



# Power Supplies for Electronic Equipment



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# **Power Supplies For Electronic Equipment**

# POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

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## TABLE OF CONTENTS

Introduction .....	1
<b>Transformers</b> .....	1
Basic Transformer Action .....	1
Transformer Losses .....	4
Transformer Efficiency .....	7
Power Distribution .....	7
Autotransformers .....	8
Summary .....	9
Self-Test Questions .....	10
<b>Rectifier Circuits</b> .....	11
Half-Wave Rectifiers .....	11
Full-Wave Rectifiers .....	13
Voltage Doublers .....	14
Summary .....	15
Self-Test Questions .....	15
<b>Filter Circuits</b> .....	16
Simple Capacitor Filters .....	16
RC Filters .....	17
LC Filters .....	19
Factors Affecting the Output Voltage .....	20
Summary .....	21
Self-Test Questions .....	21
<b>Typical Power Supplies</b> .....	22
Universal AC-DC Power Supplies .....	22
Typical Full-Wave Power Supplies .....	23
Summary .....	26
Self-Test Questions .....	26
<b>Voltage Regulators</b> .....	27
Shunt Voltage Regulators .....	27
Series Voltage Regulators .....	28
Feedback Voltage Regulators .....	29
Integrated Circuit Voltage Regulators .....	32
Voltage Regulator Performance .....	33
Summary .....	35
Self-Test Questions .....	35
<b>Circuit Protection</b> .....	36
Fuses .....	36
Circuit Breakers .....	37
Electronic Protection Circuits .....	37
Summary .....	40
Self-Test Questions .....	40
<b>Answers to Self-Test Questions</b> .....	41
<b>Lesson Questions</b> .....	43

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One of the most important sections in any piece of electronic equipment is the power supply. It is the part that furnishes the operating voltages and currents required by the rest of the circuitry. If the power supply is not operating correctly, the equipment cannot do the job it is supposed to do.

You have already studied the basic components used in power supplies. In this lesson, you will learn more about these parts and how they are used together in power supplies. You will be introduced to some new circuits and will learn the purpose of each part in the power supply. Once you know how the various parts are used and understand what each is supposed to do, you will be able to service any power supply defect you encounter.

A power supply may or may not have a power transformer. A power transformer is a convenient device that can be used either to increase or decrease the line voltage to the value needed by the equipment. In addition, a power transformer isolates the equipment from the power line, making the equipment safer to operate and repair. You will begin this lesson by learning about transformers.

After you have studied transformers, you will study the different rectifiers used in modern power supplies. The power supplied by utility companies for home and industrial use is ac power, whereas the transistors and integrated circuits used in electronic equipment require dc operating voltages. The device that changes the current from ac to dc is called a *rectifier*.

Once the ac is changed to dc, we have what is called a *pulsating dc* at the output of the rectifier. This is actually dc with ac superimposed on it. The power supply must therefore have some means of filtering or smoothing the pulsating dc to get pure dc. This is accomplished by means of a filter network, which separates the ac and dc components of the pulsating dc at the rectifier output so that only the dc appears at the output of the filter network.

Many power supplies have some type of voltage-divider network. Such a network is designed to provide several different operating voltages from one power supply. The various transistors and integrated circuits in a piece of electronic equipment may require several different operating voltages. It is more economical in most cases to use a single power supply and a voltage divider instead of a separate power supply for each voltage needed.

Often, if an electronic circuit is to work correctly, the voltage applied to it must be very carefully regulated. You've already seen how a zener diode and forward-biased diode can be used for voltage regulation. These options are satisfactory where only small amounts of power are needed. In higher current applications, more elaborate voltage regulators are needed. Your study of power supplies will include voltage regulator circuits.

## TRANSFORMERS

Our modern industrial society consumes large amounts of electricity. The transformer contributes greatly in the economical transmission of this power. We'll describe this later, but first let's learn more about transformers.

### Basic Transformer Action

Transformers are particularly useful because they can increase or decrease the available voltage. For example, a transformer can be plugged into a power line that has a nominal voltage of 120 volts, and it can step that

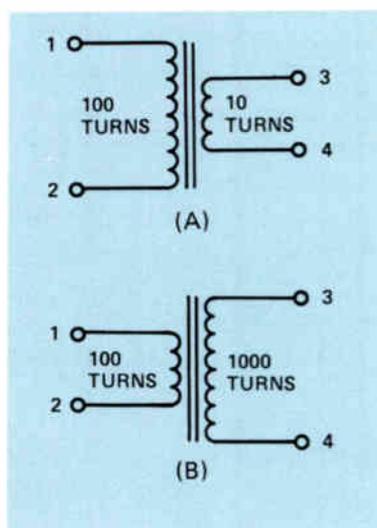
# POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

2

voltage down to any value we may require, providing the transformer has the correct turns ratio.

In Fig. 1, we've shown the schematic symbol for two transformers. The transformer in Fig. 1(A) has 100 turns on the winding connected between terminals 1 and 2 and 10 turns on the winding between terminals 3 and 4. The transformer shown at (B) also has 100 turns on the winding between terminals 1 and 2, but it has 1000 turns on the winding connected between terminals 3 and 4.

If we apply 100 volts ac to terminals 1 and 2 of the transformer shown at (A), assuming no losses in the transformer, the voltage between terminals 3 and 4 will be 10 volts. Notice that in this transformer we have 100 turns on the winding between terminals 1 and 2, which is called the primary winding, and 10 turns on the winding between terminals 3 and 4, which is called the secondary winding. The turns ratio is 100 to 10 or simply 10 to 1. Notice that applying 100 volts to the pri-



**Figure 1.** (A) A step-down transformer with 100 turns on the primary winding and 10 turns on the secondary. (B) A step-up transformer with 100 turns on the primary and 1000 turns on the secondary.

mary winding produces 10 volts in the secondary. Notice also that the ratio of the primary voltage to the secondary voltage is the same as the ratio of the primary turns to the secondary turns. Since the voltage is stepped down, that is, it is lower in the secondary than it is in the primary, we call the transformer at (A) a *step-down transformer*.

Now if we apply 100 volts ac to the primary winding of the transformer shown in Fig. 1(B), we'll get 1000 volts between terminals 3 and 4. Once again, remember that we said the primary winding has 100 turns and the secondary has 1000 turns. Here we have a primary-to-secondary ratio of 100 to 1000, which is 1 to 10. The ratio between the voltage in the primary and the voltage in the secondary will be the same as the turns ratio; therefore, we'll have 10 times as much voltage across the secondary as we have across the primary. Thus, if we apply 100 volts to the primary winding, we'll have 1000 volts across the secondary winding. Because it steps up the voltage, we call it a *step-up transformer*.

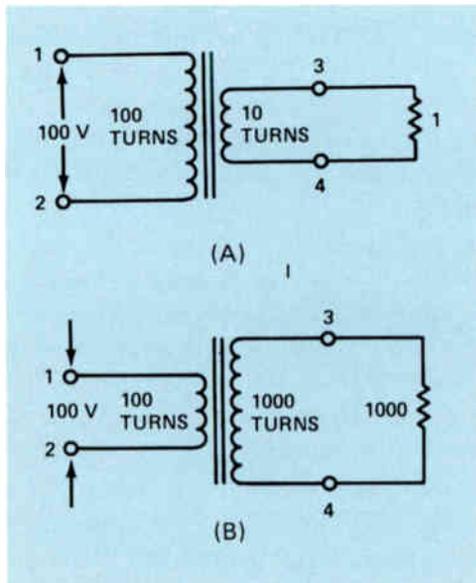
Transformers are self-regulating. By this we mean that they will draw sufficient current in the primary to supply the load connected across the secondary. Looking at Fig. 2(A), we have the same transformer that we had in Fig. 1(A), but now we've connected a 1 ohm resistor across the secondary winding. We can find the current that will flow through the resistor by using Ohm's law.

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

By substituting 10 volts for E and 1 ohm for R, we get:

$$I = \frac{10}{1} = 10 \text{ amperes}$$

Now let's consider the power that the resistor is dissipating. We know that the



**Figure 2.** The transformers of Fig.1 with (A) a 1 ohm load across the secondary and (B) a 1000 ohm load.

voltage across the resistor is 10 volts and the current through it is 10 amps; therefore, the power must be:

$$P = E \times I = 10 \times 10 = 100 \text{ watts}$$

If the resistor is dissipating 100 watts, it must be getting 100 watts from the secondary of the power transformer. This in turn has to come from the primary winding. Therefore, assuming no losses in the transformer, since the voltage across the primary is 100 volts, the current in the primary must be 1 ampere. Notice what has happened in the step-down transformer. The voltage has been stepped down at a ratio of 10 to 1, whereas the current has been stepped up at a ratio of 1 to 10. The power consumed by the primary is exactly equal to the power the secondary is supplying to the resistor.

Now let's look at the transformer shown in Fig.2(B). The resistor connected across the secondary winding is a 1000 ohm resistor. This

is the same transformer shown in Fig.1(B). The turns ratio is 1 to 10, so that with 100 volts supplied to the primary of the transformer, we know that the voltage across the secondary must be 1000 volts. If we apply 1000 volts to a 1000 ohm resistor, the current through the resistor will be 1 ampere. The power dissipated by the resistor will be equal to the voltage across it times the current through it, so in this case it is equal to 1000 watts. The primary winding must supply this power, and to supply 1000 watts, it will have to draw a current of 10 amperes. Thus, we have 1000 watts consumed by the 100 volt power line and inductively coupled to the secondary. The secondary is supplying the 1000 watts dissipated by the 1000 ohm resistor. Notice that in the step-up transformer we have the voltage stepped up at a ratio of 1 to 10 and the current stepped down at a ratio of 10 to 1.

Notice that in each case the current did the opposite of what the voltage did. If the voltage is stepped up, the current is stepped down; and if the voltage is stepped down, the current is stepped up. This occurs because the transformer is self-regulating. Thus, if the secondary is supplying the power at a lower voltage than that applied to the primary, the primary current will be lower than the secondary current. On the other hand, if the secondary is supplying the power at a higher voltage than the primary, then the primary current will be greater than the secondary current.

Transformers frequently have more than one secondary winding. One winding might be a step-down winding, where the voltage is lower than that applied to the primary, while the other might be a step-up winding, where the voltage will be higher than that applied to the primary. An example of such a transformer is shown in Fig.3.

In the transformer shown in Fig.3, we have 100 turns on the primary winding connected

# POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

4

between terminals 1 and 2. We are going to apply a voltage of 100 volts between these two terminals. The secondary winding connected between terminals 3 and 4 has 10 turns on it, and we are going to connect a 1 ohm resistor between terminals 3 and 4. The secondary winding connected between terminals 5 and 6 has 1000 turns on it, and we are going to connect a 1000 ohm resistor across it.

As before, the turns ratio between the primary winding and the secondary winding connected between terminals 3 and 4 is 10 to 1. The voltage will be stepped down from 100 volts to 10 volts, and 10 volts across a 1 ohm resistor will cause a current of 10 amperes to flow. The power supplied to the resistor by the winding connected between terminals 3 and 4 will be equal to 100 watts.

The winding connected between terminals 5 and 6 has 10 times as many turns as the primary, so the voltage will be stepped up from 100 volts to 1000 volts. With a 1000 ohm resistor connected between terminals 5 and 6, the current through the resistor will be 1

ampere. The power supplied by this winding will then be  $1000 \times 1 = 1000$  watts. Thus, the two secondary windings together are supplying a power of 1100 watts. This power must be taken from the power line by the primary winding.

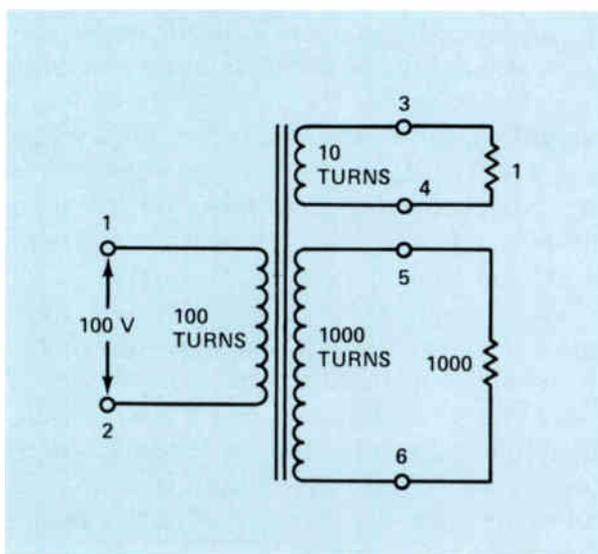
To supply 1100 watts to the secondary windings, the primary must draw a current of 11 amperes. Then the power consumed by the primary winding will be 1100 watts. Of this 1100 watts, 100 watts will be used to supply the 10-turn winding connected between terminals 3 and 4, with the 100 watts being supplied to the 1 ohm resistor. The remaining 1000 watts will be supplied to the 1000-turn winding connected between terminals 5 and 6 to supply 1000 watts to the 1000 ohm resistor. Notice that the transformer in Fig.3 is supplying the same amount of power to the loads as the two transformers in Fig.2.

There is no limit to the number of secondary windings that we can have on a transformer. The voltage that we'll have across a given secondary winding will depend upon the turns ratio between it and the primary winding. When several widely different operating voltages are needed, separate windings for each voltage are usually the most convenient way to get them.

## Transformer Losses

In the example shown in Fig.3, we said that the primary would draw 1100 watts from the 100 volt line to supply the 1100 watts to the two secondary windings. If the transformer had no losses this would be true, but a transformer does have losses. These losses can be divided into two general groups called copper and core losses.

**Copper Losses.** Copper losses in a transformer occur because the wire used to wind



**Figure 3.** A transformer with a secondary step-down winding and a secondary step-up winding.

each winding has resistance. For example, the 10-turn winding connected between terminals 3 and 4 would probably have a very low resistance because it has to supply such a high current that it would be wound with a large wire. But even if the resistance were only 1/10 of an ohm, with such a high current the loss due to the resistance of the wire could be appreciable. For example, we know that:

$$P = I^2 R$$

and since the current in this winding is 10 amperes, the power lost in the winding would be:

$$P = 10 \times 10 \times \frac{1}{10} = 10 \text{ watts}$$

The current flowing through the 10-turn winding will result in a voltage drop across that winding. This means that the voltage between terminals 3 and 4 will actually be slightly less than 10 volts. In the case of 10 amperes flowing through 1/10 of an ohm resistance, we have a voltage drop of 1 volt so that the voltage applied to the 1 ohm resistor will only be 9 volts. This in turn will cause the current flowing in the circuit to fall slightly below 10 amperes, but it will still be close to 10 amperes and there will be power lost in the transformer itself. Similarly, there will be a loss in the secondary winding connected between terminals 5 and 6 due to the resistance of the wire used for the 1000-turn winding. This will also cause the actual voltage across the 1000 ohm resistor to be slightly less than 1000 volts, but the current flowing through the 1000 turns will result in power being dissipated in the transformer itself. Thus, the primary winding not only has to supply the power being supplied by the two secondary windings, but it also has to make

up for the losses in the windings. Therefore, the primary current will be slightly greater than 11 amperes. Indeed, the 100-turn primary winding also has resistance, so even more current must be drawn from the power line to make up for the loss in this winding.

All these losses mean that the transformer will draw more than 1100 watts from the power line. The transformer will draw the power it needs to supply the power delivered to the two resistors plus the power being dissipated or wasted in the transformer itself due to the resistance of the wire used for the various windings on the transformer.

All the losses in the transformer due to the resistance of the wire used in the various windings are called copper losses. Remember that the power lost in the winding is equal to:

$$P = I^2 R$$

The loss in the winding is equal to the current squared times the resistance of the winding. Thus the copper losses are frequently called *I square R losses*.

**Core Losses.** In addition to the copper losses in the transformer, there are other losses called core losses. There are three types of core losses: *eddy current losses*, *hysteresis losses*, and *flux leakage losses*.

If we placed the windings of a transformer on a solid core, the core itself would act like a single turn of a very large wire. A voltage would be induced in this turn causing a current to flow, which would result in losses in the core of the transformer. This type of loss is called an eddy current loss. To keep eddy current losses as low as possible, the core of a transformer is made of thin sheets of metal called laminations. The laminations are stacked as shown in Fig.4. Figure 4(A) shows what the individual laminations look like and

# POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

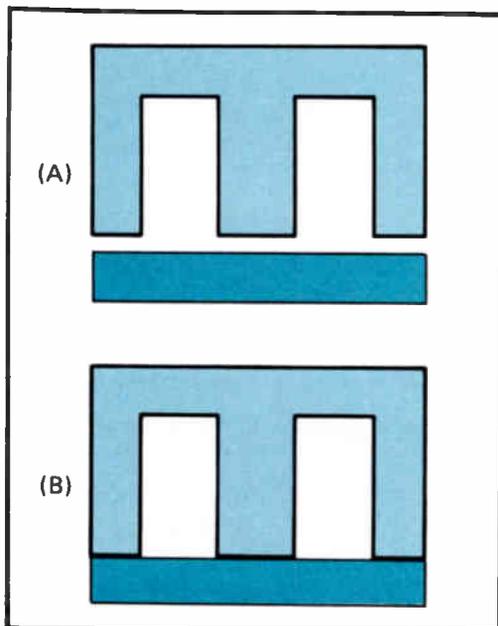
6

Fig.4(B) shows how the laminations are assembled. In building the transformer, the various windings are wound on some type of nonmagnetic form and then the core is inserted in the form after the windings have been completed. With this type of construction, eddy current losses in the transformer can be kept quite low.

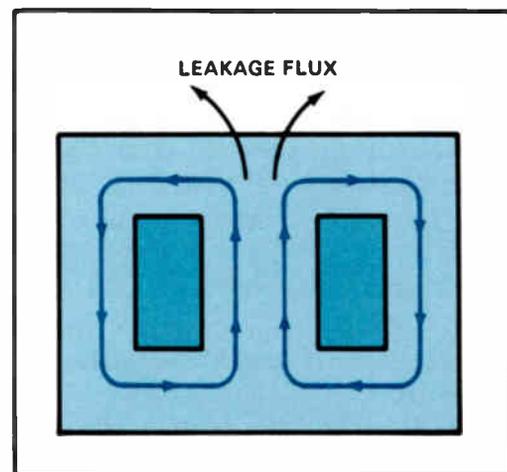
Another important core loss is known as hysteresis loss. If we apply a voltage to the primary winding of the transformer and cause a current to flow through the winding to magnetize the core, and then remove the voltage, the current will stop flowing but there will be some residual magnetism left in the core. In other words, the magnetism does not drop back completely to zero. Thus on the first half-cycle of ac, as the core is magnetized with one polarity and then the ac drops back to zero, the magnetism has not completely disappeared. As current begins flowing through the

primary winding in the opposite direction to magnetize the core with the opposite polarity, the current has built up to some value before the magnetism has dropped to zero completely and begins to build up with the opposite polarity. This inertia in the magnetism is called hysteresis. It means that power is lost each half-cycle, bringing the magnetism back to zero before it can begin to magnetize the coil with the opposite polarity. The hysteresis loss in the core of a transformer will depend upon the type of material used in the core. Usually silicon steel is used because it has a relatively low hysteresis loss.

Another type of core loss is flux leakage loss. This loss occurs when all the turns of magnetic flux produced by the primary winding do not cut all the turns of each secondary winding on the transformer. As a matter of fact, some of the flux is lost from the core entirely. Flux leakage loss is kept at a minimum by shaping the core as shown in Fig.5. The core itself provides a low reluctance path for the magnetic lines of force. Thus the lines of force follow the core, but some will be lost as shown in Fig.5.



**Figure 4.** (A) Transformer cores are made of sheets of steel called laminations. (B) They are put together as shown here. In the next layer, the M-shaped lamination is turned over like a W and put on the bottom with the straight piece on top. Each layer is alternated in this way.



**Figure 5.** The transformer winding is placed on the center leg of the core. Flux will flow around the core, but some will be lost as shown.

## Transformer Efficiency

In spite of the copper and core losses, a transformer is an extremely efficient device. The efficiency of a transformer tells us how much of the power taken by the primary winding from the power line is actually delivered to loads connected across the secondary. If a power transformer draws 100 watts from the power line and supplies 90 watts to the loads connected across its secondary, the efficiency of the transformer is:

$$\text{Efficiency} = \frac{90}{100} \times 100 = 90\%$$

Large transformers used by the power companies in the distribution of electric power are very efficient, having an efficiency as high as 98%. Smaller transformers used in electronic equipment are not as efficient, having an efficiency somewhere between 80% and 90%.

The power lost in a transformer is converted into heat in the transformer. When you first turn on a piece of electrical equipment using a transformer, the transformer will be at the temperature of the surrounding air. As the transformer is used, the losses will cause the transformer to heat. It will continue to heat until a balance is reached whereby the surrounding air carries away the heat as fast as the transformer produces it. Transformers designed for use in electronic equipment usually have a maximum temperature rating of 85°C. This means that the transformer is designed so that it will not get any hotter than 85°C. It usually does not get that hot in use because before it reaches that temperature, a balance is reached where the heat being produced is being carried away by the surrounding air as fast as the transformer produces it. When this balance is reached, the transformer will not get any hotter.

## Power Distribution

Earlier we mentioned that the transformer made the distribution of large amounts of electrical power possible. You may be interested in knowing how power is generated and transmitted.

At the power generating plant, electricity is produced by large generators that are called alternators. In an alternator, the windings into which the voltage is to be induced are stationary and the rotating device is the magnet. The magnet cutting the turns of wire on the stationary coils induces a voltage in these coils. Alternators are usually designed to produce a voltage of about 12,000 volts. The voltage from the alternator is then fed to a step-up transformer as shown in Fig.6. The transformer will step the voltage up to a very high voltage for transmission from the alternator to the main power station. The reason for stepping up the voltage to a high value is that for a given amount of power, the higher the voltage the lower the current. Since the current must flow through wires, there will be some loss in the wires. The loss depends on the current squared times the resistance of the wire. Therefore, the lower we can keep the current, the less the loss. Usually, voltages of 110,000 volts or 220,000 volts are used to transmit electricity from the power plant to the main power station. At the main power station, a second transformer is used to step the voltage down to about 13,200 volts, and it is fed from there to substations. At the substations, another transformer is used to step the voltage down to about 4400 volts.

The 4400 volts is then fed along high power lines to transformers mounted on poles or beneath ground. These transformers step the voltage down to 440 volts. Many factories have machines that operate on 440 volts that is fed directly to them. For the home user, another transformer is used on the power pole to step

# POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

8

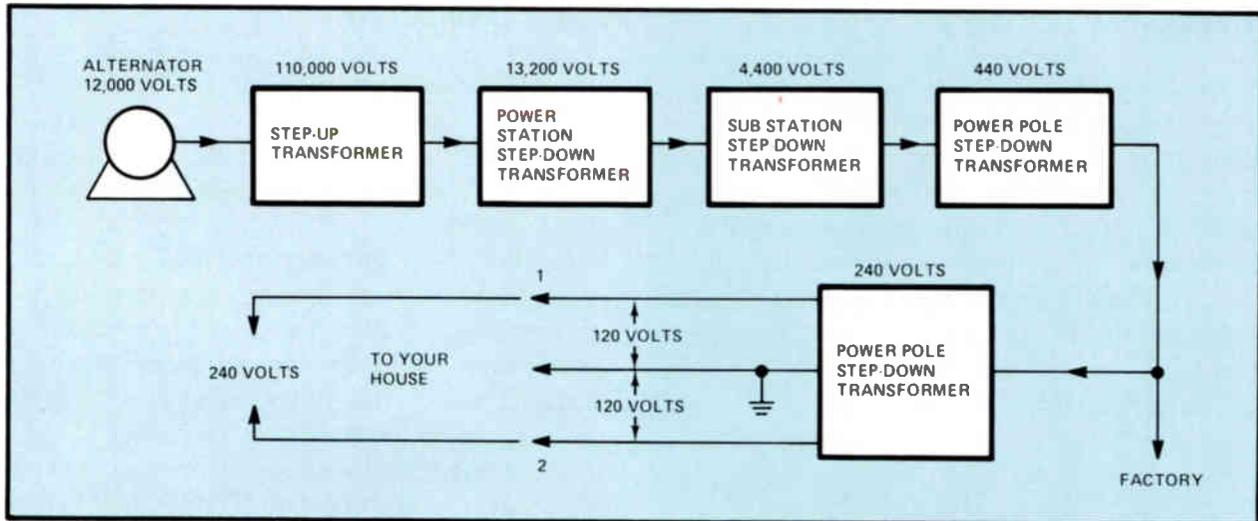


Figure 6. A typical power distribution system.

the voltage down still further. Usually the voltage fed to a residence is about 240 volts. Three wires are used to transmit this voltage as shown in Fig.6. The voltage between terminals 1 and 2 is 240 volts, which is used in electric ranges, ovens, clothes dryers, and large air conditioners. The voltage between either terminal 1 or 2 and the center wire, which is called the neutral wire, is 120 volts. This voltage is used for lighting and for operating radio and TV receivers and other small appliances.

Notice that the neutral wire is grounded. This is done for a number of reasons, the most important of which is safety. But it also points out why it is dangerous to work on electrical equipment while standing on a damp basement floor or touching a water pipe or any other grounded object. If you happen to touch the hot line and a grounded object at the same time, you could easily be electrocuted.

## Autotransformers

Transformers do not have to have two separate windings. Some transformers, called

autotransformers, have only a single winding. Two examples of an autotransformer are shown in Fig.7.

Notice that in Fig.7(A), there are three connections to the transformer. The input voltage is applied across the entire winding, and the output is taken off from just part of the winding. This type of autotransformer is a step-down transformer. It works in essentially the same way as a transformer with two windings in that the input voltage is applied across the entire winding and the output is taken off only part of the winding. Thus we have, in effect, a step-down in the transformer.

In the transformer shown in Fig.7(B), the input is applied across only part of the winding. It sets up a flux that cuts the remaining turns of the winding, inducing a voltage in these turns so that the output voltage, which is taken off across the entire winding, is stepped up. The ratio of the input voltage to the output voltage in both examples will be equal to the ratio of the turns across which the input voltage is applied to the turns across which the output voltage is taken.

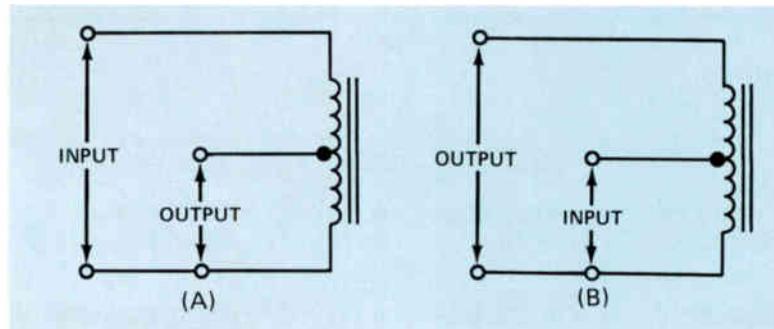


Figure 7. (A) A step-down autotransformer and (B) a step-up autotransformer.

Autotransformers are used in some special applications. They are more economical to manufacture than transformers with two separate windings. But in power-line applications, they do not provide any isolation between

the line voltage and the output voltage. So electronic equipment using an autotransformer as a power transformer is not isolated from the power line as is a conventional transformer with two separate windings.

### Summary

A step-up transformer is a transformer that has more turns on the secondary winding than on the primary. The ratio of the secondary voltage to the primary voltage is equal to the ratio of the number of turns on the secondary to the number of turns on the primary. A step-down transformer has fewer turns on the secondary winding than on the primary, so the secondary voltage is lower than the primary voltage. The transformer may have more than one secondary winding; one secondary winding would have more turns than the primary to produce a voltage higher than the primary voltage, and the other would have fewer turns than the primary winding to produce a voltage lower than the primary voltage.

