ) Disconnect the wire connected to lug 6 of terminal strip B and connect it instead to lug 3 of the potentiometer (S).

( ) Connect a short length of hookup wire from lug 2 of the ON-OFF switch (S) to lug 1 of the potentiometer (S).

( ) Adjust your EK-1 Meter to read VOLTAGE on the 10 volt scale. Connect the minus lead of the voltmeter to lug 2 of the potentiometer, and connect the plus lead of the voltmeter to lug 3 of the potentiometer. The circuit is now connected to read the variable voltage at the output of the potentiometer as shown in the Schematic of Figure 4L.

( ) Turn the ON-OFF switch to the ON position.

( ) Turn the knob of the potentiometer to its full counterclockwise position. (Counterclockwise is the opposite direction from the way a clock's hands turn.) The voltage on your meter should now be zero.

( ) Turn the Volume control knob gradually in a clockwise position while watching the voltmeter. Notice that the voltage gradually increases from zero until it is at the full voltage, 6 volts, at the full clockwise position. This illustrates the potentiometer connection of the variable resistor.

( ) Turn the ON-OFF switch to the OFF position and disconnect the meter leads.

A very common example of this type of use of a variable resistor is in the Volume control of a radio; in the radio circuit the size of the electrical sound signal that will eventually reach the speaker is increased or decreased in this manner.

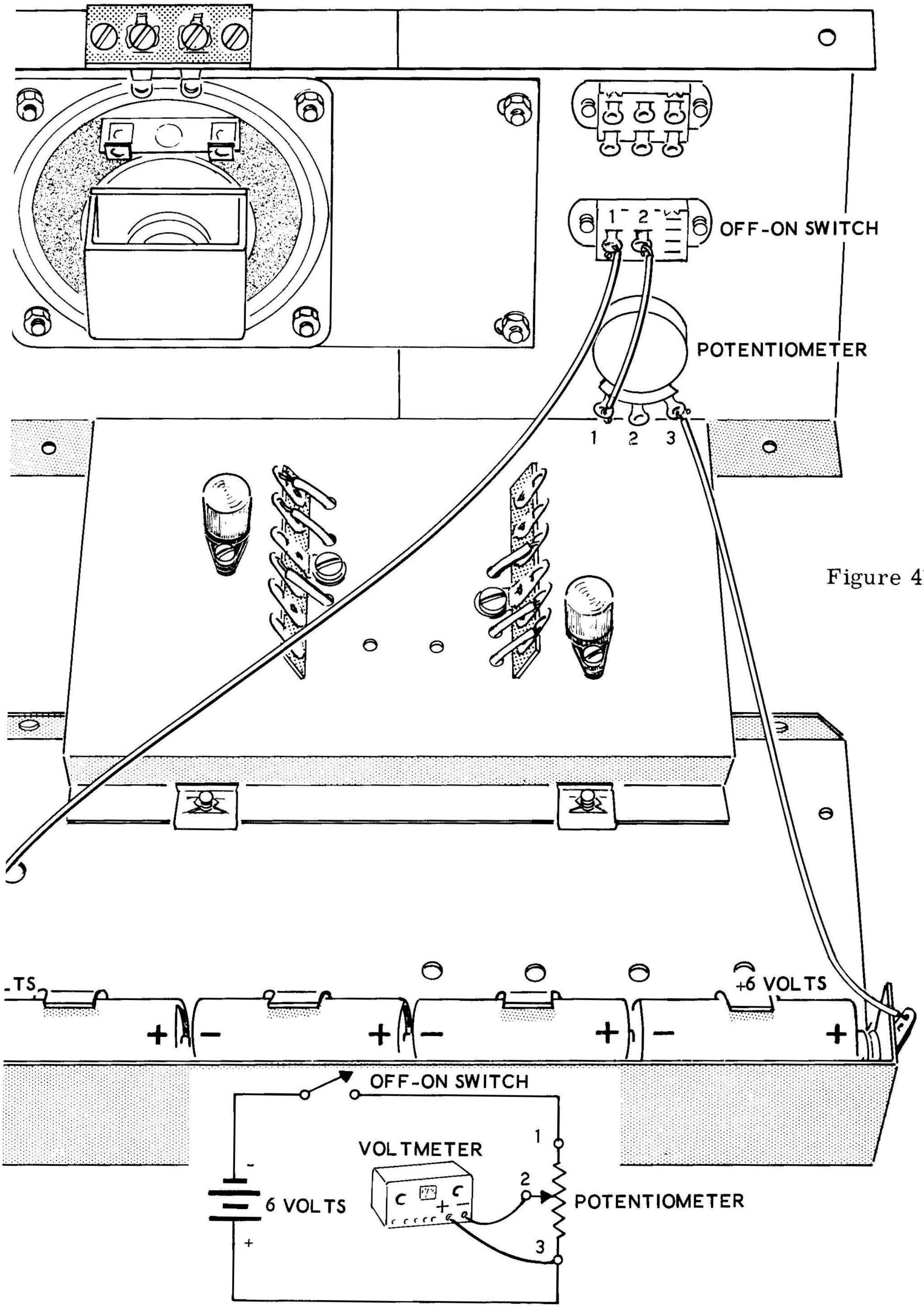
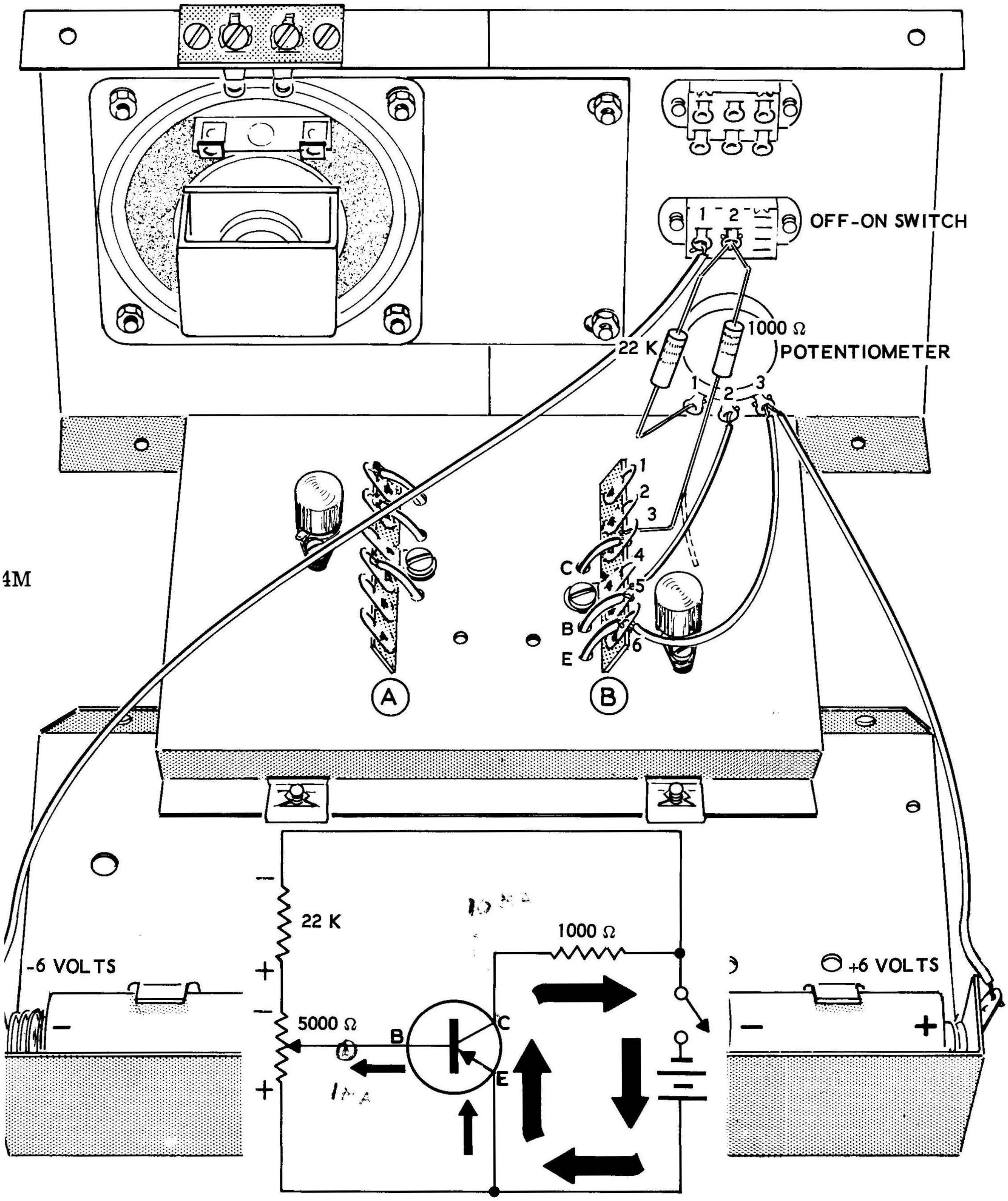

OFF-ON SWITCH
POTENTIOMETER
1
2
3
-TS
+6 VOLTS
OFF-ON SWITCH
VOLTMETER
6 VOLTS
POTENTIOMETER

Figure 4L



EMITTER-BASE → = .06 ma 30X

EMITTER-COLLECTOR CURRENT → = 3

EXPERIMENT 2

To show the smaller current controlling the larger current in a transistor.

Refer to Figure 4M for the following steps.

( ) Connect a length of hookup wire from lug 3 of the potentiometer (S) to lug 6 of terminal strip B (S).

( ) Connect a length of hookup wire from lug 2 of the potentiometer (S) to lug 5 of terminal strip B (S).

( ) Disconnect the short wire going from lug 2 of the ON-OFF switch to lug 1 of the potentiometer.

( ) Connect the 22 KΩ resistor from lug 2 of the ON-OFF switch (NS) to lug 1 of the potentiometer (S).

( ) Connect one end of a 1000 Ω resistor to lug 2 of the ON-OFF switch (S). Leave the other end free temporarily.

The circuit shown in the Schematic of Figure 4M is now connected on your experimental chassis.

( ) Switch your meter to read current on the 10 milliampere range. Connect the negative lead of the meter to the free lead of the 1 KΩ resistor. Connect the positive lead of the meter to lug 3 of terminal strip B.

( ) Your meter is now connected so it will read current flowing from the emitter to the collector (measured between the Collector and the 1000 Ω resistor) on the Schematic of Figure 4M.

( ) Place the ON-OFF switch in the ON position. Turn the knob of the potentiometer so that approximately 3 ma of current is indicated on the meter.

( ) Mark the current indicated on your meter down in the correct blank below the Schematic.

( ) Turn the ON-OFF switch to the OFF position, but do not move the setting of the potentiometer.

( ) Disconnect the meter leads from the resistor and terminal strip. Connect the free lead of the 1000 Ω resistor to lug 3 of terminal strip B (S).

( ) Disconnect the end of the wire connected to lug 5 of terminal strip B. Switch your meter to the 1 milliampere range. Connect the minus lead of the meter to the free end of the wire just disconnected. Connect the plus lead of the meter to lug 5 of terminal strip B. Turn the ON-OFF switch to the ON position.

Your meter is now indicating the amount of current flowing from the Emitter to the Base in the circuit. You may find that this current is rather difficult to read on your meter. If this is the case, notice that it indicates not only below the point that indicates 2/10ths of a milliampere (.2 ma) but it also reads below the point that indicates 1/10th of a milliampere (.1 ma). Each scale indication at the low end of the meter indicates .02 milliamperes, which can also be stated as 20 microamperes.

( ) Read the amount of current indicated on the meter and mark it down in the correct blank below the Schematic.

( ) Turn the ON-OFF switch to the OFF position. Disconnect your meter leads. Connect the end of the wire previously removed back to lug 5 of terminal strip B.

DISCUSSION

Experiment 1 gave you a demonstration of the potentiometer connection of the variable resistor. You will find this a very common method for dividing voltages in later experiments and later circuits.

Experiment 2 gave a demonstration of how the current through a transistor is controlled. Your measurements should have shown you that the current flowing from the Emitter to the Collector was about 100 times as large as the current flowing from the Emitter to the Base of the transistor.

The circuit of Figure 4M probably looks different to you than the circuits you studied previously. This is because the same battery is now shown supplying voltage to both the Emitter-Collector circuit and to the Emitter-Base circuit. Voltage is supplied to the Emitter-Base circuit through a voltage divider which consists of the 22 K ohm resistor and the 5000 ohm variable resistor.

The arm, or center terminal, of the 5000 ohm variable resistor supplies the negative voltage to the base, and the lead at the bottom of the variable resistor is connected to the positive voltage of the battery. These voltages were supplied by separate batteries in previous circuits. The 1 Kohm resistor in series with the Collector lead of the transistor is used to limit the current in the transistor to a safe value.

LESSON IV

QUESTIONS

1. If a battery is connected so that it applies reverse bias to a diode, will current flow through the diode?

2. When the transistor is operating properly, both of its junctions are connected so that they have forward bias applied to them. (True, False)

3. The base crystal of a transistor is (very thick, very thin).

4. The small current that flows from the Emitter to the Base controls the large current that flows from the Emitter to the Collector. (True, False)

5. A change in the small current flowing from the Emitter to Base causes the resistance from the Emitter to the Collector to be changed. (True, False)

6. Which terminal of the battery, (the negative or the positive) terminal, is connected to the collector of an NPN type transistor.

7. Which terminal of the battery, (the negative or the positive) terminal, is connected to the collector of a PNP type transistor.

8. In the hole current theory, a "hole" is the vacant space left when a free electron moves on to another atom. (True, False)

9. Which battery terminal do the holes flow toward?

10. What is a potentiometer?

LESSON V

HOW DOES A TRANSISTOR AMPLIFIER WORK?

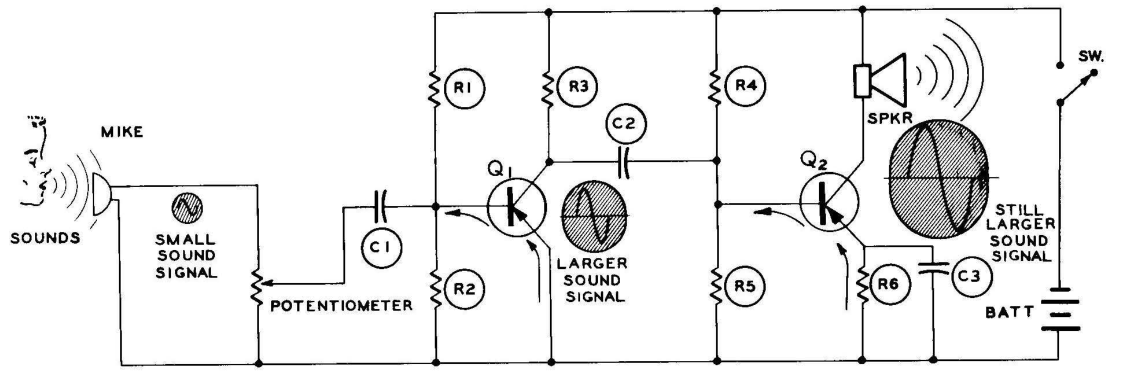


Figure 5A

In the previous lessons you became familiar with how these DC currents flow in different materials, how they are controlled and calculated, and how a small current in a transistor can be used to control a larger current.

To understand an amplifier, you must first understand sound (or "audio") signals. These sound signals, which are sounds put in electrical form, use a different form of current called AC, (Alternating Current). The purpose of this lesson is to explain the nature of these sound signals and how they are amplified (made larger) in a transistor amplifier.

AC CURRENT AND SOUND SIGNALS

Up until now you have only been studying direct current, or DC. The term DC means that the electrons flow in only one direction in the circuit. This is the type of current produced by a battery.

To create a DC current flow, a voltage is created between the two ends, or electrodes, of the battery by chemical action. When the two electrodes are connected together, the voltage causes electrons to flow out of the negative electrode and around the circuit to the positive (or button) electrode. If a circuit element such as a flashlight bulb is included in the circuit, the bulb will light because the flow of electrons is passing through it. This is illustrated in Figure 5B.

The other form of current, called AC current, is generally used by power companies to supply power to homes and factories. AC current also occurs when sounds are put into their electrical form, which are called AC signals."

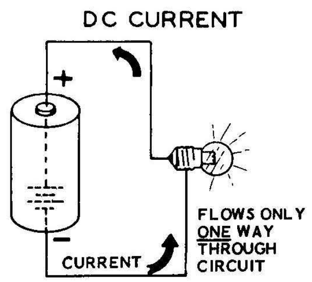


Figure 5B

AC current flows first in one direction, then in the other direction. It is almost as if the battery connections of Figure 5B were quickly reversed back and forth in alternate directions, causing the current to flow first one way and then the other way. This is shown in Figure 5C. First the voltage of the battery pushes the current up through the bulb and then the battery is reversed and the voltage pushes the current down through the bulb. When AC current flows, the voltage and current reverse in this manner at a regular rate.

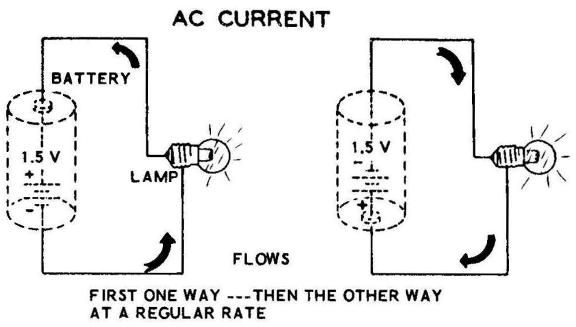


Figure 5C

Figure 5D shows what AC and DC voltage would look like if you plotted each of them on a graph for 1 second. The amount of voltage is shown vertically (-4 volts to 0 to +4 volts), and the time (how long this voltage is turned on) is shown horizontally (0 to 1 second).

The voltage that would be measured across a resistor if DC were applied is shown in part one of Figure 5D. Four volts is connected and the voltage stays at the same amount (4 volts) for the full second.

Part two of Figure 5D shows what the graph of the voltage would look like if the battery were connected first in one direction and then in the other. For the first one-half second +4 volts is measured across the resistor and for the second one-half second -4 volts is measured across the resistor. When +4 volts is measured, the current is flowing in one direction and when -4 volts is measured, the current is flowing in the other direction.

Positive (+) voltage is usually indicated above the zero line and negative (-) voltage is usually indicated below the zero line on any kind of a graph or picture of a waveform. To measure negative voltage, the leads of the voltmeter would have to be connected the other way across the resistor, otherwise the current would try to flow through the meter backwards, which could harm the meter.

The square wave of voltage shown in part two of Figure 5D was created by reversing the batteries. This crude example is used to explain in the simplest possible manner the effect of AC voltage in a circuit. This is not what the usual AC voltage (or current) waveform looks like.

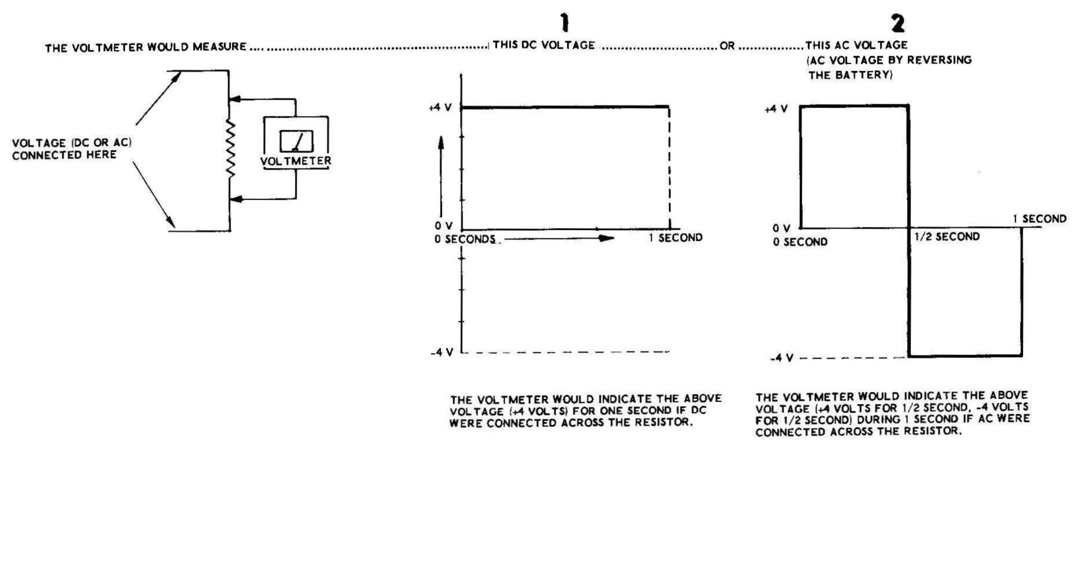


Figure 5D

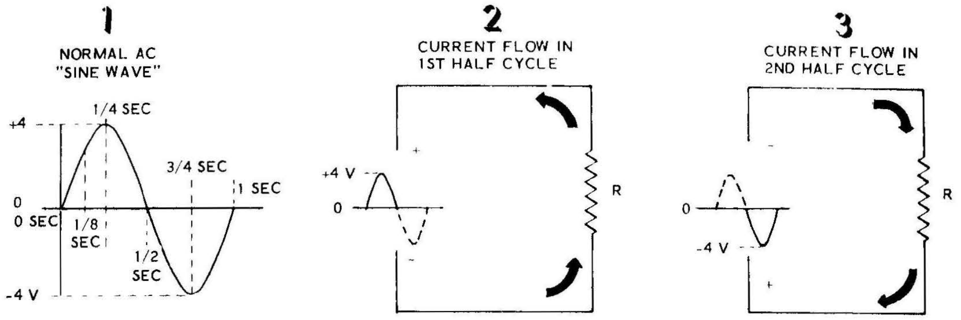


Figure 5E

Part one of Figure 5E shows what a normal pure AC waveform would actually look like. The name for this waveform is a "sine wave." Note that instead of going straight up to the +4 volts (or whatever the actual voltage is) the voltage increases gradually to 4 volts, decreases gradually through zero, goes to -4 volts, and then goes back toward zero again. Here the whole cycle starts over again. At the start of the waveform, the voltage is zero, at one-eighth of a second the voltage has increased to almost +3 volts, at one-quarter of a second the voltage is 4 volts, at one-half second the voltage has decreased to zero again. At three-quarters of a second the voltage has now become -4 volts and at the end of one second the voltage is zero once again.

Since this voltage pushes current through the circuit, the current will increase and decrease through zero in the same sine wave manner. Parts two and three of Figure 5E show how the current flows through a resistor for each half-cycle of the sine wave. Remember that the current always flows from the negative terminal to the positive terminal in a circuit. During the first half-cycle, the current flows up through the resistor and in the second half-cycle, when the voltage has been reversed, current is pushed down through the resistor.

An AC voltage that has completed one positive swing and one negative swing, and has returned to zero is called one cycle. Any number of these cycles, or voltage swings, may occur during one second. The term "frequency" refers to how many times (or how frequently) the waveform is repeated during any one second. The frequency of an AC waveform may be anywhere from one cycle up to millions of cycles during one second. A common example of the frequency of a waveform is the AC power coming to your home from the power company; this has a frequency of exactly 60 cycles for each second.

Figure 5F shows some sine waves of different frequencies. Part one is a graphic presentation of one cycle per second of AC. Part two shows what a graph of 60 cycles in one second would look like. As you can see it would be impossible to accurately graph so many cycles taking place in one second, but none-the-less each one of these cycles has a complete positive and negative alternation. Part three of Figure 5F shows that one cycle of this 60 cycle sine wave (or a sine wave of any other frequency) still looks exactly the same, only the length of the cycle on the graph has been changed. Instead of taking one second to occur (one cycle per second), the cycle now takes only one sixtieth (1/60) of a second to occur (60 cycles per second).

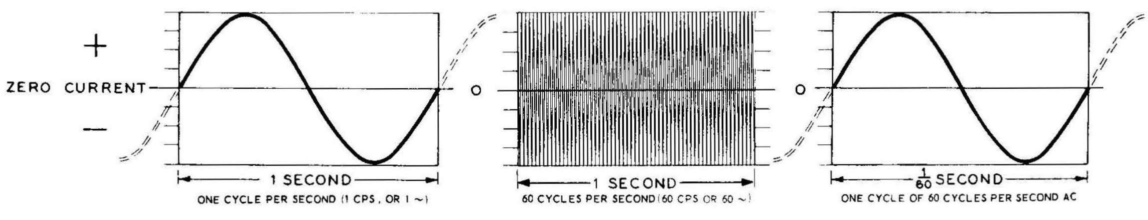


Figure 5F

To make them easier to refer to, the terms "Kilocycles" (kc) and "Megacycles" (mc) are commonly used to describe the higher frequencies. The term Kilocycle, or kc, means that the number shown must be multipled by 1000 cycles. The term Megacycle, or mc, means that the number shown must be multipled by 1,000,000 cycles.

Examples:

22 kc = 22 x 1000 cycles = 22,000 cycles/second

37 mc = 37 x 1,000,000 cycles = 37,000,000 cycles/second

SOUND SIGNALS

A sound signal, also called an "audio" signal is an AC waveform in which sounds are contained in an electrical form. An audio signal, therefore, will make sounds when connected to a speaker or earphone. A graph of a pure audio signal would show that it is a pure sine wave. All sounds consist of either a pure sine wave, or a number of sine waves of different frequencies and size that are combined together to give a very irregular AC waveform.

The two main parts of an audio signal are, the loudness of the signal and the tone (or pitch or frequency) of the sound. The tone of a sound refers to whether it consists of high notes or low notes.

Figure 5G shows how loudness is contained in an audio signal. The large the electrical signal is (the greater the number of volts of AC), the louder the sound will be when it is heard in the speaker.

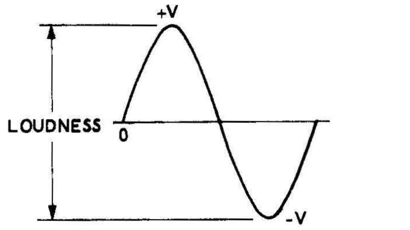


Figure 5G

The tone of a sound is determined by the frequency of the audio signal. The frequency, or number of cycles per second, determines whether you hear the sound as a high note or as a low note. The average human ear hears sound from about 20 cycles per second to approximately 15,000 cycles per second. Each sound has its own frequency or group of frequencies. Examples of the frequencies of various sounds are shown in Figure 5H.

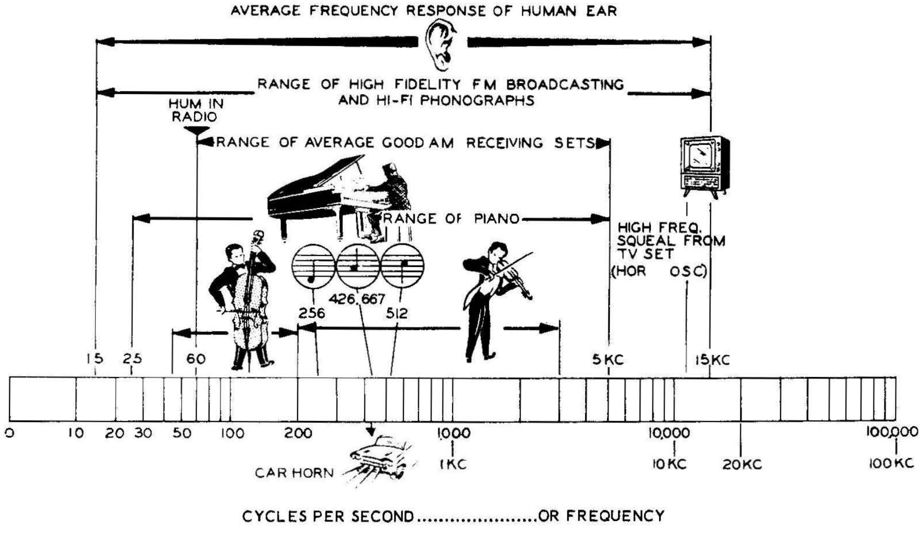
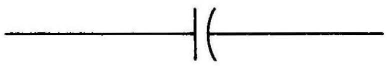


Figure 5H

HOW CAPACITORS AND SPEAKERS REACT TO AC CURRENT

A CAPACITOR, as explained in detail in the Basic Radio Course, is a circuit element through which AC currents can pass but DC currents cannot pass. The schematic symbol for the capacitor is shown in Figure 5J.



SCHEMATIC SYMBOL FOR FIXED CAPACITOR

Figure 5J

The electrical size of a capacitor is measured in quantities called "farads." In actual practice, a capacitor one farad in size would be far too large to be practical (a tubular capacitor one farad in size would be about the size of a large living room). As a result, practical capacitor values generally fall in the microfarad range (μfd or mfd). One microfarad is equal to one one-millionth (1/1,000,000) of a farad.