The transformer is very efficient, but it does have some losses. *Copper losses* are due to the resistance of the wire used to wind the coils on the transformer. The

copper loss in each winding equals the current squared in that winding times the resistance of the winding. These are often called the  $I^2R$  losses. *Core losses* are made up of eddy current losses, hysteresis losses, and flux leakage losses. The transformer core is made up of laminated stampings rather than a single piece of iron to keep the eddy current losses low. The core material is usually silicon steel, which has low hysteresis losses. Flux leakage losses are kept low by providing a complete magnetic path for the magnetic lines of flux.

Large power transformers can have an efficiency as high as 98%. Smaller transformers usually have an efficiency between 80% and 90%. The transformer is self-regulating. The power it takes from the primary power line equals the power drawn from the secondary windings plus the transformer losses.

# POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

10

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## Self-Test Questions

*Please check your answers on page 41.*

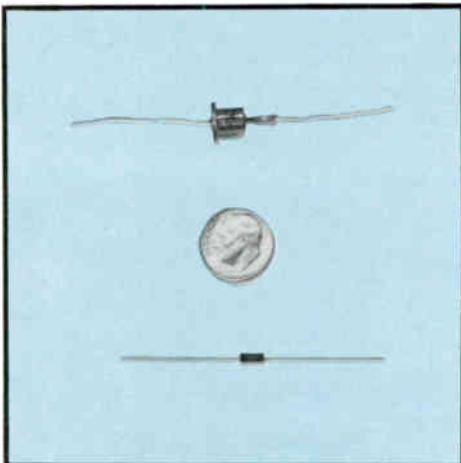
- 1 Which winding on a step-down transformer has the greater number of turns?
- 2 Which winding on a step-up transformer has the greater number of turns?
- 3 When a load is connected across the secondary winding of a step-down transformer, which winding will have the higher current?
- 4 When a load is connected across the secondary winding of a step-up transformer, which winding will have the higher current?
- 5 What is it that we mean when we say that a transformer has an efficiency of 95%?
- 6 What are copper losses due to?
- 7 Why are transformer cores made of laminations rather than a solid piece of steel?
- 8 Name the three core losses.
- 9 What is the disadvantage of an auto-transformer when compared with a transformer having two separate windings?

## RECTIFIER CIRCUITS

Any device that will pass current in one direction but not in the other direction can be used as a rectifier. Modern electronic equipment uses silicon rectifiers, which are simply silicon diodes with an n-type region for the cathode and a p-type region for the anode. Two typical silicon diodes are shown in Fig.8, along with a dime so you can get an idea of their relative size.

Silicon diodes are used as rectifiers because they are very inexpensive to manufacture and they will last indefinitely as long as the ratings of the rectifier are not exceeded. In addition, the silicon diode has a very low forward resistance. This means that when it is passing current there will be very little power lost due to the resistance of the diode. This loss of power turns up in the form of heat, which serves no useful purpose.

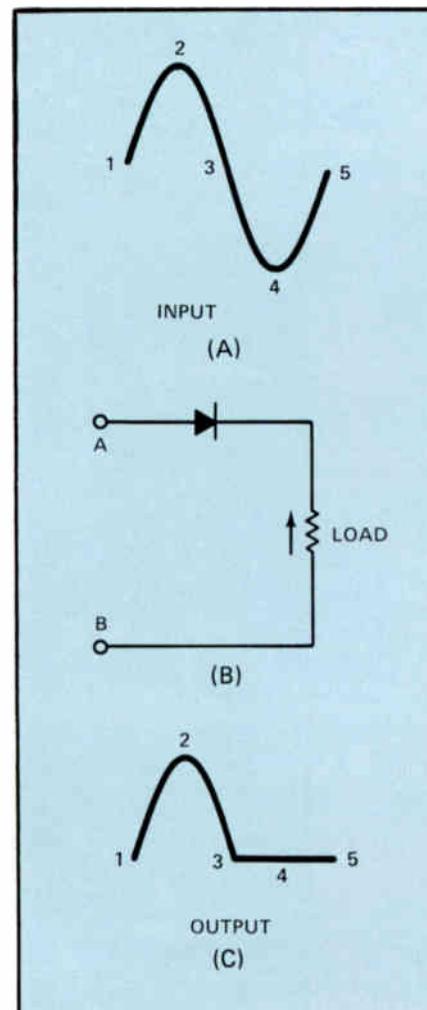
In electronic equipment, you will run into *half-wave rectifiers*, which rectify only one-half of the ac cycle, and *full-wave rectifiers*, which rectify both halves of the ac cycle. Let's start our study of rectifiers with the half-wave rectifier.



**Figure 8.** Two typical silicon rectifiers with a dime between them to show their relative size.

### Half-Wave Rectifiers

We have shown a typical half-wave rectifier circuit in Fig.9(B). Figure 9(A) shows one ac cycle. This may be the ac that is coming from the power line or the secondary of a power transformer. Since current can pass through the rectifier in only one direction, the current will flow through the load in the direction shown producing the current waveform shown in Fig.9(C).



**Figure 9.** A half-wave rectifier.

# POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

During the first half-cycle of the input voltage waveform, if terminal A is positive and terminal B is negative, electrons will flow from terminal B through the load, through the rectifier, and back to terminal A of the power source. As the input wave goes through the first half-cycle from point 1 to point 2 and then to point 3, current will flow through the load and rectifier as shown in Fig.9(C). The current will increase as the voltage applied between terminals A and B increases up to

point 2 and then will decrease to point 3 as the ac input decreases. During the next half-cycle, when terminal A is negative and terminal B is positive, there will be no current through the rectifier. Therefore, no current will flow through the load, as shown from point 3 to 5 in Fig.9(C).

While the half-wave rectifier is a simple device, it does have the disadvantage that it takes considerable filtering to smooth its pulsating dc output to a pure dc.

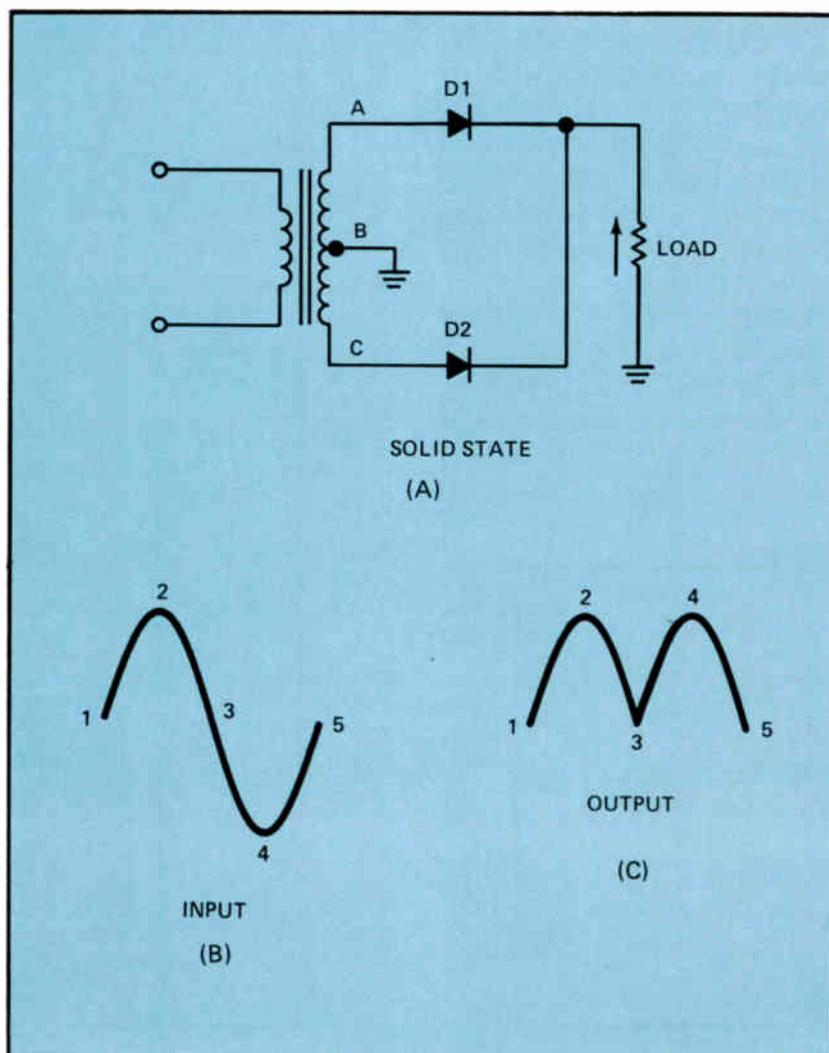


Figure 10. A full-wave rectifier.

## Full-Wave Rectifiers

A typical full-wave rectifier circuit is shown in Fig.10(A). Notice that the circuit uses two diodes, D1 and D2, and also that there are three connections to the secondary of the power transformer. Terminal B is a center tap connection, which means that the voltage between terminals A and B will be equal to the voltage between terminals B and C. When terminal A is positive, terminal B will be negative and terminal C will be even more negative. This means that terminal C will also be negative with respect to terminal B.

When terminal A is positive and terminal B is negative, electrons will flow from terminal B to ground through the load and then through D1 to terminal A. Electrons will not flow through D2 to terminal C because terminal C is negative with respect to terminal B. During the next half-cycle, terminal B will be positive with respect to terminal A and terminal C will be even more positive. This means that terminal C will be positive with respect to terminal B or, in other words, terminal B is negative with respect to terminal C. During this half-cycle, electrons will flow from terminal B to ground, through the load, and then through D2 to terminal C. Electrons will not flow through D1 to terminal A because terminal A is negative with respect to terminal B.

With an ac cycle like the one in Fig.10(B), we'll have a pulsating dc through the load as shown in Fig.10(C). Notice that for the first half-cycle of the input voltage, we get a current pulse through the load as shown by 1-2-3 in Fig.10(C). During the next half-cycle of the input voltage in Fig.10(B), we also get a current pulse as shown in 3-4-5 of Fig.10(C). In other words, for each half-cycle we get a current pulse through the load with the current flowing through D1 during the first half-cycle and D2 during the next half-cycle.

Compare the output for the full-wave rectifier shown in Fig.10(C) with the output of the half-wave rectifier shown in Fig.9(C). Assuming that both rectifiers are operating from a 60 Hz power line, notice that with the half-wave rectifier we get 60 pulses per second and the current is only flowing during the one-half cycle. In the full-wave rectifier circuit we get 120 pulses per second, and there is current flow during each half-cycle. You can see that it will be much easier to smooth the pulsating output from a full-wave rectifier than it is to smooth the output from the half-wave rectifier.

Another full-wave rectifier circuit is shown in Fig.11. This is called a *bridge rectifier*. Since a center-tap transformer winding is not required, it has the advantage of requiring only half as many turns on the secondary winding for a given output voltage, compared to the transformer used in Fig.10. In the full-wave rectifier shown in Fig.10, we use one half of the secondary winding during one half-cycle and the other half during the other half-cycle. Therefore, for a given output voltage, the voltage between terminals A and C of the transformer shown in Fig.10 must be twice the voltage across the secondary of the transformer shown in Fig.11. However, the circuit

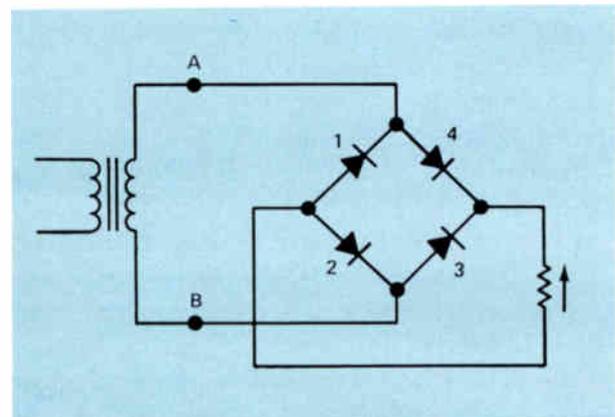


Figure 11. A bridge rectifier circuit.

shown in Fig.11 does have the disadvantage that it requires four rectifiers instead of two. But silicon rectifiers are so inexpensive that the cost of the two extra rectifiers is usually more than offset by the savings in the power transformer.

The operation of the circuit is comparatively simple. When terminal B is negative with respect to terminal A, electrons will flow from terminal B, through the diode marked 2, and then through the load and diode 4 to terminal A of the transformer. During the next half-cycle, terminal A is negative and terminal B is positive, so electrons will flow from terminal A, through diode 1, through the load, and then through diode 3 back to terminal B. Thus, during one half-cycle, current will flow through diodes 1 and 3, and during the other half-cycle, it will flow through diodes 2 and 4. Current cannot flow through diodes 2 and 4 during the half-cycle when it is flowing through diodes 1 and 3 because diodes 2 and 4 will be reverse biased. Similarly, during the next half-cycle, diodes 1 and 3 will be reverse biased and current cannot flow through them.

## Voltage Doublers

In some applications, we need a voltage higher than the voltage that is readily available. This is frequently the case in low-cost, transformerless electronic equipment. Without a power transformer, the maximum voltage available would be the 120 volt ac line voltage. But by using a voltage doubler circuit, you can obtain a higher operating voltage.

Figure 12 shows a half-wave doubler circuit. Let's see how it works. During the first half-cycle, when terminal A is negative and terminal B is positive, electrons will flow from terminal A into the side of C1 marked with

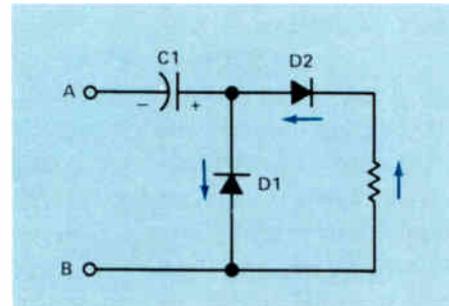


Figure 12. A half-wave voltage-doubler circuit.

a minus sign and out of the side marked with a plus sign, through D1, and back to terminal B. This will charge capacitor C1 with the polarity shown.

In the next half-cycle, when terminal A is positive and terminal B is negative, the voltage between terminals A and B will be in series with the voltage across C1. Thus, we'll have a voltage approximately equal to twice the input voltage applied across D2 and the load. During this half-cycle, current flows from terminal B, through the load and D2 into the positive side of C1, and out the negative side to terminal A. Current cannot flow through D1 because current cannot flow through the diode from the anode to the cathode.

Later, after you've studied filters, you will see that with large filter capacitors and a small load, it is possible to get a voltage equal to almost twice the peak line voltage with this type of circuit without using a power transformer.

The circuit shown in Fig.12 is called a half-wave voltage doubler because current flows through the load only when terminal A is positive and terminal B is negative. In other words, we have a current flow through the load only during one half-cycle. The circuit shown in Fig.13 is a full-wave voltage doubler. Here we have a current through the load during both half-cycles.

In the circuit shown in Fig.13, when terminal B is negative and terminal A is

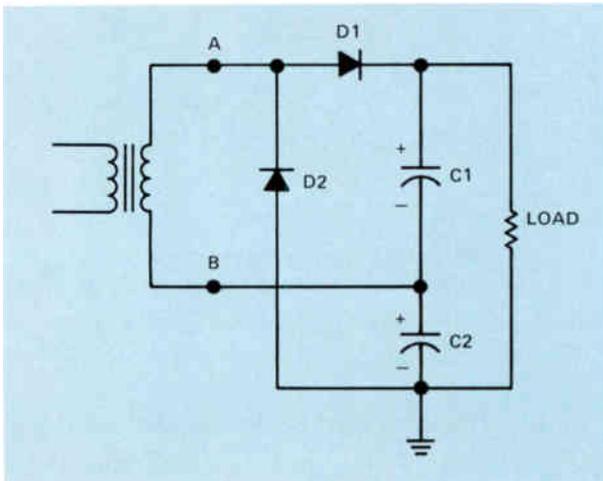


Figure 13. A full-wave voltage-doubler circuit.

positive, electrons will leave terminal B and flow into the negative plate of C1, out of the positive plate of C1, through D1, and back to terminal A. The capacitor C1 will be charged with the polarity shown. During the next half-

cycle, when terminal A is negative and terminal B is positive, electrons will flow from terminal A through D2 into the negative plate of C2, out of the positive plate, and back to terminal B. This will charge C2 with the polarity shown. Notice that now C1 and C2 are connected in series; these two capacities supply the current through the load. Since they supply the current to the load continuously, the rectifier is a full-wave rectifier.

During the half-cycle when diode D1 is conducting, diode D2 cannot conduct because the voltage applied to its cathode will be positive. During the other half-cycle when D2 is conducting, D1 cannot conduct because the voltage applied to its anode will be negative. As in the case of a half-wave voltage doubler, the full-wave doubler shown in Fig.13 gives us an output voltage across C1 and C2 in series that is equal to twice the peak line input voltage. In the case of an input voltage of 120 volts ac, this would be approximately 340 volts.

### Summary

The rectifier circuits that we have discussed in this section of the lesson are extremely important because you will find one or more of them in every piece of electronic equipment designed to operate from an ac power line.

The half-wave rectifier circuit is important because it is widely used where the current drain is relatively low. Full-wave rectifiers are used in applications where the current requirement is somewhat higher and where very pure dc is needed. Voltage doublers are important because they are widely used in high-voltage circuits used to operate cathode-ray tubes in all types of video displays.

### Self-Test Questions

- 10 In a half-wave rectifier circuit like the one shown in Fig.9, how many current pulses per second will there be through the load when the power line frequency is 60 Hz?
- 11 What is the disadvantage of a half-wave rectifier circuit?
- 12 What advantage does the bridge rectifier circuit in Fig.11 have over the full-wave rectifier in Fig.10?
- 13 What is the disadvantage of the bridge rectifier circuit shown in Fig.11?
- 14 What is the advantage of the full-wave voltage doubler shown in Fig.13 over the half-wave voltage doubler shown in Fig.12?

## FILTER CIRCUITS

The output from the rectifiers we discussed in a preceding section is not pure dc. Instead, it is pulsating dc — direct because it flows in only one direction, pulsating because it varies in amplitude rather than flowing steadily. You will remember that the half-wave rectifier shown in Fig.9 produces one pulse for each cycle. With a 60 Hz power line, there will be 60 pulses per second. Also, remember that these pulses are produced during one-half of the cycle while the output from the rectifier is zero during the other half-cycle. The full-wave rectifier produces 120 pulses per second, one pulse for each half-cycle. The output from the full-wave rectifier was shown in Fig.10(C).

Neither the output from the half-wave rectifier nor the output from the full-wave rectifier can be used directly to operate electronic equipment. The output from these rectifiers must be filtered until it is essentially pure dc. This is done by means of a filter circuit. There are many different filter circuits, the simplest of them being the *simple capacitor filter*. We'll discuss this circuit first.

### Simple Capacitor Filters

The simplest filter is the capacitor filter shown in Fig.14. When terminal A is positive and terminal B is negative, electrons will flow from terminal B to the load and through the rectifier to terminal A. They will also flow from terminal B into the negative plate of the filter capacitor C and out of the positive plate, through the rectifier to terminal A. The capacitor will charge to the peak line voltage less any small voltage drop there may be across the rectifier.

Figure 15(A) shows three ac cycles and Fig.15(B) shows what the voltage across the load in the circuit of Fig.14 will look like.

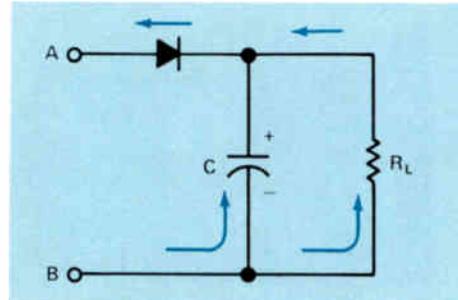


Figure 14. A half-wave rectifier circuit with a simple capacitor-type filter.

During the first half-cycle, as the ac input voltage goes from 1 to 2, the voltage across the filter capacitor charges from 1 to 2 as shown in Fig.15(B). As the ac line voltage begins to drop from 2 to 3, the capacitor begins to discharge. The amount it will discharge depends upon the size of the load resistor. If the resistance is high and the load draws very little current, the capacitor will not discharge a great deal. If the resistance is low and the load is drawing considerable current, the capacitor will discharge appreciably.

In any case, as the voltage begins to drop from 2 to 3, the capacitor voltage will begin

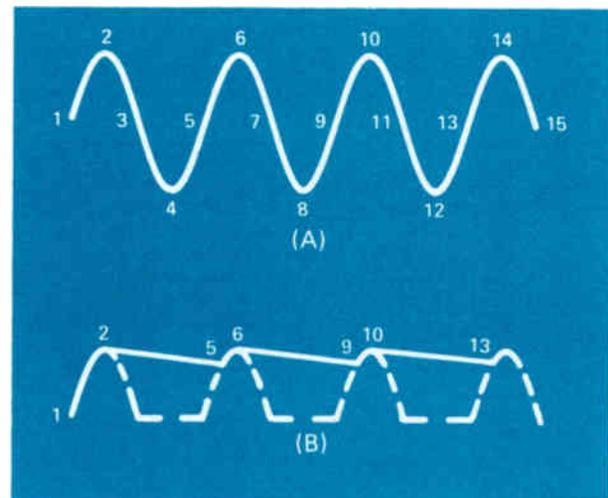


Figure 15. Voltage waveshapes for a simple filter. (A) Input voltage; (B) output voltage.

to drop from 2, as shown in Fig.15(B), until the next cycle. Then, when terminal A is positive and terminal B is negative, and the voltage builds up from 5 to 6, a point will be reached where the ac input voltage is equal to the capacitor voltage. This is point 5 in Fig.15(B). Now the capacitor will begin to charge again to point 6. Once at point 6, the ac voltage begins to drop to point 7 as shown in Fig.15(A), so the capacitor begins to discharge to 9 as shown in Fig.15(B). At this point, the ac line voltage is once again built up to a value equal to the voltage to which the capacitor has discharged, so that it again charges it back to point 10.

This action continues indefinitely as long as the equipment is turned on. During each portion of the cycle when the line voltage exceeds the voltage to which the capacitor is charged, there is a burst of current through the rectifier to charge the capacitor back to the peak line voltage. Thus, with a filter circuit, the current flows through the rectifier during only a small portion of the cycle. However, it takes a fairly large current to charge the capacitor back to the peak line voltage to replace the charge that was lost.

One of the important characteristics of a rectifier is the maximum peak reverse voltage that can be placed across the rectifier before it breaks down. In the circuit shown in Fig.14, the capacitor will be charged as shown and the charge can equal the peak line voltage. During the next half-cycle, when the polarity of the input voltage reverses, terminal A will be negative and terminal B will be positive. When this voltage reaches its peak, the peak reverse voltage across the rectifier will be equal to the capacitor voltage plus the line voltage because the two are, in effect, in series. This voltage will be equal to twice the peak line voltage less the voltage that the capacitor has discharged. For safety, we assume the voltage is twice the peak line volt-

age. The rectifier must be able to withstand this voltage without breaking down. This important characteristic by which rectifiers are rated is usually referred to as the *peak reverse voltage*, which is abbreviated prv. It may also be called *peak inverse voltage*, which is abbreviated piv. The two simply mean the maximum reverse or inverse voltages that can be applied across the rectifier without breaking it down. In the circuit shown in Fig.14, operating from the 120 volt ac power line, the prv will be about 340 volts. The rating of the rectifier should be at least 400 volts prv to allow a reasonable safety factor.

You will run into this filter circuit shown in Fig.14 only in applications where the current requirements are very low. If any sizable current is drawn from this type of circuit, the capacitor will discharge appreciably and there will be 60 Hz hum in the circuit. For applications where higher current is present, additional filtering is required to eliminate this hum.

### RC Filters

An improved filter, which is called a *pi filter* because it looks like the Greek letter ( $\pi$ ), is shown in Fig.16. You will notice that this

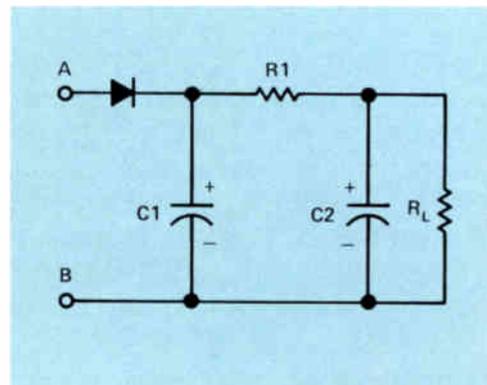


Figure 16. An RC pi-type filter.

# POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

filter consists of two capacitors, C1 and C2, and a filter resistor, R1.

The operation of the half-wave rectifier and capacitor C1, which is called the *input filter capacitor*, is exactly the same as in the simple capacitor filter shown in Fig.14. The rectifier passes current to charge capacitor C1 with the polarity indicated on the diagram. The capacitor is charged by a series of pulses as shown in Fig.15. However, if the load resistance  $R_L$  is low enough to draw appreciable current from the supply, the voltage across C1 will discharge appreciably during the portion of the cycle when the rectifier is not conducting. Thus, we have dc with ac superimposed on it across C.

To see the action of R1 and C2, let's first consider how capacitor C2 reacts to ac and to dc. Remember that a capacitor will not pass dc. It can be charged so that dc voltage will

exist across it, but applying dc to the plates of the capacitor does not cause a current to flow through it. Although electrons cannot cross the dielectric of the capacitor, applying ac to the dielectric of the capacitor produces the effect of a current flowing through it. This is because electrons will first flow into one plate and then into the other as the polarity of the ac reverses.

You will remember from your study of capacitors that a capacitor offers what is called capacitive reactance or opposition to the flow of ac through it. The exact reactance that any capacitor will offer to the flow of ac through it is given by the formula:

$$X_C = \frac{1}{6.28 \times f \times C}$$

You can see from this formula that the higher the capacity of the capacitor, the lower

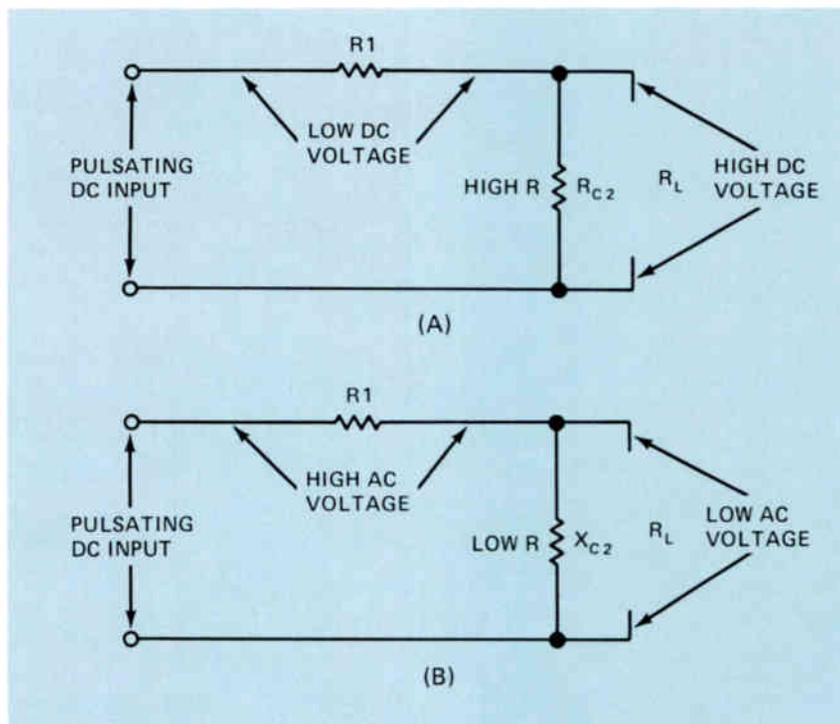


Figure 17. Equivalent circuits showing the reaction of an RC filter (A) to dc, and (B) to ac.

the capacitive reactance will be to an ac voltage of a particular frequency. As a matter of fact, a  $50\ \mu\text{F}$  capacitor, commonly used for C2 in filter circuits, has a reactance of about 50 ohms at 60 Hz.

In Fig.17(A), we have shown how the filter consisting of R1 and C2 reacts to dc; in Fig.17(B), we have shown how it reacts to ac. As you know, a perfect capacitor would not pass any dc, but there is no such thing as a perfect capacitor because there is always a small dc current called a leakage current. However, as far as dc is concerned, capacitor C2 acts like a very high resistance and the resistance of R1 will be whatever you have selected. In both cases, it is kept low enough so that the dc flowing through it will not cause any appreciable voltage drop.

Now look at Fig.17(B), which shows the reaction of the circuit to an ac voltage. The capacitor has a very low reactance to ac, and the resistance of R1 will be much higher than the reactance of C2, so most of the ac voltage will be dropped across R1. R1 and C2 act together as a voltage divider, with most of the ac being dropped across R1 because its resistance is much higher than the reactance of C2. Consider, for example, a  $50\ \mu\text{F}$  capacitor which, as we mentioned before, has a reactance of about 50 ohms at 60 Hz. Suppose R1 has a resistance of 500 ohms. Its resistance is ten times the reactance of C2. Therefore, the ac voltage appearing across R1 will be ten times the ac voltage appearing across C2. Suppose, for example, the ac voltage across C1, which is called a *ripple voltage*, is 20 volts. This 20 volts will divide between R1 and C2 at the ratio of 10 to 1 so that the ripple across C2 would be less than 2 volts.

The RC filter is a much better filter than the simple capacitor filter, but it does have one disadvantage. If we make R1 too large, there will be a substantial dc voltage across the resistor. This will reduce the voltage

available to the load. This problem can be overcome by the use of an LC filter.

### LC Filters

The disadvantage of the resistor-capacitor type of filter shown in Fig.16 soon becomes apparent if you consider what happens because of the resistance of the filter resistor and the dc current flowing through it. If the dc current in the load is 100 mA, which is 0.1 ampere, the voltage drop across the 500 ohm filter resistor referred to in the previous section would be 50 volts. In the case of a power supply operating directly from the ac power line, a substantial portion of the available voltage would be dropped across the filter resistor. You will see this type of filter in applications where the current is reasonably low. In applications where there is a high dc current, an LC filter like the one shown in Fig.18 is usually used.

In the LC filter, the rectifier and C1 act exactly like the simple capacitor filter shown in Fig.14. Capacitor C1, which once again is called the input filter capacitor, is charged by the input voltage and recharged by each pulse to meet the peak line voltage less the small voltage drop across the rectifier.

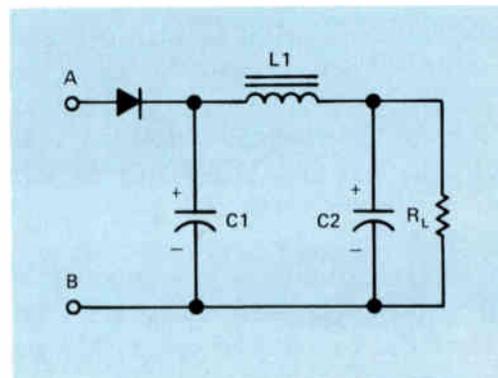
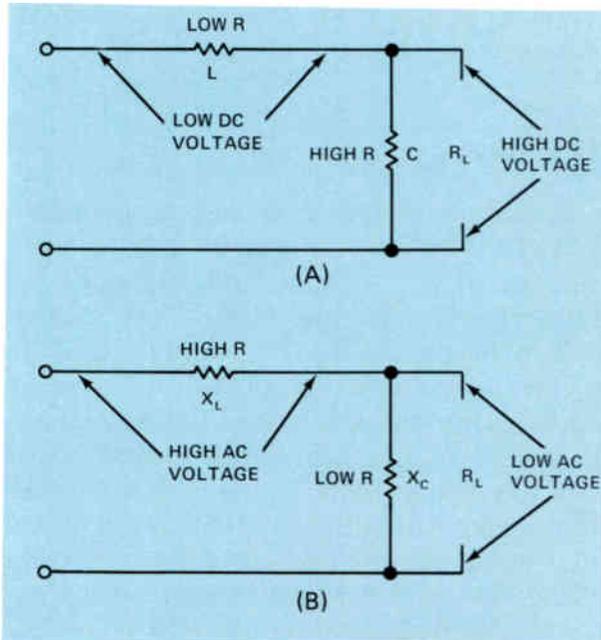


Figure 18. An LC filter.

# POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

20



**Figure 19.** Equivalent circuits showing the reaction of an LC filter (A) to dc, and (B) to ac.

The action of the filter network made up of  $L_1$  and  $C_2$  is shown in Fig.19. You already know that a capacitor has a high resistance to dc, so that the only current flow through it will be a small leakage current. Therefore, as far as the dc is concerned, the capacitor acts like a high resistance. The dc resistance of  $L_1$ , which is called a *choke*, can be kept low by using a reasonably large wire size to wind the coil. It is comparatively easy to build a 10 henry choke with a dc resistance as low as 50 ohms. With a 50 ohm dc resistance, the voltage across the choke with a current of 100 mA would be only 5 volts. This is far less than the 50 volt drop you would get across a 500 ohm filter resistor in the circuit shown in Fig.16.

The choke coil will also offer much better filtering of the ac. A 10 henry choke has an inductive reactance of about 3750 ohms at 60 Hz. You already know that a  $50\ \mu\text{F}$  capacitor has a capacitive reactance of 50 ohms

at 60 Hz. Therefore, as far as dividing the ac voltage is concerned, we see in Fig.19(B) that the inductive reactance of the choke, which is 3750 ohms, is in series with the 50 ohm capacitive reactance of the capacitor. We have a voltage-divider network in the ratio of approximately 75 to 1. If the ac voltage across  $C_1$  is 20 volts, as in the preceding example, the voltage across the capacitor would be approximately 0.25 or about one quarter of a volt. Thus, when compared to the RC filter where we had an ac voltage division of approximately 10 to 1, with the LC filter we have an ac voltage division of approximately 75 to 1. The ac at the output of the LC filter will be much lower and the dc will be much higher.

Again, this type of filter is called a pi filter because the configuration looks like the Greek letter pi ( $\pi$ ).  $C_1$  is called the input filter capacitor and  $C_2$  the output filter capacitor. Since the LC filter is a much better filter than the RC filter, you might wonder why we would ever use an RC filter. The answer is simply that resistors are very inexpensive, whereas the choke is not.

## Factors Affecting the Output Voltage

In any filter network containing a filter choke or a filter resistor, the dc current flowing through the load must also flow through the filter choke or filter resistor. Thus there will be a voltage drop across the choke or resistor. The exact value of the voltage drop will depend upon the dc resistance and the current flowing. We've already pointed out that the voltage drop is usually lower across the filter choke than across the filter resistor for a given dc current.

If the current drawn by the load changes, the output voltage at the output of the filter network will change. You can see why this is

so because the current must flow through the filter resistor or filter choke. If the current flowing through the choke or resistor were to change, the voltage drop across it would also change, and the voltage at the output of the power supply would have a tendency to change as well.

The output voltage is also affected by the size of the filter capacitors used. If the filter capacitors are too small, the rectifier won't keep them completely charged. If the capacitors are large, once the rectifier gets them charged they'll stay charged to a voltage near the peak ac voltage applied to the rectifier.

### Summary

In this section we have covered some of the more important types of filter networks you are likely to encounter in your career as an electronics technician. You have seen that these networks vary from comparatively simple networks consisting only of a capacitor up to networks containing a choke and two filter capacitors.

The simpler types of filter networks can be used where the current drain is low and where the filtering does not have to be perfect. More elaborate filters are used in power supplies having a high current drain and in cases where good filtering is required to supply pure dc at the power supply output.

The filters in this section of the lesson are shown with half-wave rectifiers. The same filter circuits are also used with full-wave rectifiers. As a matter of fact, in applications where you want pure dc with very little ripple on the output, you almost always find a full-wave rectifier.

### Self-Test Questions

- 15 To what value may the filter capacitor charge in the simple filter capacitor circuit shown in Fig.14?
- 16 In what type of application may we find a simple capacitor-type filter like the one shown in Fig.14?
- 17 What advantage does the RC pi-type filter shown in Fig.16 have over the single capacitor-type filter shown in Fig.14?
- 18 What is the advantage of an LC filter over an RC filter?

## TYPICAL POWER SUPPLIES

The two main sections of the power supply are the rectifier and the filter. Now that we have discussed both of these sections, let's examine some typical power supplies and see what they look like. First, we'll look at the universal ac-dc power supply. This type of power supply does not use a power transformer; it operates directly from the ac power line. This type of power supply is used in low-cost equipment, particularly table-model radios.

### Universal AC-DC Power Supplies

The universal ac-dc power supply was first developed for use in low-cost, table-model radios. You were supposed to be able to operate the radio from either an ac or dc power line. However, when operated from dc, the maximum voltage to which you can charge the input filter capacitor is the dc line voltage, whereas when operated from an ac power line you can charge the capacitor to the peak value of the ac power line, which is 1.4 times the voltage obtained from a dc line. Frequently, when you tried to use one of these radios on a dc power line, it wouldn't work. But today the use of dc in power lines has all but disappeared, and although these power supplies are now intended for use on ac, the old name has stuck.

Two ac-dc power supplies are shown in Fig.20. In the circuit shown at (A), the negative terminal of the power supply is the common terminal and two positive output voltages are available. The one at C2 will be a well-filtered low voltage. The output taken from across C1 will be a higher voltage, but it will not be as well filtered.

In the circuit shown at (B), the diode rectifier has been reversed and this will give us

the reverse polarity at the power supply output. The positive terminal of this power supply is the common terminal and there are two negative voltages available. As before, the voltage taken across C2 is well filtered, whereas the one taken from across C1 is not.

As you can see, both these power supplies were designed for use in table-model radios. The audio output can be taken from across C1 and this voltage is used to power the last transistor in the radio, the output transistor. The current through a transistor depends primarily on the forward bias across the emitter-base junction and not on the collector voltage. Therefore, if there is some hum on the collector, it won't cause any appreciable change

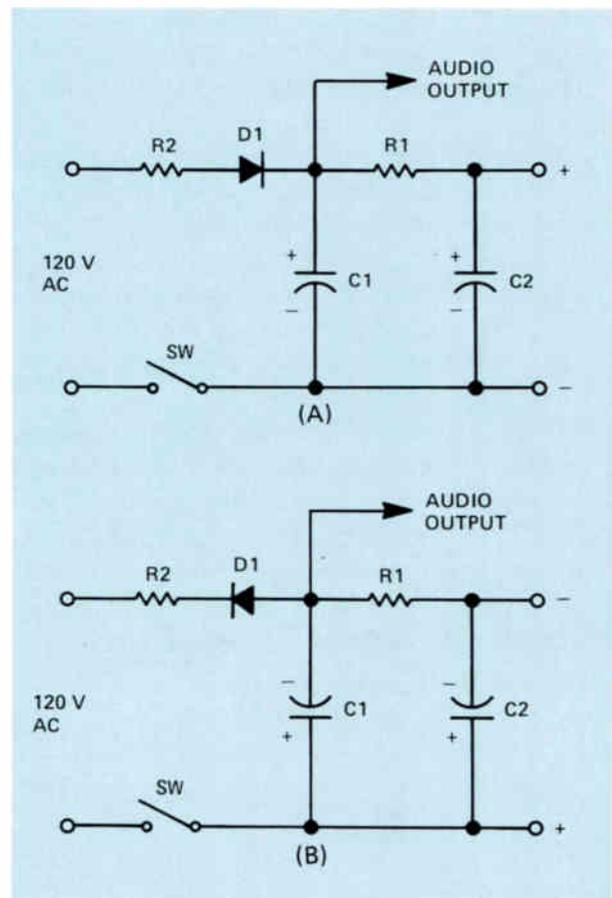


Figure 20. Universal ac-dc power supplies

## **YOUR REPUTATION**

Success in business depends on a number of things, but your reputation is probably the most important of them. Your sense of fair play and of honest dealing will determine your reputation, whether you run your own business or work for someone else. To help you get started on the right track, here are a few of the business rules you should memorize:

**Keep your promises.** Make it standard policy to only make promises you are reasonably sure you can keep.

**Keep accurate records.** Only records can show what your profits are, and what the tax bill is. Adequate records are essential to show you how to adjust your charges to be fair both to yourself and to your customers.

**Be honest in all your dealings.** Honesty goes far beyond dollars and cents; it includes fairness to your employees and clients, telling the truth in your advertising, guaranteeing your work and your merchandise, and being reasonable in dealing with your suppliers.

A good reputation is essential to a good business. With it, you are well on the road to success. Without it, you won't get very far.





# NOTES

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*Please use this page to record any notes  
you may want to review during your studies.*

# NOTES

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*Please use this page to record any notes  
you may want to review during your studies.*

# POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

44

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5. Which type of rectifier circuit produces the least ripple and the best regulation in a power supply?
  - a. Half-wave.
  - b. Voltage doubler.
  - c. Full-wave.
  - d. Simple capacitor filter.
6. In a simple capacitor-type filter such as shown in Fig.14, current flows through the rectifier for:
  - a. One half-cycle.
  - b. More than one half-cycle.
  - c. Less than one half-cycle.
  - d. As long as the capacitor is discharged.
7. The advantage of an LC filter such as shown in Fig.18 over an RC filter such as shown in Fig.16 is:
  - a. The output voltage will be higher.
  - b. Lower hum voltage at the output.
  - c. There will be less voltage drop across the choke.
  - d. All three of the choices given are correct.
8. In the power supplies shown in Fig.20(A) and (B), R2 is connected between the diode and the power line to:
  - a. Provide better filtering.
  - b. Reduce the voltage across C1.
  - c. Limit the initial charging current through D1.
  - d. Reduce the voltage across D1.
9. In Fig.29, if the output voltage decreases, the collector current of Q2:
  - a. Increases.
  - b. Decreases.
  - c. Remains the same.
10. What is the % load regulation of a power supply whose open circuit output voltage of 24 volts drops to 20 volts under full load?
  - a. 16.7%.
  - b. 83.3%.
  - c. 20%.
  - d. 80%.

## LESSON QUESTIONS

### This is Lesson Number 2229.

Make sure you print your name, student number, and lesson number in the spaces provided on the Lesson Answer Form. Be sure to fill in the circles beneath your student number and lesson number.

**Reminder:** A properly completed Lesson Answer Form allows us to evaluate your answers and speed the results and additional study material to you as soon as possible. Do not hold your Lesson Answer Forms to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

The form is a light blue document with a white background. At the top left, there is a small black square. Below it, the text "Name" is followed by "John Smith" written in a cursive font. Below that, "Print" is written. Then, "Student No." is followed by "XY01237894" in a grid of boxes. To the right, "Lesson No." is followed by "2229" in a grid of boxes. Below these fields is a grid of circles for marking answers. The circles are arranged in two columns, one for the Student No. and one for the Lesson No. Some circles are filled in, indicating answers.

- If the primary-to-secondary ratio of a step-down transformer with losses is 10 to 1, and the secondary winding is supplying 100 watts to the load, the primary power will be:
  - 10 watts.
  - 100 watts.
  - 1000 watts.
  - Somewhat over 100 watts.
- The core of a transformer is made of laminations rather than a solid piece of steel in order to:
  - Keep eddy current losses at a minimum.
  - Reduce hysteresis losses.
  - Reduce flux leakage losses.
  - Reduce copper losses.
- If the primary-to-secondary turns ratio in a transformer is 1 to 5 and the current supplied to the load by the secondary is 1 ampere, the primary current will be approximately:
  - $\frac{1}{5}$  ampere.
  - 1 ampere.
  - 5 amperes.
  - 10 amperes.
- The primary reason for using an auto-transformer over a transformer with two separate windings is that:
  - It is a better step-up transformer.
  - It is a better step-down transformer.
  - It is more efficient.
  - It is cheaper.

# POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

42

connected across C1 and C2 in series, so these capacitors are continually supplying power. In the half-wave rectifier circuit, current is supplied to the load only during the part of the half-cycle when terminal A is positive with respect to terminal B.

- 15 It may charge to the peak of the ac line voltage which in the case of a 120 volt power line is approximately 170 volts.
- 16 It may be used in applications where the current drain from the power supply is low.
- 17 The RC pi-type filter provides much better filtering, particularly if there is any appreciable current drawn from the power supply.
- 18 The inductance in an LC filter has a much lower dc resistance than the resistance in an RC filter. In addition, in most cases the inductive reactance of the choke in an LC filter is much higher than the resistance of the resistor, so that better filtering is provided.
- 19 The filter capacitors in Fig.20(B) are connected with the opposite polarity to those in Fig.20(A) because the rectifier is reversed.
- 20 For a given dc output voltage, the power transformer in the rectifier circuit shown in Fig.21 must have twice as many turns on the secondary winding as the transformer used with a bridge rectifier circuit.
- 21 The highest dc output voltage will be available between terminals 1 and 2 in the circuit shown in Fig.22.
- 22 D1 and D4.
- 23 A shunt regulator is inefficient because the current passing through it serves no useful purpose insofar as powering the equipment is concerned.
- 24 Although the voltage across a properly biased zener diode changes very little when the current changes through it, the voltage does change.
- 25 The resistance of the series transistor varies to control the output voltage in a series voltage regulator.
- 26 When compared to a series voltage regulator using discrete components, the three-terminal IC regulator is less expensive, uses less space, usually has some form of overload protection, and is quickly installed in the circuit.
- 27 The lower the percentage regulation of a voltage regulator, the better the regulation. A regulator with a load regulation of 2% provides better regulation than one with 5% regulation.
- 28 A slow-blow fuse may never be used in place of a fast-blow fuse.
- 29 You should not use a 2 ampere fuse in place of a 1 ampere fuse. A blown fuse should be replaced with one having the same rating as the original fuse.
- 30 The circuit breaker is probably defective and should be replaced.
- 31 A 6.8 volt zener diode used to protect a 6 volt power supply will not conduct if the voltage rises to 6.5 volts.
- 32 The SCR must also have a positive voltage applied to the gate before it will begin conducting.
- 33 Once an SCR begins conducting, it will continue to conduct even after the gate voltage is removed. The only way you can stop it from conducting is to temporarily remove the anode voltage.

## ANSWERS TO SELF-TEST QUESTIONS

- 1 The primary winding.
- 2 The secondary winding. In a transformer, the ratio between the primary voltage and the secondary voltage depends entirely upon the ratio of the turns on the primary winding to those on the secondary winding. If the secondary winding has more turns than the primary winding, the transformer will be a step-up transformer; if it has fewer turns, it will be a step-down transformer.
- 3 The secondary winding.
- 4 The primary winding. When a load is connected across the secondary winding of a transformer, the winding will supply power to the load. The amount of power will depend upon the secondary voltage and the load resistance. The power supplied by the secondary winding must come from power taken by the primary winding from the power line. If the secondary is supplying the power at a voltage lower than the primary voltage, then the secondary current will be higher than the primary current. On the other hand, if the secondary winding is supplying the power at a voltage higher than the primary, then the secondary current will be lower than the primary current.
- 5 The efficiency of a transformer is the ratio of the power supplied to the secondary load over the power consumed by the primary times 100. If a transformer supplies 95 watts to the secondary and takes 100 watts from the power line, then its efficiency will be 95 divided by 100 times 100 equals 95%.
- 6 Copper losses are due to the resistance of the wire used to wind the various coils in the transformer. The copper loss in each winding is equal to the current squared flowing in that winding times the resistance of the winding.
- 7 To reduce losses due to eddy currents.
- 8 Eddy current losses, hysteresis losses, and flux leakage losses.
- 9 Since the primary and secondary windings of an autotransformer are continuous, that is there is only one winding, the autotransformer does not isolate the load from the power line.
- 10 60 per second. Since a half-wave rectifier provides one pulse per cycle, there will be 60 pulses per second on the 60 Hz power line.
- 11 It is difficult to filter to pure dc. This is primarily due to the fact that a pulse flows during one half-cycle, but there is no current flow during the next half-cycle.
- 12 For a given dc output voltage, the transformer secondary need have only half as many turns as the full-wave rectifier circuit shown in Fig.10.
- 13 The bridge rectifier has the disadvantage that it requires four rectifiers, whereas a full-wave rectifier circuit with a tapped secondary requires only two.
- 14 In the full-wave voltage doubler circuit shown in Fig.13, the load is

## Summary

The important thing to remember about fuses is that if you have to replace one, you should replace it with a fuse of the same type and current rating as the original.

Circuit breakers perform the same function as fuses, but they are mechanical devices. Once the overload has been removed, they can be reset so that the circuit then will be complete. If the circuit keeps opening even though the current through it is normal, it is a sign that the circuit breaker is defective and should be replaced.

Electronic protection circuits work much faster than fuses or circuit breakers. A zener diode will provide protection against short-term overvoltage conditions. Where large or sustained overvoltage conditions may exist, a circuit such as the crowbar overvoltage protection is normally used.

## Self-Test Questions

- 28 Can you use a slow-blow fuse in place of a fast-blow fuse?
- 29 Should you use a 2 ampere fuse in place of a 1 ampere fuse?
- 30 If a circuit breaker trips after one hour's operation and the current through it is normal, what should you do?
- 31 If a 6.8 volt zener diode is used for overvoltage protection in a 6 volt power supply, will the diode conduct if the voltage rises to 6.5 volts?
- 32 In addition to a positive voltage on the anode of an SCR, what other condition must be met before the SCR will conduct?
- 33 When an SCR begins conducting, how can you stop it from conducting?

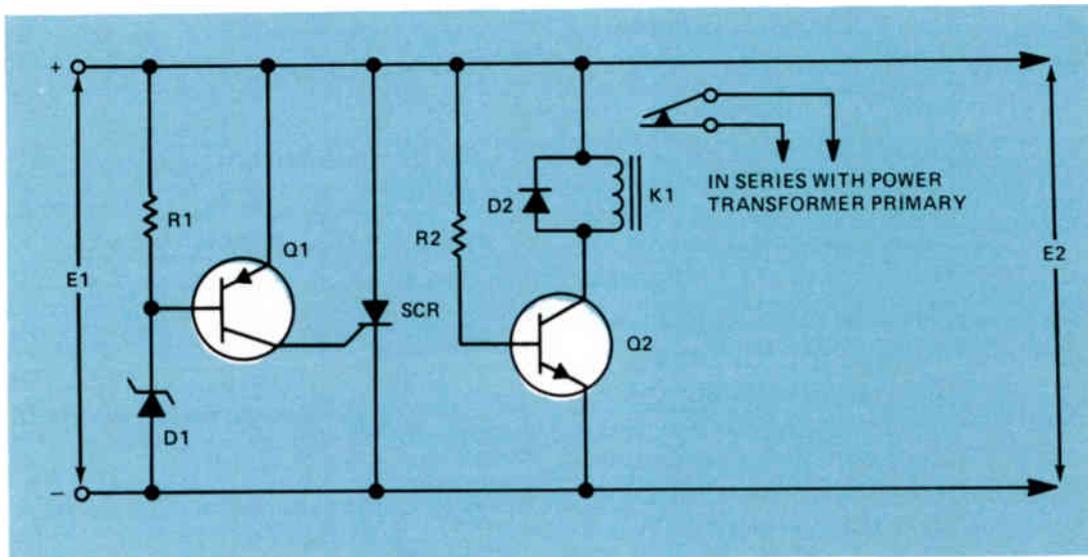


Figure 33. SCR crowbar overvoltage protection circuit.

to the primary of the power transformer through the closed relay contacts.

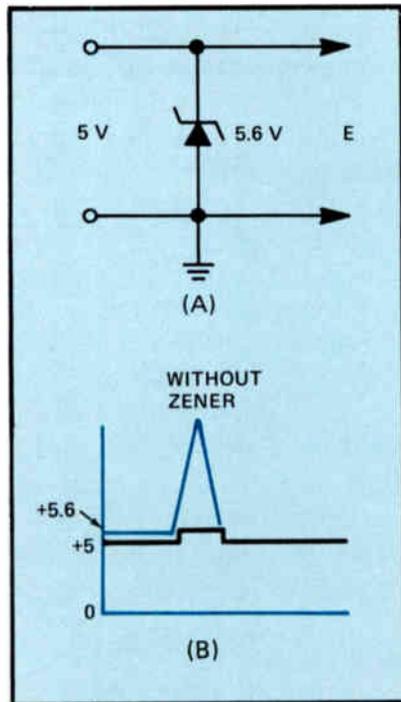
If the value of  $E1$  rises and exceeds the breakdown voltage of zener diode  $D1$ , current will flow through the diode to the cathode and through  $R1$  to  $+V$ . Current flowing through  $R1$  will develop a voltage across it so the base of  $Q1$  will be negative with respect to the emitter. Remember that this is the condition needed to provide forward bias across the emitter-base junction of the pnp transistor  $Q1$ .

When  $Q1$  turns on, it acts like a short circuit so that the gate of the SCR is connected through  $Q1$  directly to  $+V$ . This causes the SCR to fire so a high current begins flowing through it. This places a momentary short across the power supply so that the value of  $E1$  drops. When this happens, the voltage of the base of  $Q2$  will drop practically to zero and  $Q2$  will stop conducting. When  $Q2$  stops

conducting, the current through the relay coil will drop to zero and the relay contacts will open, removing the ac voltage from the primary of the power transformer. This will, in effect, shut down the power supply.

The speed at which the crowbar circuit works depends primarily on the speed of the relay. There are fast-acting relays available that will open in less than a millisecond so the input voltage to the power supply can be removed very quickly, before any damage can occur.

Diode  $D2$  connected across the relay serves no useful purpose when the relay is energized and its contacts closed. However, when  $Q2$  stops conducting, the sudden drop in current through the relay coil will induce a voltage that keeps this current flowing. The polarity of the voltage will be such that  $D2$  conducts, causing this voltage to disappear rapidly so the relay will open.



**Figure 32.** (A) A zener diode for overvoltage protection, and (B) how the zener clamps overvoltage conditions.

The zener diode is an extremely fast-acting device; even transient overvoltage conditions will be detected. If some high-amplitude, short-duration, power line transient should pass through the supply and appear on the output line, the zener diode will conduct momentarily and clamp that overload condition to 5.6 volts. Figure 32(B) shows such a condition. A zener diode connected in this way provides excellent and inexpensive protection from momentary overload conditions.

For momentary overload conditions, the zener diode provides adequate protection. It may be insufficient, however, to protect against large or sustained overvoltage. In these cases, the zener diode must have a substantial power rating to withstand the current that will flow during the overload condition. In many situations, zener diodes with the desired power rating are simply not available. Other pro-

visions must then be made to protect against overvoltage conditions.

Such a circuit is shown in Fig.33. Commonly referred to as a “crowbar,” this circuit consists of a silicon-controlled rectifier (SCR) and a current source that senses the voltage on the power supply lines. Normally, the SCR and the current source transistor (Q1) are not conducting, and the normal supply voltage is applied to the equipment.

A silicon-controlled rectifier is a diode with a cathode and an anode like any other diode. But it also has a third element called a gate. The SCR will not conduct, even when there is a positive voltage applied to the anode, until it is turned on or “fired” by a positive voltage to the gate. Once the SCR begins conducting, it will continue to conduct even if the positive voltage is removed from the gate. The only way you can stop current flow through the SCR is to momentarily remove the positive voltage applied to the anode.