Sometimes, even microfarads are too large for certain applications, so an even smaller quantity called micromicrofarads (μμf, or mmf) are used. One micromicrofarad (1 μμf) is equal to one one-millionth of a microfarad (μfd). Micromicrofarads are also sometimes called picofarads (pF).

In general, a capacitor with a large number of microfarads (10 μfd - 100 μfd) is needed to pass low frequency sound signals. Capacitors with a small number of μfds (.001 μfd or 1 μμf-500 μμf) are used to pass high frequency signals such as those used for radio or television signals.

The SPEAKER (see Figure 5K) is a device which converts electrical signals into sounds. The main elements of the speaker are a permanent magnet, a coil of wire called a voice coil (which acts like an electric magnet), and a paper cone which vibrates the air in front of the speaker. The cone and voice coil are connected together.

When the current passes through the coil (or through any coil) it creates magnetism around the coil. The area near the coil where this magnetism is strong is called the magnetic field of the coil. The amount of magnetism around the coil depends on the amount of current through the coil, a larger current creates a larger amount of magnetism and a smaller current creates a smaller amount of magnetism.

As shown by the dotted lines in Figure 5K the magnetism of the coil pushes against the magnetism of the permanent magnet. As the current in the coil changes, it moves the coil and paper cone back and forth. When the paper cone moves back and forth it pushes the air in front of the cone back and forth, and these air movements are carried to your ears and heard as sounds.

The complete operation of the speaker is as follows: The signal current increases and decreases the amount of magnetism around the voice coil. The increasing and decreasing magnetism around the voice coil pushes the cone back and forth, causing the air in front of the cone to move back and forth. The movements of air are heard as sounds when they reach your eardrums.

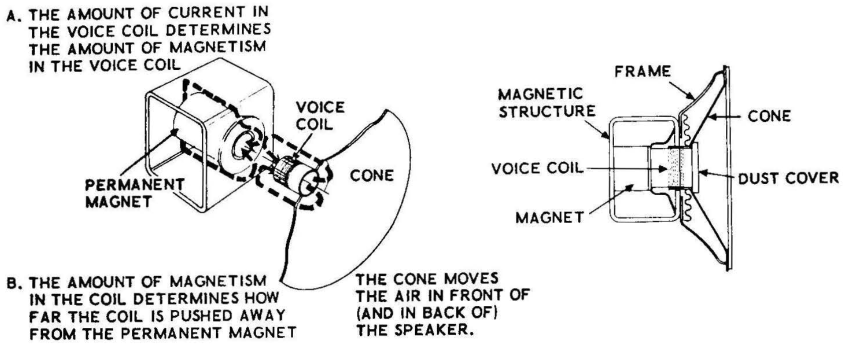


Figure 5K

A SIMPLE ONE-TRANSISTOR AMPLIFIER

One of the most common ways of changing sounds into electrical signals is by using a microphone. How a simple crystal microphone operates can be learned by looking at Figure 5L.

Certain kinds of crystals, when cut to the proper size, will vibrate when sounds are applied to them. These vibrations create an electrical (audio) signal between one side of the crystal and the other, that very closely follows the amplitude and frequency of the sounds spoken into the microphone.

In a typical microphone, such as the one shown in Figure 5L, a thin metal diaphragm is connected to the center of a piece of crystal. The crystal and the diaphragm are mounted in a small metal case, and the wires connected to the crystal carry the electrical signal from the crystal out of the microphone. When the sound waves vibrate the diaphragm and the crystal, an audio signal is generated.

Amplifiers are necessary because the signal from a microphone (or any other source of electrical signals, such as a phonograph arm) is far too small and weak to be able to make a speaker operate. The amplifier takes the small signal from the microphone, or phonograph, and amplifies it until it is large enough (more powerful) to operate a speaker.

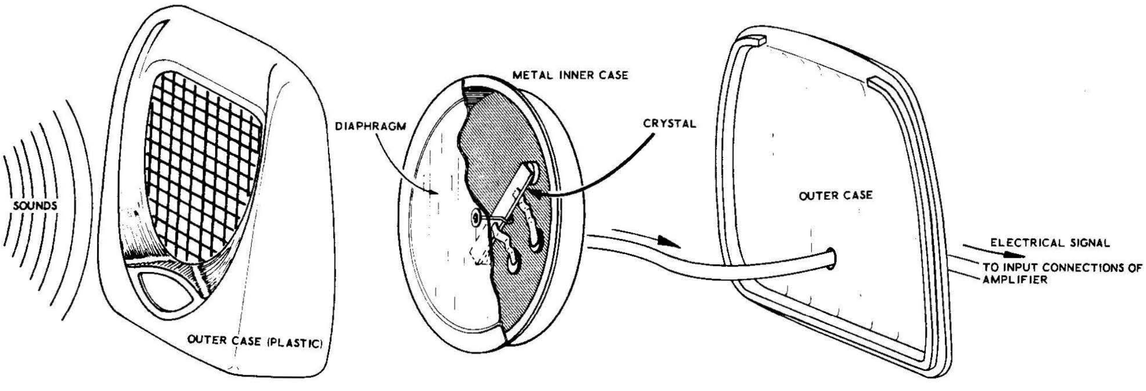


Figure 5L

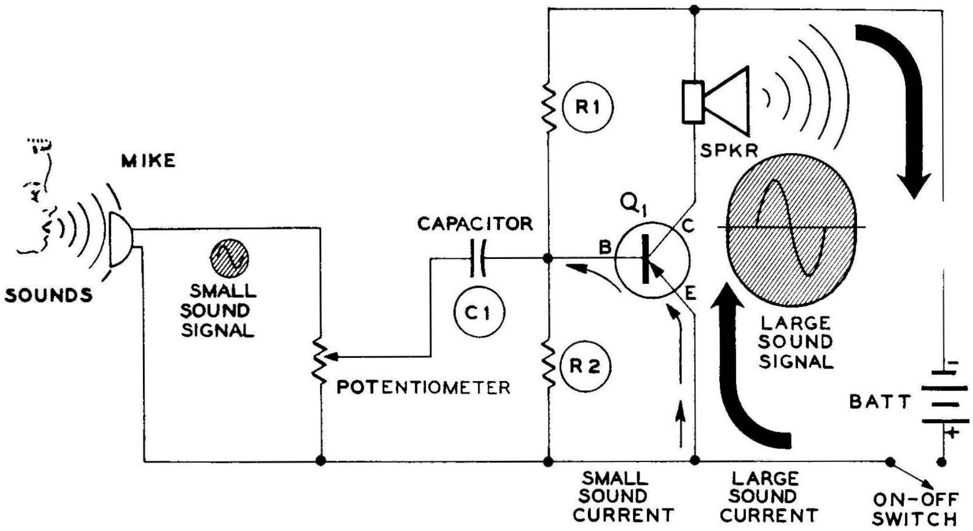


Figure 5M

Figure 5M shows a complete one-transistor amplifier. The audio signal from the crystal microphone is connected across a potentiometer. The potentiometer selects a larger or smaller amount of this signal (depending on whether you wish the sounds to be louder or quieter) and connects it through the capacitor to the Base of the transistor. The capacitor is placed in the circuit so that the AC sound signal will travel from the potentiometer to the transistor, but the DC voltages at the Base of the transistor will be blocked, so it will not effect the potentiometer or the microphone.

As shown in Figure 5N, resistors R1 and R2 form a voltage divider. This voltage divider causes a DC voltage to appear across resistor R2 that takes the place of the battery that was shown connected between the Emitter and Base in previous circuits. The main advantage of using resistor voltage dividers instead of batteries, are that they are smaller in size, and also that only one battery is needed for the whole amplifier.

The signal current from the potentiometer is connected across resistor R2 by means of the capacitor, this causes the audio signal currents to flow through resistor R2. These small signal currents also flow from the Emitter to the Base of the transistor just as the small DC currents did in previous lessons.

The small signal current flowing from Emitter to the Base controls the large current flowing from the Emitter to the Collector; as a result the large current, since it is controlled by the smaller current, looks exactly like the small signal current. The larger signal current from the collector then goes through the speaker where it is changed back into sound again.

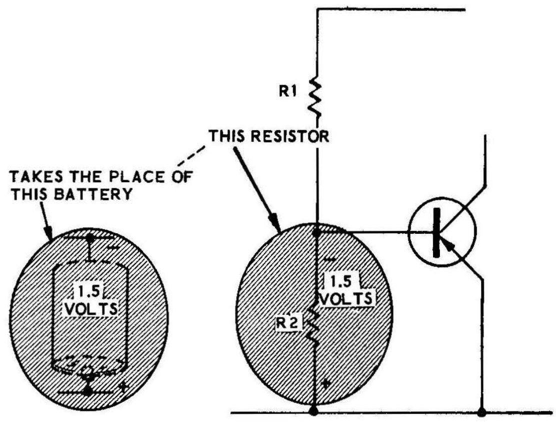


Figure 5N

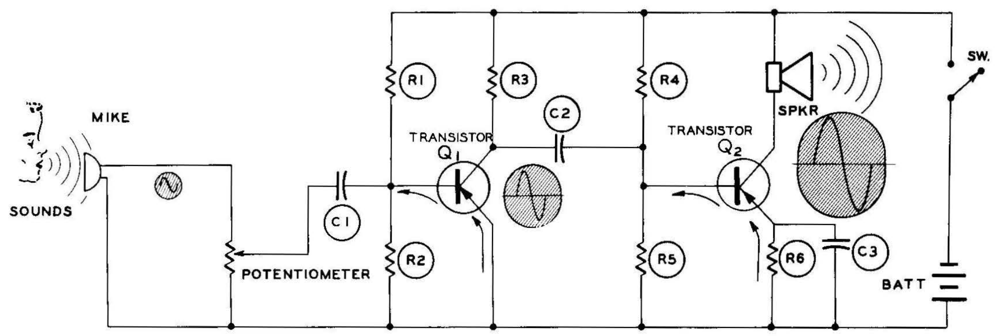


Figure 5P

A TWO-TRANSISTOR AMPLIFIER

Figure 5P shows a two-transistor amplifier. Actually, a one-transistor amplifier such as the amplifier of Figure 5M usually is not able, by itself, to create a large enough signal to drive a speaker properly.

In the two-transistor amplifier the sound signal is sent from the crystal microphone to the potentiometer, and from the potentiometer through capacitor C1 to resistor R2. The signal voltage across resistor R2 controls the Emitter-to-Base current of transistor Q1. Just as before, the smaller Emitter-to-Base (signal), current controls the larger Emitter-to-Collector (signal) current.

The amplified signal current from the Collector of transistor Q1, instead of flowing through the speaker as before, flows through load resistor R3. Since the signal current through R3 is changing just like the input signal from the microphone, it creates a voltage across R3 (by Ohm's Law) that follows all the changes of the input audio signal.

The enlarged audio signal appearing across R3 then passes through capacitor C2 and is applied to the Base of transistor Q2. Capacitor C2 operates just as it did before; it keeps the DC voltages of the two transistors from being mixed together but it allows the AC signal voltages to pass from one transistor circuit to the other.

Now, at transistor Q2, the full cycle repeats itself once again. The audio signal increases and decreases the currents flowing through resistor R5 and from the Emitter to the Base of transistor Q2. This controls the larger current that flows from the Emitter to the Collector of transistor Q2, and the audio signal is enlarged a second time, just as it was in transistor Q1. The signal from the Collector of transistor Q2 is connected to the speaker, and the original signal from the microphone is changed back into a sound signal again, but greatly amplified in size. An amplifier such as this could be used for a public address amplifier.

The purpose of resistor R6 is to provide the correct DC operating voltage at the Emitter of transistor Q2. The purpose of these operating voltages will be explained in greater detail in Lesson VI. The purpose of capacitor C3 is to pass the AC signals around resistor R6 so they will not disturb the steady DC voltage that is appearing across it.

SUMMARY

DC current flows through a circuit in only one direction at all times. AC current flows through a circuit first in one direction and then in the other, alternating back and forth at a regular rate.

One complete positive and negative excursion of AC voltage is called a cycle. One cycle, if it could be seen, would be increasing from 0 to a positive voltage, then back through 0 to a negative voltage, and then back to 0 again. The waveform thus created is called a sine wave. During the positive part of a sine wave cycle, current flows one way in a circuit, and during the negative part of the cycle, the current flows the other way.

An "audio" signal is sound in electrical form. The larger the audio signal is, (the greater the number of volts) the louder the signal will sound in a speaker. The "frequency" of the signal means how many times the sine wave repeats itself during one second. Frequency is usually expressed in cycles per second, or just plain "cycles." A low note, or low tones, are a fewer number of cycles per second, and higher notes, or higher tones, are caused by a greater number of cycles per second.

A "capacitor" is used in a circuit to pass AC currents but to block DC currents from passing through it. A speaker converts electrical signals into sounds.

In a one-transistor amplifier the sound signal from a microphone is amplified or made much larger by the transistor and then applied to the speaker where it is changed back into sound.

In a two-transistor amplifier the electrical sound signal from the microphone is amplified two different times. Transistor Q1 amplifies this audio signal the first time and transistor Q2 amplifies the signal a second time. As an example, if each of these transistors amplified the signal ten times, then the signal coming from transistor Q2 would be one hundred times larger than the signal that was going into transistor Q1!

HOW SIGNALS ARE ENLARGED

Demonstrating amplification in a transistor amplifier.

PARTS REQUIRED

1 EK-1 voltmeter (or equivalent)
1 Experimental chassis, wired for Experiment 4
1 Remote front panel (this is the other right-half front panel)
1 Left end panel
1 Right end panel
1 Remote bottom plate
1 Remote back plate
1 Speaker
4 Felt feet
1 10 Ω resistor (brown-black-black)
1 270 Ω resistor (red-violet-brown)
1 8200 Ω resistor (gray-red-red)
1 68 KΩ resistor (blue-gray-orange)
1 100 KΩ resistor (brown-black-yellow)
1 10 μfd electrolytic capacitor
2 100 μfd electrolytic capacitor
1 100 K ohm control
4 6-32 x 1/4" screw
11 4-40 x 1/4" screw
4 6-32 nut
4 4-40 nut
7 4-40 speednut
4 #4 lockwasher
4 #6 lockwasher
1 #6 solder lug
1 50 foot length (approximately) of hookup wire

WIRING THE REMOTE SPEAKER

Refer to Figure 5Q for the following steps.

( ) Fasten the right and left end panels on the remote bottom plate as shown. Use 4-40 screws, #4 lockwashers, and 4-40 nuts.

( ) Install the seven 4-40 speednuts at the locations shown. Make sure the flat side of each speednut is facing outward.

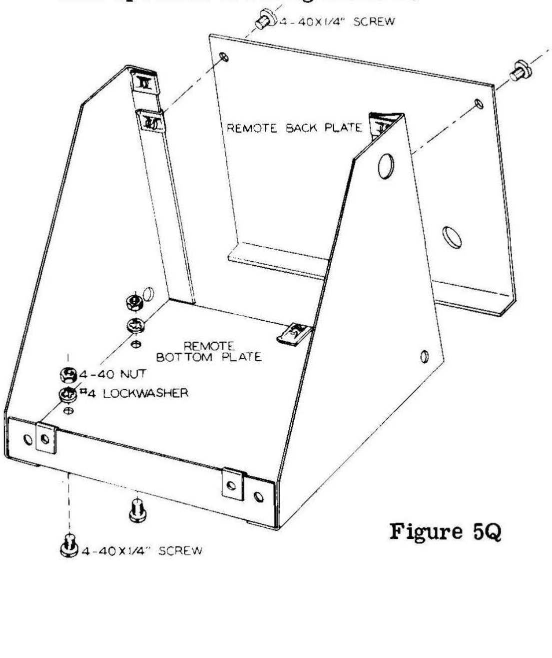


Figure 5Q

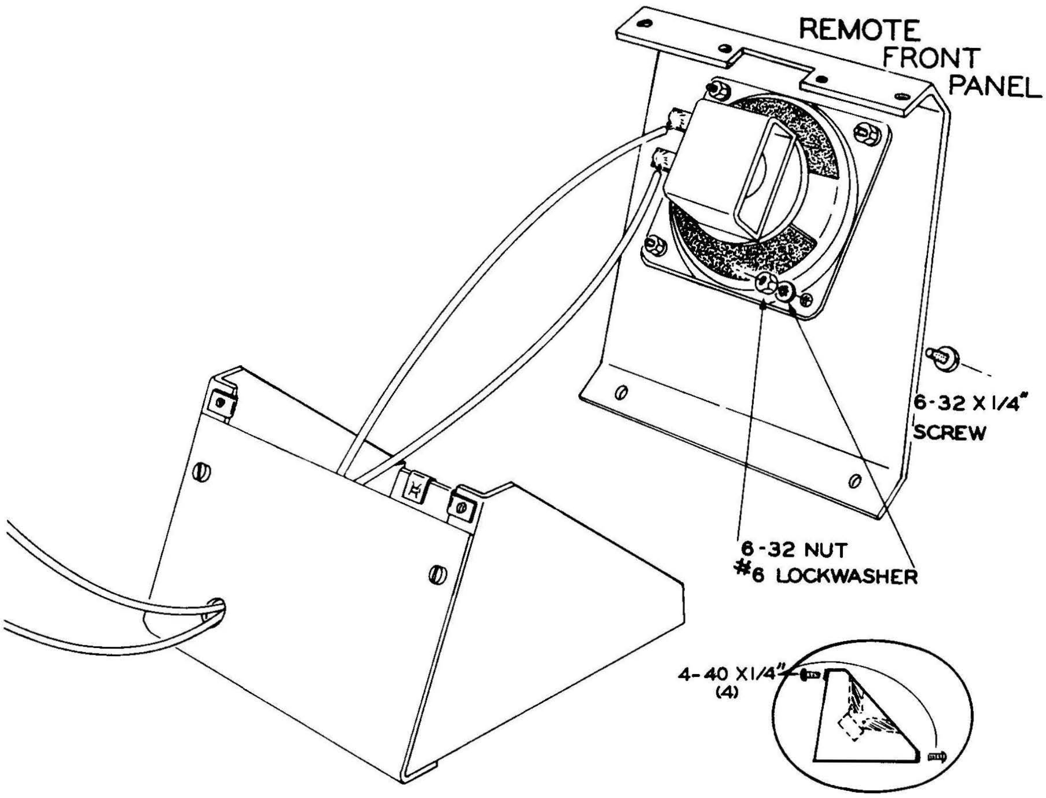


Figure 5R

( ) Install the remote back plate in position with three 4-40 screws.

Refer to Figure 5R for the following steps.

( ) Fasten the speaker on the remote front panel as shown, using 6-32 screws, #6 lockwashers and 6-32 nuts.

( ) Cut the 50 foot length of hookup wire into two equal (25 foot) lengths.

( ) Strip 1/4" insulation from both ends of the two 25 foot lengths of hookup wire, and twist the two wires together loosely.

( ) Insert one end of each wire through the round hole in the remote back plate. Solder each wire to one of the speaker lugs.

( ) Place the front panel over the end panels as shown in the inset of Figure 5R and fasten it in place with a 4-40 screw in each corner.

( ) Pull one of the gummed felt feet from its backing paper and stick it to one of the corners of the remote bottom plate.

( ) In the same way stick a gummed felt foot in each of the other three corners.

EXPERIMENT 1

To show by means of a graph how signal is amplified in the transistor.

Refer to Figure 5S for the following steps.

( ) Disconnect the 1000 Ω resistor lead from lug 2 of the ON-OFF switch and connect it instead to lug 1 of terminal strip B (NS).

( ) Connect a length of hookup wire from lug 2 of the ON-OFF switch (S) to lug 1 of terminal strip B (NS).

( ) Connect a length of hookup wire from lug 4 of terminal strip A (S) to lug 6 of terminal strip B (S).

( ) Connect an 8200 Ω resistor from lug 3 of terminal strip A (NS) to lug 3 of terminal strip B (S).

( ) Connect a 270 Ω resistor from lug 6 of terminal strip A (NS) to lug 1 of terminal strip B (S).

( ) Connect a length of hookup wire from lug 1 of terminal strip A (S) to lug 2 of the 2-way switch (S).

( ) Connect a length of hookup wire from lug 6 of terminal strip A (S) to lug 3 of the 2-way switch (S).

( ) Connect a length of hookup wire from lug 3 of terminal strip A (S) to lug 5 of the 2-way switch (S).

( ) Connect a length of hookup wire from lug 2 of terminal strip A (S) to lug 4 of the 2-way switch (S).

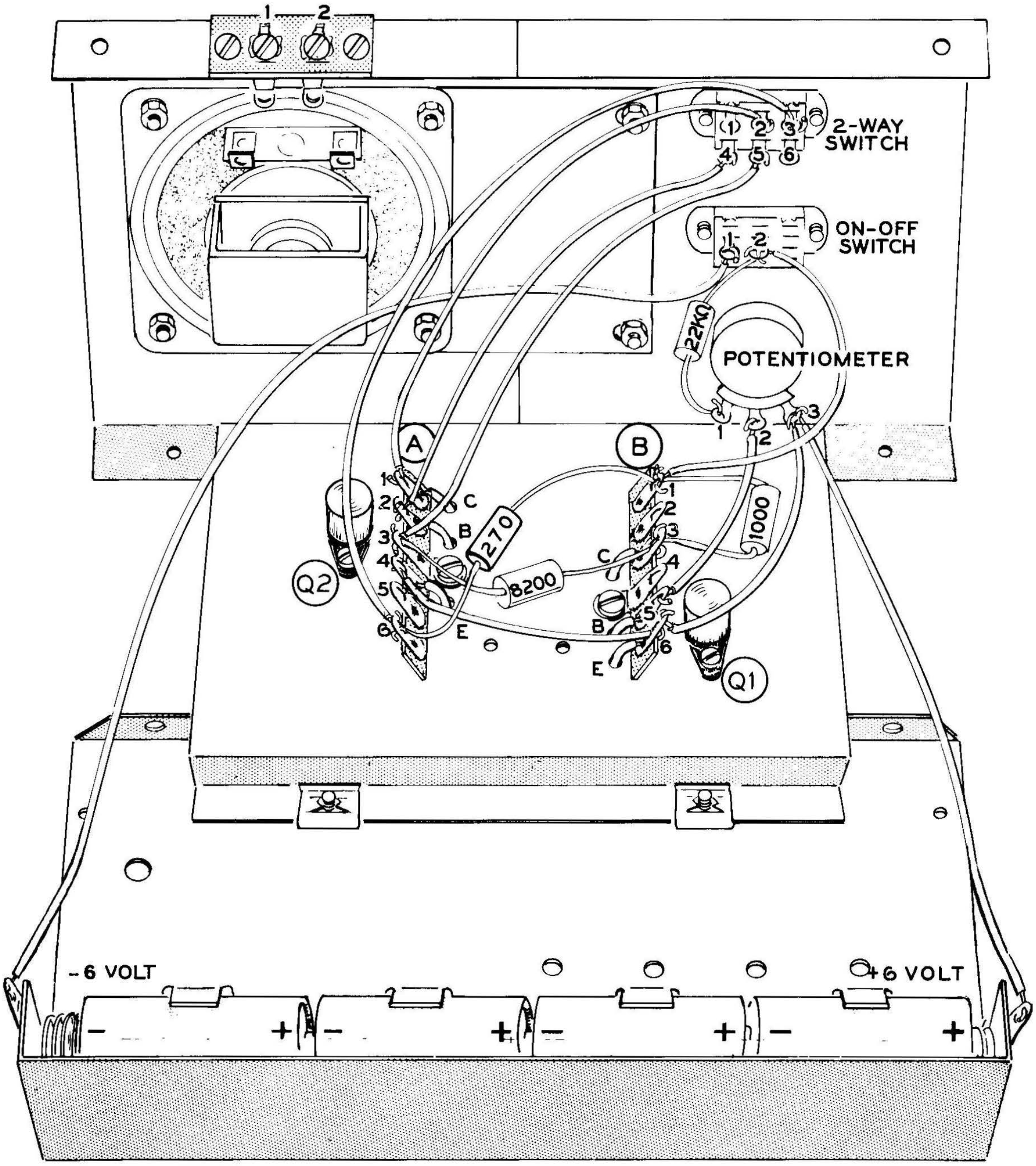

1
2
2-WAY
SWITCH
1
2
3
4
5
6
ON-OFF
SWITCH
22KΩ
POTENTIOMETER
A
B
C
B
C
B
E
E
270
8200
1000
Q2
Q1
-6 VOLT
+6 VOLT

Figure 5S

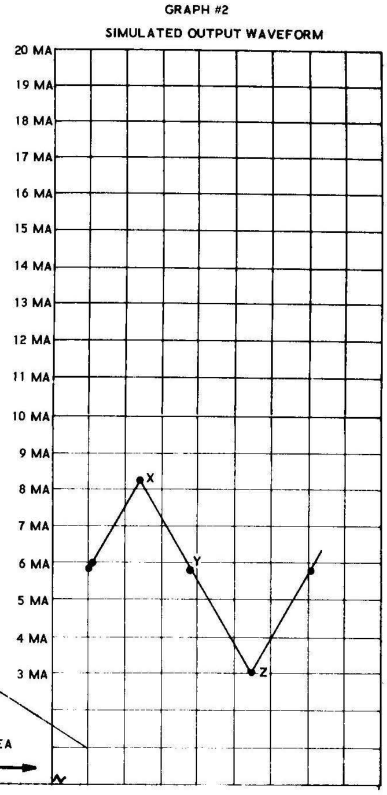
The circuit on your experimental chassis is now connected as shown by the Schematic Diagram in Figure 5T.

Refer to Figure 5T for the following steps.

The following steps will show you by means of graphs how a signal is amplified in the transistor. A sine wave has been simulated by using three different DC current measurements (at X, Y, and Z), and placing them on the graphs as they might appear at the center, at the positive and at the negative peaks of a sine wave. The amplification occurring in transistor Q2 will be shown by first measuring the small current flowing in the base of transistor Q2, and then measuring the large current flowing in the collector of transistor Q2.

Graph #1 shows the amounts of Base current for points X, Y, and Z which you will adjust to flow from transistor Q2 by turning the potentiometer. Graph #2 shows a typical example of some current readings you might obtain for Collector current measurements X, Y, and Z.

Measurement Y represents the zero line of the sine wave and for this reason it is shown three times in each graph.



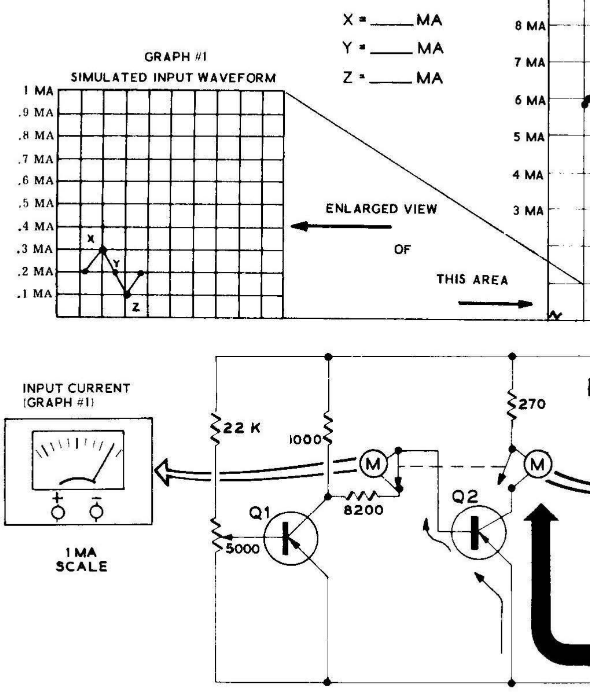


Figure 5T

Note that a slightly different type of circuit (no capacitors) was used for the experiment so that the smaller Base current would become large enough to be easily read on your meter.

The 2-way switch has been connected so that in one position (LISTEN) it will open the connection to the base of the transistor so that your milliammeter can be connected to measure the Emitter-Base current. In the other (TALK) position, the wire to the Collector is disconnected so that your milliammeter can be connected to measure the Emitter-Collector current.

( ) Switch your meter to read current on the 1 milliampere range; connect the negative lead to lug 3 and connect the positive lead to lug 2 of terminal strip A.

( ) Put the 2-way switch in the LISTEN position.

( ) Turn the ON-OFF switch ON and adjust the potentiometer so that your meter reads .1 milliampere. You have now adjusted the circuit for the current flowing at point Z in Graph #1. Turn the switch OFF.

( ) Disconnect your meter leads from the circuit and switch your meter to read current on the 10 milliampere scale.

( ) Connect the negative lead of your meter to lug 6 and connect the positive lead to lug 1 of terminal strip A.

( ) Put the 2-way switch in the TALK position. Turn the ON-OFF switch ON and read the amount of current on the meter. Mark this current down in the blank for Z milliamperes at Graph #2. Turn the switch OFF.

( ) Disconnect your meter leads, and put the 2-way switch in the LISTEN position.

( ) Switch the meter to read current on the 1 milliampere scale. Connect the negative lead to lug 3 and connect the positive lead to lug 2 of terminal strip A.

( ) Turn the ON-OFF switch ON and adjust the potentiometer so that the meter indicates .2 milliampere. The circuit is now adjusted for current Y on Graph #1. Turn the switch OFF.

( ) Disconnect the meter leads from the circuit, and switch the meter to read current on the 10 milliampere range.

( ) Turn the 2-way switch to the TALK position. Connect the negative meter lead to lug 6 and connect the positive meter lead to lug 1 of terminal strip A.

( ) Turn the ON-OFF switch ON and read current Y for your circuit which is now indicated on the meter. Mark this current down in the blank for current Y at Graph #2. Turn the switch OFF and disconnect the meter leads.

( ) Switch the meter to read current on the 1 milliampere scale and connect the meter leads as before to lugs 2 and 3 of terminal strip A. Turn the 2-way switch to the LISTEN position.

( ) Turn the ON-OFF switch ON and adjust the potentiometer so that the meter indicates .3 milliamperes. The circuit is now adjusted to indicate the current for point X in Graph #1. Turn the switch OFF and disconnect the meter leads.

( ) Switch your meter to read current on the 10 milliampere scale. Connect the meter leads as before to lugs 1 and 6 of terminal strip A. Turn the 2-way switch to the TALK position.

( ) Turn the ON-OFF switch ON and note the current indication on the meter. Mark this indication down in the blank for current X at Graph #2.

( ) Turn the switch OFF. Disconnect the meter leads from the experimental chassis.

( ) Use a pen or a pencil and mark down points X, Y and Z, for your circuit on Graph #2. Mark your indication for current Y down in three places as point Y is now shown on Graph #2.

( ) Now connect these points together to create the simulated AC wave for your circuit.

( ) Notice how much larger your output waveform is than the input waveform shown in Graph #1.

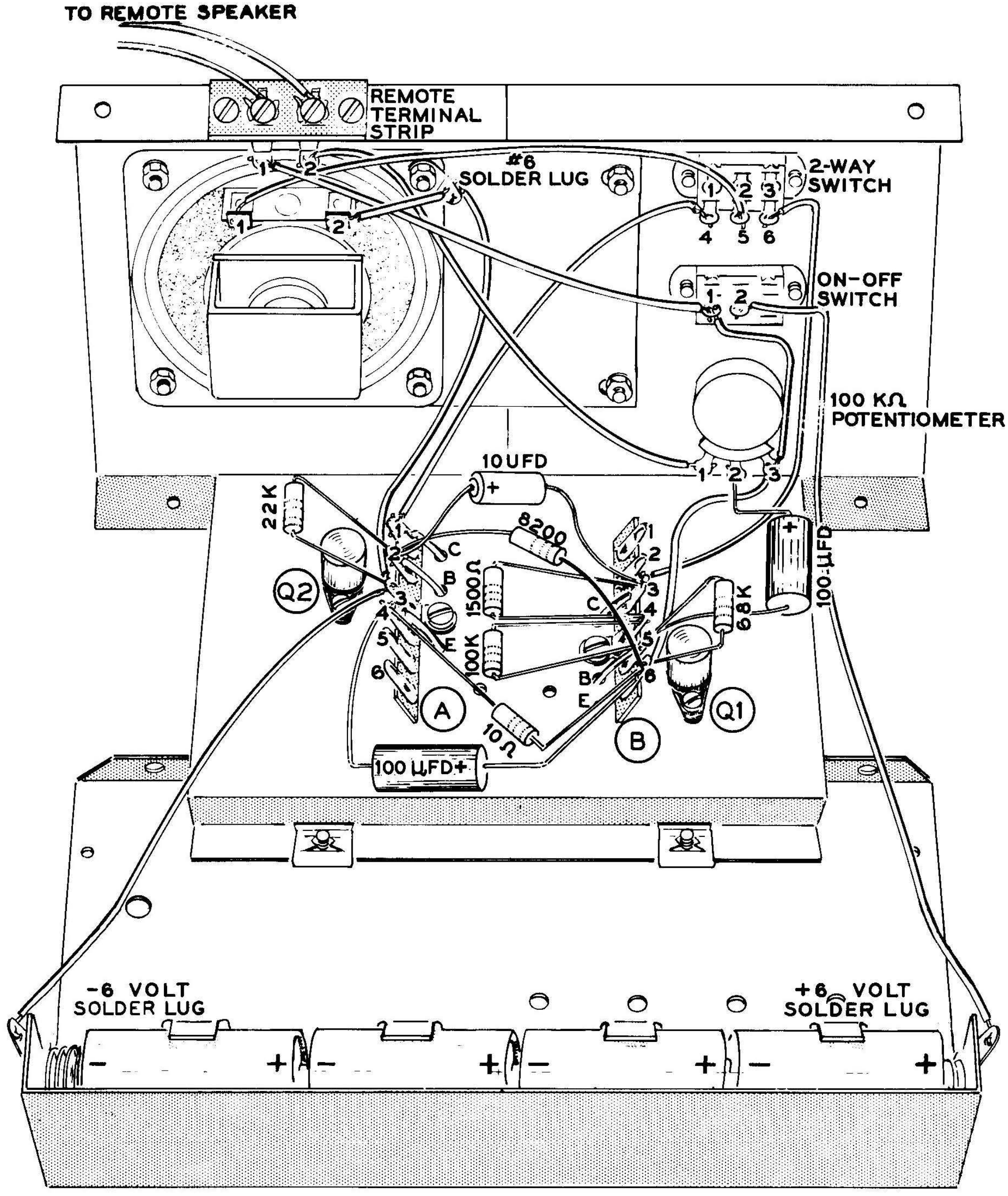


Figure 5U

EXPERIMENT 2

To give a listening test to show how a signal is amplified.

Refer to Figure 5U for the following steps.

( ) Disconnect and remove the four resistors and all wires from the experimental chassis. The 8200 Ω and 22 KΩ resistors will be used again in this experiment.

( ) Remove the knob from the shaft of the 5000 Ω control, and then remove the control from the front panel.

( ) Install the 100 KΩ control on the front panel in place of the 5000 Ω control and install the knob on its shaft.

( ) Remove the screw, lockwasher, and nut from the top right-hand corner of the speaker, as viewed from the rear. Replace the lockwasher with a solder lug, and install as shown.

( ) Connect a length of hookup wire from lug 3 of terminal strip A (NS) to the solder lug near the speaker (NS).

( ) Connect a length of hookup wire from lug 2 of the speaker (S) to the solder lug near the speaker (S).

( ) Connect a length of hookup wire from lug 1 of the remote terminal strip (S) to lug 1 of the ON-OFF switch (NS).

( ) Connect a length of hookup wire from lug 2 of the remote terminal strip (S) to lug 1 of the 100 KΩ potentiometer (S).

( ) Connect a length of hookup wire from lug 1 of terminal strip A (S) to lug 4 of the 2-way switch (S).

( ) Connect a length of hookup wire from lug 1 of the speaker (S) to lug 5 of the 2-way switch (S).

( ) Connect a length of hookup wire from lug 1 on the ON-OFF switch (S) to lug 3 of the 100 KΩ potentiometer (NS).

( ) Connect a length of hookup wire from lug 3 of the 100 KΩ potentiometer (S) to lug 6 of terminal strip B (NS).

( ) Connect a length of hookup wire from lug 6 of the 2-way switch (S) to lug 3 of terminal strip B (NS).

( ) Connect the positive (+) lead of a 100 μfd electrolytic capacitor to lug 2 of the 100 KΩ potentiometer (S). Connect the negative (-) lead of this capacitor to lug 5 of terminal strip B (NS).

NOTE: Make sure the leads of the resistors and the capacitors in this experiment do not touch either the metal of the chassis or any other lead that is not connected to the same terminal they are. If the bare wire touches a place it is not supposed to touch, it will cause a short and the circuit will not operate properly.

( ) Connect the positive (+) lead of a 10 μfd electrolytic capacitor to lug 2 of terminal strip A (NS). Connect the negative (-) lead of this capacitor to lug 3 of terminal strip B (NS).

( ) Connect a 1500 Ω resistor from lug 3 (S) to lug 4 (NS) of terminal strip B.

( ) Connect a 100 KΩ resistor from lug 4 (S) to lug 5 (NS) of terminal strip B.

( ) Connect a 10 Ω resistor from lug 4 of terminal strip A (NS) to lug 6 of terminal strip B (NS). Be careful not to confuse this 10 Ω resistor with the 10 KΩ resistor.

( ) Connect a 68 KΩ resistor from lug 5 (S) to lug 6 (NS) of terminal strip B.

( ) Connect a 22 KΩ resistor from lug 2 (NS) to lug 3 (NS) of terminal strip A.

( ) Connect an 8200 Ω resistor from lug 2 of terminal strip A (S) to lug 6 of terminal strip B (NS).

( ) Connect the positive (+) lead of a 100 μfd capacitor to lug 6 of terminal strip B (S). Connect the negative (-) lead of this capacitor to lug 4 of terminal strip A (S).

( ) Connect a length of hookup wire from the +6 volt solder lug (S) to lug 2 of the ON-OFF switch (S).

( ) Connect a length of hookup wire from the -6 volt solder lug (S) to lug 3 of terminal strip A (S).

( ) The circuit shown in the schematic for Figure 5U is now connected on your experimental chassis. The 2-way switch is connected so that in one position (marked LISTEN) you will have a one-transistor amplifier, and in the other position (marked TALK) you will have a two-transistor amplifier.

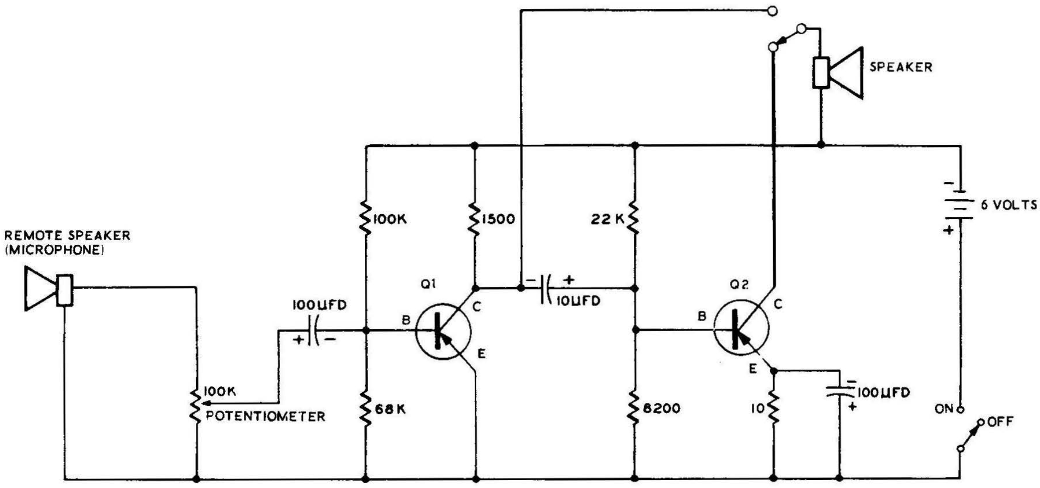


Figure 5U SCHEMATIC

( ) Connect the 25 foot wires from the remote speaker underneath the screws of the remote terminal strip.

The remote speaker can now be used as a microphone to send an electrical signal to your amplifier. Although speakers can be used in this manner, backwards, since they are not made for this purpose they will perform less efficiently than a crystal microphone.

( ) Place the remote speaker in front of the speaker of a radio, or some other source of sound. Tune a station in on the radio.

( ) Turn the amplifier on and adjust the volume control to the right level. Switch the 2-way switch back and forth from one position to the other and notice the difference in loudness (or amplitude) between the one-transistor and two-transistor amplifiers. The difference you hear between the two switch positions represents the amount of additional amplification that the signal gains in transistor Q2.

DISCUSSION

The experiments of this lesson showed you in two different ways how a signal is amplified in the transistor. In Experiment 1 you took measurements in a circuit which you plotted on the graph. Carefully observing the amount of change between Graph #1 and Graph #2 should have shown you that a signal would be about 25 times (or more) larger after it had passed through transistor Q2.

In Experiment 2 you wired a two-transistor amplifier on your experimental chassis. By switching the output speaker from the output of Q2 to the output of Q1 and back again, you were able to hear how much transistor Q2 was actually amplifying the signal.

LESSON V

QUESTIONS

1. What is an audio signal?

2. Are audio signals made up of AC or DC currents?

3. The current that flows first one way and then the other way is (DC current, AC current).

4. What type of current is generally supplied by power companies?

5. What is the name given to the normal pure AC waveform?

6. What does "frequency" mean?

7. The two main characteristics of an audio signal are its ____________ and its ____________.

8. How is loudness contained in an audio signal?

9. A capacitor passes ________ currents but will not pass ________ currents.

10. The size of a capacitor is usually marked in either ______ or ______.

11. The speaker is a device which converts electrical signals into sounds. What is the force that pushes the cone of the speaker?

12. Why are amplifiers necessary?

LESSON VI

HOW TRANSISTORS USE OPERATING VOLTAGES

Lesson IV showed you how a small Emitter-to-Base current controls a large Emitter-to-Collector current in a transistor. Lesson V showed you how a small signal current at the Base also controls the large Emitter-to-Collector current in a transistor amplifier stage. Since the small signal current controls the increases and decreases of the Emitter-to-Collector current, the larger current leaves the transistor with the same shape as the original signal, only much larger.

This lesson will show how the DC operating voltages at the Emitter, Base, and Collector, control how faithfully the signals are reproduced, after they are amplified by the transistor. Remember, since PNP transistors are being used, these circuits will be explained in terms of hole current, which flows from plus (+) to minus (-).

TRANSISTOR CURRENTS AND BIAS VOLTAGE

When the proper voltages are connected to the Emitter, Base, and Collector of a transistor, current begins to flow. Because the base region of a transistor is very thin, most of the current flows from the Emitter to the Collector, and only a very small current flows from the Emitter to the Base.

The small Base current controls the larger Collector current of the transistor. This is shown in Figure 6A. If battery #2 is made larger, causing a larger Base current to flow, then the amount of Collector current will increase. If battery #2 is made smaller, causing a smaller Base current to flow, then the amount of Collector current will become smaller.

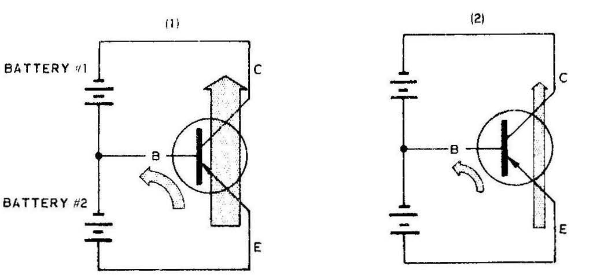


Figure 6A

Since the large Collector currents are often 100 times as large as the smaller Base currents it is almost as if the small Base current were opening and closing a valve between the Emitter and Collector. A larger Base current would compare to opening the valve wider, and letting a larger Collector current flow through the transistor. A smaller Base current would compare to closing the valve, causing a smaller amount of Collector current to flow through the transistor.

Figure 6B shows how a transistor with a normal Base circuit is likely to be connected. In place of battery #2, which was connected between the Emitter and the Base, you now find a resistor. This resistor is part of a voltage divider, consisting of R1 and R2. The voltage developed across resistor R2 keeps a voltage applied between the Emitter and the Base just as battery #2 did.

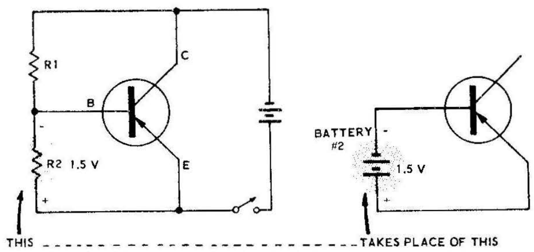


Figure 6B

The voltage developed across resistor R2 is called the "bias voltage," and resistors R1 and R2 are called the bias resistors. The bias voltage controls the current that flows from the Emitter to the Base of the transistor (the Base current). This Base current controls the much larger Collector current of the transistor.

If the values of bias resistors R1 and R2 are selected so that a larger voltage appears across R2, the Base current becomes larger causing a larger Collector current to flow. Conversely, if the values of R1 and R2 are selected to make the voltage across R2 smaller, the Base current becomes smaller and a smaller amount of Collector current flows. Thus, you can consider that the voltage across resistor R2

1ST (POSITIVE) HALF-CYCLE

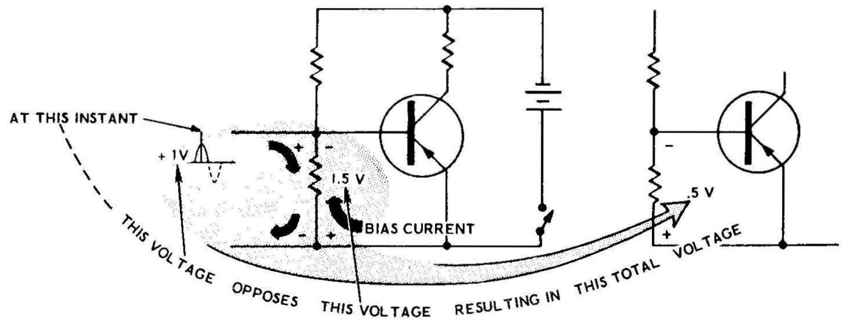


Figure 6C Part 1

acts as if it were opening and closing a gate between the Emitter and Collector, as mentioned in previous paragraphs.

BIAS VOLTAGES AND AC SIGNALS

Figure 6C shows what happens when a signal is applied to the input of a transistor. The first half of Figure 6C shows the voltages and currents at resistor R2 when the peak voltage of the positive half of a sine wave is applied. The bias voltage across resistor R2 is -1.5 volts and the divider current, which produces the bias voltage, is flowing up through the resistor.

The signal voltage at this same instant is +1 volt, and the signal current is trying to flow down through resistor R2. As a result of the two currents opposing each other 2/3 of the divider current is kept from flowing, causing part of the 1.5 volt bias voltage to be cancelled out. At this instant, only the resulting -.5 volt appears as the voltage between the Emitter and Base of the transistor.

This causes less Base current to flow which in turn causes less Collector current to flow through the transistor.

The second part of Figure 6C shows what happens in the circuit when the negative half-cycle of the input waveform is applied to the input of the transistor. The same 1.5 volts bias is appearing across resistor R2 and the divider current is flowing up through resistor R2 as before. The -1 volt now applied by the signal causes additional current to flow up through resistor R2. As a result, the two currents add and cause a total of 2.5 volts to appear across resistor R2 (Ohm's Law). This causes an increase of Base current to flow in the transistor, and the increase in Base current causes an increase in the Collector current.

The bias voltage, therefore, sets a DC reference voltage that the signal voltage will be able to add to or subtract from. The sum of these two voltages (the bias voltage and the signal voltage) will control the amount of Base current that flows. The Base current, in turn, controls the Collector current of a transistor.

2ND (NEGATIVE) HALF-CYCLE

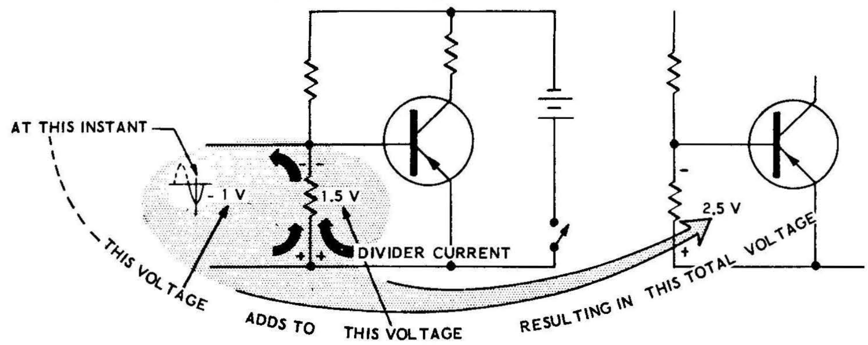


Figure 6C Part 2

SELECTING THE CORRECT BIAS

The amount of bias voltage to be developed across resistor R2 must be carefully selected. If this bias voltage is either too large or too small, any signal amplified by the transistor will become distorted and will not sound as it should in the speaker. Figures 6D and 6E, along with the following paragraphs, describe what happens to signals when too large or too small a bias voltage is developed across resistor R2.

EFFECTS OF TOO MUCH BIAS CURRENT

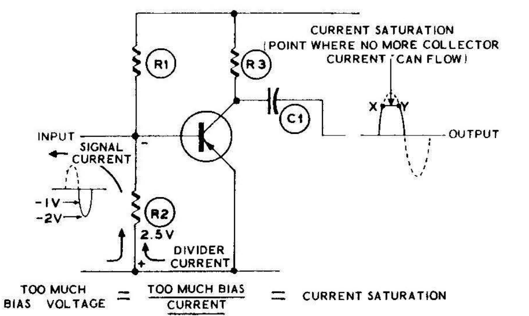


Figure 6D

For any given battery voltage, there is a certain point at which the Emitter-to-Collector resistance of a transistor cannot become any smaller. When this point is reached, a maximum amount of Collector current flows in the transistor; further increases in Base current do not cause further increases of Collector current beyond this point. When a transistor reaches this condition, where no more current can flow, it is said to be at "saturation." This condition is illustrated in Figure 6D.

If too much bias voltage appears across resistor R2, the Collector current flowing through the transistor goes into the saturation region during a certain part of the input AC waveform. During the negative half-cycle of the input waveform the signal current adds to the bias current through resistor R2. This increases the bias voltage across R2 from 2.5 volts to 3.5 volts or more, which increases the Base current of the transistor.

During the time when the input signal voltage changes from 0 volts to -1 volt in Figure 6D, the output waveform changes in a normal fashion from 0 to point "X." As the input voltage becomes still more negative from -1 volt to -2 volts, the bias current increases still further. Since point X was the point where saturation occurred in the transistor, the current through the transistor cannot increase any further. Therefore, no further change in voltage appears at the output until point Y occurs. Point Y would be the place where the input waveform once more drops below -1 volt.

As shown by Figure 6D, therefore, too much bias causes the pure sine wave applied at the input to have one side flattened at the output of the transistor. This would cause the sound to be distorted when it is heard in the speaker.

The opposite problem, too little bias voltage, is demonstrated in Figure 6E. Just as there is a point of maximum Collector current in a transistor, there is also a point of minimum Collector current. This is the point where the resistance of the transistor will not become any larger, no matter what changes the input waveform makes in the bias current.

EFFECTS OF NOT ENOUGH BIAS

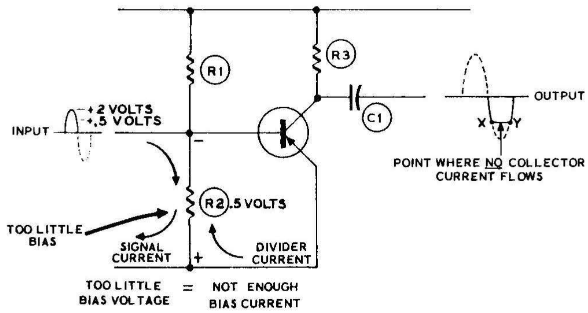


Figure 6E

Figure 6E shows the circuit condition where the bias voltage across resistor R2 is cancelled out. The bias current flows up through resistor R2 as it did before. During the positive half-cycle of the input waveform, the signal current attempts to flow down through resistor R2 with the result that it bucks up against the bias current and cancels some of it.

The output waveform increases normally as the input signal voltage increases from 0 volt to + .5 V . When the input voltage reaches + .5 V, the resistance of the transistor can become no larger, so from this point on the current flowing through the transistor and resistor R3

(Collector current) can decrease no further. This point is shown at X on the output waveform.

As the input waveform changes from + .5 to + 2 and back to +.5 volt, the output waveform does not change. Only when the input waveform again reaches +.5 V will a change again begin to occur at the output. This point (where the change begins to occur again) is shown at point Y on the output waveform. You can see then, by the input and output waveforms, that the sine wave has been distorted as it passed through the transistor, and will not sound as it should if applied to a speaker.

The correct amount of bias voltage for a transistor would be the voltage at the center point between these two extreme conditions. The correct values for bias resistors R1 and R2 are selected when the circuit is designed, in order to assure proper operation.

THE EMITTER CIRCUIT

Transistors will draw more current when they are hot than they will when they are cold, and a transistor will become overheated when too much current flows through it. Too much current would cause more heat, and more heat in turn causes more current flow. Thus, a transistor that gets too hot during operation would conduct more current than it was designed to conduct. This chain of events would cause the transistor to distort the signals by going into the saturation region, and could easily result in a burned-out transistor.

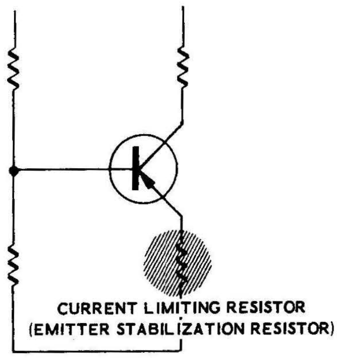


Figure 6F

A small resistor, called an "Emitter stabilizing resistor," or a "current limiting resistor," is often connected to the Emitter of a transistor.

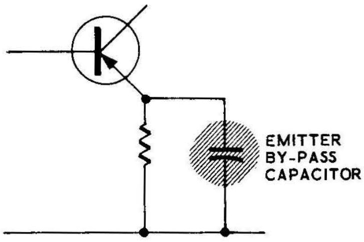


Figure 6G

This resistor stabilizes the currents flowing through the transistor and prevents the transistor from running away with itself and causing distortion by overheating.

The stabilizing voltage that appears across the stabilizing resistor must be steady DC voltage to be efficient. In order to insure that this stabilizing voltage stays a steady DC voltage, a capacitor, called a "bypass capacitor," is connected across the resistor. This bypass capacitor allows all the AC signal currents to pass around the stabilizing resistor without disturbing the DC voltage across it.

SUMMARY

The small voltage connected between the Emitter and Base of a transistor is called the bias voltage. This voltage, which is normally supplied by a resistive voltage divider, controls the Base current that flows in a transistor. This small current is called the bias current.

When an AC signal voltage is applied to the input of a transistor, it instantaneously either adds to or subtracts from the bias voltage. This changes the bias current, which in turn changes the large Collector current flowing in the transistor.

The bias voltage for a transistor must be carefully determined. If the bias voltage is too large, it causes distortion because more current flows through the transistor than it can handle. This point, beyond which too much current flows, is called "saturation."

If too little bias is applied to the transistor, the input signal is distorted because of the opposite condition. The point is reached where the input signal cannot decrease the Collector current of the transistor any further. The correct bias voltage is centered between these two extremes.

DEMONSTRATING THE EFFECTS OF CHANGING THE BIAS IN A TRANSISTOR AMPLIFIER

To show that improper bias causes distortion.

PARTS REQUIRED

1 Experimental chassis-wired for Lesson V
1 Solder lug
1 1000 Ω resistor (brown-black-red)

EXPERIMENT 1

To show that altering the bias voltages on the 2-transistor amplifier has a large effect on the sound from the speaker.

( ) Disconnect and remove the wire that connects from lug 6 of the 2-way switch to lug 3 of terminal strip B.

( ) Disconnect and remove the wire that connects from lug 1 of the speaker to lug 5 of the 2-way switch.

( ) Disconnect the wire from lug 4 of the 2-way switch and connect it instead to lug 1 of the speaker.

The circuit on your experimental chassis is now connected as shown by the Schematic of Figure 6H.

( ) Leave the remote speaker connected to the terminals but take it into the next room from where you are working. Set the remote speaker in front of the speaker of a radio. Turn the radio on but turn it down low so you cannot hear it back at the experimental chassis. If possible, close a door between the two rooms.

( ) Turn the ON-OFF switch ON. You should hear the radio from the speaker of your amplifier. Now, in the next few steps you will adjust the bias resistors so improper bias is temporarily applied to the transistors. Turn the ON-OFF switch OFF.

( ) Disconnect and remove the 22 KΩ resistor connected from lug 2 to lug 3 of terminal strip A.

( ) Replace this resistor with a 1000 Ω resistor. Connect the 1000 Ω resistor from lug 2 (S) to lug 3 (S) of terminal strip A.

( ) Turn the ON-OFF switch ON and turn up the volume. Notice that the sound is now badly distorted due to the bias change in transistor Q2. Turn the ON-OFF switch OFF.