In the circuit shown in Fig.33, the zener diode D1 has a breakdown voltage equal to the voltage at which you want overvoltage protection to occur. This will be somewhat above the normal value of E1. Under normal operating conditions, the voltage E1 is not high enough to cause the zener to conduct, so there will be no current flow through it or through R1. With no current flow through R1 there will be no voltage drop across it; the base and emitter of Q1 will be at the same potential. This means that Q1 will not have any forward bias across the emitter-base junction and therefore will not conduct; it will act like an open circuit. Thus there is no voltage applied to the gate of the SCR and the SCR does not conduct.

The base of Q2 is connected through R2 to + V. This forward biases Q2 so current flows through it and through the relay coil. Current through the relay coil will energize the relay so its contacts will close and power is applied

A slow-blow fuse is one that will open if it is subjected to a continuous overload; it is essentially immune to momentary overloads. This fuse contains an element that is heat-sensitive and it will open when it gets hot enough from self-heating. It is because of the element's heating delay that the fuse will not blow when it is temporarily overloaded. Most of these fuses contain a small spring that helps to pull apart the fuse element rapidly when it does melt.

Slow-blow fuses are used in any circuit when temporary overloads occur as a normal part of operation. A good example is their use in motor circuits where the starting current is very high for a few seconds, but operating current is relatively low. An ordinary fast-blow fuse would blow every time the motor is started because of the high motor starting current.

### Circuit Breakers

Circuit breakers work much like fuses — they open the circuit when the current exceeds a predetermined value. They have the advantage over fuses in that they can be reset once the overload has been removed. Fuses must be discarded and replaced once they blow.

There are two basic types of circuit breaker. One type has a bimetallic strip that is surrounded by a coil through which the current passes. If the current through the coil becomes too high, the heat produced causes the bimetallic strip to bend. The motion of the bimetallic strip is transferred to a mechanical linkage that releases a catch used to hold the switch contacts together. The contacts are pulled apart by a spring. Once the overload is removed, pressing the reset button will engage the catch that holds the contacts together.

A different type of circuit breaker uses an electromagnet to operate the release. If ex-

cessive current flows through the coil of the magnet, the magnet field will be sufficient to pull the core into the coil. This actuates a mechanism that releases the catch that holds the contacts together.

You do not have to know all the details of how a circuit breaker works, you simply have to know the purpose for which it is used, and if you have to replace one, be sure to get one with the same current rating as the original.

Occasionally you will encounter a circuit breaker that works when the equipment is first turned on and then opens after it has been in use for some time, even though the current through the circuit breaker is normal. When this happens, the circuit breaker is defective and you must replace it.

### Electronic Protection Circuits

Fuses and circuit breakers are electro-mechanical protection devices. While they provide adequate protection in many cases, they operate too slowly in some other cases. Where more rapid protection is required, electronic protection circuits are used.

A simple circuit for protection against momentary voltage overloads is shown in Fig.32(A). Here we have a 5 volt power supply with a 5.6 volt zener diode connected across it. As long as the power supply voltage remains 5 volts, the 5.6 volt zener diode connected across it will not conduct in its reverse direction.

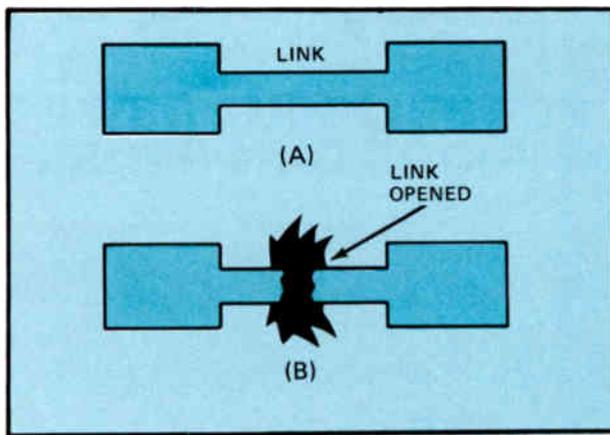
Since the diode does not conduct, it draws no current from the supply; it is essentially inactive. If some overvoltage should occur, the diode will conduct when the voltage reaches 5.6 volts. Because of its constant voltage characteristic, it tends to hold the voltage across the power supply to 5.6 volts. Thus the equipment is protected. The additional 0.6 volt causes no damage or trouble.

## CIRCUIT PROTECTION

Every power supply requires some protection from overloads. When excessive current is drawn from the power supply, there is a chance of damaging the regulators, rectifiers, power transformer, and other components. Most power supplies are designed to withstand some overload. However, when they are excessively overloaded, or overloaded for long periods of time, expensive damage can result. For that reason most power supplies are protected with fuses or circuit breakers that remove the overload before damage can occur.

### Fuses

A fuse is a part connected in series with the electric circuit it is to protect. It protects the circuit by melting and opening if an excessive current passes through it. Only when overloaded does the fuse operate, or “blow.” Otherwise, it performs no function in the normal circuit other than completing the path for current flow.



**Figure 31.** Fuse operation showing (A) a good fuse, and (B) a blown fuse.

Fuses are made from metal alloys which, when made to a precise width and thickness, will melt and open as a predetermined current passes through. Figure 31 illustrates this. The links in fuses designed to operate at currents of about 1 ampere or more are shaped like the link shown in Fig.31. Fuses designed to operate at lower currents are generally made of a round piece of fuse wire.

Fuses are usually made with the link strung between two metal end caps, the housing being a glass tube. Some of the higher current units use a ceramic tube housing for splatter protection and heat dissipation. The glass envelope offers an advantage over the opaque ceramic: the fuse condition is visible.

It is often impossible to determine whether or not the fuse is good by visual inspection in the case of a very low current fuse because the fuse link is so thin. Any doubtful fuse can be checked with an ohmmeter. If the fuse is good, there will be a low resistance across it.

Fuses come in a wide range of standard values and can be used in either ac or dc circuits. Whenever you have to replace a blown fuse, never use one having a higher current rating than originally specified by the manufacturer. If you do, you will forfeit the protection the fuse is supposed to supply.

There are three different types of fuses used in electronic equipment: fast-blow, very fast-blow, and slow-blow. The most commonly used is the fast-blow type and, unless otherwise specified, you can assume that a fuse is of this type. Fast-blow fuses are used in many solid-state circuits where transistors, ICs, or diodes would be damaged unless the overload is removed quickly.

The very fast-blow types have been developed recently for critical semiconductor circuits where extremely rapid overload removal is needed. The very fast-blow fuse will blow in about  $\frac{1}{10}$  of a second or faster when 100% overloaded.

### Summary

One important thing for you to remember about voltage regulators is that there are two types: shunt voltage regulators and series voltage regulators. Shunt voltage regulators are normally used when the power requirements of the load are low. While simple shunt regulators are quite satisfactory for maintaining the voltage constant, they are very inefficient since all the current flowing through them is wasted.

Series regulators are more efficient than shunt regulators and they can be used for higher power requirements.

Series regulators with some type of error detection and feedback provide better regulation than simple series regulators.

The trend in modern series voltage regulators is to use three-terminal integrated circuit regulators. They are available in a wide number of voltage ratings. They provide effective regulation, take up less space than regulators made up of discrete components, and are generally less expensive. In addition, they usually have some type of overload protection built into them so that in the event of an overload they simply shut down.

### Self-Test Questions

- 23 Why is a shunt regulator inefficient?
- 24 Will the voltage across a properly biased zener diode remain constant if the current through the diode changes?
- 25 How does the series transistor in a series voltage regulator control the output voltage?
- 26 Name three advantages of the three-terminal IC regulator over series regulators using discrete components.
- 27 Which regulator provides better load regulation, one with a load regulation of 5% or one with a load regulation of 2%?

is one of the most important regulator parameters. It is usually measured with a constant load current so variations in the load do not come to play. Line regulation can be expressed as follows: % line regulation equals

$$\frac{\text{change in dc output voltage}}{\text{change in ac input voltage}} \times 100$$

If for an input change of 5 volts, the output were to change by 50 millivolts (0.05 volt), the regulation factor would be:

$$\frac{0.05}{5} \times 100 = 1\%$$

It is important to notice that the smaller the percentage of line regulation, the better the job the voltage regulator is doing.

**Load Regulation.** The percentage of change in regulated output voltage for a change in load from zero to the maximum load current specified is called the *load regulation*. The load on the regulator is changed from no load (open output) to full load where maximum safe current is drawn and the change in output voltage noted. Load regulation is as important as line regulation; it is a true measure of how well the regulator maintains the constant voltage with varying loads. Load regulation is expressed as follows: % load regulation equals

$$\frac{\text{change in output voltage}}{\text{full load output voltage}} \times 100$$

The change in output voltage in this formula is simply the difference between the no-load or open circuit output voltage and the output voltage with maximum or full load. For example, assume we have a power supply with a no-load voltage of 5 volts. If we place a full load on the supply and the output drops to 4.75 volts, we have

$$\begin{aligned} \% \text{ load regulation} &= \frac{5 - 4.75}{4.75} \times 100 \\ &= \frac{0.25 \times 100}{4.75} \\ &= \frac{25}{4.75} = 5.263\% \end{aligned}$$

Once again, the lower the percentage of load regulation, the better the regulator is working. In other words, a power supply with a load regulation of 1% has better regulation than power supply with a load regulation of 5%.

**Ripple Rejection.** Any ripple or hum voltage fed from the filter network to the voltage regulator appears to the voltage regulator just like a change in the input voltage. The regulator will try to maintain the output voltage constant. A measure of the capability of the regulator to reduce ripple voltage is termed ripple rejection. How well the regulator rejects this ripple is the *ripple rejection factor*. Ripple voltage is actually a rapid change in the dc input to the regulator; the regulator sees it as any other input voltage variation and, therefore, attempts to compensate for it. The regulator substantially reduces the output ripple. This is true of any regulator circuit.

bipolar transistor, has three terminals. The terminals on the regulator are the *input*, to which is applied the unregulated dc voltage, the *regulated output voltage terminal*, and the *common* or *ground terminal*. These are terminals 1, 2, and 3, respectively, in Fig.30. As you can imagine from the description, the device is extremely easy to use. The unregulated voltage from the power supply is applied between the input terminal and ground. The load is connected across the output terminal and ground. Such regulators are available in a wide range of current and voltage ratings. Typical regulated output voltage ratings are 5, 6, 8, 12, 15, 18, and 24 volts, both positive and negative, with current ratings as high as 1 ampere.

Three-terminal regulators are usually used as remote regulators on printed circuit boards to supply the voltage requirements of the circuits on individual printed circuit boards. This arrangement allows a relatively inexpensive unregulated power supply to supply the power needs for a collection of printed circuit boards as might be present in any large electronic system. The regulators on the individual circuit boards need to handle only the modest power requirements of the circuitry on their own circuit boards.

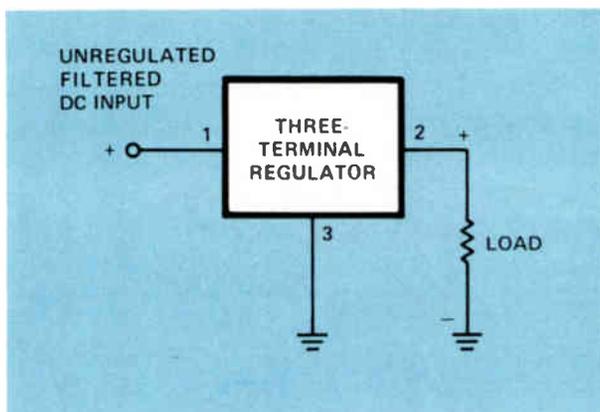


Figure 30. Typical three-terminal IC regulator.

The three-terminal regulators usually contain protective circuitry that causes the device to shut down when its internal temperature becomes too high. This might happen if too much current were drawn from the load or if the input voltage were too high, resulting in a large power dissipation in the regulator. In most instances, the regulator will resume normal operation when the cause of the excessive heat is removed.

Integrated circuit voltage regulators are replacing discrete component regulators because they are smaller and require less space (you have to make only three connections to the regulator and the entire circuit is wired), they are usually provided with their built-in overload protection, and they are considerably cheaper than regulators using discrete components.

**Adjustable Regulators.** Adjustable IC voltage regulators are also available. A typical one is the Fairchild 723. This device can supply positive or negative output voltages. The output voltage can be set to any value between 2 and 37 volts. The IC can supply an output current up to 150 mA.

You do not have to know how these devices work, but simply that they are available. They are more expensive than the fixed voltage regulators, but in some applications the increased cost may be justifiable.

### Voltage Regulator Performance

Voltage regulator performance is measured in several ways. You do not have to know all of them, but there are several important specifications with which you should be familiar.

**Line Regulation.** The percentage a regulated dc output voltage may change for a change in ac input voltage is called *line regulation*, or *regulation factor*. Line regulation

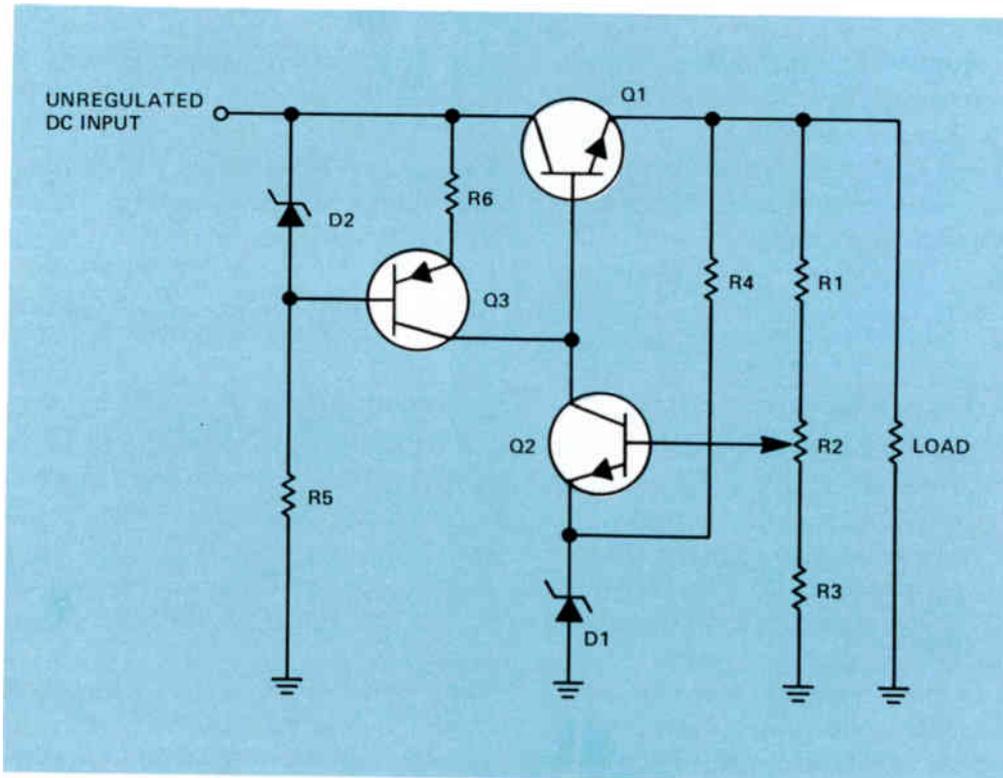


Figure 29. An improved feedback voltage regulator.

offset by equal and opposite variations in the base current of Q1. These current changes can change the voltage across the resistor R5 in Fig.28. As a result, the current it supplies changes, forcing the circuit to compensate for changes in the bias current as well as output voltage variations. Naturally, this reduces the effectiveness of the regulator in compensating for load variations. The constant-current source eliminates this effect.

A further improvement in the basic feedback regulator can be obtained by increasing the gain of the error amplifier circuit. Very small changes in the output voltage must be amplified sufficiently to provide control to the base of the series-pass transistor. The higher the gain of the circuit, the more control small variations in output voltage will have on the series-pass transistor.

## Integrated Circuit Voltage Regulators

While some electronic voltage regulator circuits are still constructed with discrete components, more and more integrated circuits are being used in this application. Using modern integrated circuit technology, it is possible to construct the entire feedback regulator circuit on a single chip of silicon. Many integrated circuit voltage regulators are available. Some of these devices require absolutely no external components other than the usual power supply parts for proper operation.

**Three-Terminal Regulators.** One of the simplest and most widely used integrated circuit voltage regulators is the three-terminal regulator. This device is packaged in a standard power transistor housing and, like any

in the output voltage will cause a change in the base current of Q2, which in turn changes its collector current. This causes the base current of Q1, and hence its collector current, to vary. By changing the conduction of Q1, the output voltage will be adjusted to compensate for the original output change.

Assume that because of some line or load variation, the output voltage increases. This will cause an increase in the voltage occurring at the base of Q2. The base current of Q2 will increase. In turn, the collector current of Q2 increases. This brings about a reduction in the base current of Q1. Since Q1 conducts less, its effective resistance will increase. This causes the output voltage to decrease. As you can see, the original output voltage increase is corrected. A decrease in output voltage causes the base and collector current of Q2 to decrease. Therefore, the base current of Q1 will increase. Q1 will conduct more, and its effective resistance will decrease. This results in an offsetting increase in the output voltage.

Resistor R2 in the output voltage divider is a potentiometer. This permits you to adjust the base current of Q2. The voltage at the base of Q2 is essentially fixed at a value equal to the zener voltage plus the emitter-base drop of Q2. Despite the changes in the adjustment of R2, the voltage between the base of Q2 and ground will remain essentially constant. However, the base current of Q2 will vary as R2 is adjusted. Adjusting R2, therefore, controls the collector current of Q2 and the base current of Q1. This in turn varies the output voltage. R2, then, is a control that can be used to adjust the output voltage to the desired level. Once it is set, the circuit will automatically maintain the output voltage at this desired value.

Any hum voltage on the unregulated dc input or change in the unregulated dc input will cause some change in the regulated out-

put voltage in the circuit shown in Fig.28. A change in the input voltage will change the current through the zener diode D1 and R4 so there will be some slight change in the voltage across D1 which will change the emitter voltage of Q2. Similarly, a change in the unregulated dc input will cause the current through R5 and hence the base current of Q1 to change. This also will affect the regulated output voltage. These two problems can be overcome or greatly reduced by modifying the circuit slightly as shown in Fig.29.

Notice that in the improved feedback voltage regulator R4 has been moved from the unregulated input to the output. This will result in a more constant current through the zener diode and R4 so that the voltage applied to the emitter of Q2 will be essentially constant.

The resistor R5 in Fig.28 has been replaced by the constant-current source made up of D2, Q3, R5, and R6. Notice that Q3 is a pnp transistor, so current flows from the collector of Q2 and the base of Q1 to the collector of Q3. Electrons flow from the emitter of Q3 through R6 to the power supply output. Notice that the zener diode, D2, holds the base of Q3 constant, keeping the current through this transistor constant.

In addition to preventing ac ripple and changes in the input from changing the base current of Q1, the constant current source also improves the load regulation of the circuit. In order to provide perfect regulation, the sum of the base current of Q1 and the collector current of Q2 should be constant. An increase in the collector current of Q2 will then result in an equal decrease of the base current of Q1 and vice versa. If the sum of the currents is not constant, poor regulation will result. By using a simple resistor for this bias source, as we did in Fig.28, we create variations in the output voltage that will affect the collector current of Q2. These variations should be

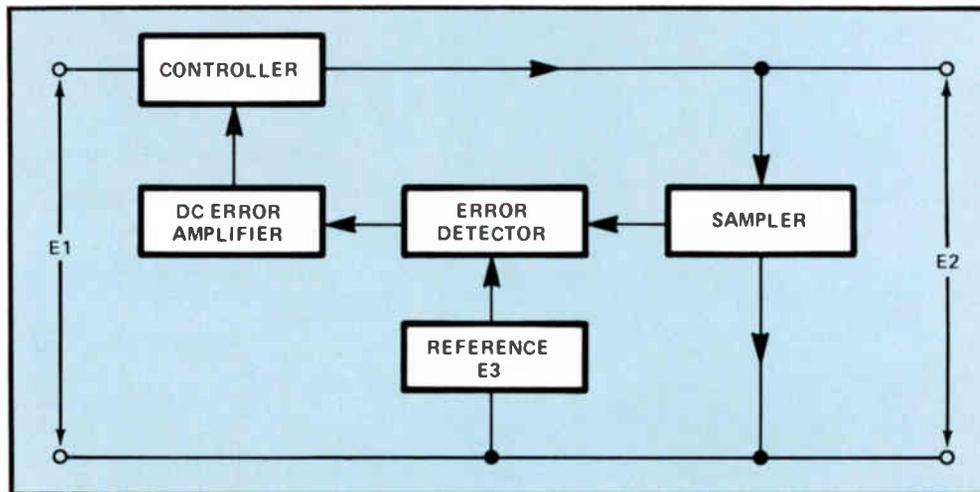


Figure 27. Block diagram of a feedback regulator.

establishes a standard for this circuit against which the output will be compared. The sample taken from the output and the reference are both applied to an error detector, which compares the two.

Any fluctuation in the output produces a positive or negative dc voltage at the output of the error detector. The error voltage is amplified and applied to the controller (usually a series transistor acting as a variable resistance). The amplified error signal changes the bias on the control element in Fig.27 to shift the output back to the desired level.

The simplest form of feedback voltage regulator is shown in Fig.28. The series-pass transistor, Q1, is an emitter follower similar to that used in the regulator discussed earlier. Here the base voltage of the series-pass transistor is controlled by the error amplifier Q2. Q2 performs the functions of comparison, error detection, and amplification.

A sample of the output voltage is taken from the output through the voltage divider made up of R1, R2, and R3. This sample is applied to the base of Q2. The emitter of Q2 is biased by the zener diode D1 and through resistor R4 to provide a fixed voltage at the

emitter of Q2. The output voltage sample and the zener reference voltage are compared by Q2. The current flowing through Q2 is a function of the output voltage and the zener voltage. The base bias for Q1 is obtained from resistor R5. The current through this resistor is a combination of the base current of Q1 and the current from the collector of Q2. A change

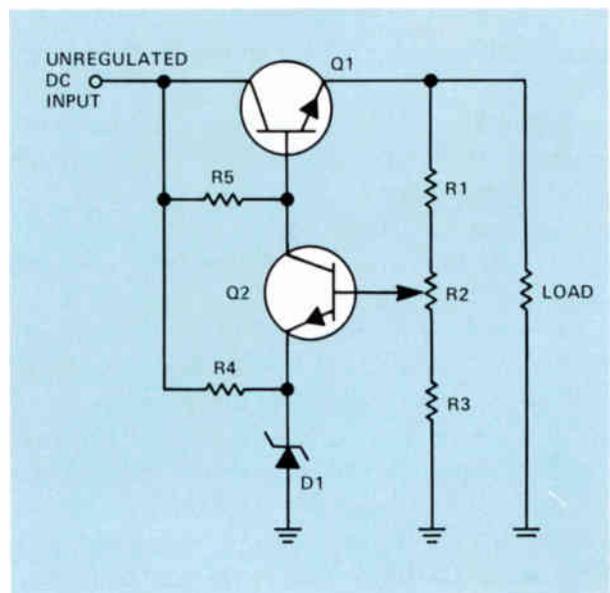


Figure 28. Simple feedback voltage regulator.

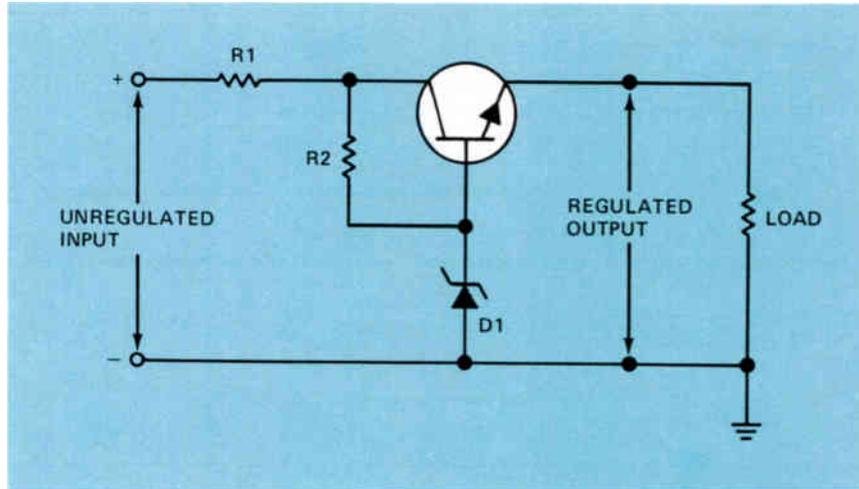


Figure 26. A simple emitter-follower series voltage regulator.

in collector current. Since the resistance of a transistor is equal to the collector-emitter voltage divided by the collector current, the transistor resistance must increase as the collector-emitter voltage increases. The transistor therefore acts as a variable resistor.

We use this characteristic of a transistor in the series-regulated supply shown in Fig.26. Notice that the transistor base voltage is held at a fixed value by the zener diode D1. Let's see what happens if the dc input voltage increases.

When the dc input voltage increases, the current flowing through the series circuit consisting of R2 and D1 will increase. The voltage across diode D1 will remain essentially constant and the voltage drop across R1 will increase. The base voltage applied to the transistor will remain essentially constant.

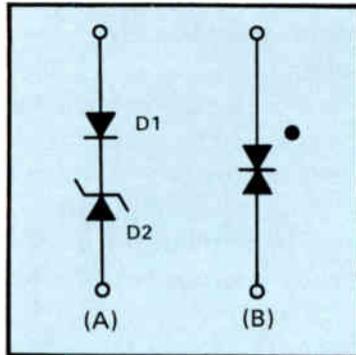
At the same time, the collector-emitter voltage of the transistor will increase because of the increased input voltage. Since the base voltage remains constant, there will be little or no increase in collector current and hence little or no increase in emitter current. The resistance of the transistor increases so that the voltage across the load will remain

essentially constant. If the input voltage should drop, the opposite happens. The voltage drop across R1 goes down, but the base voltage remains almost constant. The resistance of the transistor will decrease so that the voltage across the load will remain essentially constant.

Of course, if the input voltage should change, the current through D1 will change, so there will be some small change in the voltage across it. This will result in a slight change in the collector and emitter currents of the transistor; the voltage across the load will change slightly, but far less than it would without the series regulator. More elaborate circuits can be used to provide better regulation.

### Feedback Voltage Regulators

Figure 27 is a block diagram of an improved series regulator, often called a feedback regulator. In this circuit, the sampler is a sensing element, usually a resistor voltage-divider network. It samples a part of the output voltage. This sample is usually set equal to a reference level. The reference voltage



**Figure 24.** (A) Connections for a temperature-compensating zener diode, and (B) its schematic symbol.

connecting a zener diode and a normal silicon diode in series. The temperature coefficient of a conventional forward-biased diode is negative, and that of a zener diode above approximately 6 volts is positive. Therefore, the possibility of one diode compensating for a change in the other exists when they are connected back-to-back as shown in Fig.24(A).

Diode D1 is a silicon diode connected in the forward-biased direction; D2 is a zener diode connected in the reverse-biased configuration. Sometimes both diodes are packaged together, as shown in Fig.24(B). The dot end should be connected to the positive terminal so that the zener diode is properly back biased.

A silicon diode has a voltage drop of approximately 0.7 volt across it when it is conducting. When it is in series with the zener, the drop across the combination will be 0.7 plus the zener voltage. For example, an 8.2 volt zener in series with a series diode regulates the voltage to  $8.2 + 0.7 = 8.9$  volts.