( ) Remove the 1000 Ω resistor and replace the original 22 KΩ resistor from lug 2 (S) to lug 3 (S) of terminal strip A.

( ) Now use the same 1000 Ω resistor to alter the bias of transistor stage Q1. Connect the 1000 Ω resistor from lug 4 (S) to lug 5 (S) of terminal strip B. The 1000 Ω resistor is now connected in parallel with the 100 KΩ resistor connected to the base of transistor Q1. This has changed the resistance of the two parallel resistors to slightly less than 1000 Ω, altering the bias voltage drastically.

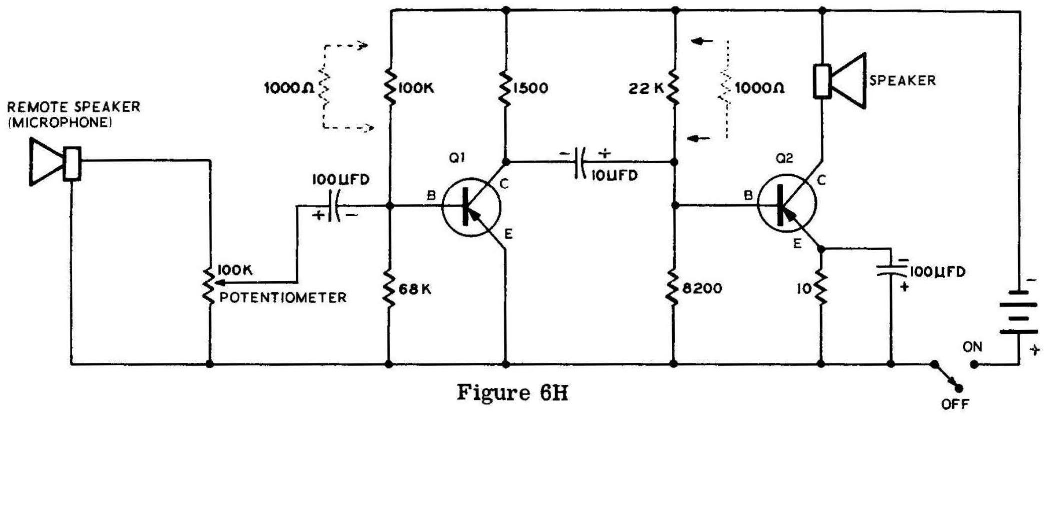


Figure 6H

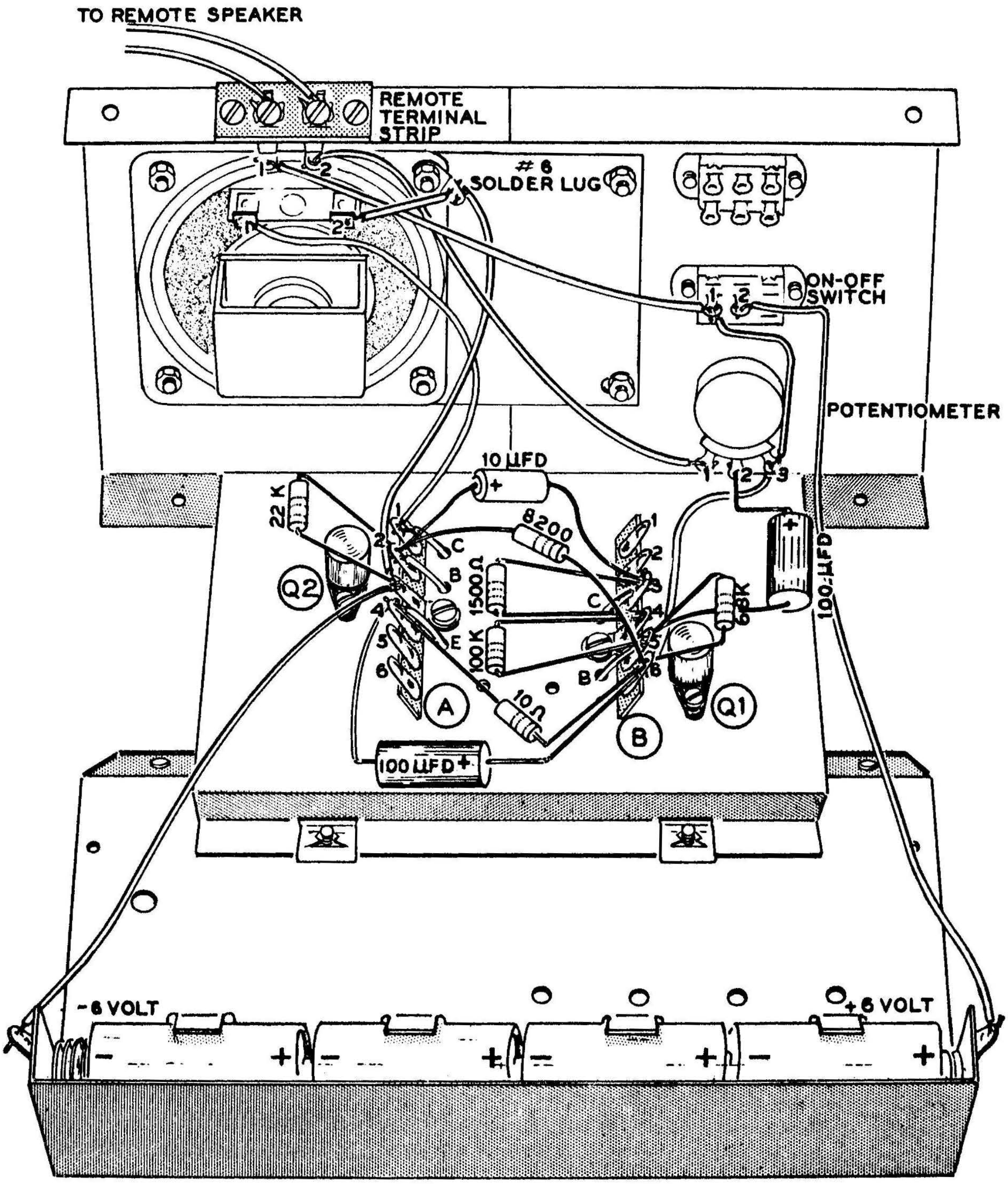


Figure 6H

( ) Turn the ON-OFF switch ON and notice the sound has once again become drastically changed (usually the sound will be completely cut off in this case).

( ) Turn the ON-OFF switch OFF. Remove the 1000 Ω resistor from lug 4 and lug 5 of terminal strip B.

DISCUSSION

The experiments for Lesson VI gave you listening tests to show you what effect faulty bias or faulty operating voltages can have on the operation of a transistor amplifier. Faulty operating voltages will generally result in a distorted signal in almost any type of transistor circuit, including the circuits you will study in the remaining lessons.

Experiment 1 changed the bias first on one transistor and then on the other transistor. In one case the sound was badly distorted, and in the other case it was completely cut off. In both of these cases the bias resistors were altered so that too much bias voltage appeared across the lower resistor. The result as was pointed out in the theory section of this lesson, was current saturation in the transistor.

In the amplifier circuit of Experiment 1 no Emitter stabilizing resistor is used for transistor Q1. This resistor can be eliminated here because the 1500 ohm resistor in the Collector circuit stabilizes the operation of Q1 as well as performing its regular function.

LESSON VI

QUESTIONS

1. In a normal circuit, is a battery usually connected between the Emitter and Base to supply bias voltage?
2. How is bias voltage for a transistor usually developed?
3. AC signals either add to, or subtract from, the bias voltage. (True, False.)
4. Too much bias can result in __________.
5. Insufficient bias can cause an input signal to become distorted because the transistor will operate in the region where its resistance cannot become any (larger, smaller).
6. What does a current limiting resistor do?
7. What does the Emitter bypass capacitor do?

LESSON VII

HOW DOES A TRANSISTOR RADIO WORK?

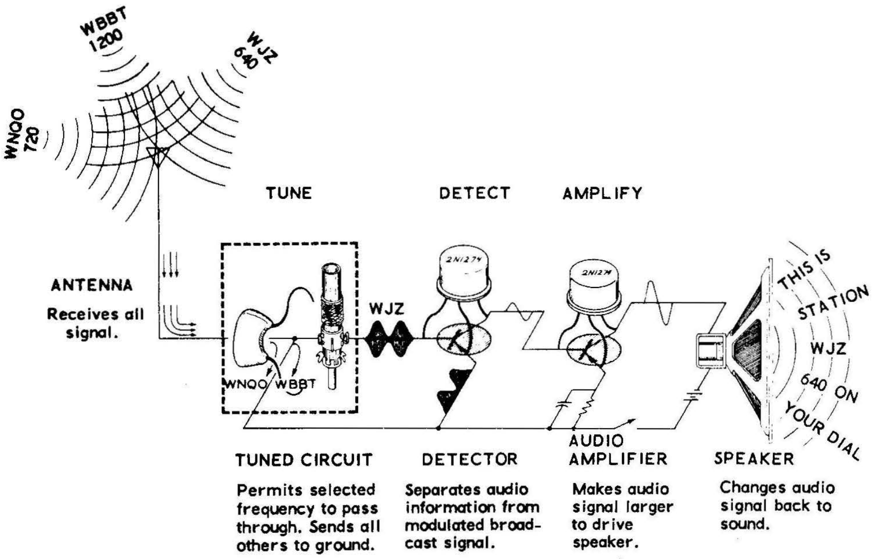


Figure 7A

Previous lessons showed you the general theory of transistors. They also showed what audio (or sound) signals are and how they are amplified.

This lesson will show you how transistors are used in a simple transistor radio. You will find that the basic principles of how the transistors operate are the same, but new effects are obtained by connecting the circuit parts in different ways.

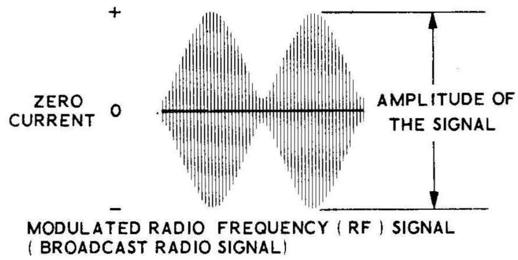
For more detailed explanations of the theory of the radio circuits involved in this lesson, refer to the HEATHKIT Basic Radio Course.

RADIO SIGNALS

It is impractical to broadcast a pure audio signal, thus the signal sent out by the transmitter and received by the antenna of your radio is of a much higher frequency than those studied in previous lessons. These higher frequency signals (called "radio frequency signals" or just "RF signals") are AC signals above 20,000 cycles per second.

This RF signal must somehow contain intelligence and transport it from the radio station to your receiver. One way it can contain intelligence is by turning the signal on and off in such a way that dots and dashes are formed. This is generally the way Morse code is transmitted and received. Another way that an RF signal can contain intelligence is by arranging it so that the intelligence from an audio signal is contained in the RF signal itself. This last method of carrying information is called "modulation," and a signal of this type is called a "modulated RF signal."

Figure 7B shows what a graph of a modulated RF signal would look like. Notice that the modulation process first increased and then decreased the amplitude of the RF signal in



MODULATED RADIO FREQUENCY (RF) SIGNAL (BROADCAST RADIO SIGNAL)

Figure 7B

the form of swells of energy. The audio information is contained in these swells of RF signal; first there is very little energy, and then there is a lot of energy. To put it another way, the audio information exists in the way the RF signal changes in amplitude.

RADIO RECEIVERS

Your radio receiver must do three things to remove the audio information from the modulated RF signal. These three functions can be seen in Figure 7A.

First, the receiver must select the desired signal and reject the signals from all other stations. This function of selecting the desired frequency and rejecting all others is called "tuning."

Second, the receiver must separate the audio information from the modulated RF signal. This is called "detecting" a signal. The circuit in which this is done is called the "detector."

The third thing the receiver must do is to amplify the signal until it is large enough to drive the speaker or earphone. In most receivers, the RF signal is amplified before it gets to the detector, and then the audio signal is amplified after it leaves the detector circuit.

The following paragraphs will explain how tuning and detecting takes place.

HOW THE RADIO TUNES

A capacitor and a coil connected in parallel are called a "tuned circuit," and this "tuned circuit" has a unique property. At a certain frequency (which depends on their electrical sizes), the coil and capacitor act like a very large resistor. At all other frequencies they act like a short circuit, as if a piece of wire were shorted across the two parts.

A tuned circuit is shown in Figure 7C. It is a tuned circuit such as this which tunes in the desired signal on all radio receivers. Usually, either the coil or capacitor is made so its electrical size can be adjusted. Adjusting the size of one of these components changes the frequency tuned by the circuit (the frequency at which it appears like a large resistor). By carefully selecting the correct values for these two parts, the circuit will tune all of the frequencies between 1650 kc and 550 kc, the top and bottom limits of the broadcast band.

A regular home receiver will generally have a number of these tuned circuits in the RF sections of the receiver. This makes the receiver tune much more sharply, so that close together stations are easier to separate.

HOW THE SIGNAL IS DETECTED

To "detect" a signal means to remove the audio information from the modulated RF signal.

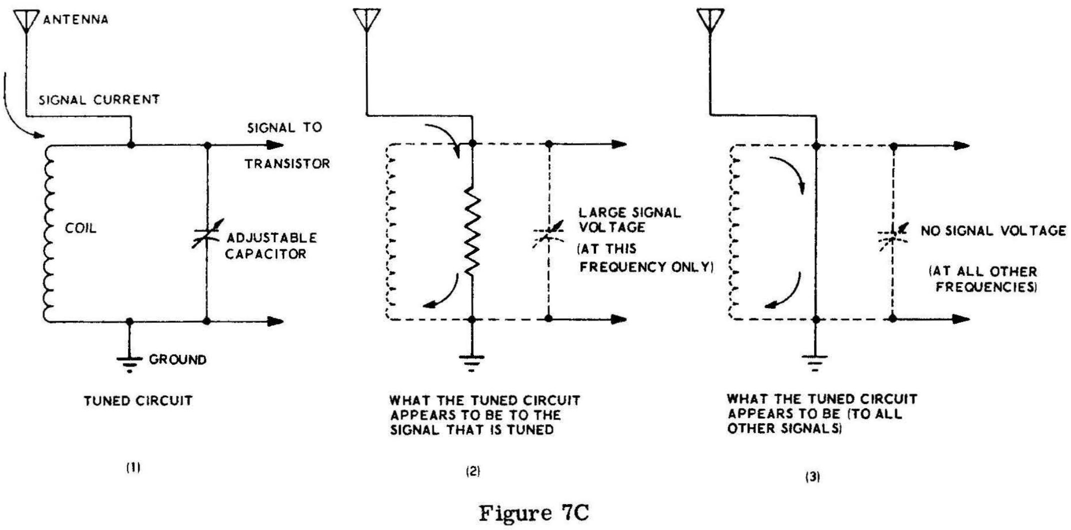


Figure 7C

This is generally done in two steps by the detector circuit; the first step is to rectify the signal, and the second step is to filter the RF from the signal.

RECTIFICATION: Figure 7D shows the changes in amplitude (swells of energy) that represent the audio signal in the modulated broadcast signal. In Part 2, the individual cycles of RF have been left out so that these swells may be seen more clearly. A careful examination shows that as the signal increases in a positive direction, it also increases the same amount in a negative direction at the same time. These two opposing increases, if they were converted into audio signals and applied directly to an audio amplifier in this form, would cause equal and opposite currents to flow. The equal and opposite currents would cancel each other out, with the result that no signal at all would emerge from the circuit.

Rectifying removes one-half of the signal, thus preventing the positive and negative swells from cancelling each other out.

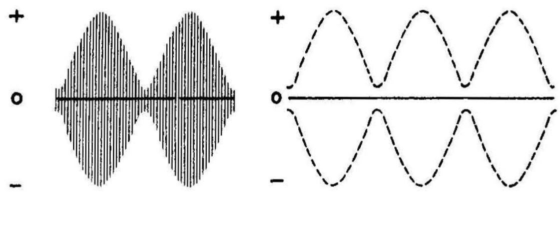


Figure 7D

A signal is rectified by passing it through a crystal diode as shown in Figure 7E. As stated in Lesson I, current will flow in only one direction through a diode. During the positive portion of each cycle of RF, current flows up througn the resistor and through the diode (Part 1 of 7E). During the negative portion of each cycle, no current flows (Part 2 of 7E). The result, as shown in Part 3 of Figure 7E, is rectification, which has removed one-half of the input signal.

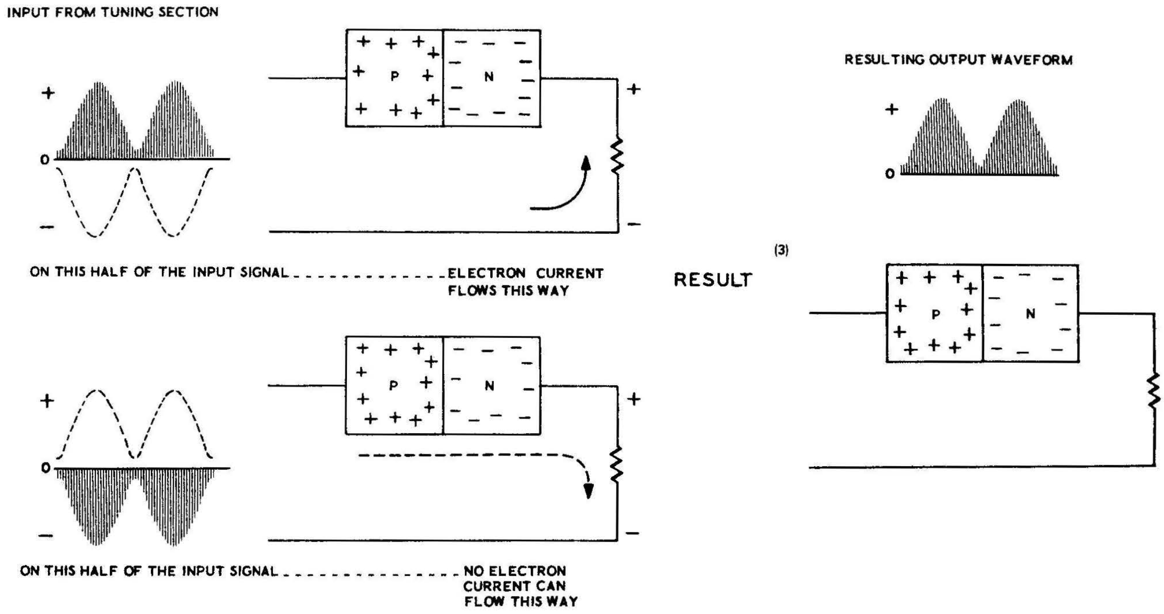


Figure 7E

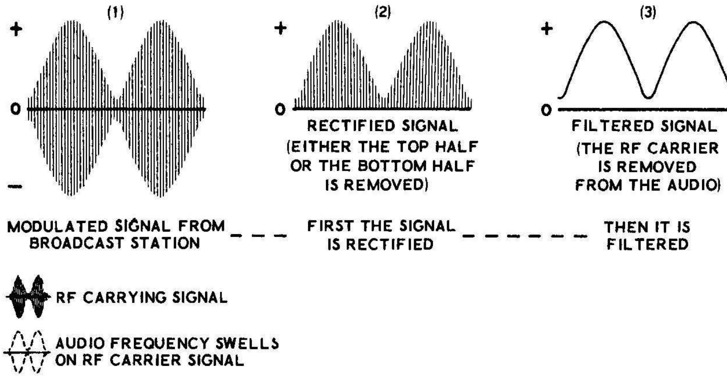


Figure 7F

FILTERING: Figure 7F shows an overall picture of the signal into and out of the detector circuit. Part 1 shows the signal received from the tuning circuits of the receiver. Part 3 shows the signal with the audio completely restored and the RF filtered from it.

Figure 7G shows what an actual filter circuit might look like. The action of the capacitor smooths out the spaces in between the peaks of the RF waveform and shorts out the RF waveform itself to ground. The audio signal is developed across the resistor and from there is coupled to the audio amplifier section.

A TWO-TRANSISTOR RADIO CIRCUIT

Figure 7H shows the circuit of a two-transistor radio. The modulated RF signals are received by the antenna and connected to the tuned circuit. The small arrow alongside the coil means that the electrical size of this coil is adjustable. Only one of the RF signals (the one at the frequency at which the tuned circuit acts like a large resistor), causes a voltage to appear across the tuned circuit. This causes signal currents to flow from the tuned circuit through the Emitter and Base of transistor Q1.

Notice that there are no bias resistors to supply bias voltage to the base of transistor Q1. This causes the Emitter and Base to react like a crystal diode (see Lesson I) to the signal currents applied across them. Thus, signal currents can flow in only one direction; from the Emitter to the Base of the transistor. If a bias current were present, both halves of the signal could pass through the transistor, since the bias voltage would give the signal voltage something to add to or subtract from.

Transistor Q1 then is actually turned on and off by the input signal. For one half of the input signal, base current flows and the signal is im-

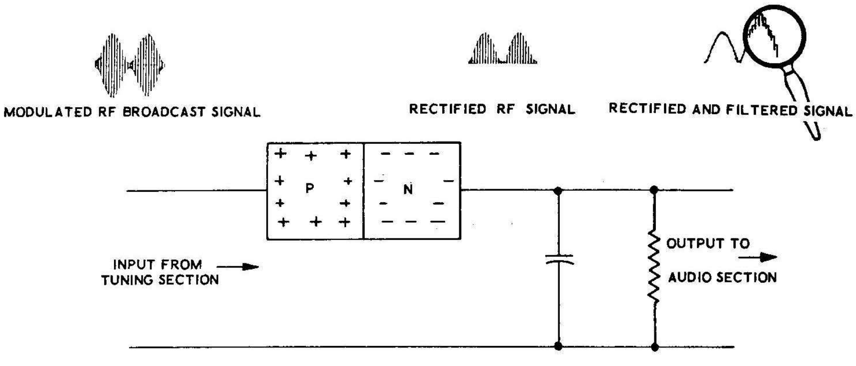


Figure 7G

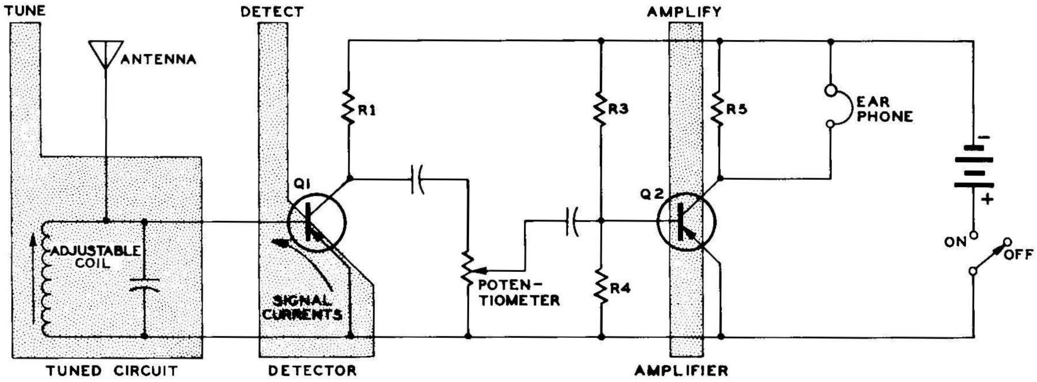


Figure 7H

pressed on the Collector current in the normal manner. In the other half-cycle, no base current flows, thus no Collector current flows. As a result, the input signal is rectified. The filtering of this signal, which takes place in the earphone in this circuit, will be explained in a few moments.

The rectified signal from transistor Q1 passes through the capacitor to the potentiometer. Part of the signal is selected at the arm of the potentiometer and coupled through the capacitor to the Base of amplifier Q2. Resistors R3 and R4 supply bias for transistor Q2.

The large Collector current of transistor Q2 causes the signal current to create a voltage drop across resistor R5. The signal voltage across R5 operates the earphone, which is connected in parallel, and the earphone changes the signal back into sound.

The EARPHONE: The earphone shown in Figure 7J works on exactly the same principle as a crystal microphone, except that it is used in the reverse direction. The audio signal causes the crystal to vibrate at the same frequency as the original sound. The vibrating crystal is connected mechanically to a diaphragm. When the crystal moves the diaphragm, the diaphragm moves a column of air, and these vibrations of air are heard in your ear as sounds.

The earphone also acts as a mechanical filter to separate the RF from the audio signal. The earphone has the effect of filling in the spaces between the quick little cycles of radio frequency energy. This happens because its mechanism just cannot move fast enough to follow the radio frequency pulsations, so it follows the "average" amplitude at a slower rate (this is the audio rate).

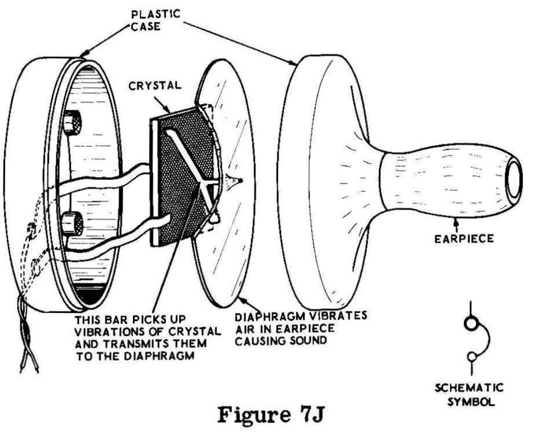


Figure 7J

SUMMARY

Modulated RF signals broadcast from the radio station are picked up by the antenna of your receiver. The audio information from the radio station is contained in the swells of energy found on these modulated RF waveforms. The modulated RF signal consists of AC sine waves of a much higher frequency than audio signals. This type of signal is tuned between 550 kc and 1650 kc on the broadcast band of your receiver.

The first thing a receiver does to the signals it receives is to "tune" only one of the signals from the antenna and reject all of the others. The desired signal is selected by applying all of the signals across a "tuned circuit." The tuned circuit which consists of a coil and capacitor connected in parallel, acts like a large resistor at the desired signal frequency, and acts like a short circuit at all other signal frequencies. The frequency which the tuned circuit selects is changed by adjusting the electrical size of either the coil or the capacitor.

After the desired signal is selected, the audio information must be extracted from the modulated RF waveform by the "detector" circuit. First the signal is "rectified," which means that either the top half or the bottom half of the signal is removed. After the signal is rectified, it is "filtered" which means that the remaining RF is removed from the audio signal. The audio signal is then coupled to the amplifier where it is amplified and applied to the speaker or earphone.

HOW TO BUILD A SIMPLE TRANSISTOR RADIO

PARTS REQUIRED

1 Experimental chassis - wired for Lesson VI
1 RF tuning coil
1 180 $\mu\mu$f silver mica capacitor
1 .05 μfd disc capacitor
1 Earphone
1 Coil mounting bracket
2 #6 x 3/8" sheet metal screw
1 1000 Ω resistor (brown-black-red)
1 10 KΩ resistor (brown-black-orange)
1 47 KΩ resistor (yellow-violet-orange)
1 1 megohm resistor (brown-black-green)

BECOMING FAMILIAR WITH THE NEW PARTS

The RF TUNING COIL. When a tuning coil and a capacitor are connected in parallel, a tuned circuit is formed. The construction of a tuning coil is shown in Figure 7K. By turning the screw, the adjustable powdered iron core moves up and down inside the coil. As the adjustable core is moved, it changes the electrical size of the coil, and changing the size of the coil changes the frequency to which the circuit tunes.

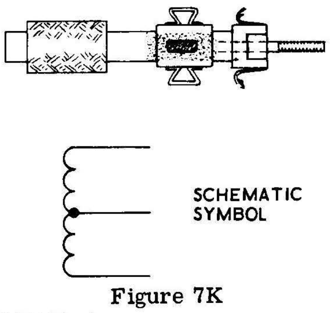


Figure 7K

EXPERIMENT 1

To build a simple transistor radio.

Refer to Figure 7L for the following steps.

( ) Make sure the ON-OFF switch is turned OFF and then remove all resistors and capacitors from the experimental chassis. Place the 10 μfd and 100 μfd capacitors, and the 8200 Ω resistor with the Parts Required for this experiment.

Remove the following wires from the experimental chassis.

( ) Disconnect the remote speaker wires from the remote terminal strip.

( ) The wire from the #6 solder lug to lug 2 of the speaker.

( ) The wire from lug 1 of the remote terminal strip to lug 1 of the ON-OFF switch.

( ) The wire from lug 2 of the remote terminal strip to lug 1 of the 100 KΩ potentiometer.

( ) Disconnect the wire from lug 1 of the speaker and connect it instead to lug 1 of the remote terminal strip.

( ) Connect a length of hookup wire from lug 2 of the 100 KΩ potentiometer (S) to lug 5 of terminal strip B (S).