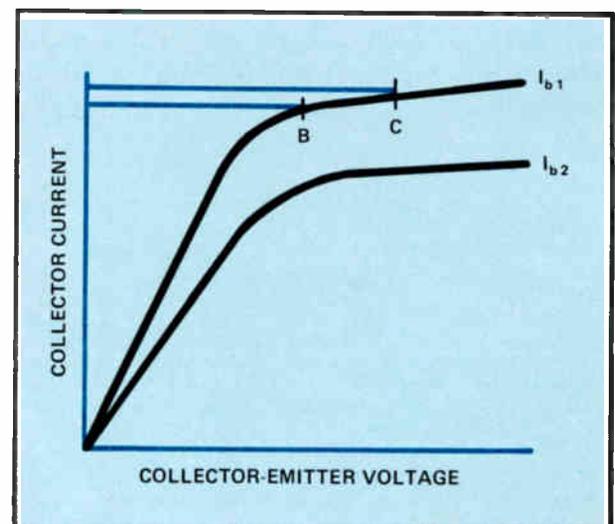
The simple shunt regulator shown in Fig.23 is quite satisfactory and economical, as long as the current requirements of the load are not too high. One-half watt and one watt zener diodes are inexpensive, have a low resistance, and will provide good regulation. If the power consumed by the load does not exceed 5 watts, this type of circuit works well. In higher power applications we must use high-

wattage zeners. They are expensive and have a fairly high resistance, providing less effective regulation than the low-power units. When the current requirements exceed those that can be regulated by low-wattage zener diodes, it is better to use a series voltage regulator circuit.

## Series Voltage Regulators

Before going into the series regulator, let's look at the transistor characteristic curves shown in Fig.25. Each curve is a plot of collector current versus collector-emitter voltage for a given base current. Once the collector-emitter voltage reaches a certain value, any further increase causes little or no change in collector current for a given base current. If the base current changes, the collector current changes appreciably; if the base current remains constant, the collector current remains almost constant even with wide changes in collector voltage.

As an example, notice that on the curve for  $I_{b1}$  that if the collector-emitter voltage changes from point B to point C, there is little change



**Figure 25.** Transistor characteristic curves.

## VOLTAGE REGULATORS

The function of a voltage regulator is to take the voltage provided by the transformer-rectifier-filter arrangement and convert it into a stable output voltage. This must be accomplished in spite of variations of the input line voltage or of the load.

There are two basic kinds of voltage regulators, shunt and series. In the shunt type, the voltage regulation is obtained by a series-dropping resistor and by diverting current through some device, with a constant voltage characteristic, in parallel with the load. The shunt regulator is inefficient, but possesses the significant advantage of not being destroyed under short-circuit conditions.

A series regulator uses some type of variable resistance device in series with the load. If the input voltage or load current changes, this series resistance adjusts itself to compensate for the change.

### Shunt Voltage Regulators

A simple shunt voltage regulator using a zener diode is shown in Fig.23. You will remember that a zener diode is operated under reverse-bias conditions and that once the diode breaks down and begins conducting, changes

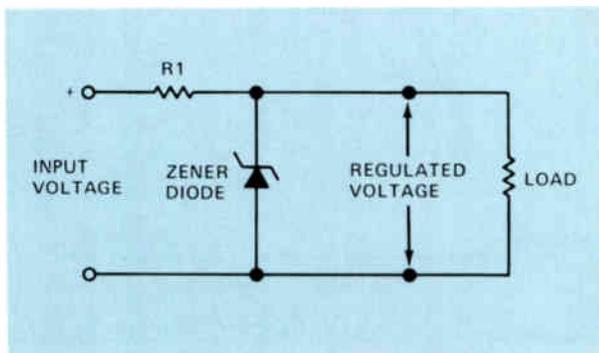


Figure 23. A shunt zener diode voltage regulator.

in the current through it result in only a very small change in the voltage across it. As the current through the diode varies to compensate for changes in the load current or input voltage, there will be some change in the output voltage, but the change will be much less than it would be without the diode regulator.

The regulated voltage will be equal to the input voltage less the voltage drop across R1. The value of R1 is selected so that, under normal operating conditions, the current through the zener diode will be about 20% of the current flowing through the load. If the input voltage increases, the current through the zener diode will increase so that the voltage drop across R1 will increase. This will keep the regulated voltage constant. If the input voltage decreases, the current through the diode will decrease so the voltage drop across R1 will decrease.

If for any reason the load current increases, the current through the zener diode will decrease once again, keeping the voltage drop across R1 almost constant. If the load current decreases, the zener diode current increases, keeping the current through and the voltage drop across R1 almost constant.

One problem with silicon zener diodes is the effect that temperature has on the reverse breakdown voltage. Zener diodes with breakdown ratings of less than about 6 volts have a negative temperature coefficient. The breakdown voltage of a diode with a negative temperature coefficient decreases as the temperature increases. Zener diodes with a voltage breakdown above 6 volts have a positive temperature coefficient. This means that the breakdown voltage increases with increases in temperature. At about 6 volts, the zener diode has almost a zero temperature coefficient. The 6 volt zener is very stable with temperature changes.

A temperature-compensating zener, designed for use above 6 volts, can be built by

# POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

## Summary

Most modern electronic equipment you will encounter will use full-wave power supplies with either a rectifier circuit like the one shown in Fig.21 or a bridge rectifier. Bridge rectifiers are widely used because the savings in the cost of the transformer more than offsets the cost of the two extra rectifiers. While half-wave rectifiers are not as common, they are useful in some applications.

Modern power supplies use a pi-type filter network. The filter network may be either an RC network or an LC network. LC networks usually provide better filtering and better voltage regulation.

## Self-Test Questions

- 19 Why are the filter capacitors in Fig.20(B) connected with the opposite polarity to those in Fig.20(A)?
- 20 What is the disadvantage of the full-wave power supply shown in Fig.21 compared to a bridge rectifier?
- 21 Between which two output terminals of the power supply shown in Fig.22 is the highest output voltage available?
- 22 In the bridge rectifier circuit in Fig.22, when terminal 7 of the transformer is negative and terminal 9 is positive, which two diodes will conduct?

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to the junction of D1 and D2 and terminal 9 connects to the junction of D3 and D4. When terminal 7 is positive with respect to terminal 9, electrons will flow from terminal 9 to the junction of D3 and D4 and then through D3 to the minus terminal, which is terminal 2. From there they will flow through the load to terminal 1, through the choke and D2 to terminal 7 of the transformer. During the next half-cycle, when terminal 7 is negative and terminal 9 is positive, electrons will flow from terminal 7 through D1 and then to terminal 2 of the power supply output, through the load to terminal 1, through L1, and then through D4 to terminal 9 of the transformer. You can see we have a bridge rectifier circuit rectifying the full voltage between terminals 7 and 9. The pi-section LC filter consisting of C1, L1, and C2 filters the output from the rectifiers and changes the pulsating dc to smooth dc.

Now notice that terminal 7 of the transformer connects to D5 and terminal 9 connects to D6. Terminal 8 of the transformer is grounded. When terminal 8 is negative with respect to terminal 7, electrons will flow from terminal 8 to ground, to terminal 4 at the output of the power supply, through the load to terminal 3, and then through L2 and D5 back to terminal 7. During the next half-cycle, when terminal 8 is negative with respect to terminal 9, electrons will flow from terminal 8 to ground and then to terminal 4, through the load to terminal 3, through L2, and through D6 to terminal 9 of the trans-

former. Here we have a full-wave power supply using the center tap of the transformer and producing a voltage between terminals 3 and 4 such that terminal 3 is positive with respect to terminal 4. C3, L2, and C4 form a pi-section LC filter network.

Now let's see what happens in the power supply made up of D7 and D8. When terminal 7 is negative with respect to terminal 8, electrons will flow from terminal 7 to D7, through the diode, and then through R1 to the negative terminal (terminal 5), through the load back to terminal 6, and from there to ground and over to terminal 8. During the next half-cycle, when terminal 9 is negative with respect to terminal 8, electrons will flow from terminal 9 through D8, through R1 to terminal 5, through the load to terminal 6, from terminal 6 to ground, and back to terminal 8. Now we have a power supply where terminal 5 is negative with respect to terminal 6. Thus we have a negative voltage available between ground and terminal 5. The RC filter consisting of C5, R1, and C6 smooths the pulsating output from rectifiers D7 and D8 to smooth dc.

Thus, from the one transformer we have three separate output voltages. We have a high voltage between terminals 1 and 2, a positive voltage that is about half as high between terminals 3 and 4, and a negative voltage at terminal 5 that would be approximately equal to the positive voltage on terminal 3.

# POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

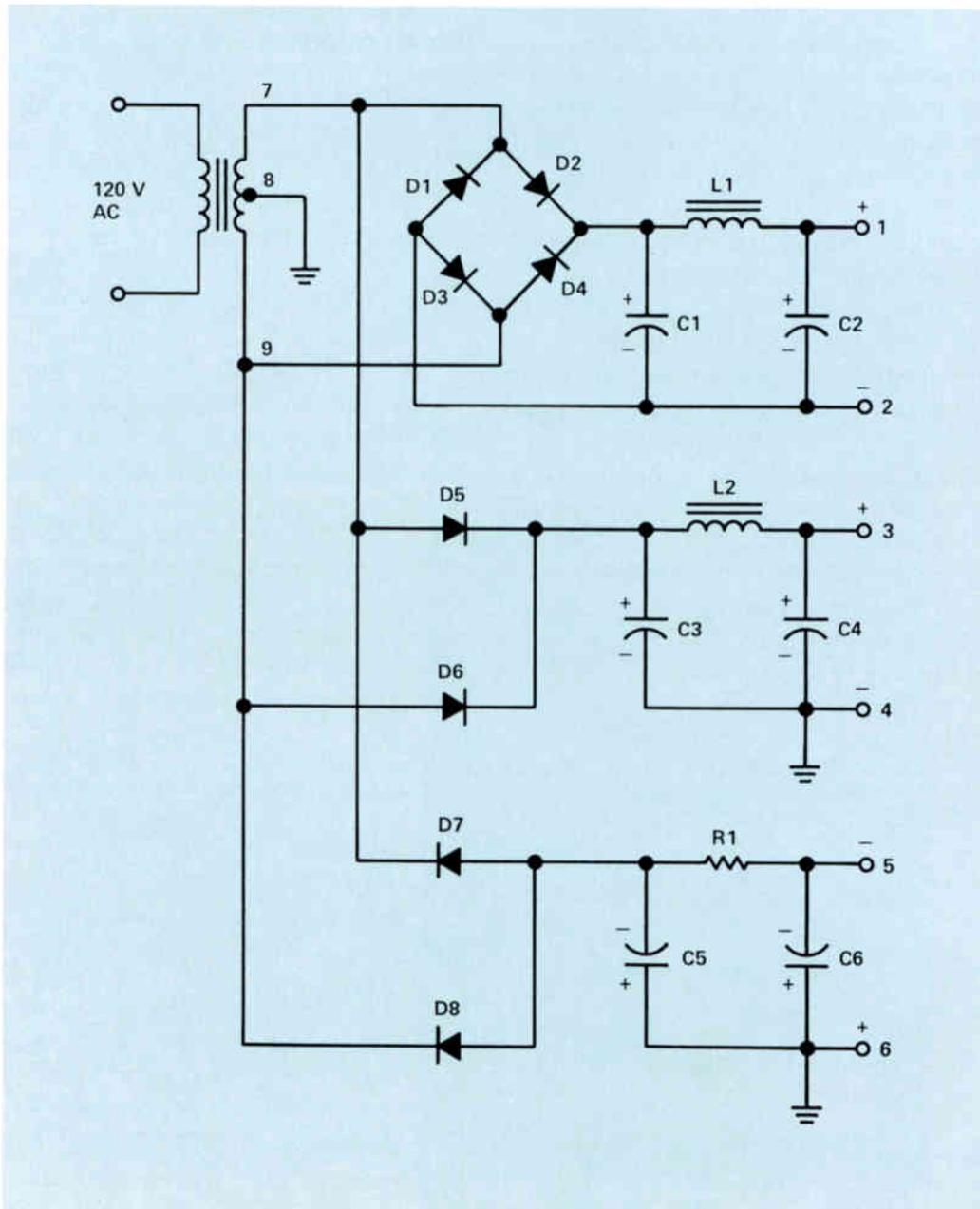


Figure 22. A multiple output voltage power supply.

A power supply designed to produce multiple output voltages is shown in Fig.22. At first this might look like a complicated supply, but actually it is made up of three simple

supplies operating from a single transformer. To see how it works, first look at the circuit made up of diodes D1, D2, D3, and D4. Notice that terminal 7 of the transformer connects

in the current through the transistor so you will not hear any hum in the output of the radio. The power supply at (A) is designed for use with a radio using npn transistors, while the one shown at (B) is designed for use in a radio using pnp transistors.

Notice the resistor R2 connected between the diode and the power line in both supplies. When the equipment is first turned on, C1 will be discharged. Without R2 in the circuit, the initial charging current through the diode would be so high the diode could be destroyed. R2 limits the initial charging current to a safe value.

Although these two power supplies were designed for use in radio receivers, you will find similar power supplies in other low-cost electronic equipment. It is not always possible to take a voltage from across the input filter capacitor, but in many cases where some hum voltage does not matter and a higher voltage is needed, this is done.

### Typical Full-Wave Power Supplies

A simple full-wave power supply is shown in Fig.21. Notice that this power supply uses a power transformer and that the secondary of the transformer is tapped and the tap is grounded. During one half-cycle, D1 will conduct and during the other half-cycle D2 will conduct.

Notice that we have resistors R1, R2, and R3 across the output. These resistors will make it possible for us to get three different operating voltages from the power supply. The resistors are also connected across the output of the power supply to serve another purpose. They will discharge the capacitors C1 and C2 when the equipment is turned off. Usually the filter capacitors will have a fairly high capacity, so it is desirable to discharge them when the equipment is turned off to prevent an accidental shock.

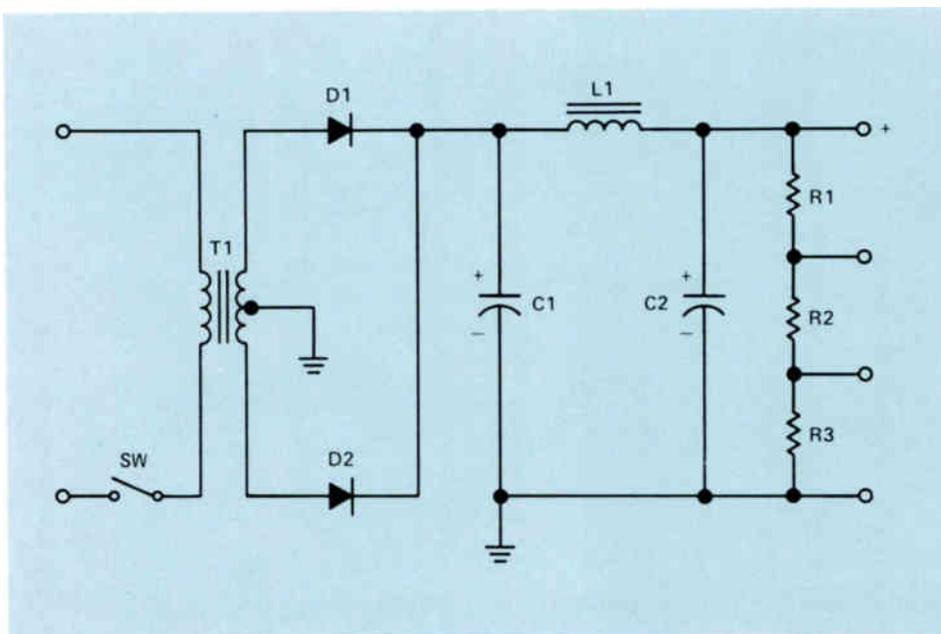


Figure 21. A full-wave power supply.



# How Amplifiers Work

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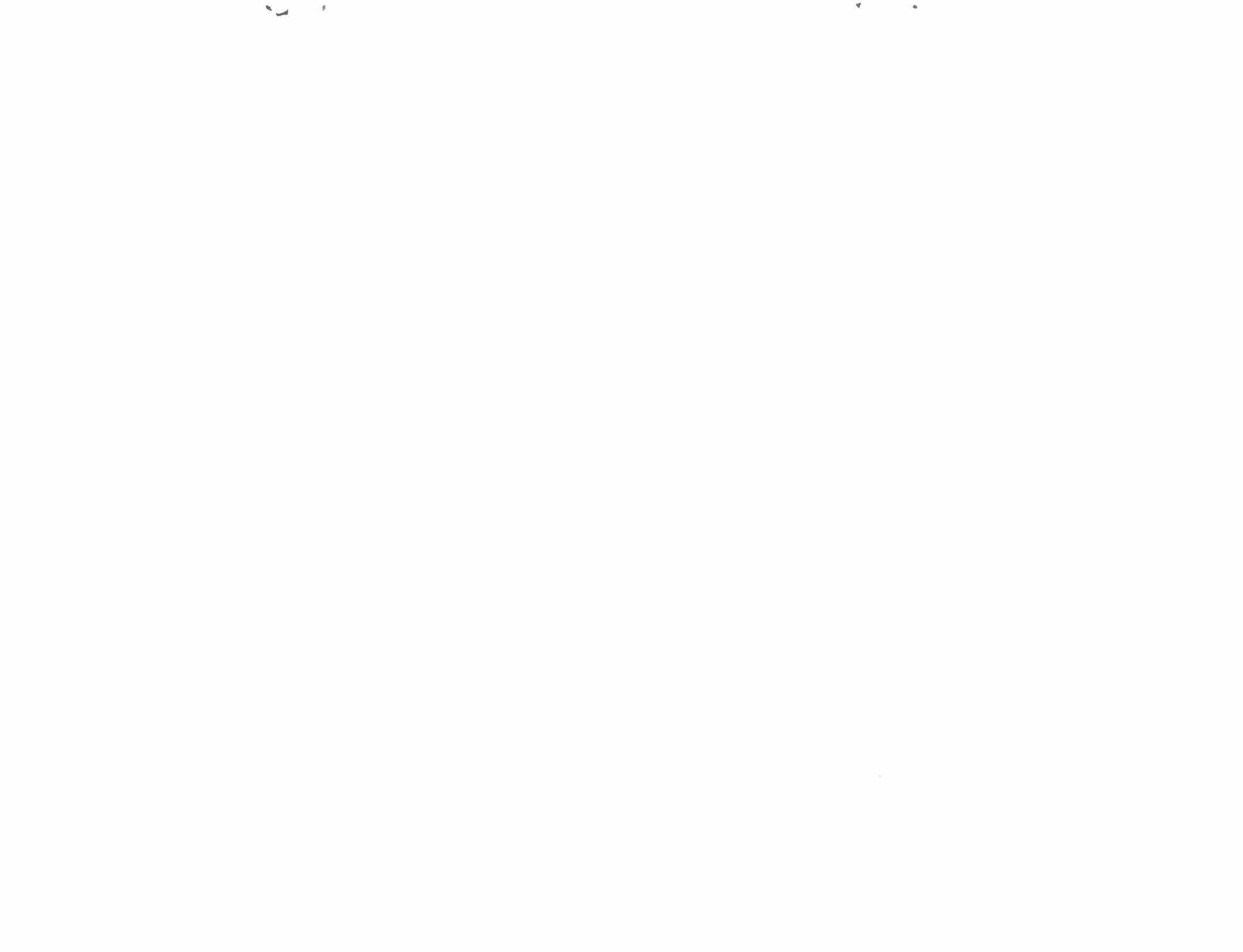


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# **How Amplifiers Work**

# HOW AMPLIFIERS WORK

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## TABLE OF CONTENTS

<b>Introduction</b> .....	<b>1</b>
<b>Types of Amplifiers</b> .....	<b>1</b>
Resistance-Capacitance Coupled Voltage Multipliers.....	1
A Two-Stage NPN Transistor Amplifier .....	2
A Two-Stage PNP Transistor Amplifier.....	5
A Two-Stage FET Amplifier .....	8
A Typical IC Amplifier .....	9
Operational Amplifiers.....	10
Summary.....	15
Self-Test Questions.....	15
<b>Low-Frequency Power Amplifiers</b> .....	<b>16</b>
Single-Ended Power Amplifiers .....	16
Push-Pull Amplifiers.....	19
Eliminating the Output Transformer.....	21
Inverse Feedback .....	23
IC Amplifiers .....	27
Summary.....	28
Self-Test Questions.....	28
<b>Radio Frequency Amplifiers</b> .....	<b>29</b>
Resonant Circuits .....	30
Transistor RF Amplifiers .....	33
I-F Amplifiers.....	37
IC Amplifiers .....	40
Summary.....	41
Self-Test Questions.....	41
<b>Logarithms and Decibels</b> .....	<b>42</b>
The Theory of Logarithms.....	42
The Decibel .....	43
Using the Decibel .....	44
Summary.....	46
Self-Test Questions.....	46
<b>Answers to Self-Test Questions</b> .....	<b>47</b>
<b>Lesson Questions</b> .....	<b>49</b>

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An amplifier is a circuit designed to take a weak signal at its input, and produce an amplified copy of the original signal at its output. Often, amplifiers are classified according to the frequencies they are designed to handle. In the first part of this lesson, we will study low-frequency amplifiers. Later in this lesson, you will study high or radio frequency amplifiers. Both types of amplifiers are important, because you will find either or both of them in practically every type of electronic equipment.

Amplifiers can also be classified as either voltage amplifiers or power amplifiers. A voltage amplifier is one that is designed to amplify a weak signal voltage, and make it stronger. A number of voltage amplifiers may be used in cascade to take a very weak signal voltage, and amplify it to a usable value. Power amplifiers are used to produce power to drive some external device. For example, every radio receiver has a power amplifier in the output. It takes the audio signal voltage that has been detected and amplified by preceding stages, and produces the power necessary to drive the loudspeaker to produce sound.

The ability of transistors to amplify signals is essentially what makes many of our modern electronic devices possible. Therefore, if you understand how these amplifiers work, and how they are put together to perform specific tasks, you will be able to analyze the operation of many different types of electronic equipment. Since amplifiers are so important, it is worthwhile to spend as much time as necessary on this lesson to be sure you have a complete understanding of them.

## **TYPES OF AMPLIFIERS**

When we speak of low-frequency amplifiers, we are generally concerned with amplifiers that are designed to amplify low frequency signals. No sharp dividing lines exist at the low-frequency or high-frequency end of the range over which the amplifier is supposed to work. Originally, a low-frequency amplifier was an amplifier that operated in the audio range, within the limits of our hearing. Of course, these amplifiers will amplify signals beyond these frequency limits, but not as well. The basic low-frequency amplifier can be modified so that it can amplify signals over a much broader range than the audio range. In fact, video amplifiers, which amplify picture signals having frequencies up to several megahertz, are simply modified low-frequency amplifiers.

Radio frequency amplifiers can be designed to amplify a specific frequency signal, or to amplify signals over a specific frequency range.

There are radio frequency amplifiers designed for very low frequencies, as low as 18 to 20 kHz. Other radio frequency amplifiers are designed to amplify very high-frequency signals over 1000 MHz. While they all do the same thing, the circuitry may be quite different because of the frequency of the signal being handled.

When we study low-frequency amplifiers in this lesson, we will study both voltage and power amplifiers. However, we will limit our study of radio frequency amplifiers to voltage amplifiers.

We'll start our study of low-frequency voltage amplifiers with the most widely used amplifier, the resistance-capacitance coupled voltage amplifier.

### **Resistance-Capacitance Coupled Voltage Amplifiers**

Resistance-capacitance coupling, most often called RC coupling or resistance coupling, is so

# HOW AMPLIFIERS WORK

2

named because resistors and capacitors are used to couple the signal from one stage to another.

This type of coupling is widely used between voltage amplifiers and between voltage amplifiers and Class A power amplifiers in audio work. You will learn about Class A power amplifiers later in this lesson. While the low-frequency amplifiers we will be discussing are primarily designed to amplify audio or sound signals, remember that these amplifiers can be used to amplify any low-frequency signal.

## A Two-Stage NPN Transistor Amplifier

In Fig.1, we've shown a typical two-stage transistor RC coupled amplifier using npn transistors. We are going to explain the operation of this amplifier in considerable detail because it is very important that you understand exactly how it works. After you have studied this amplifier, you will study another two-stage amplifier using pnp transistors.

The input signal to be amplified is fed into the input terminal in Fig.1 and coupled through C1 to the base of Q1. C2 holds the emitter at ground potential insofar as the signal is concerned, because it has a high capacitance and therefore a very low reactance. The signal is applied directly between the base and the emitter of the transistor. It is in series with the forward bias across the emitter-base junction.

The applied signal, which is an ac signal having a frequency in the audio range, causes the emitter-base current to vary, which in turn causes the collector current to vary. The varying collector current causes a varying voltage drop across R4, so that the effective voltage between the collector of the transistor and ground is varying.

If the input signal drives the base in a positive direction, the collector current will increase. This will cause the voltage drop across R4 to increase, so the voltage between the collector of the transistor and ground decreases. On the other hand, if the input signal swings the base in a negative direction, this will cause the

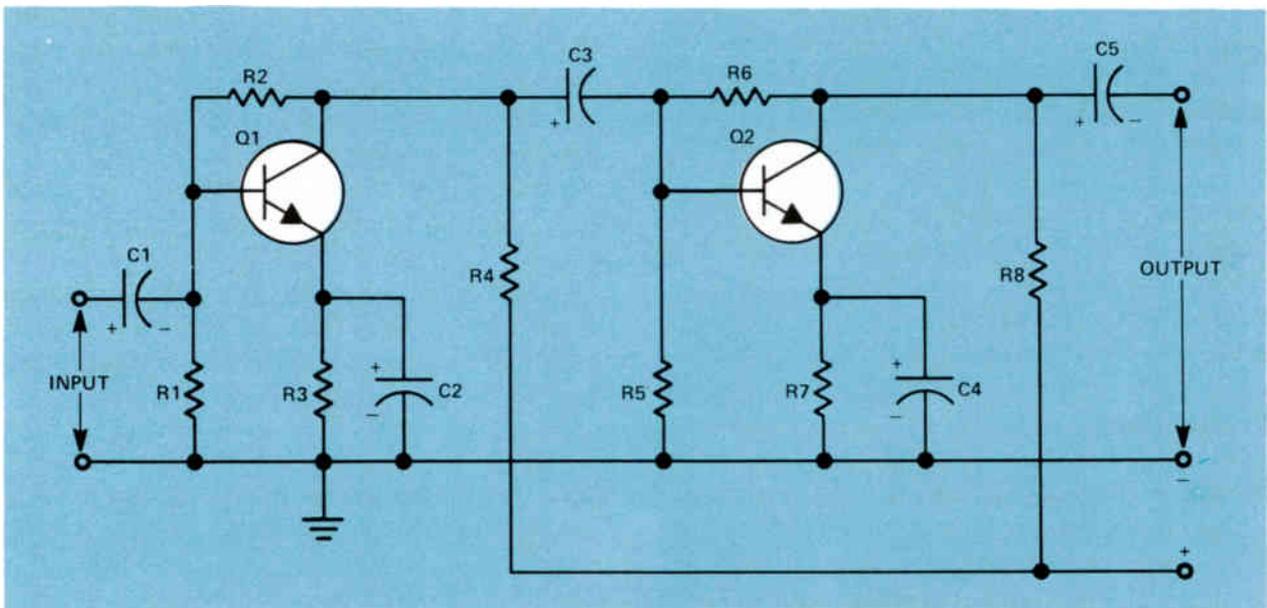


Figure 1. A two-stage RC coupled amplifier using npn transistors.