( ) Connect a length of hookup wire from lug 2 of the remote terminal strip (S) to the #6 solder lug (NS).

( ) Mount the coil mounting bracket in position between terminal strips A and B as it is shown in Figure 7L. Install two #6 x 3/8" sheet metal screws into the bracket from below the chassis to hold it in place.

( ) Mount the RF tuning coil in the bracket by pressing it into position from the rear of the bracket. Rock the coil back and forth slightly until the two tabs snap into place.

( ) Connect the green lead of the RF tuning coil to lug 1 of terminal strip B (NS).

( ) Connect the red lead of the RF tuning coil to lug 5 of terminal strip A (NS).

( ) Connect the black lead of the tuning coil to lug 6 of terminal strip A (NS).

( ) Connect a .05 μfd disc capacitor from lug 1 of the 100 KΩ potentiometer (S) to lug 1 of terminal strip B (S).

( ) Connect a 10 KΩ resistor from lug 3 (NS) to lug 4 (S) of terminal strip B.

( ) Connect a 47 KΩ resistor from lug 1 (S) to lug 3 (NS) of terminal strip A.

( ) Connect a 1 megohm resistor from lug 2 (NS) to lug 3 (S) of terminal strip A.

( ) Connect a length of hookup wire from lug 6 of terminal strip B (S) to lug 5 of terminal strip A (NS).

( ) Connect a 1000 Ω resistor from lug 4 of terminal strip A (NS) to lug 5 of terminal strip A (NS).

( ) Connect the minus (-) lead of a 10 μfd 10 volt electrolytic capacitor to lug 3 of terminal strip B (S). Connect the positive (+) lead of this capacitor to lug 2 of terminal strip A (NS).

( ) Connect the positive (+) lead of a 100 μfd 10 volt electrolytic capacitor to lug 5 of terminal strip A (NS). Connect the negative (-) lead of this capacitor to lug 4 of terminal strip A (S).

( ) Connect an 8200 Ω resistor from lug 2 (S) to lug 5 (NS) of terminal strip A.

( ) Connect a 180 μμf silver mica capacitor from lug 5 (NS) to lug 6 (NS) of terminal strip A.

( ) Connect the earphone wires under the screws of the remote terminal strip.

( ) Unsolder the two 25 foot wires from the remote speaker, they will be used for the antenna of your radio. You can use either one of these wires as a 25 foot antenna or both of them soldered together as a 50 foot antenna. Start with one of the wires, and then later, if you wish, you can add the other wire to the end of the first one to see if you can receive additional stations.

( ) Connect one end of a 25 foot (antenna) wire to lug 6 of terminal strip A (S). Route the other end of the wire as high as possible around inside the house, or preferably, out through a window to a nearby tree. If you live near strong stations, running the wire around inside the house will no doubt be sufficient. If all the stations you receive are weak or far distant, an outside antenna will be necessary. Often connecting a wire to a bedspring, metal lamp base or one of the wires of a TV antenna will work very well.

( ) Make a "ground" connection by connecting a wire from lug 5 of terminal strip A (S) to the closest available ground connection. A ground connection is one that connects to the earth around your home. It can be made by connecting the ground wire to a metal stake driven into the earth or by connecting the wire to an unpainted place on a radiator or water pipe (all water pipes eventually connect to the ground outside the house). NOTE: Often, if a local station is too strong, your receiver may work better without a ground connection. In this case the sound becomes quieter, and you would be able to tune in more stations. Experimenting will often show you how to get the best results.

( ) Turn the ON-OFF switch ON and turn the VOLUME level up to maximum. Listen in the earphone, turn the screw of the RF tuning coil to tune in a station. The slug of the RF tuning coil may be tuned best by using a small screwdriver.

If your location is close to any powerful radio broadcasting stations you may notice the following interesting effect. Even when the ON-OFF switch is turned Off - you can still hear the radio station weakly in the earphone. This happens because the signal received by your antenna has enough power to send a small signal current through the circuit. This small signal current is detected by passing through the transistors, and then it is filtered by the earphone.

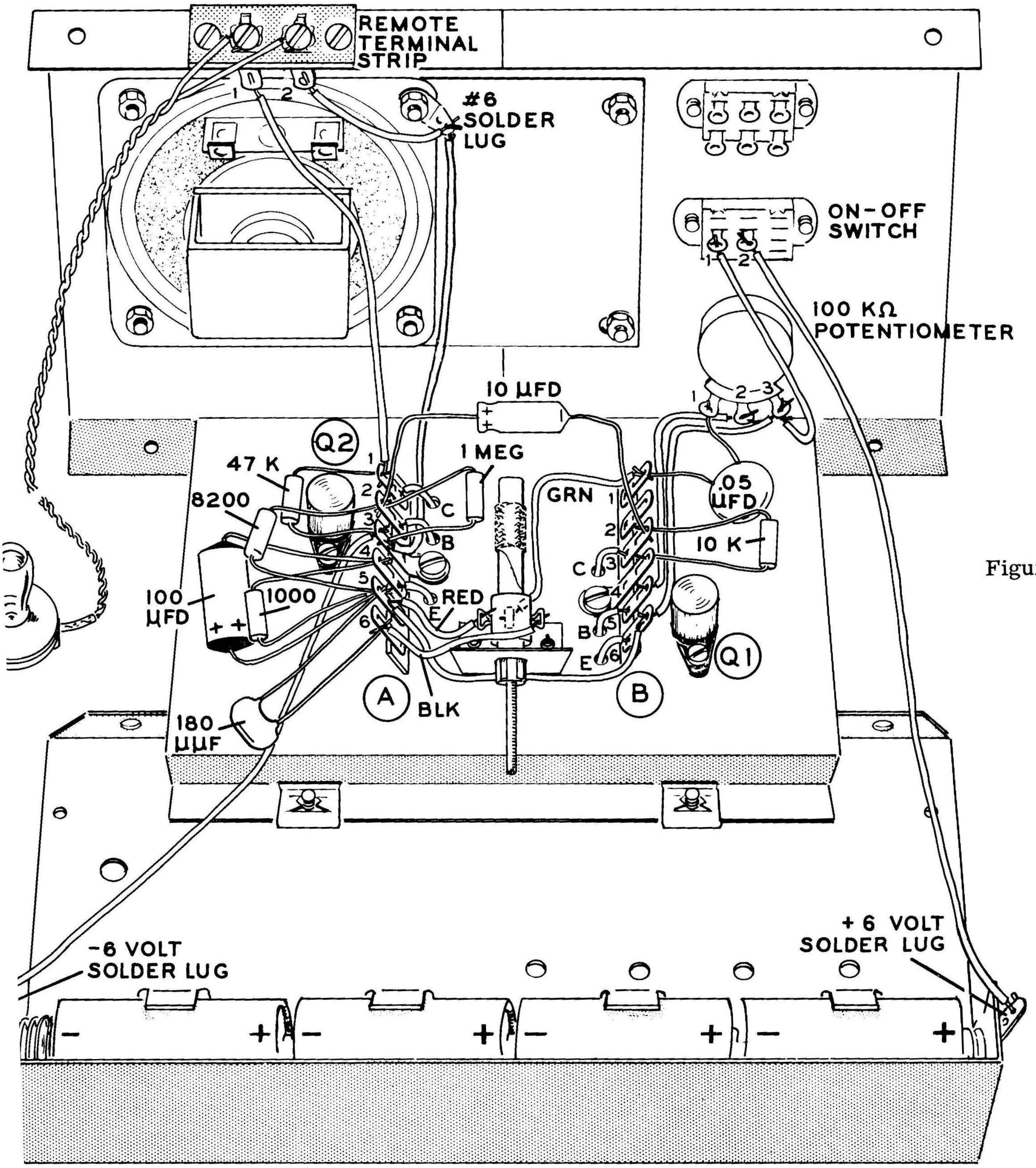

REMOTE
TERMINAL
STRIP
1
2
#6
SOLDER
LUG
ON-OFF
SWITCH
1
2
100 KΩ
POTENTIOMETER
1
2-3
10 μFD
Q2
1
47 K
1 MEG
2
8200
C
3
B
4
100
μFD
5
1000
RED
E
6
GRN
1
.05
μFD
2
10 K
C
3
4
B
5
E
6
Q1
A
BLK
B
180
μμF
-6 VOLT
SOLDER LUG
+ 6 VOLT
SOLDER LUG

Figure 7L

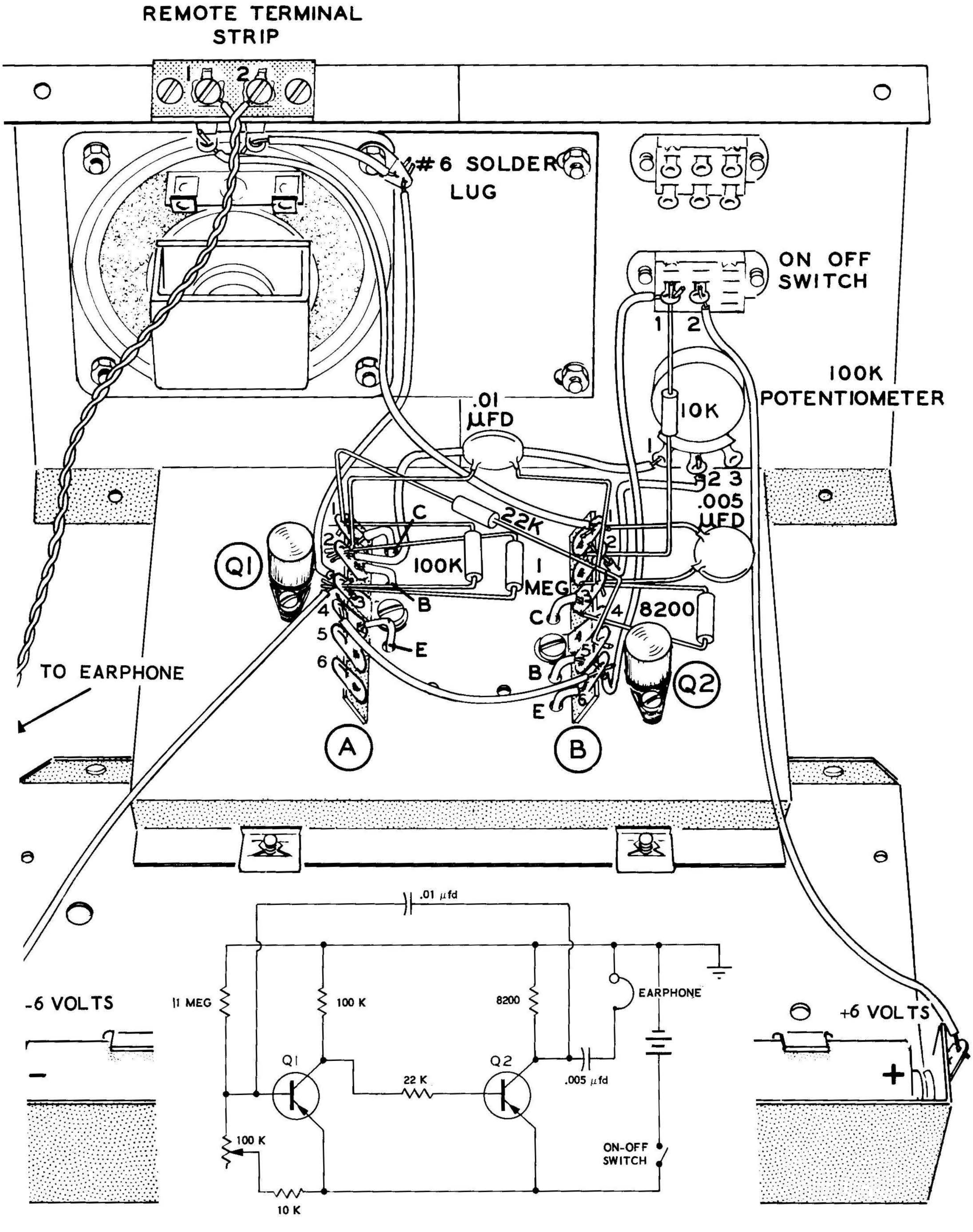

REMOTE TERMINAL STRIP
#6 SOLDER LUG
ON OFF SWITCH
100K POTENTIOMETER
10K
.01 µFD
22K
.005 µFD
100K
1 MEG
8200
Q1
Q2
A
B
C
E
TO EARPHONE
-6 VOLTS
+6 VOLTS
.01 µfd
11 MEG
100 K
8200
EARPHONE
Q1
Q2
22 K
.005 µfd
100 K
ON-OFF SWITCH
10 K

Figure 8G

DISCUSSION

In the experiment for this lesson you assembled and wired the two-transistor radio shown in the schematic of Figure 7L on your experimental chassis. The input signal was received by your antenna, and from there it went to the tuned circuit. The stations that you tuned in were connected from a wire part way down the coil, through the .05 μfd capacitor, to the volume control. From the volume control the signal was applied to detector transistor Q1.

The rectified RF signal (1/2 of the original signal received from the tuned circuit) was coupled from the Collector of transistor Q1, through the 10 μfd capacitor, to the Base of transistor Q2. Transistor Q2 amplified the signal and applied it to the earphone. The earphone changed the signal back into sound, and also served as a mechanical filter to eliminate the RF portion of the signal.

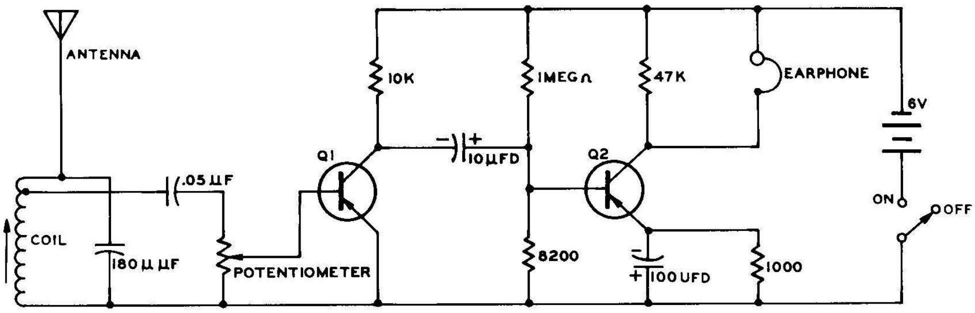


Figure 7L

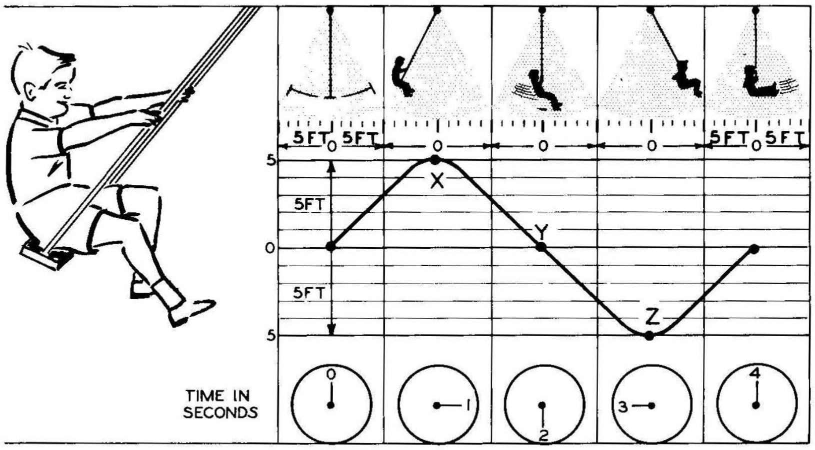
LESSON VII

QUESTIONS

1. It is (common practice, impractical) to broadcast pure audio signals from radio stations.
2. What do you call the type of signal that is received on the broadcast band of your radio?
3. Where is the audio information contained in this signal?
4. What are the three things your radio must do to allow you to hear the audio information contained in the modulated RF signal?
5. A radio is tuned by means of a tuned circuit. How does this tuned circuit act with respect to the signal you are tuned to?
6. What does it mean to detect a signal?
7. What two things must the detector circuit do to the signal it receives?
8. Transistor Q1 in Figure 7H is actually turned on and off by the input signal. (True, False)
9. The earphone, like a crystal microphone, also contains a __________ and a __________.

LESSON VIII

WHAT MAKES A TRANSISTOR OSCILLATOR WORK?



MOTION OF THE BOY IN THE SWING PUT IN FORM OF A GRAPH.

Figure 8B

An "oscillator" is a circuit used to create AC signals. These AC signals may be either audio signals or RF signals. The RF signals used by radio stations in their modulated broadcast signals are created by RF oscillator circuits. Oscillators are also widely used in all types of radio transmitters, television, and many other types of electronic equipment.

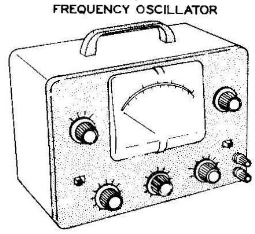
Figure 8A shows a commercial "audio frequency oscillator" such as might be found in an electronics laboratory or repair shop. The audio signal that this oscillator creates is used to test audio circuits. The meter shows how large the oscillator's signal is, and the knobs adjust the frequency and amplitude (or size) of the output signal. The purpose of this lesson is to show you what an oscillation is, and how an oscillator such as this one creates a signal.

By definition, to oscillate means to swing back and forth. A common example of this would be a child on a swing as shown in Figure 8B. The graph in the center of Figure 8B, shows how many seconds it takes the swing to move in each part of the cycle, and how far it moves in feet.

Four seconds of time are shown on the clocks horizontally. Ten feet, five feet each side of center, are shown vertically on the graph.

The swing starts at the center position, position Y, 0 feet. At the end of one second, it has moved back five feet to position X. At the end of two seconds, it moves through the Y position (or 0). At the end of three seconds, the swing moves to position Z, 5 feet on the other side of the 0 position. At the end of four seconds, the swing returns again to position Y, where the cycle begins all over again.

AUDIO FREQUENCY OSCILLATOR



10 CYCLES— 100,000∿ (100 KC)

Figure 8A

Notice, that when the motion of the swing is drawn in this manner, it takes the form of a sine wave. This is a mechanical oscillator. In an electrical oscillator circuit, the current must be made to oscillate back and forth in this same manner; the current must flow first in one direction and then in the other direction.

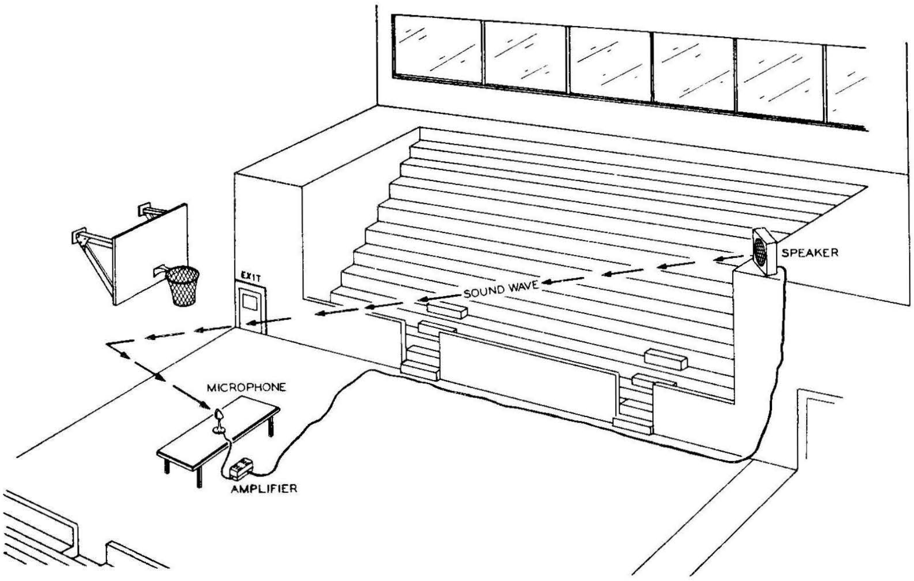


Figure 8C

You would have to give the boy a small push during each cycle, if you wanted to keep him swinging back and forth without gradually lessening the 10 foot distance. The same thing would be true in an electrical circuit, a little extra current (or push) would have to be added to the circuit from the power supply during each cycle, to sustain the oscillation at the same level (or voltage).

To generate an AC waveform, then, something is needed that will cause the current to reverse itself at a regular rate; first it must go one way and then it must go the other way, just like the motion of the swing. The circuits that generate these AC waveforms are "oscillator" circuits. AC waveforms may also be generated by using a large motor-generator, such as the one at the electric power station, when large amounts of power are desired. An example of a signal of this type is the AC current received in homes and factories from the power stations.

WHAT CIRCUITS NEED TO OSCILLATE

When some of the output signal of an amplifier is connected back to its own input in such a way that it adds more voltage to its own input signal, the amplifier begins to oscillate. As the output signal begins to add to its own input signal, the currents in the amplifier begin to run away with themselves, and the circuit keeps on oscillating, even without an input signal. The circuit will keep on oscillating until the connection that sends the signal from the output to the input is removed. A common example of this type of an oscillation is shown in Figure 8C. When the volume of a public address amplifier is turned up too high, the signal from the speakers (output) begins to be carried back to the microphone (input) through the air, and an oscillation in the form of a loud squeal is heard.

The name "feedback" is given to that part of the output signal that is connected back to the input of an amplifier. This name can easily be remembered by thinking of its meaning, that some of the output is fed back to the input of an amplifier.

An oscillator circuit must be connected so that the feedback will ADD to its own signal at the input. How this feedback could either add or subtract from its own signal at the input is shown in Figure 8D and Figure 8E.

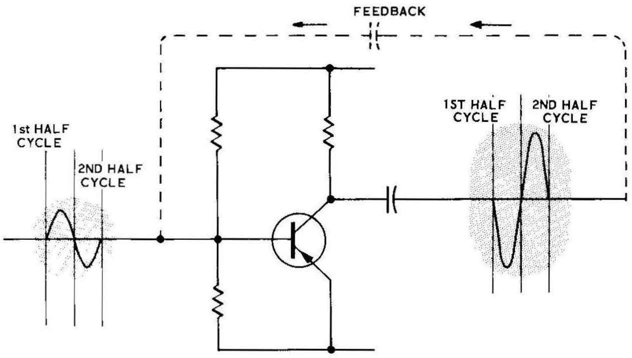


Figure 8D

One of the inherent properties of an amplifier is that signals or sine waves are inverted each time they pass through each transistor of an amplifier. This is shown in Figure 8D. Note that the output signal is turned over, or inverted, from the way it was at the input. The first half cycle was increasing at the input, and at the output of the amplifier it is shown decreasing. The second half-cycle is shown decreasing at the input and it is increasing at the output of the amplifier. If some of this output signal were connected back to the input by a capacitor, as shown, the two signals would be going in opposite directions. The output signal would try to cancel out, or decrease, some of the input signal.

The amplifier of Figure 8E contains two amplifier stages, Q1 and Q2. In this case, the signal from the input of the amplifier has been inverted in transistor Q1 just as it was in the previous circuit. The inverted signal from transistor Q1 is inverted once again in transistor Q2. Now, when the signal at the input of the amplifier increases, the signal at the output of the amplifier also increases the same way at the same time. When the signal at the input of the amplifier goes in the negative direction, the signal at the output of the amplifier also goes in a negative direction.

Now, when the output of the two stage amplifier is fed back to the input, it adds to the input signal instead of subtracting from it. This causes an oscillation to occur, and once this oscillation has been started, no input signal is needed. The circuit oscillates back and forth just like the swing did and only a little additional push from the power supply is needed to keep the oscillator going.

In actual circuits, just turning on the ON-OFF switch starts current increasing through the oscillator circuit, and this action, all by itself, starts the oscillator oscillating.

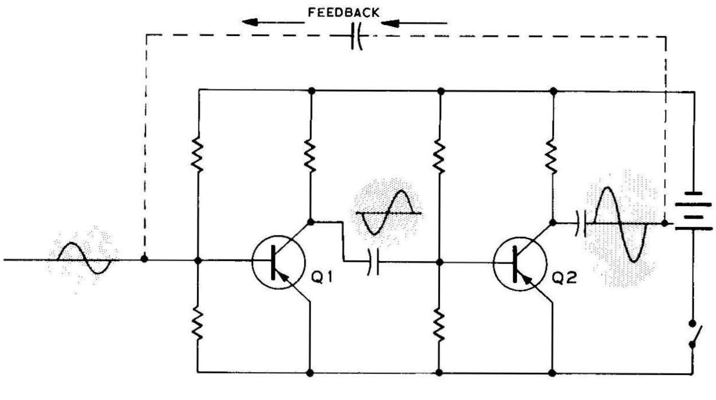


Figure 8E

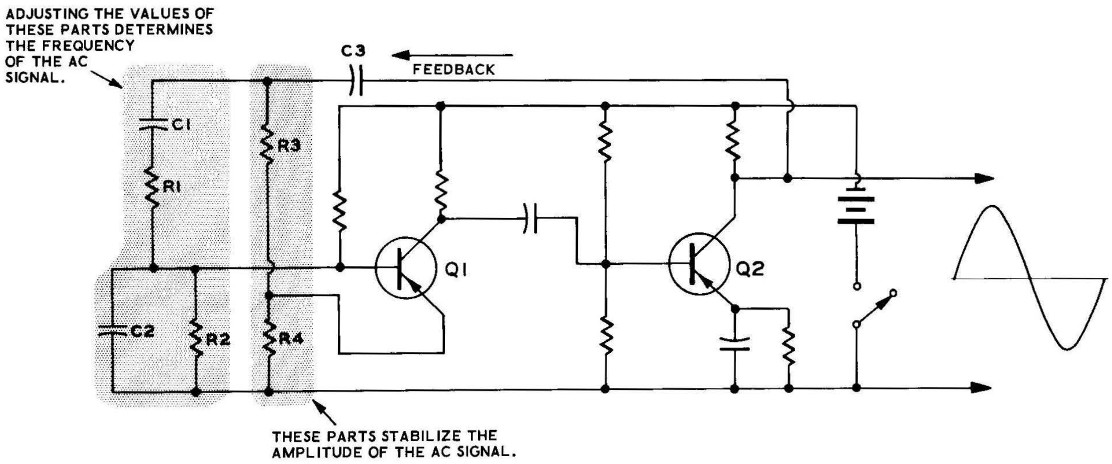


Figure 8F

A COMMON AUDIO OSCILLATOR CIRCUIT

Figure 8F shows the circuit diagram for a standard type of audio frequency oscillator. The name for this type of oscillator is the "wien bridge" oscillator. Notice that the oscillator contains a two stage amplifier just like the oscillator of Figure 8E. Capacitor C3 feeds a portion of the output signal back to the input of the amplifier.

Some additional parts shown in the shaded areas have been added to the input of the amplifier to adjust the frequency and regulate the amplitude of the oscillation. Changing the values of C1, C2, R1 and R2, shown in the shaded part at the left, changes the frequency of the AC signal. Resistors R3 and R4 in the other shaded area are used to stabilize the output amplitude of the AC signal.

SUMMARY

An oscillator is the circuit that is used to create an AC signal. This AC signal may be either at an audio rate or an RF rate.

A musical instrument, such as a violin, would be one kind of mechanical oscillator. By moving the bow across the strings, the wooden box of the violin would vibrate (or "oscillate"). The oscillations of the wooden box vibrate the air around the box, and these vibrations of air are heard by your ears as sounds.

To oscillate, some of the output signal from an amplifier must be connected back to the input. This signal that is connected back is called "feedback," and it must be connected in such a way that it will add more signal to the input signal. This causes the current in the amplifier to increase as far as it will go in one direction. The swinging back and forth of the current, first in one direction and then in the other direction, at a regular rate, is called an oscillation.

HOW TO BUILD A TRANSISTOR AUDIO OSCILLATOR

PARTS REQUIRED

1 EK-3 Experimental chassis - wired for Lesson VII
1 .005 μfd capacitor
1 .01 μfd capacitor
1 22 KΩ resistor (red-red-orange)
1 100 KΩ resistor (brown-black-yellow)

EXPERIMENT 1

To build an audio oscillator.

Refer to Figure 8G (fold-out from Page 74) for the following steps.

( ) Disconnect and remove all resistors and capacitors from the chassis. Place the 8200 Ω, 10 KΩ, and 1 megohm resistors with the Parts Required for this experiment.

( ) Disconnect the red, black, and green wires of the coil from the lugs of terminal strips A and B. Now remove the coil and bracket from the chassis by removing the two sheet metal screws from below the chassis.

Remove the following wires from the chassis.

( ) The wire between lug 1 of the ON-OFF switch and lug 3 of the potentiometer.

( ) The wire between lug 1 of the remote terminal strip and lug 1 of terminal strip A.

( ) The wire between lug 6 of terminal strip B and lug 3 of the potentiometer.

( ) The wire between lug 5 of terminal strip B and lug 2 of the potentiometer.