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collector current to decrease, because it reduces the forward bias across the emitter-base junction. When the collector current decreases, the voltage drop across R4 will decrease, so the voltage between the collector of the transistor and ground will increase. In other words, when the input signal swings positive, the signal between the collector of the transistor and ground swings negative. When the input signal swings negative, the voltage between the collector of the transistor and ground swings positive. Thus, we have a 180° phase reversal, which happens in the common-emitter amplifier circuit.

The varying input signal applied to the input of Q1 results in an amplified varying signal appearing between the collector of Q1 and ground. This is coupled through C3 to the base of Q2. The way this happens is quite simple.

With no signal applied, there will be a certain current flow through Q1 and a voltage drop across R4, so that the collector of Q1 will be at a certain positive voltage. At the same time, there will be a current flow from ground, which is connected to the negative side of the power supply, through R5, R6, R8, and back to the positive side of the supply that will place the base of Q2 at a slightly positive voltage. Capacitor C3 will charge to a value equal to the difference between the base voltage of Q2 and the collector voltage of Q1. It will charge with the polarity shown.

When the input signal causes the collector current of Q1 to increase, the voltage drop across R4 increases, and the net voltage between the collector of Q1 and ground decreases. The voltage between the collector of Q1 and the base of Q2 is lower, so C3 must discharge to this lower voltage level. When C3 discharges, electrons flow out of the negative plate through R5 to ground. This will set up a voltage drop across R5, having a polarity that makes the base end negative. The capacitor will have to discharge the same voltage that the

collector voltage of Q1 drops. Thus, we have a negative signal at the collector of Q1 appearing at the base of Q2.

When the input signal swings the base of Q1 negative, the collector current decreases, and the voltage drop across R4 decreases. This causes the voltage between the collector of Q1 and ground to increase. C3 must charge to this new value. To charge the capacitor, electrons flow from ground through R5 into the negative plate of C3, out of the positive plate, and through R4 to the plus side of the power supply. The electrons flowing through R5 to charge C3 to the higher voltage develop a positive voltage at the end of the resistor that is connected to the base of Q2, so that the swing in positive voltage at the collector of Q1 appears at the base of Q2.

The signal appearing between the collector of Q1 and ground is coupled through the RC network, consisting of C3 and R5, to the base of Q2. The emitter of Q2 is held at signal ground potential by C4 so the signal is appearing directly between the base and the emitter of Q2. The positive-going signal at the input of Q1, which produced a negative-going signal at the collector of Q1, produces a negative-going signal at the base of Q2. This reduces the forward bias across the emitter-base junction so that the current through Q2 goes down. If the collector current of Q2 decreases, the voltage drop across R8 will decrease, so that the voltage between the collector of Q2 and ground will increase. Notice that we have an increasing voltage at the base of Q1, producing an increasing voltage between the collector of Q2 and ground.

When the input signal to the base of Q1 swings in a negative direction, the current through the transistor and R4 decreases. The voltage drop across R4 will decrease, so the voltage between the collector of Q1 and ground swings positive. This will cause the voltage between the base of Q2 and ground to

# HOW AMPLIFIERS WORK

4

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swing positive; the current through Q2, and hence the collector current, will increase. This will increase the voltage drop across R8 so that the voltage between the collector of Q2 and ground decreases. In other words, we have a negative input signal at the input of Q1 producing a negative-going signal at the output of Q2.

In both cases, the input signal at the input of Q1 is in phase with the output signal at the output of Q2. This is what we might expect. We know that in a common-emitter amplifier, we have a 180° phase shift. So we have a 180° phase shift in Q1 and another 180° phase shift in Q2. Two 180° phase shifts equal 360°, so that the output signal after going through two amplifier stages will be in phase with the input signal. The output signal between the collector of Q2 and ground is coupled through C5 to the output terminal.

Notice how we have provided the forward bias across the emitter-base junction. In Q1, we connect a resistor, R2, between the collector of the transistor and the base. We have another resistor R1 between the base and ground. These two resistors form a voltage-divider network and by selecting the correct values, we can bias the base at the value required. Current will flow from ground through R1 and then through R2 and R4 to the positive side of the power supply. The value of R4 is usually selected so that the voltage between the collector of Q1 and ground will be about half the power supply voltage. This will permit the voltage on the collector of the transistor to swing a maximum in either positive or negative direction as the input signal changes. Once the value of R4 has been selected, then the values of R1 and R2 are selected to provide the desired positive voltage on the base of the transistor.

It is important to notice that the base voltage is determined by the voltage drop across R1 and the voltage drop across R2. The voltage drop across each resistor is determined by the

resistance of the resistor and the current flowing through it. The current flowing through R2 is made up of the current through R1 plus the base current of Q1. If anything causes the current through R2 to change, the voltage drop across it and the bias on the transistor will change.

Some minority carriers, which are holes, will cross the collector-base junction and flow from the collector into the base. These holes will capture some of the electrons flowing from the emitter to the base. Some of these electrons would normally flow out of the base and through R2, and contribute to the voltage drop across R2, which sets the forward bias across the emitter-base junction.

If the transistor begins to heat, the number of holes crossing from the collector to the base will increase. This will result in an increase in the number of electrons flowing into the base that are captured by these holes. This will cause a further reduction in the base current through R2, causing a voltage drop across R2 to decrease. This will cause the voltage on the base of the transistor to rise. In turn, the current flow through the transistor will increase, causing the transistor to heat still further. When this happens, the number of holes crossing from the collector to the base will increase further, capturing still more electrons, which will increase the base voltage even further. Eventually this high base voltage will overheat and destroy the transistor. This action is called *thermal runaway*.

Thermal runaway is prevented by the insertion of R3 in the emitter circuit. If the base voltage tends to rise, the current through the transistor will increase and this will increase the voltage drop across R3. Thus, the emitter will become more positive with respect to ground. If the base voltage becomes more positive, so will the emitter voltage, which will prevent or minimize any increase in forward bias across the emitter-base junction. Thus, the

sole purpose of R3 in the circuit is temperature stabilization. R7 in the emitter circuit of Q2 is used for the same purpose.

Let's consider another effect caused by the way we provide this forward bias. When a signal is applied to the input and drives the emitter-base junction in the positive direction so that the collector current increases, the voltage drop across R4 increases so that the collector voltage swings in the negative direction. Thus, the voltage between the collector of the transistor and ground decreases. We are using this voltage to provide the forward bias across the emitter-base junction of the transistors. Therefore, the forward bias will decrease. The positive-going signal has the effect of increasing the forward bias on the transistor. The drop in output voltage has the effect of reducing the forward bias on the transistor. This is called *degenerative*, or *negative*, feedback. It reduces the effect of the input signal, which in turn reduces the strength of the output signal. You might at first think this is a disadvantage, but it does have the advantage of increasing the frequency response of the amplifier. The frequency response of the amplifier is its ability to amplify equally all the different frequencies fed to it.

You could see why this is so if you consider what happens if the amplifier has a tendency to amplify some frequency or frequencies more than others. They will appear as a stronger signal in the output of the stage, meaning that the feedback would increase. This will reduce the gain of the stage more than it will in the case of frequencies that receive less amplification. Therefore, the degenerative feedback tends to equalize the gain of the stage over a wide range of frequencies.

When amplifiers are connected one stage after another as they are in Fig.1, we say they are connected *in cascade*. The total gain of the two amplifiers will be equal to the product of the gain of each stage. If each stage in the

example shown in Fig.1 has a gain of 10, the total gain will be 100. Suppose we feed a signal of 10 millivolts into the first stage having a gain of 10. At the output, the signal should have an amplitude of 10 millivolts times 10 equals 100 millivolts. Now, we feed the 100 millivolts into the second stage, where it is again amplified by a factor of 10. We then have 100 millivolts times 10 equals 1000 millivolts or 1 volt.

### A Two-Stage PNP Transistor Amplifier

In Fig.2, we've shown a typical two-stage RC coupled amplifier using pnp transistors. The operation of this amplifier is basically the same as the one shown in Fig.1, except that the power supply connections are reversed and the carriers through the transistors will be holes instead of electrons. Notice that we have obtained the forward bias for the emitter-base junction for each transistor in the same way as we did for the npn transistors in Fig.1. Also, notice in Fig.2 that resistors R3 and R7 in the emitter circuit of each transistor, are used to prevent thermal runaway.

Even though the operation of this two-stage amplifier is basically the same as the one shown in Fig.1, we are going to explain its operation in considerable detail. Read over the explanation carefully in order to note the differences between these two amplifiers.

First, let's consider what is happening in Q1 under zero signal conditions. Essentially the same thing is also happening in Q2. Notice that the emitter of Q1 connects through R3 to the positive side of the power supply. Electrons will be attracted from the emitter through R3 to the positive side of the power supply. The electrons leaving the emitter will produce holes that will cross the emitter-base junction if the base is negative with respect to the emitter.

Notice that the negative side of the power supply connects through R4 to the collector of Q1. Electrons can flow from the negative side

# HOW AMPLIFIERS WORK

6

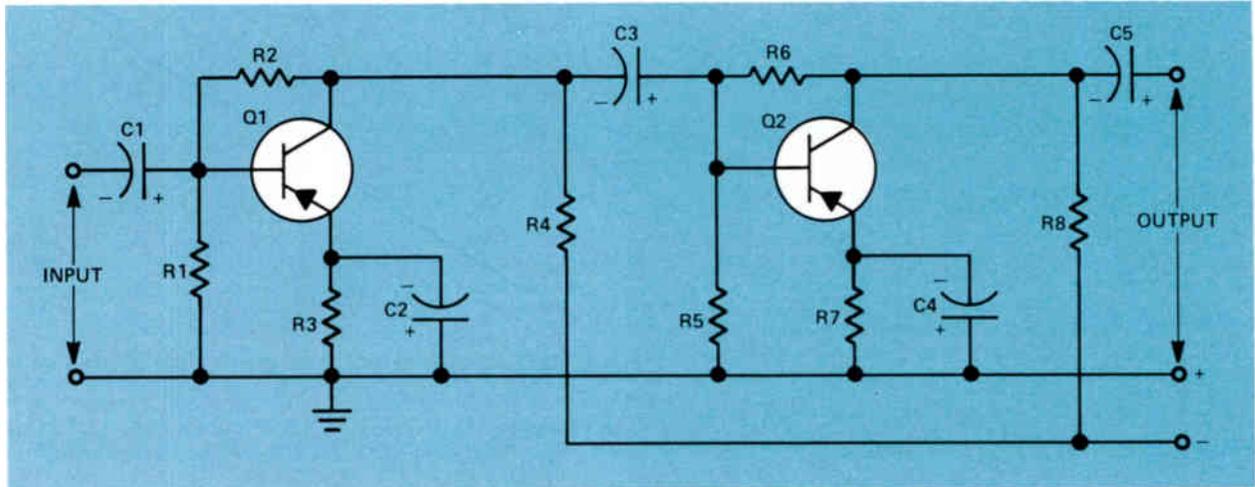


Figure 2. A two-stage RC coupled amplifier using pnp transistors.

of the power supply through R4 to the collector, where they will fill holes arriving at the collector. Some electrons flowing through R4 will flow through R2 and R1 to the positive side of the supply. The voltage drop across R1 will make the base negative with respect to ground. By selecting the values of R1 and R2 correctly, the base can be made negative with respect to the emitter so we have the correct forward bias across the emitter-base junction.

It is important to notice that the current flow through R2 is made up of the current flow through R1, plus some electrons that will flow into the base and will fill holes crossing the emitter-base junction. In the pnp transistor, the electrons are the minority carriers and some electrons will cross from the collector to the base and fill some of the holes that would normally be filled by electrons flowing through R2. We have the same condition where thermal runaway can be produced in the pnp transistor that we had in the npn transistor. If the transistor current begins to increase because of thermal runaway, the current through R3 will increase. This will swing the emitter in a negative direction, which will reduce the change in

potential between the emitter and base, and reduce any change in the forward bias due to the transistor heating.

When the input signal fed to Q1 swings in a positive direction, it will reduce the forward bias across the emitter-base junction. This will cause the number of holes flowing through the transistor to decrease. When this happens, the current through R4 decreases so the voltage drop across it decreases. This will cause the voltage between the collector of Q1 and ground to swing in a negative direction.

When the input signal swings in a negative direction, it will add to the forward bias across the emitter-base junction. The increased forward bias will cause the number of holes flowing through the transistor to increase, and therefore the number of electrons flowing through R4 to fill the holes arriving at the collector will increase. This will cause the voltage drop across R4 to increase so that the voltage between the collector of Q1 and ground becomes less negative, or swings in a positive direction.

Notice that we have the same situation in Q1 in Fig.2 that we had in Q1 in Fig.1. The positive-

going incoming signal causes the voltage between the collector and ground to swing in a negative direction. A negative-going input signal causes the voltage to swing in a positive direction. In both transistors, we have the  $180^\circ$  phase reversal.

The signal developed between the collector of Q1 and ground is coupled to the RC coupling network consisting of C3 and R5 to the base of Q2. Here the signal is amplified and once again we have the  $180^\circ$  phase reversal that we have in any common-emitter amplifier. The signal at the output of Q2 has gone through a  $180^\circ$  phase reversal in Q1 and a second  $180^\circ$  phase reversal in Q2 and is therefore back in phase with the input signal.

The coupling capacitor, C3, couples the signal from the collector of Q1 to the base of Q2 in the same manner as in the preceding amplifier. To see how it works, let's consider the amplifier first under zero signal conditions.

With no signal applied to the input, there will be a certain number of holes crossing the emitter-base junction and the base, and flowing to the emitter. These holes will be filled by electrons coming from the negative side of the power supply and flowing through R4. Electrons flowing through R4 will result in a voltage drop across it. The collector of Q1 will be negative with respect to ground. The collector voltage will be approximately one half the supply voltage.

Electrons flowing through R8, R6, and R5 will develop a voltage across R5 so that the base of Q2 is negative with respect to ground. However, the collector of Q1 will be much more negative, so the capacitor C3 will charge with the polarity shown.

When a signal fed to the input swings in a positive direction, it will subtract from the forward bias across the emitter-base junction of Q1, so the number of holes reaching the collector will decrease. This means that the number of electrons flowing through R4 will

decrease causing the voltage drop across R4 to decrease. The voltage between the collector of Q1 and ground will swing in a negative direction so that the voltage between the collector and ground increases. Capacitor C3 must charge to this higher voltage. Electrons will flow from the negative terminal of the power supply through R4 and into the negative plate of C3. Electrons will flow out of the positive plate of C3 through R5 to ground. In flowing through R5, the electrons will cause a voltage to be developed across the resistor having a polarity such that the base end of the resistor will be negative. Thus the negative voltage swing at the collector of Q1 appears as the negative voltage swing at the base of Q2.

When the input signal swings in a negative direction, it will add to the forward bias across the emitter-base junction of Q1 so the number of holes flowing through the transistor to the collector will increase. This means the number of electrons flowing from the negative side of the supply through R4 to the collector to fill these holes will increase. The increase in current through R4 will cause the voltage drop across it to increase. Thus the negative voltage between the collector of Q1 and ground decreases. Now C3 must discharge to this lower value. Electrons will leave the negative terminal of C3 and flow to the collector to fill some of the holes arriving at the collector of Q1. Electrons will flow from ground through R5 and into the positive side of C3. Electrons flowing through R5 will swing the base voltage in a positive direction. Thus we have the voltage between the collector of Q1 and ground becoming less negative, or swinging in a positive direction and a positive-going voltage appearing between the base of Q2 and ground. The base of Q2 will not swing positive, it will simply be less negative.

As in the case of the two-stage amplifier using npn transistors, the gain of the two-stage amplifier using pnp transistors will be equal to

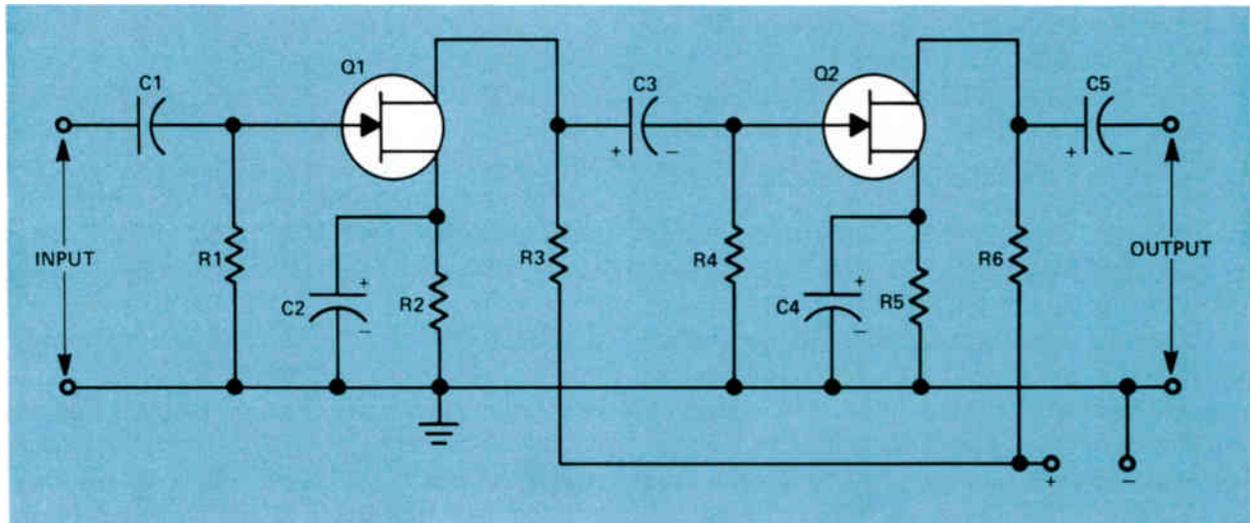


Figure 3. A two-stage RC coupled amplifier using JFETs.

the product of the gain of each stage. For example, if we have a gain of 10 in each stage, the overall gain of the two-stage amplifier will be 100.

### A Two-Stage FET Amplifier

Field-effect transistors are not used as frequently as bipolar transistors in low-frequency voltage amplifiers, but there is no reason why they can't be. A typical two-stage RC coupled amplifier using n-channel FETs is shown in Fig.3.

You will remember that with a junction FET there must be a reverse bias between the gate and the channel to prevent current flow from the channel to the gate. With an n-channel FET, the gate must be negative with respect to the channel. In the circuit, R2 is connected between the source of Q1 and ground, and is used to provide the required reverse bias between the gate and the channel. Current flowing from the negative side of the power supply flows through R2 to the source. In so doing, a voltage is developed across the resistor having a polari-

ty such that the source end is positive with respect to ground. The gate is connected to ground through R1 and since there will be no current flow through R1, there will be no voltage drop across it. The gate will be at dc ground potential. Since the source is positive with respect to ground, it will be positive with respect to the gate. This means that the gate is negative with respect to the source and the channel. R5 is connected between the source of Q2 and ground for the same reason.

Notice that we have a capacitor, C2, connected across R2. This is a large capacity capacitor so it has a very low reactance. Insofar as the signal is concerned, the source of the transistor is connected directly to ground. Therefore any signal fed to the input will be applied directly between the gate and the source.

When the incoming signal swings in a positive direction, it will reduce the reverse bias between the gate and the channel. This will permit the number of electrons flowing through the channel to increase so the voltage drop across R3 increases. Thus the voltage between the drain of the FET and ground decreases. Under zero signal conditions, C3 will be

charged with the polarity shown. When the voltage between the drain of the transistor and ground decreases, the level of the charge on C3 must decrease. Electrons will flow from the negative plate of C3 through R4 to ground, and will develop a voltage having a polarity such that the end connected to the gate is negative. Thus the negative-going voltage appearing between the drain of Q1 and ground is coupled through C3 to the gate of Q2. The negative voltage on the gate of Q2 will increase the reverse bias between the gate of Q2 and the channel so that current flow through Q2 will decrease. This means that the current through R6 will also decrease so the voltage drop across it will decrease. The voltage between the drain of Q2 and ground will increase. Thus we have a 180° phase reversal on Q1 followed by another 180° phase reversal on Q2 so that the voltage at the output of Q2 is in phase with the voltage at the input.

When the signal at the input swings in the negative direction, it will add to the reverse bias between the channel of Q1 and the gate so the

current through Q1 will decrease. This will cause the voltage between the drain of Q1 and ground to increase. C3 must charge to this higher voltage. To charge C3 at a higher voltage, electrons will flow from ground through R4 and into the negative plate while electrons will leave the positive plate of C3 and flow through R3 to the positive side of the power supply. The electrons flowing through R4 will develop a voltage so that the gate end is positive. This will reduce the reverse bias between the gate and channel of Q2 so the current flow through the transistor will increase. The increased number of electrons flowing through Q2 will result in a greater voltage drop across R6 so the voltage between the drain of Q2 and ground will decrease. Thus we have a negative-going signal at the input producing a negative-going signal at the output.

As in the preceding examples, the overall gain of the two-stage amplifier is equal to the product of the gain of the individual stages. Once again, if each stage has a gain of 10, the overall gain of the two-stage amplifier will be 100.

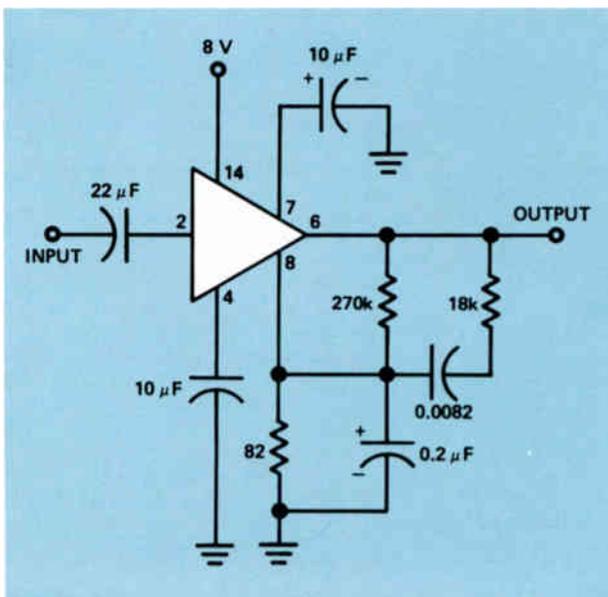


Figure 4. An IC low-frequency amplifier.

### A Typical IC Amplifier

Integrated circuits are also used as low-frequency voltage amplifiers. A typical circuit is shown in Fig.4. This circuit is actually the input circuit of one channel of a stereo tape player. The input circuit for the other channel is contained in the same IC.

The schematic diagram does not indicate what circuit may be used inside the IC. This is the only information you will get on the schematic diagram. If you can find out who manufactured the IC, the chances are that you can find out what circuitry is inside the IC. But as a technician, this information probably won't be of much help to you. You know that the IC is supposed to take a weak signal applied

between terminal 2 and ground and produce an amplified signal between terminal 6 and ground.

If you encounter a circuit of this type that fails to work properly, the only thing you can do is check the input signal at terminal 2 and the output signal at terminal 6. If the output signal is much stronger than the input signal, you know that the IC is working. If you do not get an amplified signal at terminal 6, you know there is something wrong with the circuit. With no amplified output signal, you should check the voltage on terminal 14 to be sure that you have 8 volts. If you do, make sure that the external components used in the circuit are good. If they are in good condition, the chances are that the IC is defective, and the only thing you can do is try a replacement.

You might not expect an amplifier such as shown in Fig.4 to have a very high gain because it shows only one block for the IC. However, there is no way of telling what is inside the integrated circuit. Usually there will be a number of stages connected in cascade so that the amplifier normally has considerable gain. Most often amplifiers of this type have a gain of 100 or more.

## Operational Amplifiers

Operational amplifiers, which are usually called op amps, are simply a combination of some of the individual amplifier circuits you have already studied. A typical op amp may consist of a differential amplifier directly coupled to an emitter follower, which in turn is coupled to another differential amplifier that is coupled to an emitter follower. In most cases, the device that is used as an operational amplifier has a very high gain, but this gain is controlled by an external feedback network.

Figure 5 is a diagram of a differential amplifier and an emitter follower.

studied this circuit, but it is so widely used in op amps we will review it.

Notice there is no forward bias shown across the emitter-base junction of Q1 and Q2. This is taken care of in the input circuit. You will remember that there are two inputs to this type of amplifier, one marked with a + symbol sign and the other with a - sign. The input marked with the + sign is called the noninverting input. The reason for this is that the phase of the signal coming out of the emitter follower will be the same as the phase of the input signal. For example, if the signal applied to the input of Q1 swings in a positive direction, this will cause the emitter current through Q1 to increase. This will increase the voltage drop across R1, swinging the emitters of Q1 and Q2 in a positive direction. This will reduce the forward bias across the emitter-base junction of Q2 which in turn will reduce the collector current of Q2. If the collector current goes down, the voltage drop across R2 will go down, so the collector of

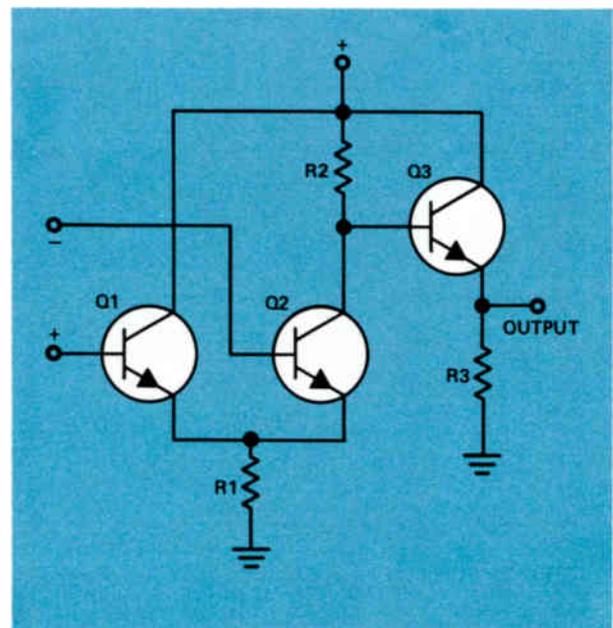


Figure 5. A differential amplifier and an emitter-follower combination forming an operational amplifier.

Q2 will swing in a positive direction. This will increase the forward bias across the emitter-base junction of Q3, causing the current through this transistor to increase. This will cause the voltage drop across R3 to increase, and since current flows from ground to the emitter, the emitter will become more positive. Thus, a positive-going signal applied to the base of Q1 will cause a positive-going signal at the output.

If a positive-going signal is fed to the inverting input, which is marked with a  $-$  sign, the positive-going signal will be fed to the base of Q2. This will increase the forward bias across the emitter-base junction of Q2, so that the collector current through the transistor will increase. This will increase the voltage drop across R2 so that the voltage between the collector of Q2 and ground will decrease. This will reduce the forward bias across the emitter-base junction of Q3, causing the current to go down. The drop in current will reduce the voltage drop across R3 so that the output signal will swing in a negative direction.

In summary, the signal fed into the noninverting input, which is marked with a  $+$  sign, will cause a signal having the same phase to appear in the output. A signal fed into the inverting input, which is marked with a  $-$  sign, will cause a signal  $180^\circ$  out of phase to appear in the output.

The symbol for an op amp is shown in Fig.6. Input 1, marked with a  $-$  sign, is the inverting input and input 2, marked with a  $+$  sign, is the noninverting input. The letter A stands for the gain of the op amp. If we apply an input signal to the amplifier, an output signal will be generated. The input signal will be amplified by an amount equal to the gain A of the amplifier. If the input signal is very small, it will appear greatly enlarged at the output because of the high gain.

If the input signal to an op amp is too high, the amplifier output will be clipped. For exam-

ple, if we apply a 1 volt input signal to an op amp with a gain of 10,000, our output would theoretically be equal to the input multiplied by the gain, or 10,000 volts. This cannot actually happen. The output of any amplifier is limited by the power supply voltages. Most op amps are powered with both positive and negative voltages. A typical op amp, for example, may use power supplies of  $+12$  and  $-12$  volts. For this reason, the output cannot swing any greater than  $\pm 12$  volts or no more than 24 volts peak-to-peak for a sine wave.

Since the gain of an op amp is so high, it can be used only with very low level signals. Another problem with the op amp is that it is very unstable and its gain may vary considerably from one amplifier to another. One amplifier may have a gain of 10,000, and the next one, which is supposed to be identical, might have a gain of 15,000. For many applications, this is a disadvantage.

To overcome this problem we use negative feedback with op amps by feeding some of the output voltage from the amplifier back to the inverting input through a resistor. As you learned earlier, negative feedback reduces the overall gain of an amplifier. At the same time, it stabilizes the amplifier and improves its frequency response.

Figure 7(A) is a diagram of a typical op amp circuit. Here, the noninverting input to the amplifier is grounded. This eliminates the differential characteristics of the amplifier so we can use it as a single-ended circuit. Negative

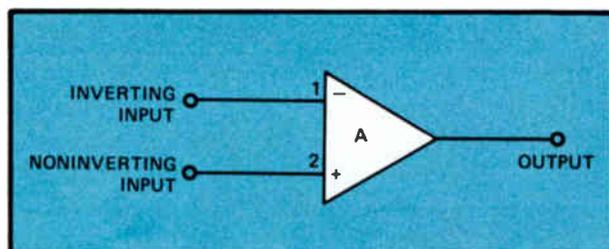


Figure 6. Operational amplifier symbol.

# HOW AMPLIFIERS WORK

feedback is provided by resistor R2 connected between the output and the inverting input. An input resistor, R1, is also connected to the inverting input. The free end of R1 is the input to the circuit. With this circuit, the gain of the op amp is determined entirely by the ratio of R2 to R1 rather than A. If this is difficult to see at first, see Fig.7(B) for an explanation.

Figure 7(B) shows the current and voltages in the op amp circuit. Current flowing through R1 is designated I1, while current flowing through the feedback resistor R2 is designated I2. The current flowing in the input of the op amp is designated I3. I3 is generally the base current of a transistor. The input voltage to this circuit is labeled E1, and the input to the amplifier is shown as E2. The output voltage is Eo.

Since the gain of the amplifier is A, we know that the output voltage is equal to A times the input voltage of the amplifier. We can write this:

$$E_o = E2 \times (-A)$$

We use a - sign because the input signal is inverted. We can rearrange this formula to find the input voltage of the amplifier:

$$E2 = \frac{E_o}{-A}$$

To continue our explanation, you will remember from earlier lessons that the voltage across any part is equal to the difference in the voltages at the ends with respect to ground. For example, if we measure 10 volts between one end of the resistor and ground, and 4 volts between the other end and ground, the voltage across the resistor is 6 volts.

With this in mind, we can write the formula for the voltage across R1 and R2. The voltage across R1 is equal to E1 - E2. The voltage across R2 is equal to E2 - Eo. Knowing the voltages across the resistance, we can write a

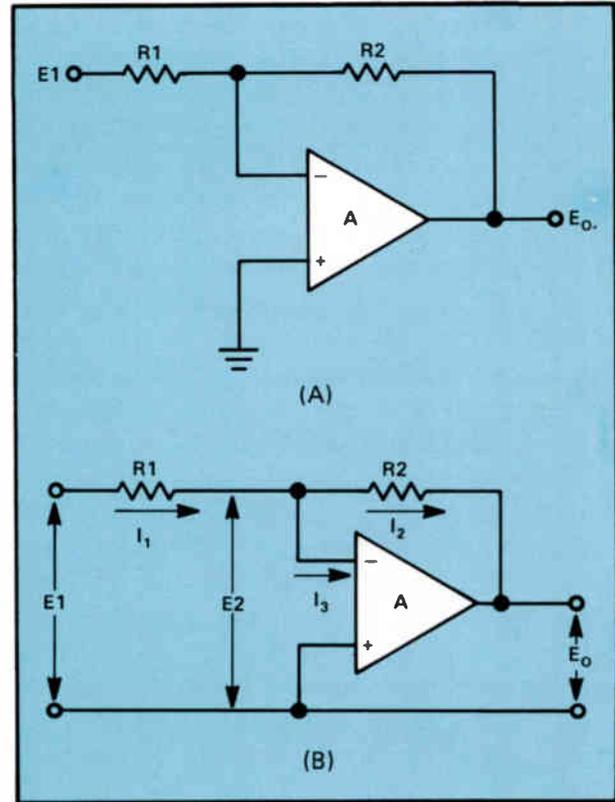


Figure 7. (A) A standard op amp circuit. (B) Currents and voltages in the op amp.

simple Ohm's law expression for the current through each resistance. For example, current I1 through resistor R1 is equal to the voltage across it, which is E1 - E2, divided by R1. The current through R2 is equal to the voltage across it, E2 - Eo divided by R2.

In Fig.7(B), the current flowing in the amplifier is I3. If we assume that the op amp is a perfect amplifier and has an infinite impedance, we can conclude that it will not draw current from the input source and I3 = 0. In fact, I3 will be so low that this is a valid assumption. The entire input current I1 must flow through R2. This means that I1 must be equal to I2. Now if:

$$I1 = I2$$

then,

$$\frac{E_1 - E_2}{R_1} = \frac{E_2 - E_o}{R_2}$$

Earlier we said that the input voltage  $E_2$  is equal to the output voltage  $E_o$  divided by the gain, which is  $-A$ . The gain is so high that the input voltage  $E_2$  is extremely small. It is so small we can call it zero. If we assume a zero value for  $E_2$ , we can remove the  $E_2$  figure from the formula. Thus,

$$\frac{E_1}{R_1} = -\frac{E_o}{R_2}$$

From this we can find that the output voltage is equal to the ratio of the feedback resistance  $R_2$  to the input resistance  $R_1$  multiplied by the input to the circuit.

$$E_o = -\frac{R_2}{R_1} \times E_1$$

The negative sign indicates inversion.

If you have any difficulty working with these formulas, don't worry. You don't have to go through all the mathematics we have gone through. We show it only for the benefit of those who want to see why the gain of the op amp depends entirely upon the ratio of  $R_2$  to  $R_1$ . All you need to do is remember this ratio. The important thing to realize is that the op amp is capable of a very high gain, and we can control it so it will be stable by selecting the correct values of the feedback resistor and the input resistor.

While operational amplifiers can be made using discrete components, the operational amplifiers you will encounter will be integrated circuits. Not only is an IC op amp less expensive than one using discrete components, but the characteristics can be controlled better.

There is also less possibility of running into some problem, such as feedback that could cause the amplifier to be very unstable.

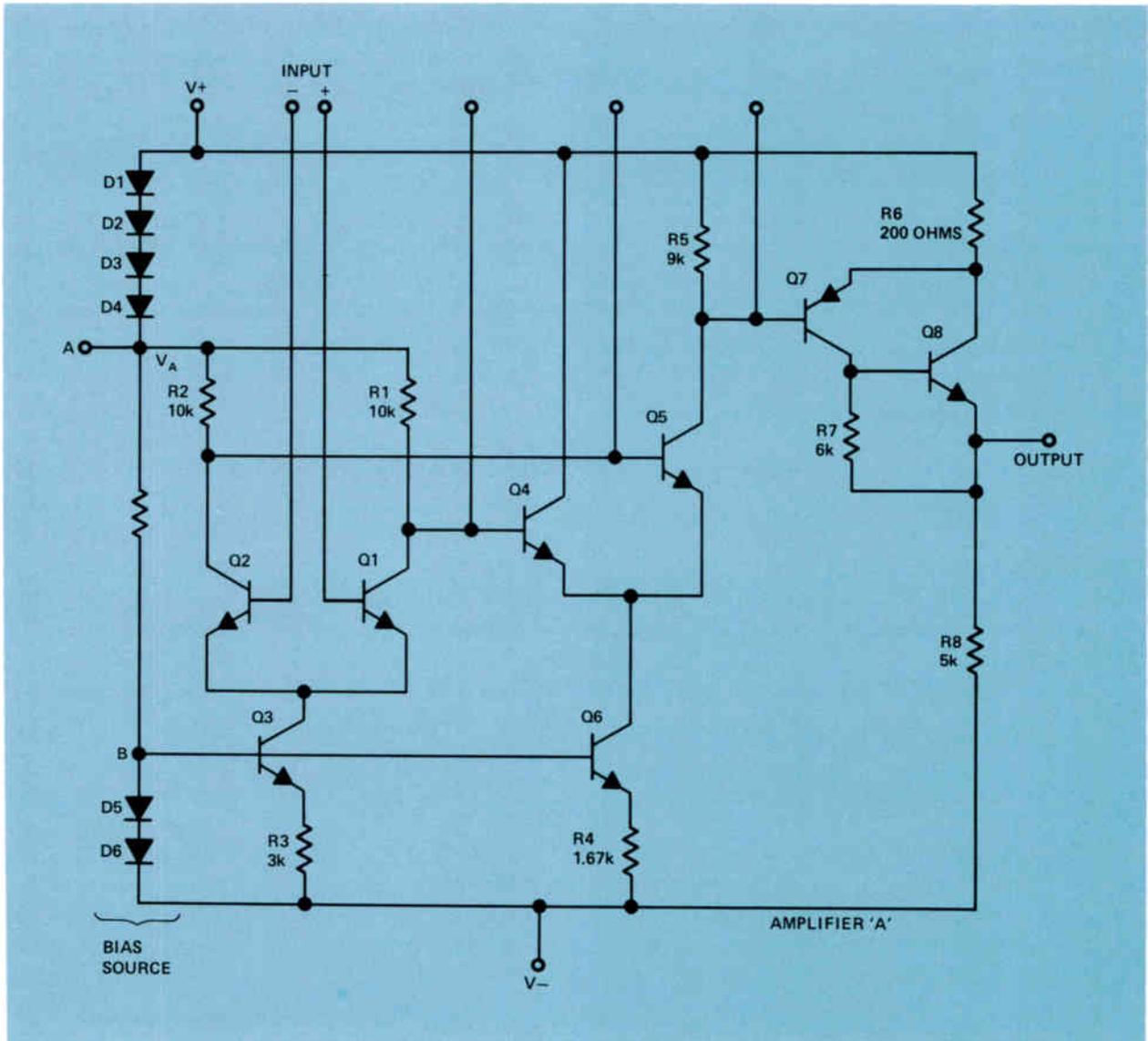
Figure 8 is a schematic diagram of one-half of an IC that contains two operational amplifiers. The other half consists of another operational amplifier that is identical to the one shown. The diodes  $D_1$  through  $D_4$  are used to help maintain a constant input voltage to the input transistors,  $Q_1$  and  $Q_2$ .  $D_5$  and  $D_6$  are used to help maintain a constant base voltage to the two constant-current sources,  $Q_3$  and  $Q_6$ . Notice that the input to  $Q_1$  is the noninverting input, and the input to  $Q_2$  is the inverting input. The output from  $Q_1$  connects directly to  $Q_4$  and the output from  $Q_2$  connects directly to  $Q_5$ . The output from  $Q_5$  connects directly to the combination of  $Q_7$  and  $Q_8$ , which form an emitter-follower. This type of amplifier has considerable gain and could be used as an amplifier in a stereo system, as shown in Fig. 4. The amplifier we have shown will be used in one channel, while the other identical amplifier in the IC is used for the other channel.

Even though the gain of the two amplifiers in one IC should be equal since they are all formed at the same time, there might be considerable difference in their gains. However, since the gain is going to be controlled primarily by the ratio of the feedback resistor to the input resistor, by using resistors with a 1% tolerance, you can have two op amps with practically identical gain. For example, with a 1% tolerance one amplifier might have a gain of 100, and the other would have a gain of no less than 99 or more than 101.

The op amp is a very flexible amplifier. Since its gain can be readily controlled by external resistance, it is a very useful amplifier. In addition, it lends itself to low-cost mass production in ICs so it is widely used in all types of electronic equipment. The three-terminal voltage regulators you studied in a preceding lesson use an op amp as the error amplifier.

# HOW AMPLIFIERS WORK

14



*Courtesy Fairchild Semiconductor*

**Figure 8.** Schematic diagram of one operational amplifier in a dual op amp IC.

## Summary

In the two two-stage amplifiers shown in Figs.1 and 2, there is a  $180^\circ$  phase reversal in each stage so that the signal at the output will be in phase with the signal at the input. In both amplifiers, the amplified signal between the collector of Q1 and ground is coupled through C3 to the base of Q2. In each amplifier the charging and discharging of C3 as the voltage between the collector of Q1 and ground varies, causes a current to flow through R5 so the varying voltage between the collector of Q1 and ground will be coupled between the base of Q2 and ground. The overall gain of the two stage amplifier is equal to the product of the gain of the two stages.

An operational amplifier is a high-gain amplifier that readily lends itself to IC manufacturing techniques. Op amps have two inputs, an inverting input and a noninverting input. An op amp has such a high gain that it has a tendency to be somewhat unstable. To prevent this, the gain is controlled by means of feedback from the output to the inverting input. The gain of an op amp will be equal to the ratio of the feedback resistor to the input resistor. By using a feedback resistor and an input resistor with a tolerance of 1% or less, we can control the gain of an op amp quite precisely.

## Self-Test Questions

*Please check your answers on page 47.*

- 1 In the amplifier shown in Fig.1, what is the phase relationship between the amplified output voltage and the input voltage?
- 2 In the circuit shown in Fig.2, if the input signal voltage swings in the positive direction, what will happen to the collector voltage on Q1?
- 3 In the circuit shown in Fig.3, what is the purpose of R5?
- 4 In the circuit shown in Fig.4, if the voltage applied to terminal 14 is normal, you have an input signal voltage on terminal 2 and all other parts check good, yet there is no output on terminal 6, what should you do?
- 5 What is the meaning of the + and - signs on the leads going to the base of Q1 and Q2 in Fig.5?
- 6 What type of circuit is used in Q3 of Fig.5?
- 7 In Fig.6, what does the letter A in the center of the triangle indicate?
- 8 What determines the gain of the circuit shown in Fig.7?
- 9 How many differential amplifiers are there in the circuit shown in Fig.8?

## LOW-FREQUENCY POWER AMPLIFIERS

After the weak audio signal has been amplified, it is fed to a power amplifier that develops the power necessary to operate the loudspeaker. Power amplifiers can be divided into three classes called Class A, Class B, and Class C.

In a Class A power amplifier, the transistor is biased on the midpoint of its characteristic curve. Current flows through the transistor during the entire cycle. We say that current flows for 360°. Class A power amplifiers can be used both as low-frequency power amplifiers and radio frequency power amplifiers.

Class B power amplifiers are biased at cutoff. Current flows through a Class B power amplifier only when it is driven into conduction by the incoming signal. Current flows for approximately one half-cycle or for 180°. Class B power amplifiers can be used both as low-frequency power amplifiers and radio frequency power amplifiers. However, when a Class B power amplifier is used as a low-frequency power amplifier, two transistors will always be used, one to amplify each half of the cycle. We call this arrangement a *push-pull amplifier*.

A Class C power amplifier is an amplifier that is biased beyond cutoff so that current flows through it for less than one half-cycle. Class C power amplifiers cannot be used as low-frequency power amplifiers. Their use is restricted to radio frequency power amplifiers. In a Class C rf power amplifier, current will flow through the transistor for about 120°.

Low-frequency power amplifiers using a single transistor are always Class A power amplifiers. They are called *single-ended power amplifiers*. A low-frequency power amplifier using two transistors may be either a Class A power amplifier or a Class B power amplifier. In both cases they are called push-pull ampli-

ers. Let's look at single-ended amplifiers first, then we'll look at push-pull amplifiers.

### Single-Ended Power Amplifiers

A single-ended power amplifier is shown in Fig.9. This amplifier is a Class A amplifier. A Class A amplifier is biased at the midpoint of its characteristic curve. This means that the forward bias across the emitter-base junction is adjusted so that the current flowing through the transistor is halfway between zero current and maximum current.

The transistor used in the circuit of Fig.9 is an npn transistor. Forward bias for the emitter-base junction is provided by R1 and R2. Current flowing from ground through R1 will develop a voltage across the resistor having the polarity so that the end connected to the base will be positive. Current flowing through R3 will also develop a voltage across this resistor so that the emitter is positive with respect to ground. However, the values of R1 and R2 are adjusted so the base is more positive than the emitter. Thus, the base current will be equal to the current needed to cause the collector current to be about halfway between zero and saturation.

When the incoming signal swings in a positive direction, the base current will increase, causing the collector current to increase. An equal swing in the input signal in a negative direction will cause an equal decrease in base current and hence an equal decrease in collector current. As a result, the average current through the transistor does not change.

The varying collector current flows through the primary winding of T1, which is called an *output transformer*. The output transformer is a step-down transformer and is used to match the comparatively high output impedance of the transistor to the low impedance of the speaker voice coil. A step-down transformer will produce a step-up in the current so that a

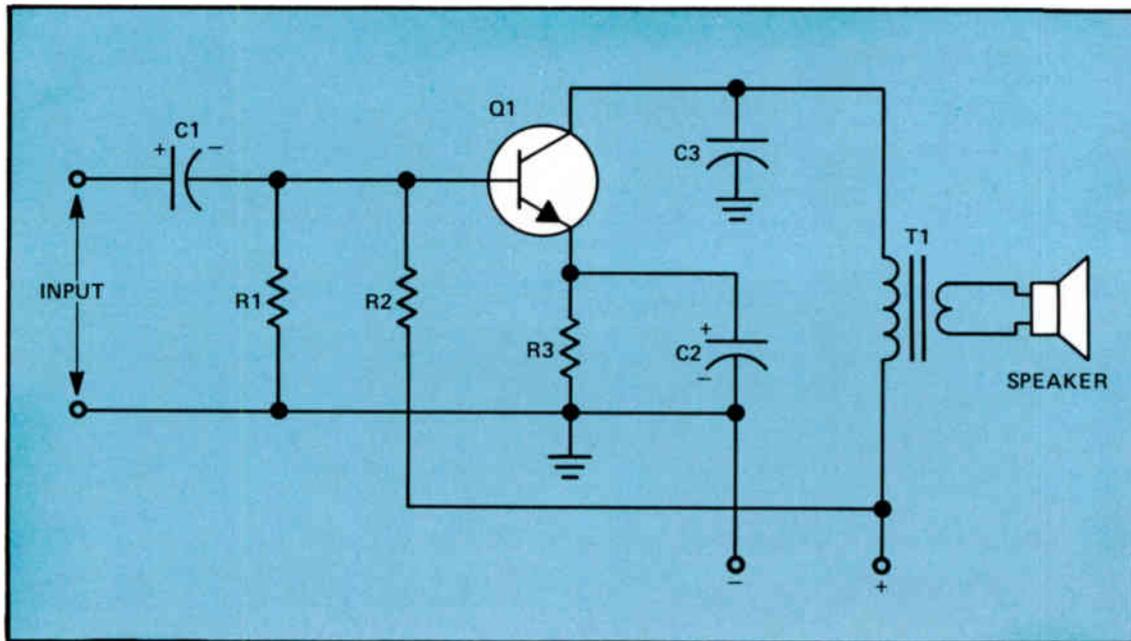


Figure 9. Schematic diagram of single-ended Class A amplifier using an npn transistor.

relatively high current flows through the secondary winding of the output transformer and through the speaker voice coil. This will cause the speaker voice coil and the speaker cone to vibrate in and out generating sound.

Capacitor C2 is a large capacitor and therefore has a low reactance. As far as the input signal is concerned, the emitter is connected directly to ground. Resistor R3, connected between the emitter of a transistor and ground, is used to prevent thermal runaway.

Capacitor C3, connected between the collector of the transistor and ground, is needed to prevent *parasitic oscillations*. These are unwanted high-voltage signals that might develop between the collector of the transistor and ground. These signals can have a high enough amplitude to arc through the transistor and destroy it. Capacitors C1 and C2 are relatively large capacity capacitors that offer little or no reactance at the frequencies to be amplified. C3

is a much smaller capacitor that has a high reactance at the frequencies to be amplified, but a low reactance at the frequency of the parasitic oscillations that might occur.

Figure 10 shows a single-ended Class A power amplifier using a pnp transistor. In this circuit the forward bias across the emitter-base junction is set by R1 and R2. When the transistor is operating, electrons are pulled from the emitter and flow through R3. The voltage drop across R3 will have a polarity such that the end connected to the emitter is negative (less positive) with respect to its lower end. Current flowing through R1 and R2 will develop a voltage across R2 so that the base end is more negative (even less positive) than the voltage on the emitter. To forward bias a pnp transistor, the base must be negative with respect to the emitter.

The holes flowing through the transistor will reach the collector, where they will be filled by

# HOW AMPLIFIERS WORK

18

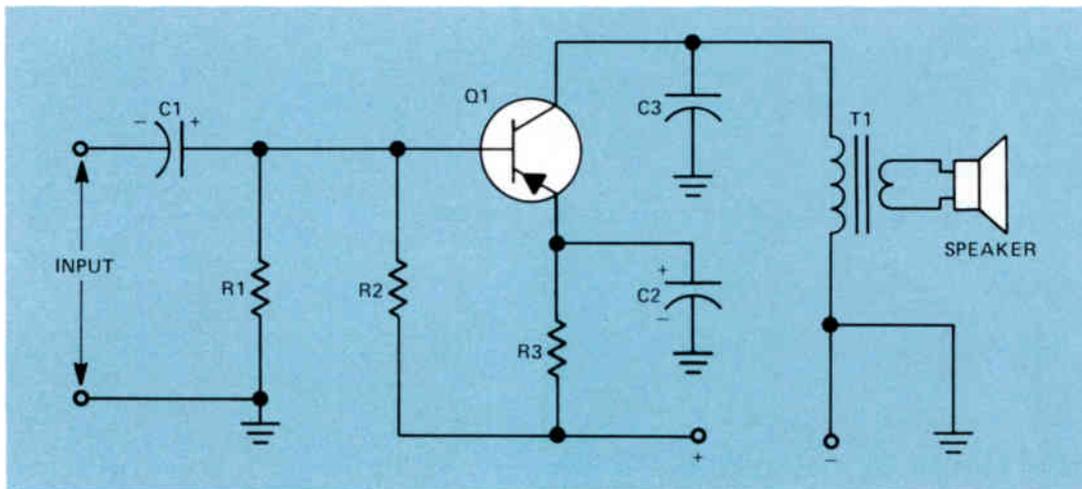


Figure 10. Schematic diagram of single-ended Class A amplifier using a pnp transistor.

electrons flowing from the negative side of the supply through the primary winding of the output transformer to the collector.

In this circuit a positive increase in the input signal voltage will cause a reduction in the number of holes flowing through the transistor. An equal amplitude negative input voltage swing will cause an equal increase in the number of holes flowing through the transistor.

The varying number of holes reaching the collector due to changes in the input signal will cause the number of electrons flowing through the primary winding of the output transformer to vary. In turn, this will induce a varying current in the secondary which is in series with the speaker voice coil.

Figure 11 is a simplified sketch showing how the loudspeaker is made. The speaker is made with a permanent magnet usually made of a material called alnico. This is an alloy made of aluminum, nickel, and cobalt that produces a very strong magnet.

The speaker movement consists of a voice coil form on which is wound a voice coil. This is simply a coil consisting of a relatively few number of turns. The voice coil form fits into a slot in the permanent magnet. The leads from

the voice coil are cemented to this paper speaker cone. Additional flexible leads are connected to them and they are brought out so they can be connected to the secondary winding of the output transformer.

The secondary winding of the output transformer is connected in series with the voice coil. The varying current in the secondary of the output transformer causes a varying current to

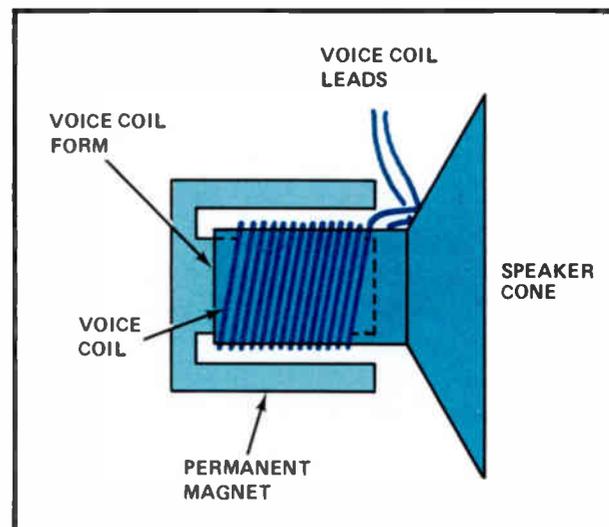


Figure 11. A sketch of a permanent magnet speaker.

flow through the voice coil. Remember that the output transformer is a step-down transformer, so the varying current will be much greater than the varying current in the primary winding of the transformer. The varying current flowing through the voice coil produces a magnetic field which alternately adds to and opposes the field from the magnet. This causes the voice coil to move, and hence the speaker cone, to move in and out at an audio rate. The speaker cone sets the air around it into vibration to produce the sound.

Some speakers are much more elaborate than the simple one shown in Fig.11, but all permanent magnet speakers operate on the basic principle described.

Single-ended, Class A power amplifiers are used in table-model receivers and in most TV receivers. They are used in table-model receivers to keep the cost down. They are used in TV receivers because most people are interested in the quality of the picture rather than the quality of the sound. Since they are less expensive than push-pull amplifiers, you will find them even in expensive color TV receivers. Push-pull amplifiers, however, can produce a higher output, and in some cases, such as in portable receivers, are an advantage because they can be designed to consume less power.

## Push-Pull Amplifiers

The push-pull output stage got its name in the early days of radio. In this circuit, two tubes are used so when the current through one increases, the current through the other decreases. The increasing magnetic field, produced in one half of the output transformer, is aided by the decreasing magnetic field produced in the other. Thus, you have the effect of one stage pushing and the other pulling.

A push-pull stage using npn transistors is shown in Fig.12. In this circuit, forward bias on

the transistors is set so they are operating at approximately midway between zero current and saturation. When the input signal causes the base of Q1 to swing in a positive direction and the base of Q2 to swing in a negative direction, the collector current in Q1 will increase while the collector current from Q2 will decrease. This will cause the current through the upper half of the primary winding of T2 to increase and the current through the lower half to decrease. These two changes cause changes in the magnetic field produced by the primary winding of T2, which induces a voltage in the secondary of T2, which in turn causes a high current to flow through it and through the speaker voice coil.

Notice that the resistor R2 in the emitter circuit of Q1 and Q2 is not bypassed. In single-ended amplifiers this resistor must be bypassed. Otherwise, the varying current through the resistor will produce a varying voltage at the emitter, which will be in phase with the signal voltage applied to the base. This will tend to reduce the net base-to-emitter signal voltage, and hence, the gain of the stage. However in this circuit, as the current through Q1 increases, the current through Q2 decreases an equal amount so that the current through R2 remains constant. Therefore, there is no signal voltage produced across the resistor.

The circuit shown in Fig.12 is a Class A push-pull amplifier. Class A push-pull amplifiers are widely used because they produce little distortion. Distortion is any change that occurs in a signal that is amplified. For example, suppose a musical instrument is producing a note as a pure sine wave having a frequency of 300 Hz. If the signal is picked up by a microphone, fed to an amplifier, and the signal shape is changed in the output, we have distortion.