( ) Connect a length of hookup wire from lug 1 of the remote terminal strip (S) to lug 1 of terminal strip B (NS).

( ) Connect a length of hookup wire from lug 3 of terminal strip A (NS) to the #6 solder lug (S).

( ) Disconnect the end of the wire from lug 5 of terminal strip A (this is the wire that comes from lug 6 of terminal strip B). Connect this wire to lug 4 of terminal strip A (S).

( ) Connect a hookup wire from lug 2 of the potentiometer (S) to lug 2 of terminal strip B (NS).

( ) Connect a hookup wire from lug 1 of the potentiometer (S) to lug 2 of terminal strip A (NS).

( ) Connect a length of hookup wire from lug 1 of the ON-OFF switch (NS) to lug 6 of terminal strip B (S).

( ) Connect a 1 megohm resistor from lug 2 (NS) to lug 3 (NS) of terminal strip A.

( ) Connect a 100 KΩ resistor from lug 1 (NS) to lug 3 (S) of terminal strip A.

( ) Connect a .005 μfd capacitor from lug 1 (S) to lug 3 (NS) of terminal strip B.

( ) Connect a 10 KΩ resistor from lug 2 of terminal strip B (S) to lug 1 of the ON-OFF switch (S).

( ) Connect the 8200 Ω resistor from lug 3 (NS) to lug 4 (S) of terminal strip B.

( ) Connect a .01 μfd capacitor from lug 2 of terminal strip A (S) to lug 3 of terminal strip B (S).

( ) Connect a 22 KΩ resistor from lug 1 of terminal strip A (S) to lug 5 of terminal strip B (S).

( ) If they are not already connected, connect the wires of the earphone under the screws of the remote terminal strip.

( ) Turn the ON-OFF switch ON and listen to the sound in the earphone. Since the circuit is now connected as shown by the Schematic of Figure 8G, the sound you hear in the earphone is the oscillation coming from this audio oscillator.

NOTE: The ground (⏚) symbol, used in Schematic 8G, means that all parts connected to these points (to the negative battery voltage wires) are also connected to the metal of the chassis. Often, the metal of the chassis can be used in place of wires to connect from one point to another. This is done in this experiment where the metal of the chassis is used for a minus voltage connection between lug 3 of terminal strip A and lug 4 of terminal strip B.

( ) Turn the 100 KΩ control back and forth and notice that this changes the tone of the oscillator.

( ) Turn the ON-OFF switch OFF.

( ) Unsolder and remove the .01 μfd and .005 μfd capacitors.

( ) Connect the .01 μfd capacitor from lug 1 (S) to lug 3 (NS) of terminal strip B.

( ) Connect the .005 μfd capacitor from lug 2 of terminal strip A (S) to lug 3 of terminal strip B (S). You have now connected the .005 μfd capacitor in the circuit in place of the .01 μfd feedback capacitor.

( ) Turn the ON-OFF switch on and listen to the sound in the earphone. Notice that the tone is much higher than it was previously. This is because the electrical size of the feedback capacitor (which helps determine the frequency) has been made smaller. Turn the 100 K control and note the change in tone (frequency).

( ) Turn the ON-OFF switch OFF.

DISCUSSION

In the Experiment of Lesson VIII you wired an audio oscillator on your experimental chassis. Notice that this audio oscillator circuit contains the requirements that were termed necessary for oscillation in the theory section of this lesson; the two-stage audio amplifier, and the means to feed back some of the output signal of the amplifier back to its input.

The output signal from transistor Q2 connects back to the input of transistor Q1 through the feedback capacitor. The output signal adds to the input signal at Q1, resulting in oscillation.

The frequency at which the circuit oscillates is determined by the value of the feedback capacitor and by the amount of resistance in the 100 K ohm potentiometer.

In the second part of the experiment, when the .005 μfd capacitor was used in place of the .01 μfd feedback capacitor, the frequency changed quite noticeably. The frequency also varied quite widely by changing the size of the 100 K ohm potentiometer.

LESSON VIII

QUESTIONS

1. What is an oscillator circuit?

2. What is the definition of the word "oscillate?"

3. The AC power that is sent to your home from the power company is generated by a large oscillator circuit at the power station. (True, False)

4. What is the cause of the loud squeal you so often hear in a public address system?

5. What is "feedback?"

6. An oscillator circuit must be connected so that the feedback will (add to, subtract from) its own signal at the input of the amplifier.

7. Each time a signal passes through an amplifier stage, it is inverted (turned over). (True, False)

8. In actual circuits, just turning on the ON-OFF switch starts the circuit oscillating. (True, False)

LESSON IX

WHAT MAKES A TRANSISTOR BROADCASTER WORK?

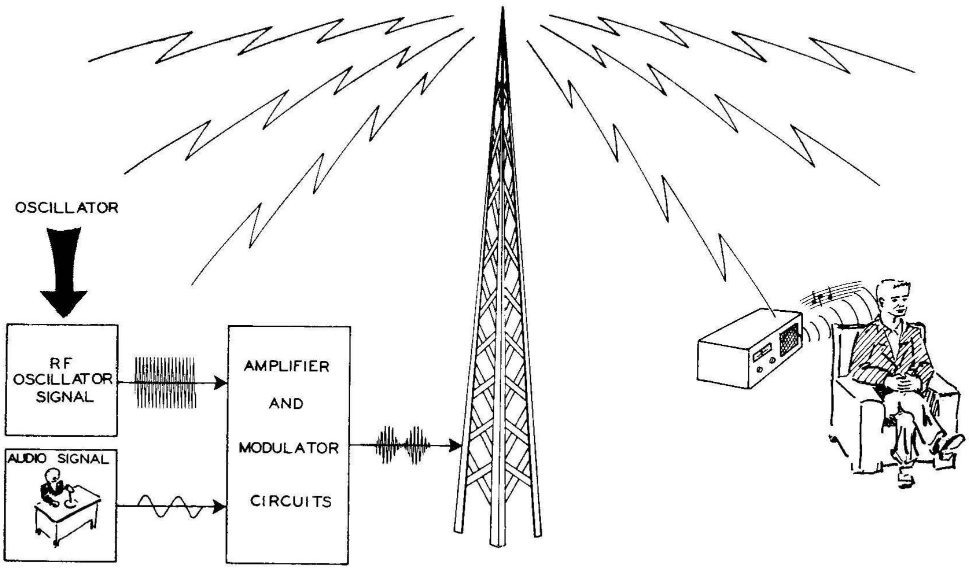


Figure 9A

Lesson VIII explained how an AC signal was generated by an oscillator circuit. The basic principles of all oscillator circuits were also explained, with the emphasis on oscillators that generated audio (AF) signals. This lesson will explain how a typical Radio Frequency (RF) oscillator operates; although the principles are the same as for audio oscillators, the circuits are somewhat different.

After the RF oscillators have been introduced, you will be shown how audio information is impressed on the RF oscillation, to create a "modulated RF signal." The modulated RF signal can then be transmitted from a broadcaster through the air to your radio receiver. (A "broadcaster" is also called a radio transmitter.

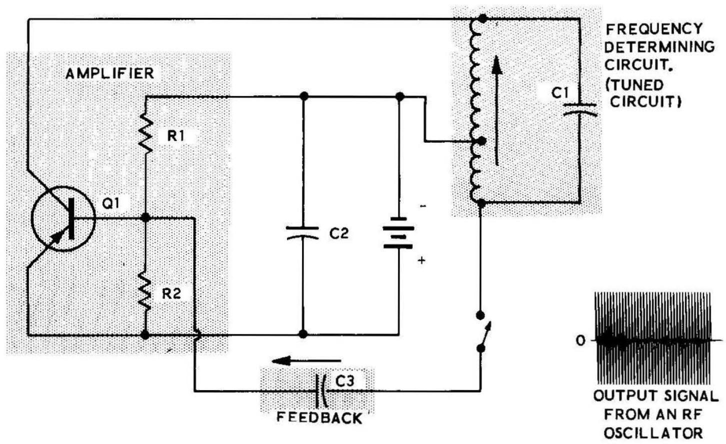


Figure 9B

AN RF OSCILLATOR

RF oscillators have the same requirements as audio oscillators; an amplifier, feedback, and a frequency determining circuit. In the RF oscillator circuit of Figure 9B these requirements are shown in their three separate (shaded) areas. The amplifier area includes transistor Q1 and bias resistors R1 and R2. The frequency determining circuit of the oscillator consists of capacitor C1 and the coil. The electrical size of the coil can be adjusted. Capacitor C3 at the lower part of the schematic provides a path to apply feedback to the input of amplifier transistor Q1.

The amplifier . In this oscillator, like most RF oscillators, a way has been found so that a 1-transistor amplifier can be used instead of a two-transistor amplifier. The input signal at the Base of the amplifier is inverted only one time in the amplifier instead of twice as in the previous (audio) circuits. The signal is inverted the second time in the tuned circuit because of the way the feedback capacitor and capacitor C2 are connected to it.

Resistors R1 and R2 are a voltage divider which supply proper operating bias for the Base of the transistor. The output signal from the Collector of the amplifier is applied to the tuned circuit instead of to a resistor as it has been in the other circuits you have studied.

Feedback. To provide feedback, some of the output signal from the tuned circuit is connected back through capacitor C3 to the input of the amplifier. Since this feedback signal has been inverted twice (once in the transistor and once in the tuned circuit), it adds to the signal at the input of the amplifier and the circuit begins to oscillate.

Actually, since no external input signal is connected to the oscillator, the oscillation starts all by itself when the ON-OFF switch is turned ON. Turning the switch ON causes the current in the circuit to start to flow. When the current starts to flow, it appears just like the first part of a signal to the circuit, causing an oscillation to start. From this point on, no external input signal is needed.

The tuned circuit. It is a property of a tuned circuit to contain electrical energy. In it, a current circulates back and forth, first one way and then the other way between the coil and capacitor. The current circulating back and forth in the tuned circuit is just like the swing of the previous lesson. The swing contains mechanical energy as it moves back and forth, and the current in a tuned circuit contains electrical energy as it moves back and forth.

The current will circulate back and forth in the tuned circuit at only one frequency, and this frequency depends on the electrical size of the coil and capacitor. This frequency is called the "resonant frequency."

If the swing of the previous lesson did not get pushed during each cycle, it would gradually swing less and less, until it stopped. To keep

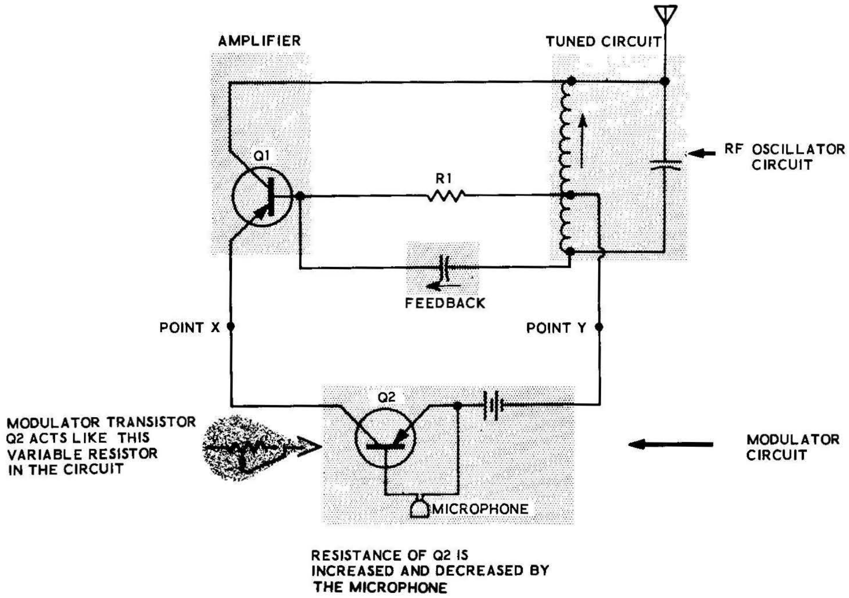


Figure 9C

it swinging back and forth for the same distance, it would have to have a small amount of push at one part of each cycle. The circulating currents in the tuned circuit act in the same manner; they also must have a small amount of push at one part of each cycle to keep them from gradually becoming smaller and smaller. It is the purpose of the amplifier part of the circuit along with the feedback circuit to supply this "push" to the tuned circuit.

When the electrical size of the coil or capacitor is changed, it causes the current to circulate back and forth either faster or slower. This changes the frequency of the RF oscillation in the tuned circuit, therefore it changes the operating frequency for the whole oscillator circuit.

MODULATING THE RF OSCILLATOR

Figure 9C shows a simple RF oscillator circuit with a simple modulator circuit connected to it. (The "modulator" circuit puts the audio information on the "modulated RF signal.") Notice that modulator transistor Q2 is in series with the battery that supplies the power to the RF oscillator. The modulator transistor acts like a variable resistor connected in series with the battery voltage and the RF oscillator circuit. The negative side of the battery connects directly to the RF oscillator circuit, and the positive side of the battery connects to the RF oscillator circuit through the resistance of transistor Q2.

The oscillator circuit itself is much like the oscillator circuit of Figure 9B; it contains the three necessary ingredients of an oscillator, the tuned circuit, the amplifier, and feedback. Resistor R1 is used to supply the correct bias voltage for the Base of transistor Q1.

The amount of voltage supplied to the RF oscillator circuit is increased or decreased by transistor Q2, and transistor Q2 increases or decreases its resistance according to the sound signal from the microphone. The actual change in resistance in Q2 is caused by the small audio signal current that flows through the Base of transistor Q2 from the microphone. (No bias resistors are shown for transistor Q2 so this circuit will be easier to understand).

When the audio signal causes the resistance of Q2 to become larger, more battery voltage is dropped across it, leaving less battery voltage to be supplied to the RF oscillator circuit. Less voltage applied to the RF oscillator circuit causes a smaller amount of oscillation to occur in the RF oscillator. In the modulated RF signal this would be the smaller amount of RF signal (or the valleys) between the swells.

When the audio signal causes the resistance of Q2 to become smaller, less battery voltage is dropped across it, causing more battery voltage

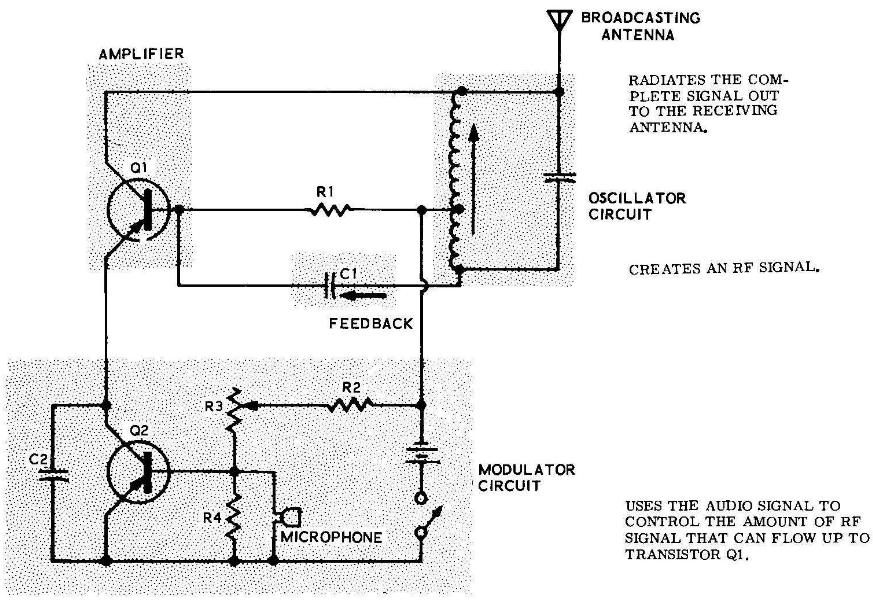


Figure 9D

to be supplied to the RF oscillator circuit. More voltage applied to the oscillator circuit causes a larger amount of oscillation to occur in the RF oscillator. In the modulated RF signal this would be the swells of RF energy.

Figure 9D shows the complete circuit for a simplified radio broadcaster (or transmitter) of Figure 9C. Actually, the drawing of Figure 9C was drawn in an oversimplified fashion in order to better explain how the modulation takes place.

The modulator circuit of Figure 9D actually works in exactly the same manner as the modulator of Figure 9C. The resistance of transistor Q2 is increased or decreased by the audio signal from the microphone, and these increases or decreases change the amount of supply voltage to the RF oscillator circuit. Transistor Q2 and the battery are still in series as they were before, only their relative positions in the circuit have been changed slightly. Modulator stage Q2 allows the audio signal to control the amount of RF signal that is being produced by the oscillator.

Resistors R2, R3, and R4 supply bias voltage to the Base of transistor Q2. Potentiometer resistor R3 makes the bias for transistor Q2 adjustable in order to make sure that transistor Q2 does not distort the audio signal. Capacitor C2 bypasses the RF signal from the oscillator around transistor Q2 so that the RF signal itself does not upset the lower frequency (audio) changes taking place in transistor Q2.

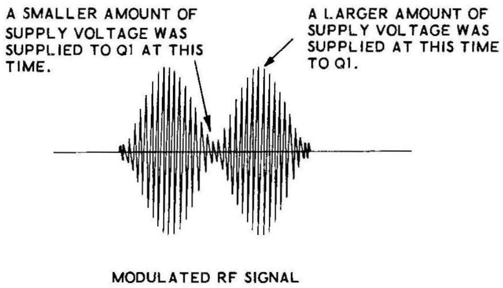


Figure 9E

Figure 9E shows the modulated RF signal and points out the connection between the swells and valleys in this signal and the modulator circuit at the transmitter. The valleys between the swells were caused when only a small amount of supply voltage was supplied to the RF oscillator circuit. The swells themselves were caused when a large amount of supply voltage was allowed to reach the RF oscillator.

The antenna. The complete signal is broadcast from the antenna, since the antenna is connected directly to the tuned circuit. From the antenna the signal is broadcast through the air to the receiver.

SUMMARY

An RF oscillator has three basic requirements. It must have an amplifier, it must supply the right type of feedback from the output back to the input of the oscillator, and it must have a frequency determining circuit.

The amplifier in an RF oscillator usually contains only one transistor. Nevertheless the signal is still inverted twice before it is fed back to the input of the amplifier. The transistor inverts the signal the first time, and it is inverted the second time in the tuned circuit by the manner in which connections are made to it.

In a tuned circuit, current circulates back and forth between the coil and capacitor. The size of the coil and capacitor determine the frequency at which this circulating current, or oscillation, will occur. The amplifier supplies a small amount of push to keep the current circulating.

The modulator circuit allows the audio signal to control the amount of RF signal that will flow in the RF oscillator. In the modulator circuits of this lesson, the modulating transistor acts as a series resistance and varies the amount of supply voltage for the RF oscillator circuit at an audio rate.

HOW TO BUILD A SIMPLE TRANSISTOR BROADCASTER

PARTS REQUIRED

1 Experimental chassis - wired for Lesson VIII
1 1000 Ω resistor (brown-black-red)
1 1500 Ω resistor (brown-green-red)
1 180 $\mu\mu$f capacitor
1 Coil assembly
2 #6 sheet metal screw

EXPERIMENT 1

Refer to Figure 9F for the following steps.

( ) Disconnect the earphone from the experimental chassis.

( ) Disconnect and remove all resistors and capacitors from the experimental chassis. Place the .01 μfd and the .005 μfd capacitors, and the 22 K ohm and the 1 megohm resistors, with the Parts Required for this experiment.

Unsolder and remove each of the following wires from the circuit:

( ) The wire from lug 4 of terminal strip A to lug 6 of terminal strip B.

( ) The wire from lug 1 of the ON-OFF switch to lug 6 of terminal strip B.

( ) The wire from lug 2 of the potentiometer to lug 2 of terminal strip B.

( ) The wire from lug 1 of the remote terminal strip to lug 1 of terminal strip B.

( ) Connect a length of wire from lug 1 of the speaker (S) to lug 5 of terminal strip A (NS).

( ) Connect a wire from lug 2 of the speaker (S) to lug 4 of terminal strip A (NS).

( ) Connect a wire from lug 1 of the ON-OFF switch (S) to lug 4 of terminal strip A (NS).

( ) Connect a wire from lug 1 of the remote terminal strip (S) to lug 3 of terminal strip B (NS).

( ) Mount the coil and coil mounting bracket in position on the experimental chassis with two #6 sheet metal screws from below the chassis.

( ) Connect a wire from lug 1 of terminal strip A (NS) to lug 6 of terminal strip B (S).

( ) Connect the red wire from the coil to lug 3 of terminal strip B (NS).

( ) Connect the black wire of the coil to lug 2 of terminal strip B (NS).

( ) Connect the green wire of the coil to lug 4 of terminal strip B (NS).

NOTE: There are quite a few resistors and capacitors to be mounted for this experiment. Since this is the case, make sure that wires from different lugs or different parts do not touch each other when they should not, or that bare wires from the parts do not touch the metal case of the transistors or the chassis.

( ) Install a .005 μfd capacitor from lug 1 (S) to lug 4 (NS) of terminal strip A.

( ) Connect a 1000 Ω resistor from lug 2 (NS) to lug 4 (S) of terminal strip A.

( ) Connect a 1500 Ω resistor from lug 2 (S) to lug 5 (S) of terminal strip A.

( ) Connect a 22 KΩ resistor from lug 2 of the potentiometer (S) to lug 4 of terminal strip B (NS).

( ) Connect a 1 megohm resistor from lug 4 (S) to lug 5 (NS) of terminal strip B.

( ) Connect a .01 μfd capacitor from lug 2 (NS) to lug 5 (S) of terminal strip B.

( ) Connect a 180 $\mu\mu$f capacitor from lug 2 (S) to lug 3 (S) of terminal strip B.

You have now connected the circuit of the transistor broadcaster as it is shown in the Schematic of Figure 9F.

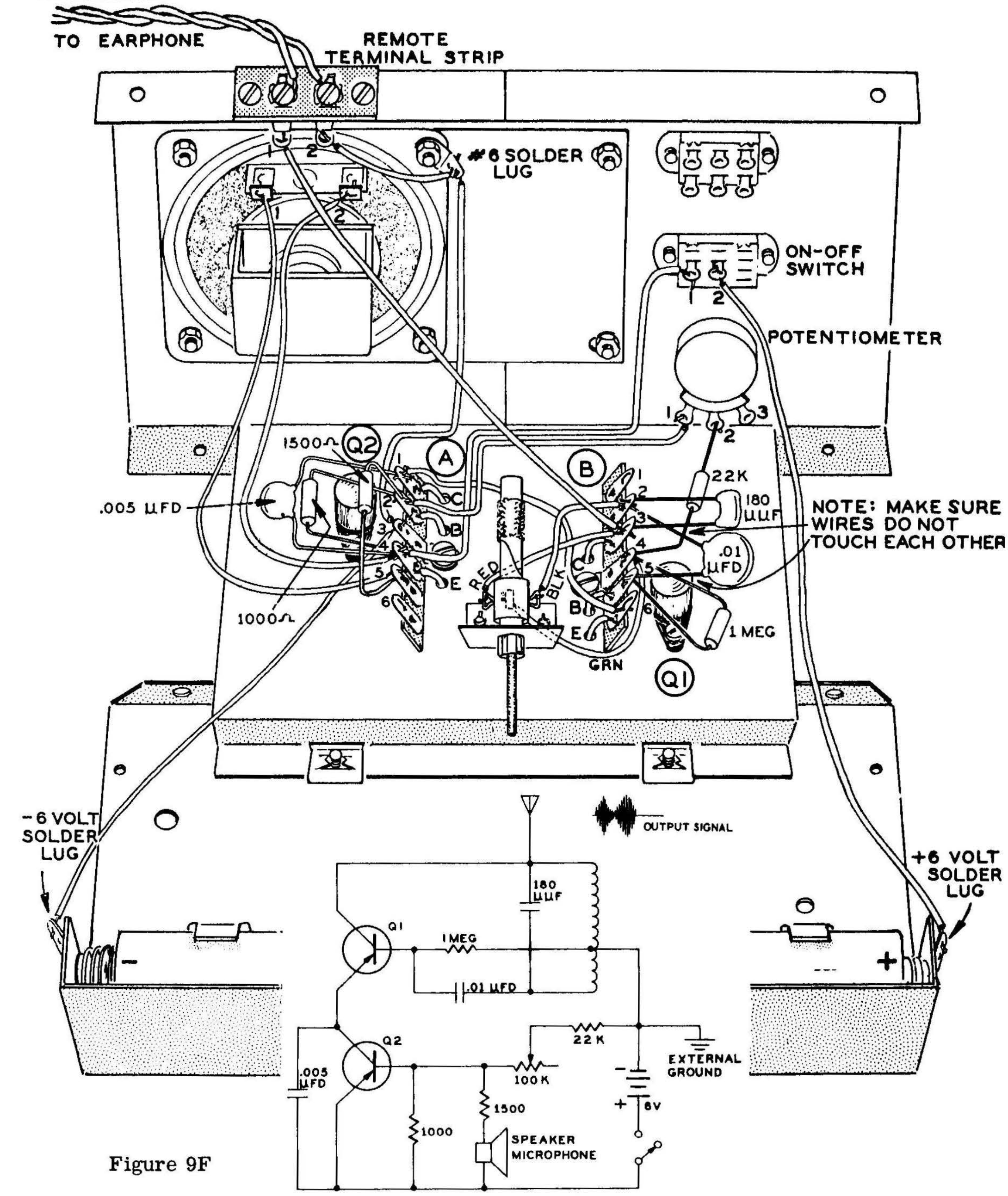


Figure 9F

NOTE: According to law, no more than a 10 foot length of antenna wire can be used with this transmitter. If this wire is connected to some metal object, such as a floor lamp, then the total length of the wire and the metal object should not be more than 10 feet.

( ) Connect a wire (less than 10 feet long) underneath the screw for lug 1 of the remote terminal strip. This wire will act as the antenna for the broadcaster. Tie the other end of this wire to some nearby object, fairly high up in a room in which you are working (a curtain rod, a floor lamp, etc.)

TO TUNE THE TRANSMITTER

( ) Turn the potentiometer to the full clockwise position and turn the transmitter on with the ON-OFF switch.

( ) Tune your radio into a place where there is no station near the high end of the dial, preferably between 1200 and 1600 kc. Usually you will tune in fewer stations during the day than at night.

( ) Place the speaker of your broadcaster up close to the speaker of your radio and turn the screw of the coil all the way in and out until you hear a loud squealing in the speaker. This loud squealing, which is feedback between the radio and the transmitter, indicates that the coil is tuned to approximately the right place for this setting of the dial on your radio.

( ) Move your transmitter away a short distance from the radio and speak into the speaker. Carefully adjust the coil to where your voice sounds loudest in the radio.

( ) Now adjust the potentiometer to where your voice is loudest and clearest in the radio. This completes the adjustment. Turn the broadcaster off when you are through.

DISCUSSION

Study the Schematic of Figure 9F carefully to determine the functions of the various parts of the circuit. The upper part of the schematic, which is the RF oscillator, includes transistor Q1, the tuned circuit, the 1 megohm resistor, and the .01 μfd capacitor.

The lower part of the schematic contains the battery, the ON-OFF switch, and the modulator section. You should recall from the theory part of this lesson that the sound of your voice created an audio signal in the speaker, and that this audio signal controlled the resistance of transistor Q2. As the audio signal increased and decreased the resistance of transistor Q2, it allowed more or less supply voltage to reach the RF oscillator circuit. The overall result was increases and decreases in the amount of RF energy produced by the RF oscillator. These increases and decreases of RF signal appeared as swells and valleys (or narrow spots) in the modulated RF signal.

LESSON IX

QUESTIONS

1. What are the three parts of an RF oscillator?

2. The input signal at the Base of the amplifier of an RF oscillator, is inverted twice in the amplifier. (True, False)

3. What causes the RF oscillator to start oscillating?

4. Current circulates back and forth in a tuned circuit at (many, only one) frequency (or frequencies).

5. What are two ways of adjusting the frequency of an RF oscillator?

6. In the simple modulated RF oscillator circuit, the modulator transistor is connected in (series, parallel) with the battery voltage.

7. In the modulated RF oscillator, the audio signal from the microphone increases and decreases the resistance of the modulator transistor. (True, False)

8. The audio signal controls the amount of RF signal that will flow in the RF oscillator. (True, False)

LESSON X

WHAT MAKES A TRANSISTOR INTERCOM WORK?

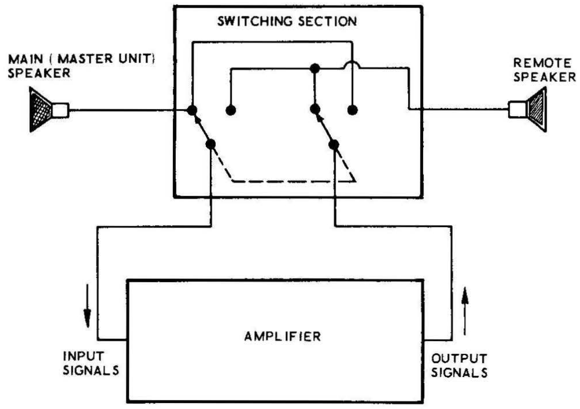


Figure 10A

An intercom is something like a small telephone system. It is an extremely handy way of having instant communications between points at home, on the farm, or in places of business. This lesson will show you how the transistor intercom operates, how to build it, and how to install it.

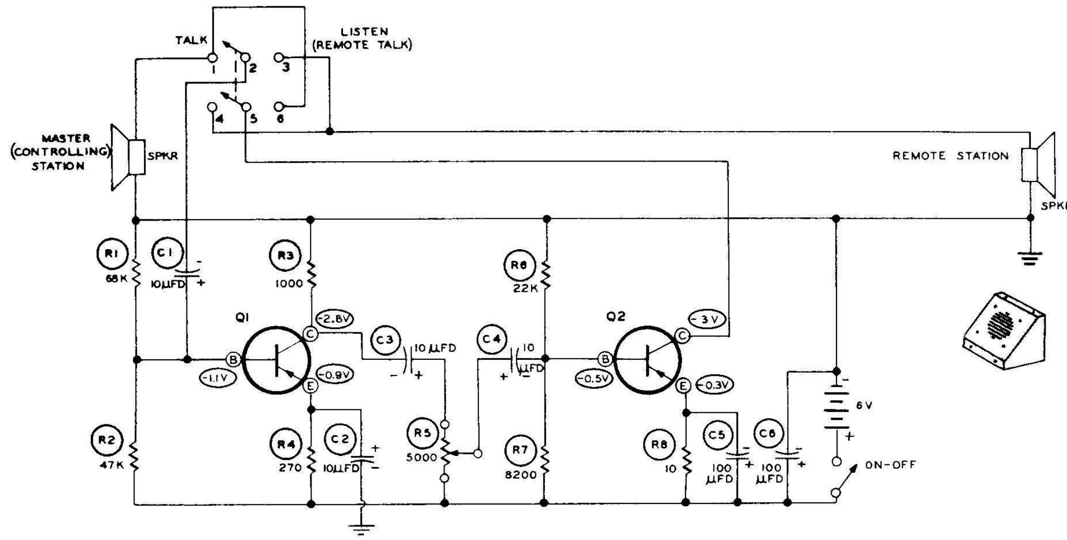
GENERAL CIRCUIT FUNCTIONS

Figure 10A shows a block diagram of a typical intercom unit. A block diagram is one that contains the general units, but not each of the individual parts of an electronic circuit. By using a block diagram the general nature of how an electronic device works can be explained with out getting bogged down with too many details.

An intercom is actually just an amplifier in which the input and output connections can be switched back and forth; the switching is done in such a way that any of the speakers connected to the amplifier can act either as a speaker, or be used backwards, as a microphone. The main parts of any intercom are: the amplifier, the switching section and the speakers (two or more). This kit uses two speakers, the master speaker, which is located at the amplifier, and the remote speaker, which is located some distance away from the amplifier in a separate cabinet.

The purpose of the speakers is to convert the sounds into audio signals (used as a microphone) or to convert the audio signals into sounds (used as a normal speaker). The purpose of the amplifier is to increase the size of the small audio signal that it receives from the switching section. The switching section selects one of the speakers (see Figure 10A) for the input of the amplifier, and another speaker for the output.

Figure 10B shows a complete circuit diagram for the intercom of Figure 10A. This is the circuit for the intercom that you will build as a permanent unit in the experiment part of this lesson. In this intercom, as in most intercoms,



NOTES:

1. All resistor values are in Ω; K = 1000.
2. ⬭ indicates negative DC voltage measurement from point marked to positive (+) battery terminal.
3. Voltages measured with VOLUME control full clockwise and no sound input to speakers. Voltages measured with a 20,000 ohms/volt voltmeter.

Figure 10B

the controlling station (or master station) contains the amplifier, the master speaker, and the switch. The remote station (or remote speaker) shown at the right hand edge of the schematic, would be located at the distant location at the end of the long wires.

The switch in Figure 10B is shown in the TALK position. This means that a person talking into the speaker at the master station, will be heard at the remote speaker. The audio signal from the speaker of the master station passes through lugs 1 and 2 of the switch, and then is connected through capacitor C1 to the Base of transistor Q1. Capacitor C1 keeps the DC bias voltages of Q1 from being applied to the speaker.

The audio signal is amplified in transistor Q1, and from there it is coupled through capacitor C3 to VOLUME control R5. A larger or smaller part of the signal is taken from the arm of VOLUME control R5 and connected through capacitor C4 to the Base of transistor Q2.

The audio signal is amplified a second time in transistor Q2, and from the Collector of Q2 it goes back to the switch again. The signal from the Collector of Q2 passes through lug 5 to lug 4 of the switch. From lug 4 of the switch the signal goes out through the long wire to the remote speaker where it is changed back into sounds again.

If the switch in Figure 10B were in the LISTEN position, lugs 2 and 3 would be connected together and lugs 5 and 6 would be connected together. An audio signal from the remote station would pass from lug 3 to lug 2 of the switch. From lug 2 of the switch, the signal would go through capacitor C1 to the input of the amplifier. The output signal of the amplifier would go from the Collector of transistor Q2 through lug 5 to lug 6 of the switch. From lug 6 of the switch, the signal would pass through the wire to lug 1 of the switch, and from there it would go to the master speaker where it would be changed back into sounds.

THE FUNCTION OF EACH OF THE CIRCUIT PARTS (A REVIEW)

The transistor intercom does not contain any new parts or concepts that you have not studied in previous lessons. The following paragraphs, which review the function of each of these parts, are presented to give you a more thorough understanding of the circuit. Stop after you read the name of the part in the heading for each paragraph, and before you read the explanation, try to explain to yourself what the purpose of this part is in the circuit. By reviewing your knowledge of each of these parts before reading, you will test yourself on how much knowledge you have retained from previous lessons. This will also help you to learn more from the lessons since repetition is one of the keys to learning.

Resistors R1 and R2. Resistors R1 and R2 form a voltage divider which supplies the correct bias voltage between the Emitter and Base of the transistor. The correct bias voltage prevents the audio signals from being distorted when they pass through the transistor.

Capacitor C1. Capacitor C1 is called a coupling capacitor. It allows the AC audio signal from the speakers to pass through it to the Base of transistor Q1, but it blocks the bias voltage on the Base of Q1 from being connected to the speaker.

Transistor Q1. The small current flowing in the Base of transistor Q1 controls the resistance of the transistor, therefore it controls the large current flowing through the transistor from the Emitter to the Collector. The small sound signals that flow to the Base of the transistor are therefore duplicated in the large current that flows to the Collector of the transistor.

Resistor R3. The large Collector current of the transistor flows through resistor R3. Since the Collector current has taken the shape of the audio signal, a large signal voltage now appears across resistor R3.

Resistor R5. Resistor R5 is a variable resistor connected in the circuit as a potentiometer, or variable voltage divider. Either a larger or a smaller portion of the signal voltage applied across it is connected by the arm of the potentiometer through capacitor C4 to transistor Q2.

Capacitors C3 and C4. Capacitors C3 and C4 both have the same function. They allow the AC signal to pass through them, but they block DC voltages from transistors Q1 and Q2 from appearing across the potentiometer.

Resistor R4 and Capacitor C2. Resistor R4 stabilizes the currents flowing through the transistor, thus preventing the transistor from "running away with itself" and causing distortion or burning out by overheating. Capacitor C2 bypasses the AC signal currents around resistor R4 so that the DC voltage across R4 will not be disturbed.

Since the individual parts for amplifier stage Q2 operate in the same manner as the parts for stage Q1 they will not be explained since to explain them would just repeat the previous paragraphs.

Capacitor C6. Capacitor C6 is a stabilizing capacitor which helps to keep undesirable oscillations from occurring in the circuit.

The ground symbol. The ground symbol indicates that all connections on this wire are connected to the metal on the chassis either directly or through a piece of wire.

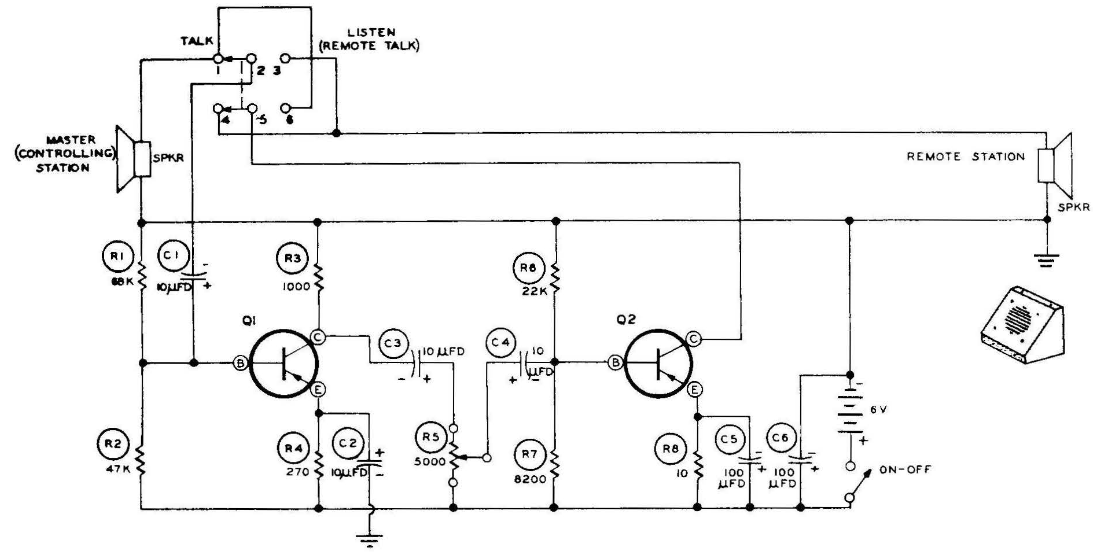


Figure 10C

TRACING THE SIGNALS

The LISTEN-TALK switch is in a different position in each of the following two Schematics, Figures 10C and 10D. To make your understanding of the circuit more thorough, use a colored pencil or a crayon to trace the path of the signal through each of the complete circuits. Start with whichever speaker it originates from, and trace the signals path through the switch and amplifier to the other speaker. After you have finished, correct your own work by re-reading the previous paragraphs in this lesson where the signal paths have been described.

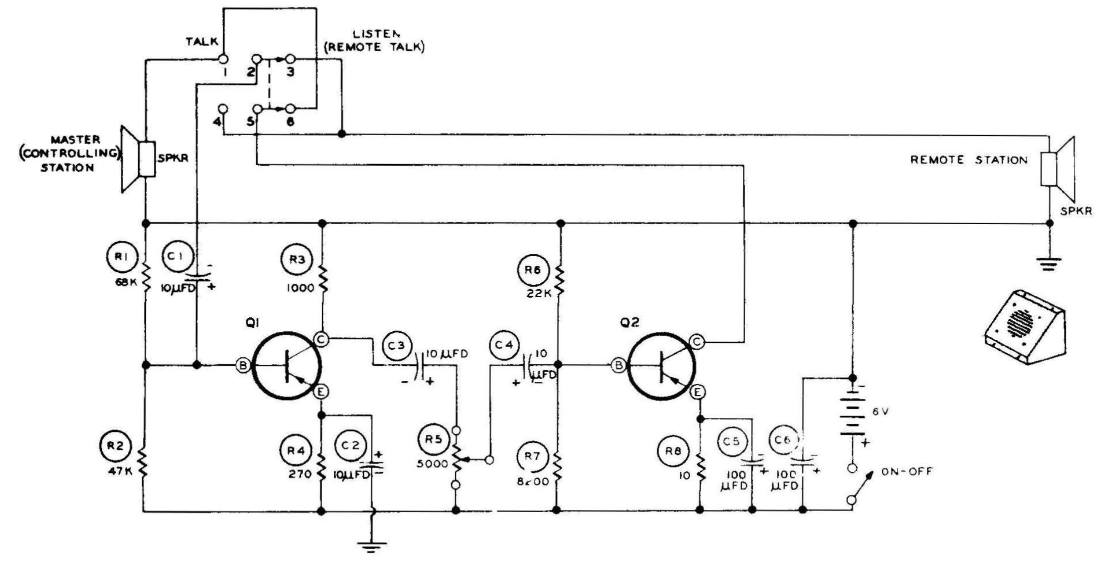


Figure 10D

HOW TO BUILD YOUR COMPLETE TRANSISTOR INTERCOM

PARTS REQUIRED

1 10 Ω resistor (brown-black-black)
1 270 Ω resistor (red-violet-brown)
1 47 KΩ resistor (yellow-violet-orange)
1 68 KΩ resistor (blue-gray-orange)
2 100 μfd electrolytic capacitor
4 10 μfd electrolytic capacitor
8 4-40 x 1/4" screw
3 6-32 x 5/8" screw
4 4-40 nut
6 6-32 nut
4 #4 lockwasher
3 #6 lockwasher
8 #4 speednut
3 spacer
1 Right end panel
1 Left end panel
1 Chassis plate
1 Master back plate
4 Felt feet
1 EK-3 experimental chassis wired for Lesson IX

ASSEMBLING AND WIRING THE INTERCOM

Disassembly of experimental chassis.

( ) Unsolder and remove all resistors and capacitors from the experimental chassis. Save these components.

( ) Unsolder and remove all hookup wires from the experimental chassis, front panel, and battery retaining bracket.

( ) Disassemble the battery bracket from the master bottom plate. Remove and save the hardware on each end of the battery bracket.

( ) Disassemble the experimental chassis from the front panel and master bottom plate.

( ) Remove the remaining parts from the experimental chassis and set them aside to be used later in the following steps.

Chassis Plate Assembly

Refer to Figure 10E for the following steps.

( ) Mount the two transistor sockets at Q1 and Q2 of the chassis plate exactly as shown. Use 2-56 x 3/8" screws and 2-56 nuts.

( ) Mount the two 6-lug terminal strips at A and B exactly as shown. Use 6-32 x 1/4" screws, #6 lockwashers, and 6-32 nuts.

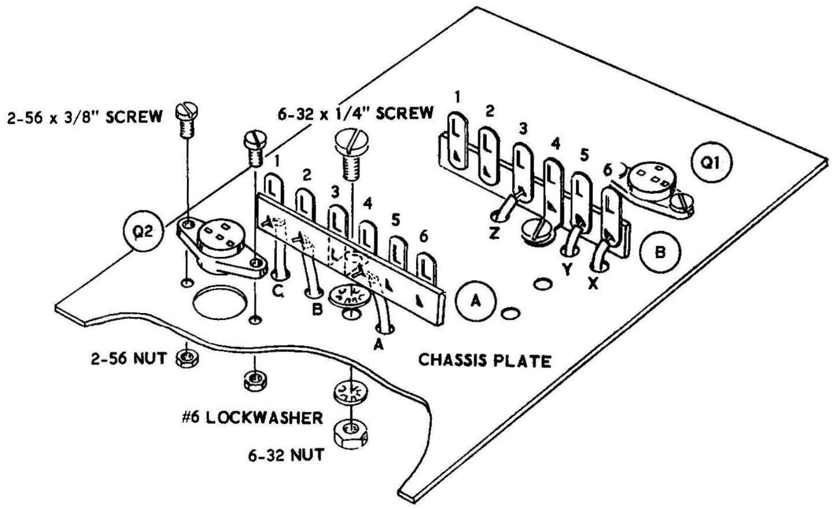


Figure 10E

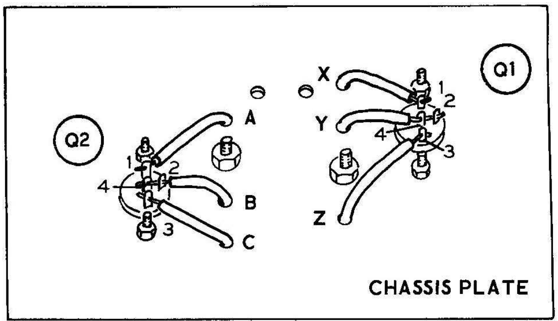


Figure 10F

Refer to Figures 10E and 10F for the following steps.

NOTE: All of the connections in this lesson are permanent connections as described in the Soldering Techniques. When resistors or capacitors are mounted, cut their leads to the proper length so they will be wired neatly between the terminal lugs as they are shown.

( ) Cut six 1-3/4" lengths of hookup wire for the following six steps.

( ) Connect a 1-3/4" wire from lug 3 of transistor Q2 (S), through hole C, to the lower hole in lug 1 of terminal strip A (S).

( ) Insert one end of a 1-3/4" wire through lug 2 (S) to lug 4 (S) of transistor Q2. Insert the other end of this wire through hole B and connect it to the lower hole in lug 2 of terminal strip A (S).

( ) Connect a 1-3/4" wire from lug 1 of transistor Q2 (S), through hole A, to the lower hole in lug 4 of terminal strip A (S).

( ) Connect a 1-3/4" wire from lug 1 of transistor Q1 (S), through hole X, to the lower hole in lug 6 of terminal strip B (S).

( ) Insert one end of a 1-3/4" wire through lug 2 (S) to lug 4 (S) of transistor Q1. Insert the other end of this wire through hole Y and connect it to the lower hole in lug 5 of terminal strip B (S).

( ) Connect the last 1-3/4" wire from lug 3 of transistor Q1 (S) through hole Z, to the lower hole in lug 3 of terminal strip B (S).

Refer to Figure 10G for the following steps.

( ) Mount the chassis plate to the master bottom plate as shown with 6-32 x 5/8" screws. Fasten the screws and spacers to the bottom plate first with three 6-32 nuts. Next, fasten the chassis plate with #6 lockwashers, and three 6-32 nuts.

( ) Install four 4-40 speednuts on the front of the master bottom plate with the flat side facing toward the outside of plate as shown. Set the chassis plate assembly aside.

Prewiring Front Panel

Refer to Figure 10H for the following steps. Route each of the following hookup wires as shown.

( ) Remove the volume control knob from the shaft and remove the 100 KΩ volume control from the front panel. Save the hardware. Install the 5000 Ω volume control and position it as the 100 KΩ control was. See Figure 10H. Reinstall the volume control knob.

( ) Connect a 6" wire from lug 1 of the remote terminal strip (S) to lug 3 of the LISTEN-TALK switch (NS).

( ) Connect a 2-3/4" wire from lug 3 (S) to lug 4 (S) of the LISTEN-TALK switch.

( ) Connect a 1" wire from lug 6 (S) to lug 1 (NS) of the LISTEN-TALK switch. Bend the lugs of this switch outward slightly, if necessary, to keep this wire from touching other wires or lugs.

( ) Connect a 5" wire from lug 1 of the LISTEN-TALK switch (S) to lug 1 of the speaker (S).

( ) Connect a 1" wire from lug 2 of the remote terminal strip (S) to lug 2 of the speaker (NS).

( ) Connect a 1-1/2" wire from lug 2 of the speaker (S) to the #6 solder lug (NS).

( ) Connect one end of a 6-1/2" wire to the solder lug (S). Leave the other end free.

( ) Connect a 2-1/2" wire from lug 3 of the VOLUME control (S) to lug 1 of the ON-OFF switch (NS).

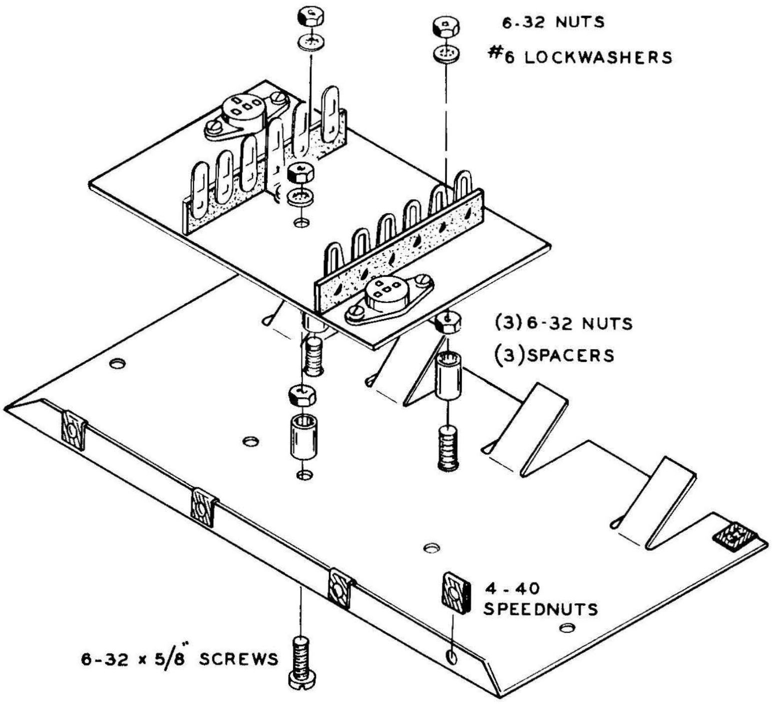


Figure 10G

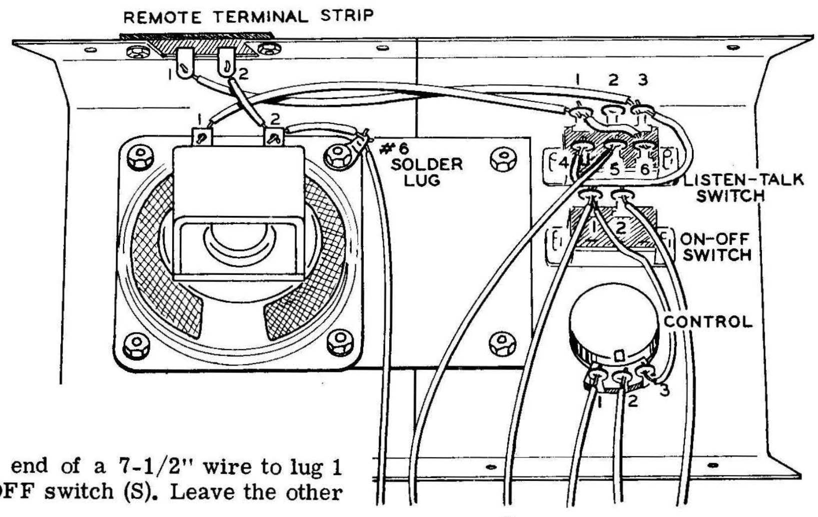


Figure 10H

( ) Connect one end of a 7-1/2" wire to lug 1 of the ON-OFF switch (S). Leave the other end free.

( ) Connect one end of a 6-1/4" wire to lug 5 of the LISTEN-TALK switch (S). Leave the other end free.

( ) Connect one end of an 8" wire to lug 2 of the ON-OFF switch (S). Leave the other end free.

( ) Connect one end of a 2-1/2" wire to lug 1 of the VOLUME control (S). Leave the other end free.

( ) Connect one end of a 3" wire to lug 2 of the VOLUME control (S). Leave the other end free. Set the panel aside.

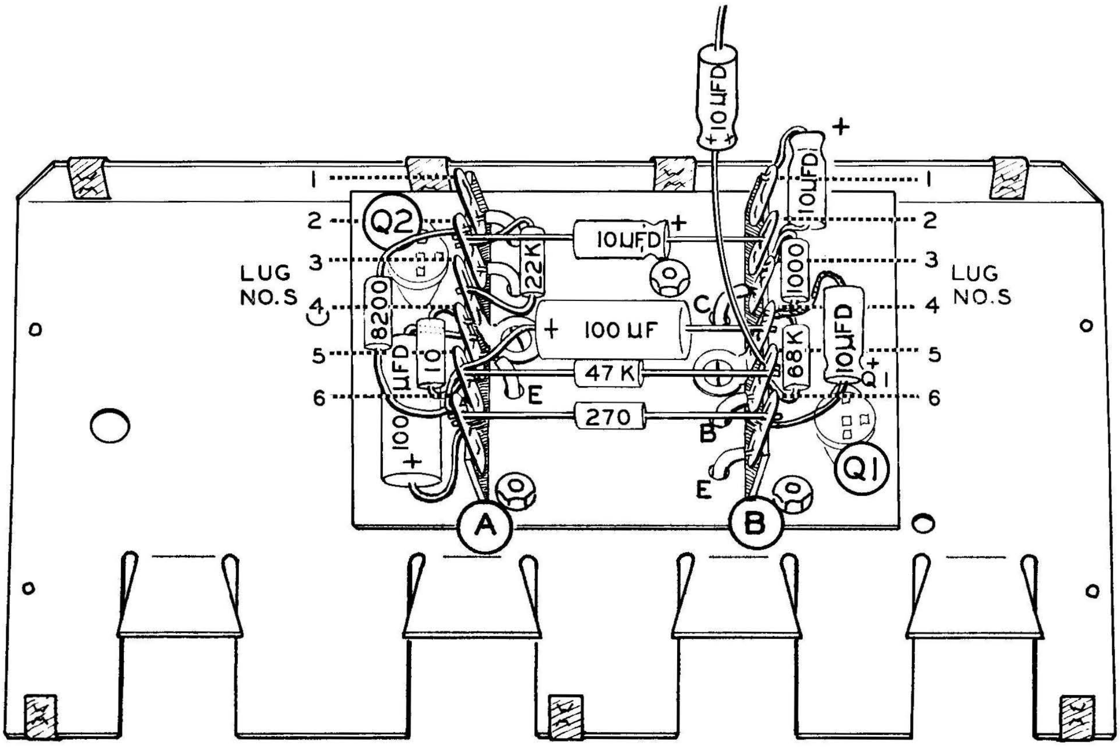


Figure 10J

Chassis Plate Wiring

Refer to Figure 10J for the following steps. Position each component as shown. Cut off any excess lead length.

( ) Connect the lead on the positive (+) end of a 100 μfd electrolytic capacitor to lug 6 (NS) and the other lead to lug 4 (NS) of terminal strip A.

( ) Connect a 10 Ω (brown-black-black) resistor between lugs 4 (S) and 5 (NS) of terminal strip A.

( ) Connect a 22 KΩ (red-red-orange) resistor between lugs 2 (NS) and 3 (NS) of terminal strip A.

( ) Connect an 8200 Ω (gray-red-red) resistor between lug 2 (NS) and 6 (NS) of terminal strip A.

( ) Connect the lead on the positive (+) end of a 10 μfd electrolytic capacitor to lug 2 of terminal strip B (NS). Connect the other lead to lug 2 of terminal strip A (S).

( ) Connect the lead on the positive (+) end of a 10 μfd electrolytic capacitor to lug 1 (NS) and the other lead to lug 3 (NS) of terminal strip B.

( ) Connect a 1000 Ω (brown-black-red) resistor between lugs 3 (S) and 4 (NS) of terminal strip B.

( ) Connect a 68 KΩ (blue-gray-orange) resistor between lugs 4 (NS) and 5 (NS) of terminal strip B.

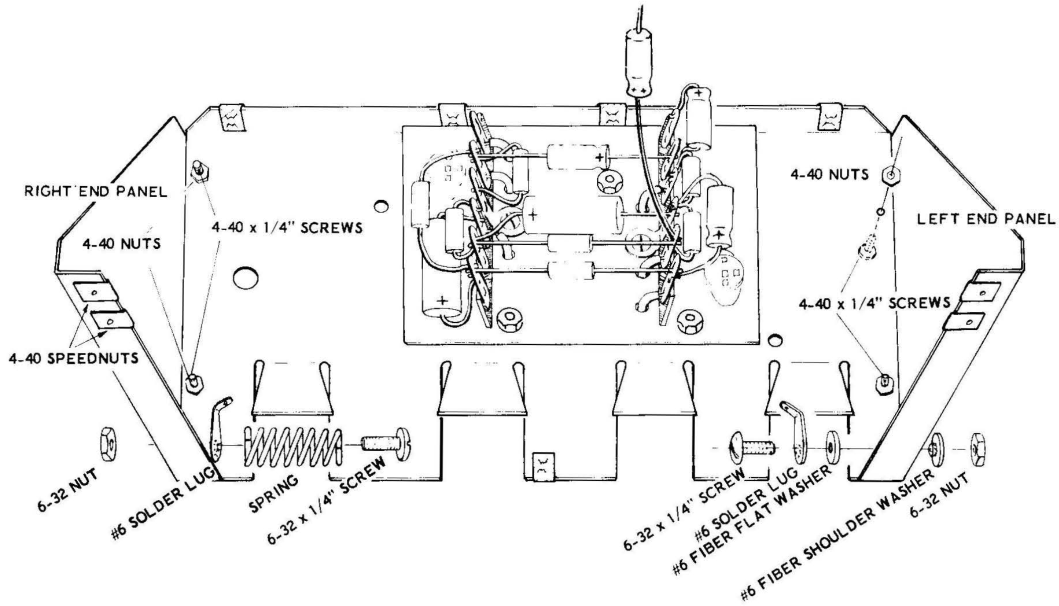


Figure 10K

( ) Insert the lead on the positive (+) end of a 100 μfd electrolytic capacitor through lug 5 (NS) to lug 6 (NS) of terminal strip A. Connect the other lead to lug 4 of terminal strip B (NS).

( ) Connect a 47 KΩ (yellow-violet-orange) resistor from lug 5 of terminal strip A (S) to lug 5 of terminal strip B (NS).

( ) Connect a 270 Ω (red-violet-brown) resistor from lug 6 of terminal strip A (NS) to lug 6 of terminal strip B (NS).

( ) Connect the lead on the positive (+) end of a 10 μfd electrolytic capacitor to lug 6 of terminal strip B (S). Connect the other lead to lug 4 of terminal strip B (S).

( ) Connect the lead on the positive (+) end of a 10 μfd electrolytic capacitor to lug 5 of terminal strip B (S). Leave the other lead free for later connection and do not cut either of the leads.

Side Panel Assembly

Refer to Figure 10K for the following steps.

( ) Install the battery contact spring, and a #6 solder lug on the right end panel as shown using a 6-32 x 1/4" screw, and a 6-32 nut.

( ) Install a 6-32 x 1/4" screw, #6 solder lug, fiber shoulder washer, fiber flat washer, and 6-32 nut to the left end panel as shown.

( ) Remove the two 4-40 speednuts from each end of the master bottom plate. (Located where the batteries are to be positioned.)

( ) Mount the left and right end panels to the master bottom plate as shown, using 4-40 x 1/4" screws, #4 lockwashers, and 4-40 nuts.

( ) Install four 4-40 speednuts on the left and right end panels as shown with flat side facing toward the outside of panels.

Final Wiring

Refer to Figure 10L for the following steps. Place the front panel and chassis plate assembly together as shown and make the following wire connections.

( ) Connect the wire coming from lug 2 of the ON-OFF switch to the solder lug of the left end panel (S).

( ) Connect the wire coming from lug 1 of the ON-OFF switch to lug 6 of terminal strip A (S).

( ) Connect the wire coming from lug 2 of the VOLUME control to lug 2 of terminal strip B (S).

( ) Connect the wire coming from lug 1 of the VOLUME control to lug 1 of terminal strip B (S).

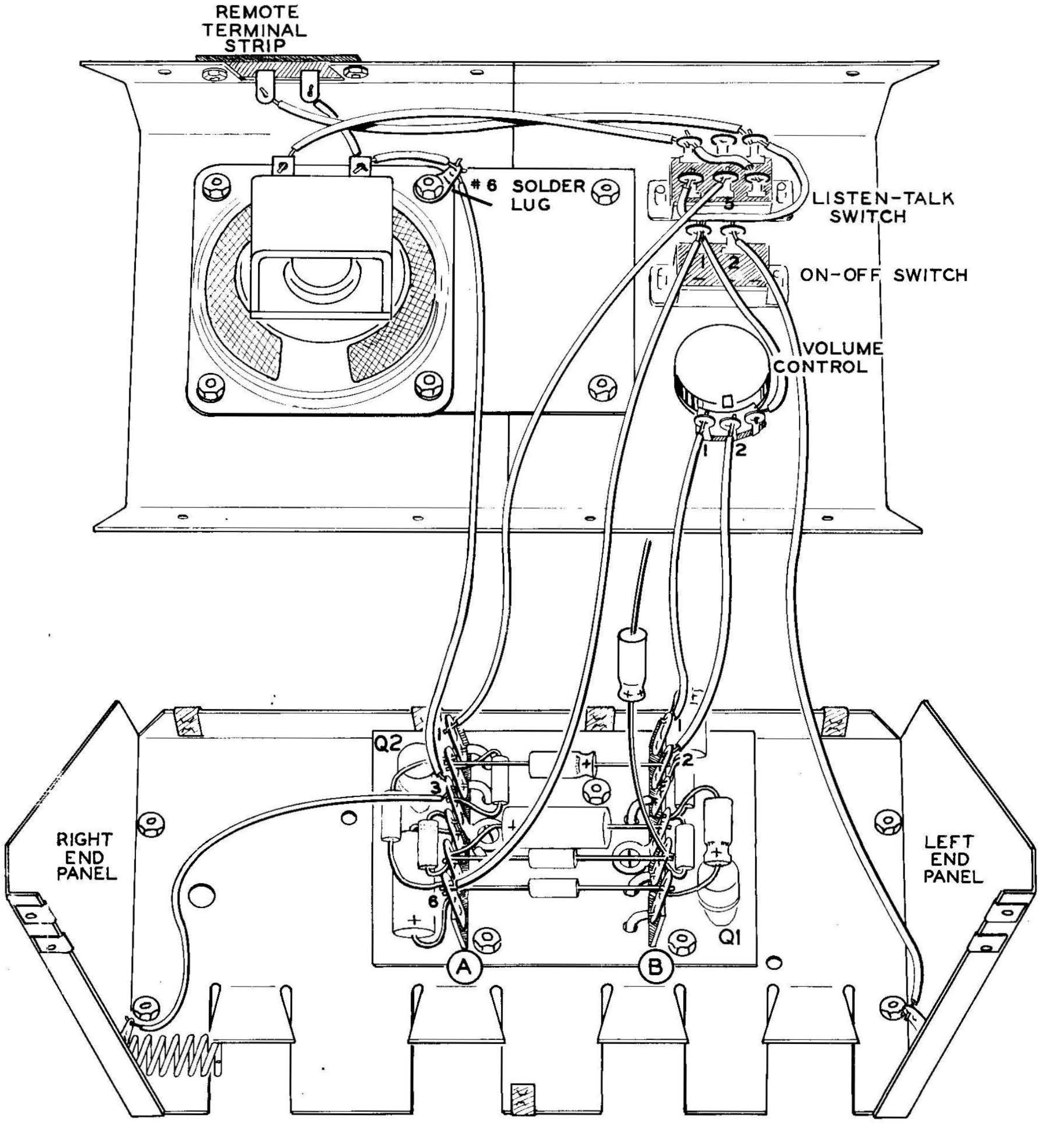


Figure 10L

( ) Connect the wire coming from lug 5 of the LISTEN-TALK switch to lug 1 of terminal strip A (S).

( ) Connect the wire coming from the #6 solder lug on the front panel to lug 3 of terminal strip A (NS).

( ) Connect a 4-1/4" wire from lug 3 of terminal strip A (S) to the solder lug of the right end panel (S).

( ) Install the two transistors in their sockets Q1 and Q2.

EXPERIMENT 1

Except for the free lead of the 10 μfd capacitor and the connecting wires between the two stations, the wiring of the intercom is now complete. Refer back to Figures 10B, 10C, or 10D and trace the signal paths back and forth on the wired assembly from the remote terminal strip (where the remote speaker will connect) to the speaker of the master station. Trace out the connections to each of the other parts also. This will help you to associate the schematic diagram more closely with the actual circuit.

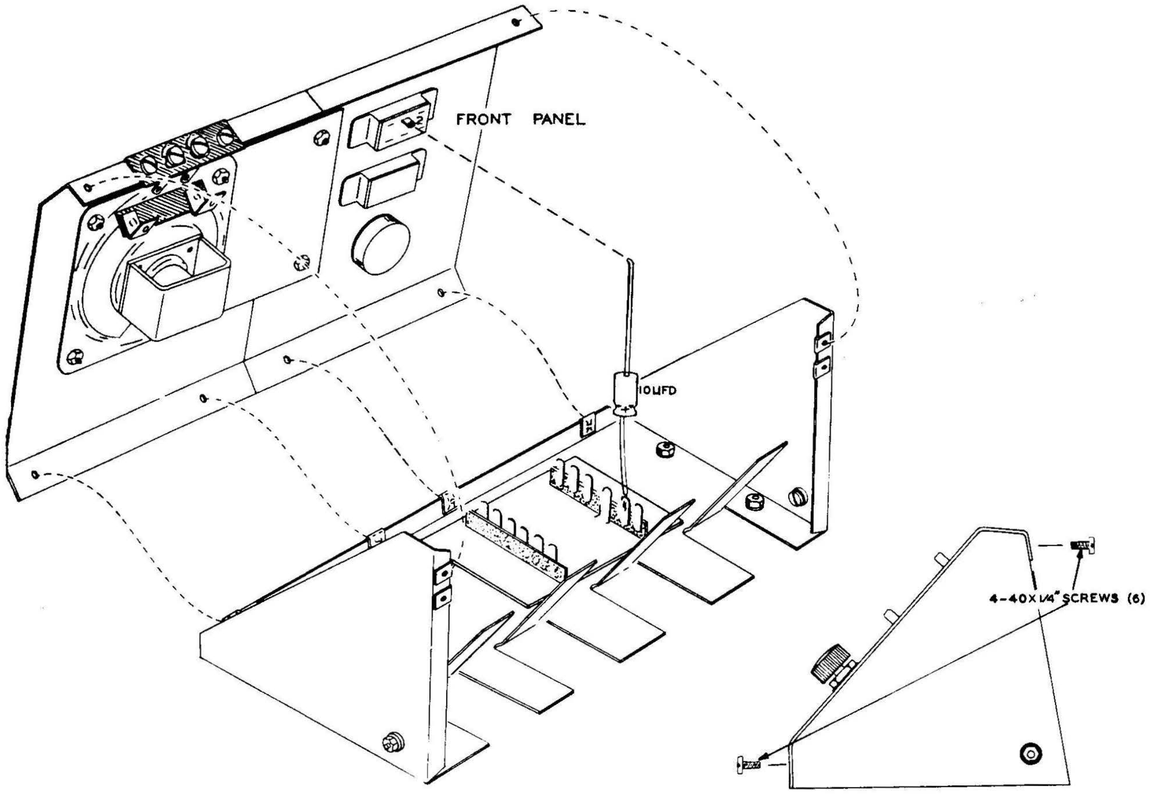


Figure 10M

Final Assembly

Refer to Figures 10M and 10N for the following steps.

( ) Carefully place the front panel on the two end panels as shown. Check the wiring to see that there is no possibility for a short circuit to occur. Tighten the front panel to the master bottom plate and the two end panels using 4-40 x 1/4" screws as shown.

( ) Cut the free lead of the 10 μfd capacitor to the proper length and connect it to lug 2 of the LISTEN-TALK switch (S).

Make sure the ON-OFF switch is in the OFF position before performing the following step.

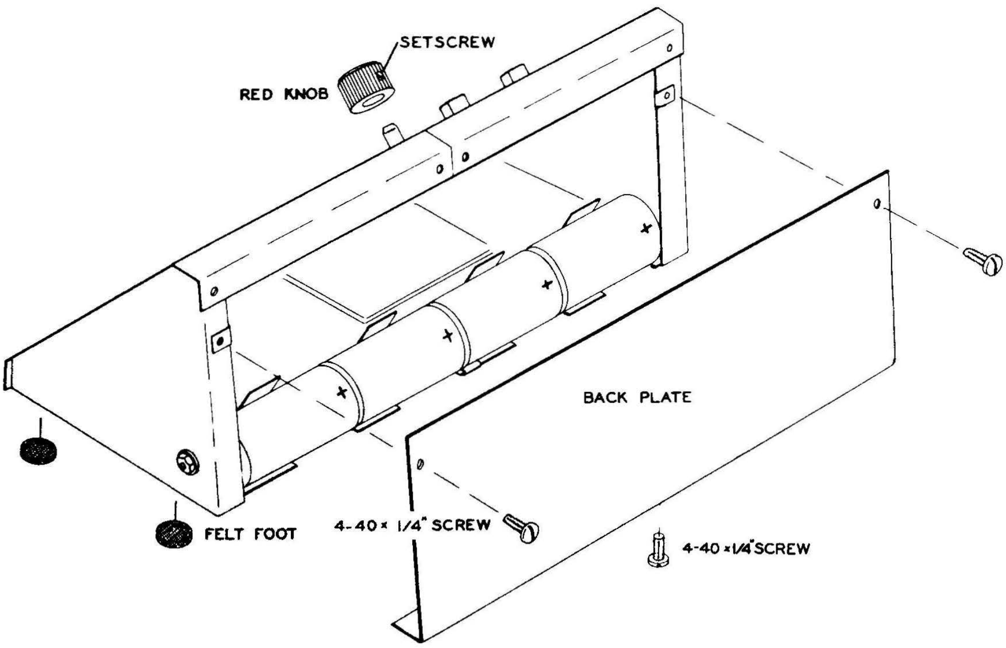


Figure 10N

( ) Install the four batteries as shown in Figure 10N. Now install the back plate to the two end panels and master bottom plate as shown, using three 4-40 x 1/4" screws.

( ) Remove the four felt feet from the plastic strip and install them in each corner of the master bottom plate as shown.

This completes the assembly of your transistor intercom.

EXPERIMENT 2

To demonstrate an oscillation due to audio feedback.

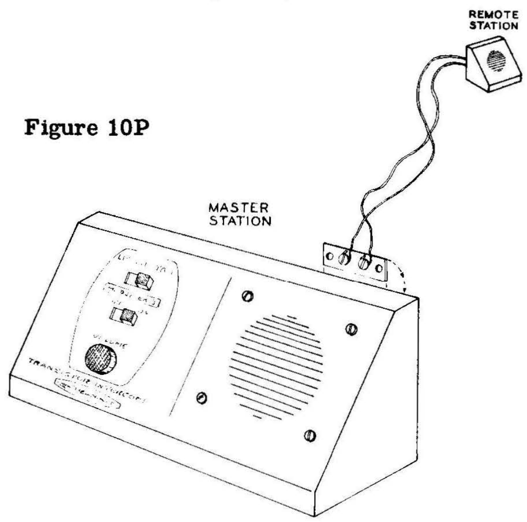
( ) Connect the remote station to the master station as shown in Figure 10P with two short lengths of wire.

( ) Turn the ON-OFF switch ON and the LISTEN-TALK switch to the TALK position.

( ) Turn the VOLUME control to its maximum position.

( ) Move the remote station speaker toward the master station speaker until a loud squeal is heard. This is the type of oscillation that was shown in Figure 8C, where the signal from the speakers was connected back (feedback) through the air to the microphone, and then reamplified.

Figure 10P



As described in Lesson VIII, some of the output of the (intercom) amplifier was connected from the output speaker back to the input (microphone) speaker - resulting in the oscillation. Note that this oscillation continues in both positions of the LISTEN-TALK switch.

( ) Turn the ON-OFF switch OFF. Remove the short wires between the two stations.

NOTE: The blue and white identification label shows the Model Number and Production Series Number of your kit. Refer to these numbers in any communications with the Heath Company; this assures you that you will receive the most complete and up-to-date information in return.

( ) Install the identification label in the following manner:

1. Select a location for the label where it can easily be seen when needed, but will not show when the unit is in operation. This location might be on the rear panel or the top of the chassis, or on the rear or bottom of the cabinet.
2. Carefully peel away the backing paper. Then press the label into position.

Installing The Intercom

( ) Select the positions where you wish your Master station and Remote station to be permanently located. This intercom can easily be used over distances of 50 feet to 150 feet, or even further.

( ) Twist two wires together so the twisted length will reach between the two stations. If you wish to cover a greater distance between the units than can be reached with the wire supplied with the kit, additional lengths of 2-conductor twisted wire may be obtained from your local radio store or department store, or from a mail-order electronic supply house. Twenty-two gauge wire, or larger (lower gauge number), should be used.

( ) Route the twisted wires between the two locations. At one end, connect the wires under the screws of the remote terminal strip of the master unit. At the other end of the wires solder one wire to each of the speaker lugs of the remote station's speaker.

The following method is one of the ways of routing the twisted wires between the two units when they are in separate rooms of a home. Carefully, so as not to break it, remove the quarter-round molding (also called the shoe-molding), from where it is nailed in place where the wall meets the floor. Do this near where you wish to install each unit.

Next drill a small (1/4" is fine) hole through the floor at each location, as close to the wall as possible. Route the wire down through one hole, across the ceiling of the basement, and up through the other hole. A small notch can be cut where the wires will come up behind the shoe-moldings; the moldings can then be replaced.

NOTE: If possible, always keep the intercom wires away from the 60 cycle power wires in your home (or other installation areas as well). This will tend to keep bothersome 60 cycle hum from being heard in the speaker.

When using the intercom - always speak directly into the speaker for the best sound quality. Do not talk into the units from the sides. Do not get too close to the unit, since this will also cause distortion. Usually, distortion occurs when you get any closer than about 3 inches from the speaker.

IN CASE OF DIFFICULTY

Finding the cause of the trouble in a particular circuit is like a detective trying to solve a crime, the trouble most often can be found by the clues you find in the circuit. For this reason it is a very good idea to review how the circuit operates before trying to find the trouble.

Finding your difficulty can be divided into two general parts. The first part (Steps 1, 2, and 3) are general checks where you try to find the trouble by looking for visible errors or difficulties. In the second part (Step 4) you try to locate the trouble by finding the clues with your meter. First you locate the area (or stage) the trouble is in, and then you track down the offending part itself.

1. Recheck your wiring against the wiring shown in the Figures and the wiring given in the step-by-step instructions. Often if someone else looks at the unit they will notice something that you have consistently overlooked. Check to see that no two wires are shorting, or touching each other or the chassis. Check to make sure that you have the proper part values in the proper places.

2. Check the solder connections. Poor solder connections are responsible for a great many difficulties. Often troubles can be eliminated by reheating all questionable connections. Clean off excess solder from any lugs where it might be causing a short circuit or a poor connection.
3. Check for bits of solder or pieces of wire which may be lodged in the wiring.
4. Try to locate the trouble by checking the voltages in the circuit. Normal voltages will vary plus or minus 10% from the voltage shown on the schematic. If the trouble seems to be narrowed down to a certain area, turn off the power and then check the resistors and the capacitors in that area to make sure that they have not opened up or shorted out.

SERVICE INFORMATION

SERVICE

If continued operational difficulties are experienced with the completed Intercom Unit, the facilities of the Heath Company Service Department are at your disposal, or you may contact our Technical Consultation Department by mail. Local Service is available in some areas through authorized HEATHKIT Service Centers. Should you choose to return the unit to the Heath Company for inspection, repair, and adjustment, you will be charged a minimal service fee, plus the price of any additional parts or material required. However, if the completed kit is returned within the Warranty period, parts charges will be governed by the terms of the Warranty. State the date of purchase, if possible. THIS SERVICE POLICY APPLIES ONLY TO THE COMPLETED CIRCUIT OF LESSON X, CONSTRUCTED IN ACCORDANCE WITH THE INSTRUCTIONS AS STATED IN THIS MANUAL. Kits that are not entirely completed or that are modified in design will not be accepted for repair. Kits showing evidence of acid core solder or paste fluxes will be returned NOT REPAIRED.

REPLACEMENTS

Material supplied with HEATHKIT products has been carefully selected to meet design requirements and ordinarily will fulfill its function without difficulty. Occasionally improper instrument operation can be traced to a faulty component. Should inspection reveal the necessity for replacement, write to the Heath Company and supply all of the following information:

A. Thoroughly identify the part in question by using the part number and description found in the manual Parts List.

B. Identify the kit Model Number and Series Number.

C. Mention date of purchase.

D. Describe the nature of defect or reason for requesting replacement.

The Heath Company will promptly supply the necessary replacement. Please do not return the original component until specifically requested to do so. Do not dismantle the component in question as this will void the guarantee. This replacement policy does not cover the free replacement of parts that may have been broken or damaged through carelessness on the part of the kit builder.

SHIPPING INSTRUCTIONS

In the event that your Intercom must be returned for service, these instructions should be carefully followed.

ATTACH A TAG TO EACH UNIT BEARING YOUR NAME, COMPLETE ADDRESS, INVOICE NUMBER ON WHICH THE KIT WAS PURCHASED, AND A BRIEF DESCRIPTION OF THE DIFFICULTY ENCOUNTERED. Wrap the units separately in heavy paper, exercising care to prevent damage. Place both wrapped units in a stout carton of such size that at least three inches of shredded paper, excelsior, or other resilient packing material can be placed between all sides of the chassis and the carton. Close and seal the carton with gummed paper tape, or alternately, tie securely with stout cord. Clearly print the address on the carton as follows:

TO: HEATH COMPANY
Benton Harbor, Michigan 49023

Include your name and return address on the outside of the carton. Preferably affix one or more "Fragile" or "Handle With Care" labels to the carton, or otherwise so mark with a crayon of bright color. Ship by insured parcel post or prepaid express; note that a carrier cannot be held responsible for damage in transit if, in HIS OPINION, the article is inadequately packed for shipment.

SPECIFICATION CHANGES

All prices are subject to change without notice. The Heath Company reserves the right to discontinue instruments and to change specifications at any time without incurring any obligation to incorporate new features in instruments previously sold.

ANSWERS FOR LESSON I

1. Atoms
2. Nucleus
3. Electrons
4. Number
5. Impedes (or resists)
6. The amount of resistance is determined by the amounts of carbon and nonconducting compounds that are mixed together.
7. Physical size
8. True
9. Less
10. Junction
11. High
12. Point contact

ANSWERS FOR LESSON II

1. the electrical size of the resistor and the voltage across the resistor.
2. An electrical circuit is any arrangement of electrical parts which allows for the flow of electricity.
3. An open circuit is a circuit in which there is no complete path from one side of the battery to the other.
4. Too much current
5. True
6. False
7. True
8. Add the currents flowing in each current path.
9. Total resistance: $R = R_1 + R_2 = 1000\ \Omega$

   Total current:

   $I = \frac{E}{\text{TOTAL R}} = .01$ amps $= 10$ ma

   Voltage across resistor R1:

   $E = IR_1 = 2.5V$

   Voltage across resistor R2:

   $E = IR_2 = 7.5V$

10. Total Resistance: $\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{R\ \text{TOTAL}}$

    $R\ \text{TOTAL} = 187\frac{1}{2}\ \Omega$

    Current in R_1:

    $I = \frac{E}{R_1} = .0133$ amps $= 13.3$ ma

    Current in R_2:

    $I = \frac{E}{R_2} = .04$ amps $= 40$ ma

    Total Current = 13.3 ma + 40.0 ma = 53.3 ma

ANSWERS FOR LESSON III

1. A variable resistor is a resistor whose electrical size can be adjusted.
2. Yes.
3. Two types.
4. Emitter, Base, and Collector.
5. Away from.
6. Emitter and Base.
7. No.

ANSWERS FOR LESSON IV

1. No
2. False
3. Very thin
4. True
5. True
6. The positive terminal
7. The negative terminal
8. True
9. The negative battery terminal
10. A potentiometer is the name given to a variable resistor when it is used as a voltage divider.

ANSWERS FOR LESSON V

1. An audio signal is sound in electrical form.
2. AC currents.
3. AC current..
4. AC current.
5. The "sine" wave.
6. Frequency refers to how many times a waveform repeats itself in any one second.
7. Loudness (or amplitude) and frequency.
8. Loudness is contained in an audio signal by the size of the signal in volts.
9. AC currents......DC currents.
10. Microfarads (μfd) or micromicrofarads ($\mu\mu$f).
11. Magnetism.
12. Amplifiers are necessary because a signal from a microphone is far too small to be able to make a speaker operate

ANSWERS FOR LESSON VI

1. No.
2. By means of a voltage divider.
3. True.
4. Current saturation in the transistor, or distortion.
5. Larger.
6. The current limiting resistor prevents too much current from flowing in the transistor. Too much current would create heat and heat would create more current...ultimately resulting in a burned out transistor.
7. The Emitter bypass capacitor passes the AC signal currents around the current limiting resistor.

ANSWERS FOR LESSON VII

1. Impractical.
2. A modulated RF signal.
3. In the swells of energy (modulation).
4. Tune, detect, and amplify.
5. Like a large resistor.
6. To detect the signal is to remove the audio information from the modulated RF signal.
7. It must rectify and filter the signal.
8. True.
9. A crystal and a diaphragm.

ANSWERS FOR LESSON VIII

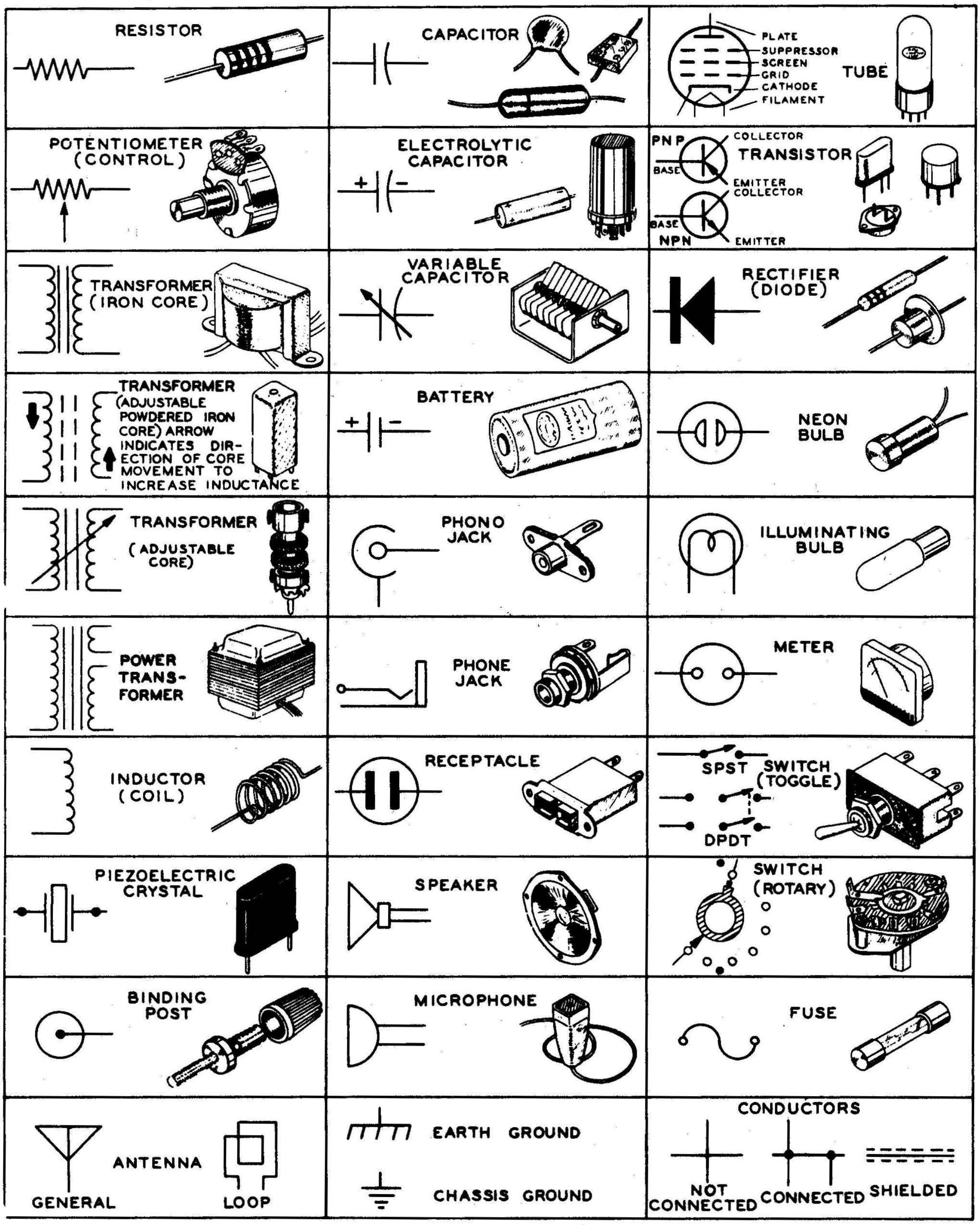
1. An oscillator circuit is a circuit that is used to create AC signals.
2. To oscillate means to swing back and forth.
3. False.
4. Some of the output sound from the speakers is picked up by the microphone and re-amplified, causing an oscillation, which is heard as a loud squeal.
5. Feedback refers to that part of the signal that is connected back to the input of the amplifier.
6. Add to.
7. True.
8. True.

ANSWERS FOR LESSON IX

1. An amplifier, feedback, and a tuned circuit.
2. False.
3. Turning the ON-OFF switch ON.
4. Only one frequency.
5. By changing the electrical size of either the coil or capacitor of the tuned circuit.
6. Series.
7. True.
8. True.

TYPICAL COMPONENT TYPES

This chart is a guide to commonly used types of electronic components. The symbols and related illustrations should prove helpful in identifying most parts and reading the schematic diagrams.



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