Distortion is also present if any additional signals are added in the amplifier. One of the characteristics of amplifier stages is that they tend to generate harmonics. Harmonics are

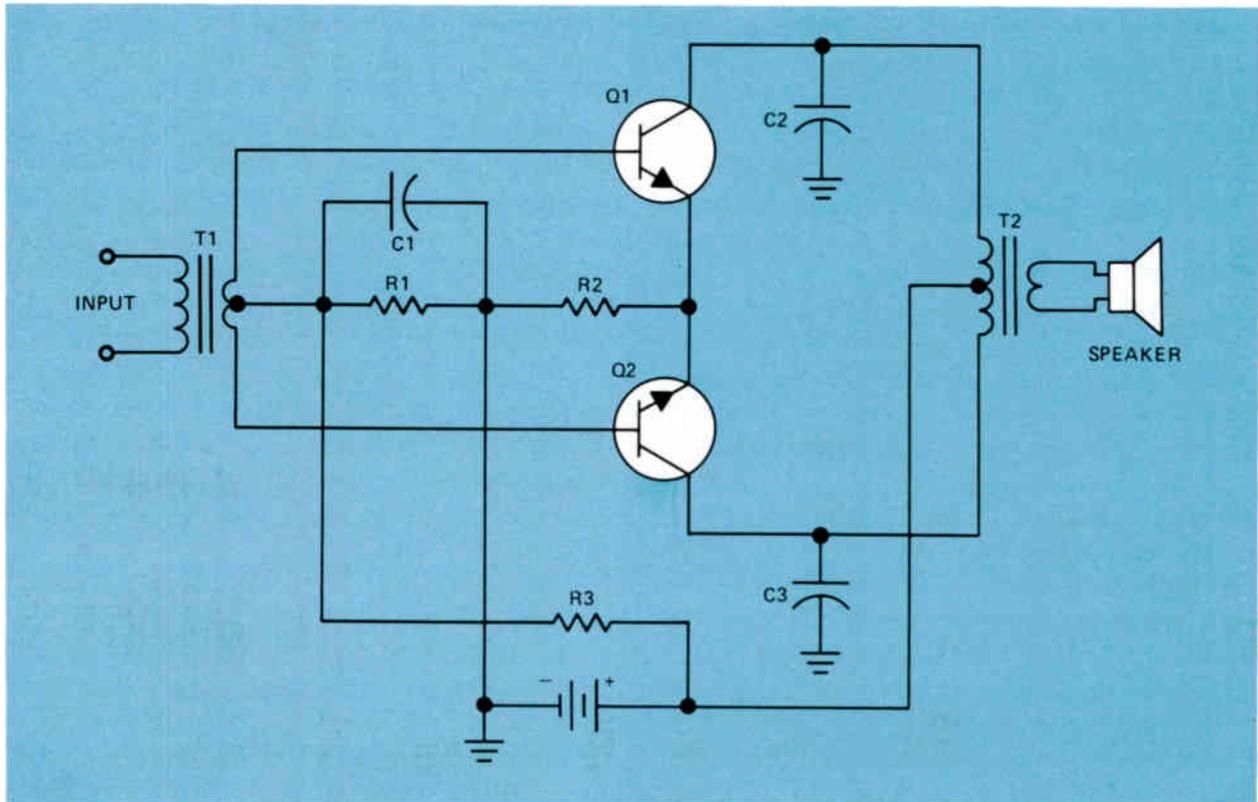


Figure 12. Class A push-pull npn transistors.

signals with frequencies that are multiples of the original signal frequency. In other words, when the 300 Hz signal is amplified, a 600 Hz signal may be produced. Since this signal is twice the frequency of the original signal, we call it the second harmonic. In addition, a 900 Hz signal might be produced. This is called the third harmonic because 900 Hz is three times the 300 Hz signal.

An amplifier stage can produce many harmonics but fortunately the second is usually the strongest, the third weaker, the fourth still weaker and so on. One of the characteristics of push-pull amplifiers is that they cancel any even order harmonics produced in the stage. Therefore, in a push-pull amplifier there is no second, fourth, sixth, etc., harmonic distortion. The most important thing is canceling the sec-

ond harmonic distortion, since this usually has a much higher amplitude than the higher order distortion.

A push-pull Class A power amplifier has the disadvantage that even with no signal present, it consumes considerable power. As a matter of fact, in a radio receiver using a Class A push-pull power amplifier, the push-pull output stage will consume far more than half the power used by the entire receiver. This is not a serious problem in equipment operated from the power line because the power lost in the stage with no signal present, is generally never more than 20 or 25 watts. However, in a portable receiver, this can be a serious consideration. The high zero signal current consumed by the power output stage is wasted, and this will tend to run the batteries down. We can overcome this

problem by using a Class B push-pull amplifier. In the Class B circuit, the transistors are biased essentially at cutoff so that with no signal input, there is very little current through the transistors in the output stage.

A schematic diagram of a Class B, push-pull power amplifier using pnp transistors is shown in Fig.13. The circuit is not too different from the one shown in Fig.12, except there is little or no forward bias applied to the transistors. Thus, with zero signal input, there will be very little current consumed. However when the signal arrives and drives the base of Q1 positive and the base of Q2 negative, the number of holes flowing through Q2 will increase whereas the number flowing through Q1 will drop to zero. This will mean that current flowing from

ground through one-half of the winding of the output transformer to the collector of Q2 will increase, while the current flowing from ground through the other half of the primary winding of the output transformer will drop to zero. This changing current will set up a changing magnetic field, which will induce a voltage in the secondary of the output transformer, causing a varying current in the speaker voice coil.

### Eliminating the Output Transformer

The output transformer used in a push-pull amplifier usually limits the frequency response of the amplifier. The transformer causes the output to drop off both at low and high frequencies.

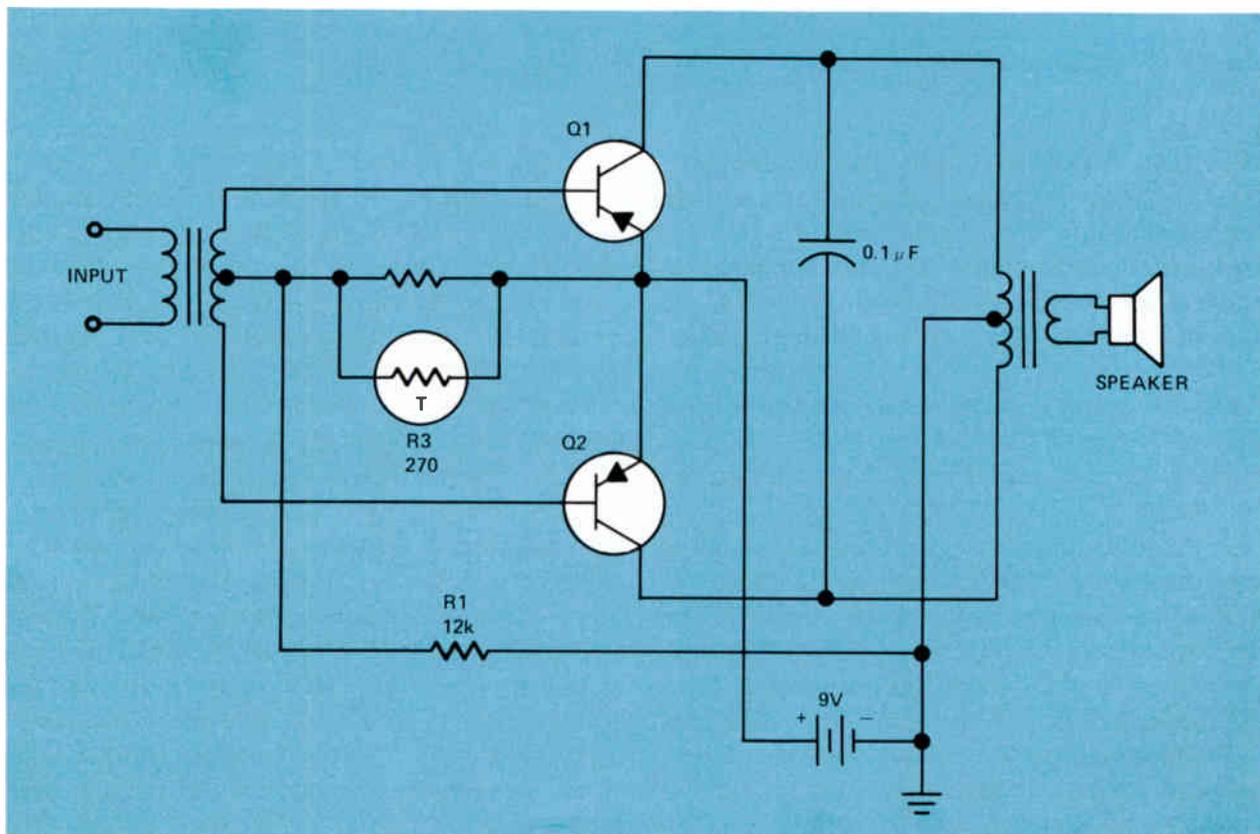


Figure 13. Class B push-pull pnp transistors.

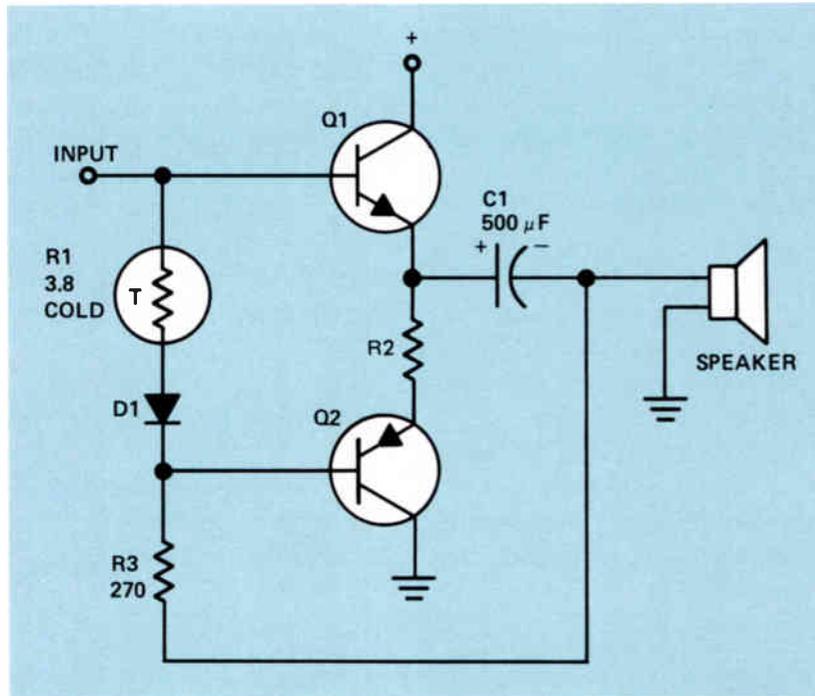


Figure 14. A complementary symmetry push-pull amplifier.

Transformers can be built that have a reasonably good frequency response, but these transformers are expensive. Figure 14 shows a circuit that eliminates both the input and output transformers in a push-pull stage. This circuit uses a pnp and an npn transistor, and is called a *complementary symmetry push-pull amplifier*. To make this circuit work, you need an npn transistor and a pnp transistor that have essentially identical characteristics. Let's see how this circuit works.

First, notice that there is no negative connection from the power supply shown. This connection is simply omitted to simplify the diagram. When the diagram is drawn this way, you know that the negative connection from the power supply is to ground. Also, notice that at the input, we've shown only one input terminal. You know that the input signal is applied between this terminal and ground. Again, the second input is omitted for simplicity.

The stage preceding this push-pull output stage is a pnp driver stage. It is direct-coupled to the push-pull amplifier. Electrons flow from the negative side of the supply to ground, through the speaker, through the 270 ohm resistor R3, and through diode D1 and resistor R1, to the collector of the driver stage, where they fill holes arriving at the collector. This current flow through the speaker and through R3 develops the forward bias needed across the emitter-base junction of Q2. Notice that Q2 is a pnp transistor, so its base must be negative with respect to the emitter. The emitter connects through R2 to the emitter of Q1, which is an npn transistor. The collector of Q1 is in turn connected to the plus side of the power supply.

The emitter of Q2 will be positive with respect to ground. The base will also be positive with respect to ground but it will be less positive than the emitter, so we'll have a forward bias across the emitter-base junction. The

diode D1 and R1 are in the circuit to ensure that the base of Q1 will be positive with respect to its emitter in order to forward bias the emitter-base junction of this transistor.

With zero signal, since both transistors are forward biased, electrons will flow from ground to the collector of Q2 where they will fill holes arriving at the collector terminal. Meanwhile, electrons will be leaving the emitter of Q2 creating the holes that flow through the transistor. The electrons leaving the emitter flow through R2 to the emitter of Q1. Since Q1 is an npn transistor, the electrons flow through it to the collector and to the positive side of the supply.

This current flow will develop a voltage so that the emitter of Q1 is positive. Electrons will flow through the speaker into the plate of C1 marked with a - sign and out of the positive plate to charge C1 to the voltage between the emitter of Q1 and ground.

When the input signal swings in a positive direction, the current flow from ground through the speaker, through R3 and D1, and through R1, will increase. This will swing the base of Q2 in a positive direction, reducing the forward bias across the emitter-base junction of the transistor. Therefore, the number of holes flowing through the transistor will decrease, which means the number of electrons leaving the emitter of Q2 will decrease. At the same time, the base of Q1 will swing in a positive direction, increasing the forward bias across the emitter-base junction of this transistor. Therefore, the current through Q1 must increase. This will cause electrons to flow from ground through the speaker and into the negative plate of C1, and out of the positive plate to Q1. This increase in current through the speaker produces a magnetic field in the speaker voice coil.

When the input signal swings in the negative direction, the current flow from ground through the speaker, R3, D1, and R1 will decrease. This will decrease the voltage drop across R3 so that

the base of Q2 will become less positive. This will increase the forward bias across the emitter-base junction of Q2. At the same time, the reduced current flow will reduce the positive voltage at the base of Q1, reducing the forward bias across the emitter-base junction of this transistor, causing the number of electrons flowing through it to decrease. Here, we have the opposite situation to what we had before in that we have the electron current through Q1 decreasing, but the hole current through Q2 increasing.

The increased number of holes flowing through Q2 will result in more electrons flowing from ground to the collector of Q2 and additional electrons flowing out of the emitter of Q2. Since the current of Q1 has dropped, these electrons will flow through R2 and into the positive plate of C1, and will begin to discharge this capacitor. Electrons will then flow out of the negative plate of C1 and through the speaker voice coil in the opposite direction. This change in the direction of current flow through the speaker will set up a magnetic field around the speaker voice coil that has the opposite polarity. This changing magnetic field will cause the speaker voice coil to move in and out and will set the air in front and back of the speaker in motion. It is this motion of air columns that produce sound.

### Inverse Feedback

We have already briefly mentioned inverse feedback. It is negative feedback that reduces the output. It also reduces distortion and improves the frequency response of an amplifier.

Negative feedback can be applied to the single-ended Class A power amplifiers shown in Figs.9 and 10 by omitting C2. C2 is the emitter bypass in the circuit.

In the circuit in Fig.9, if the input signal swings the base of Q1 in a positive direction,

it will increase the forward bias across the emitter-base junction of the npn transistor. This will cause the number of electrons flowing through the transistor and through R3 to increase. This will increase the voltage drop across R3, driving the emitter end in a positive direction, which will tend to reduce the forward bias across the emitter-base junction. This will tend to reduce the net effect of signal voltage between the base and the emitter and reduce the gain of the stage.

In the circuit in Fig.10, if the input signal of Q1 swings in a negative direction, it will increase the forward bias across the emitter-base junction of the pnp transistor. This will cause the number of holes that are crossing the emitter-base junction to increase, which will cause the electrons leaving the emitter and flowing through R3 to the positive side of the power supply to increase. This will increase the voltage drop across R3, driving the emitter end

in a negative direction, which will tend to reduce the forward bias across the emitter-base junction.

In both cases, this negative, or degenerative, feedback tends to reduce the gain of the stage. If either stage amplifies some particular frequency in the band more than it does another frequency, this feedback will be greatest at this frequency or band of frequencies. Therefore, the gain will be reduced most for these frequencies. This will tend to keep the overall gain of the amplifier constant over a wider frequency range.

A more elaborate feedback system where the signal is fed back three stages is shown in Fig.15. In this system, if the base of Q2 (an npn transistor) is driven positive by the signal, the feedback signal drives the emitter positive, reducing the net effect of change in emitter-base forward bias. Similarly, when the base of Q2 swings negative, the feedback signal drives

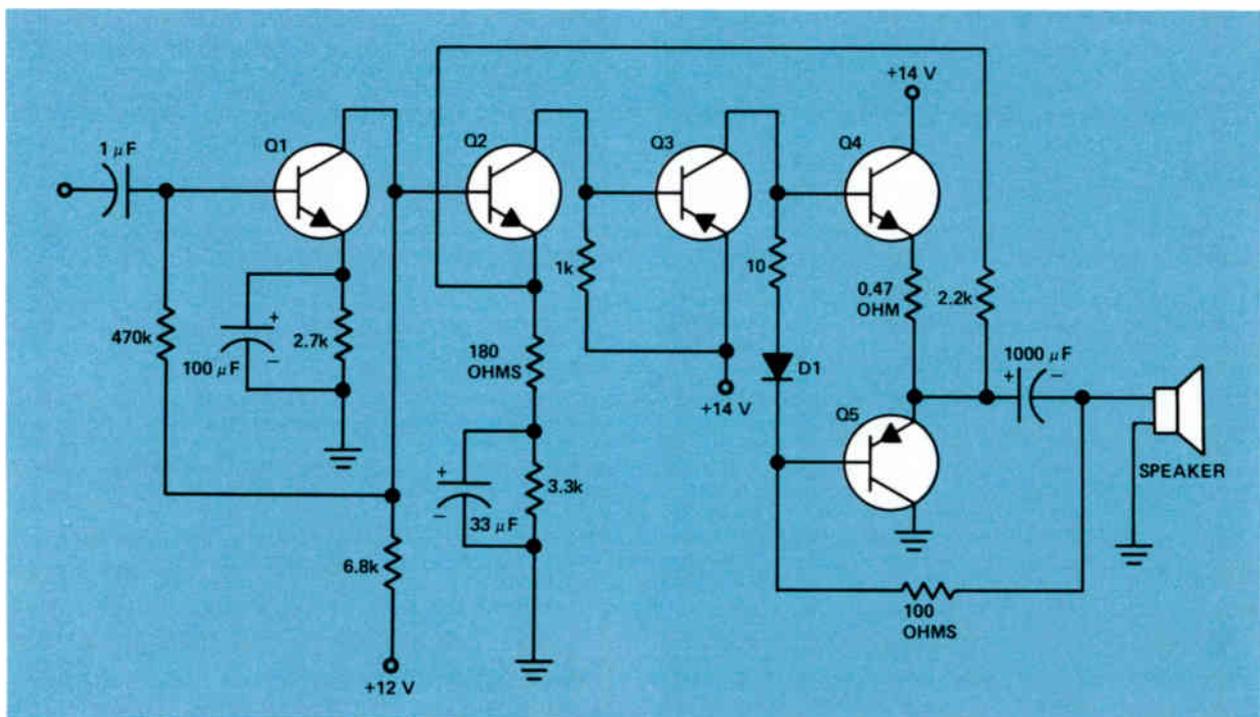


Figure 15. A three-stage negative feedback system.

the emitter negative, which again reduces the effect of change in the emitter-base bias. Let's trace the signal through the amplifier.

If the incoming signal swings the base of Q1 negative, current through Q1 will decrease so the voltage drop across the 6.8k load resistor will decrease. This causes the collector of Q1 and the base of Q2 to swing in a positive direction. When the base of Q2 swings positive, it will increase the forward bias across the emitter-base junction of the transistor so the current through Q2 will increase. This will cause the voltage drop across the 1k collector resistor to increase so that the collector of Q2 will swing in a negative direction. Since Q3 is a pnp transistor, the increased voltage drop across the 1k resistor will increase the forward bias across the emitter-base junction of Q3. This will cause the collector current to increase. The collector current for this transistor flows from ground through the speaker, through the 100 ohm resistor, through the diode D1, and through the 10 ohm resistor to the collector, where the electrons fill holes arriving at the collector. This increased current flow will drive the base of Q4, which is an npn transistor, in a positive direction. This will cause the current flow through this transistor to increase so that the current will flow through the speaker, into the 1000  $\mu$ F capacitor, through the 0.47 resistor, and through the transistor. This causes the voltage across the capacitor to increase so that a positive signal is fed through the 2.2k resistor and back to the emitter of Q2. This will reduce the effect of the positive-going signal on the base of Q2.

When the input signal drives the base of Q1 positive, it will cause the current through this transistor to increase so the voltage drop across the 6.8k collector resistor will increase, swinging the collector of Q1 and the base of Q2 in a negative direction. This will cause the current flow through Q2 to decrease so that the voltage drop across the 1k resistor in the collec-

tor circuit decreases, which in turn decreases the forward bias across the emitter-base junction of the pnp transistor Q3. This causes the current through it to decrease, so that the current through the speaker, the 100 ohm resistor, D1, and the 10 ohm resistor decreases. This will increase the forward bias across the emitter-base junction of Q5 and reduce the forward bias across the emitter-base junction of Q4, so that the current through Q4 will go down but the current flow through Q5 goes up. This will cause the electrons that are leaving the emitter of Q5 to flow into the 1000  $\mu$ F capacitor to reduce the charge on the capacitor. In other words, the voltage swings in the negative direction. This voltage is fed through the 2.2k resistor, back to the emitter of Q2. This will reduce the effect of the negative voltage applied to the base of Q2 by attempting to increase the forward bias across the emitter-base junction of the transistor. Overall feedback of this type tends to flatten out the frequency response of the amplifier.

Another feedback circuit is shown in Fig.16. Notice that in this circuit we have no output transformer but we do have an input transformer. Also notice that all three transistors are pnp transistors.

We are not going through all of the details of this circuit, but briefly with no input signal, the transistors Q2 and Q3 are biased so that the current flow through them is equal. Therefore, electrons will enter the negative terminal, and flow to the collector of Q2 where they will fill holes arriving there. Electrons will leave the emitter of Q2, flow through R9 and over to the collector of Q3 where they will fill holes arriving there. Electrons will leave the emitter of Q3 and flow through R10 to the positive side of the power supply. With zero signal applied, there will be no current flow through the speaker and the collector of Q3 will be at ground potential.

The windings of T1 are phased so that with a positive input to Q1, we'll get a negative signal

# HOW AMPLIFIERS WORK

26

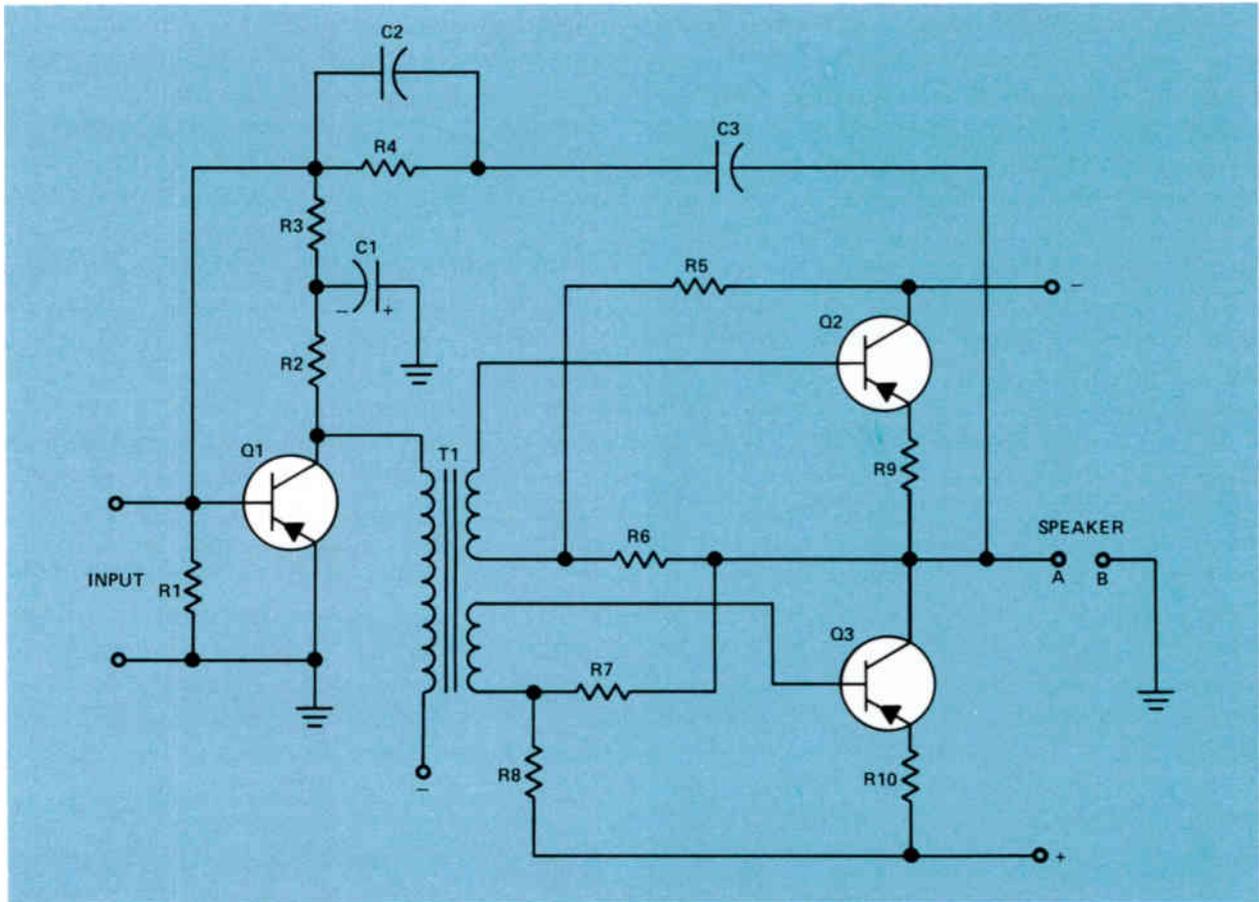


Figure 16. Three transistor amplifiers where there is no output transformer.

on the base of Q2 and a positive signal on the base of Q3. Current through Q2 will increase; current through Q3 will decrease. Electrons will leave the negative terminal of the power supply to fill holes arriving at the collector of Q2. Some of the electrons leaving the emitter of Q2 will flow through R9 to the collector of Q3, but most will flow through the speaker, making terminal A of the speaker negative. This negative voltage is fed through C3 and C2 and R4 in parallel, back to the base of Q1 where it tends to reduce the input signal.

When the base of Q1 swings in the negative direction, the base of Q2 will swing in a positive direction and the base of Q3 in the negative

direction. The number of holes flowing through Q3 will be greater than the number of holes flowing through Q2. Electrons will leave the negative terminal supply to fill holes arriving at the collector of Q2. Electrons will leave the emitter of Q2 and flow through R9 to the collector of Q3 to fill holes arriving there. However, there will not be enough electrons leaving the emitter of Q2 to fill all the holes arriving at the collector of Q3 so electrons flow from ground through the speaker to terminal A and then to the collector of Q3. This will make terminal A of the speaker positive. This voltage is fed back to the base of Q1 to reduce the negative voltage fed to the base of Q1.

Feedback of this type from the output back to Q1 tends to make up for any lack of flat frequency response in T1. Sometimes transformers have a peak where a certain signal frequency will receive considerably more amplification than other signals. If this happens, the output signal will increase, resulting in increased feedback to Q1, which will tend to flatten out the frequency response. Transformers also have a tendency of falling off at low frequencies. They just don't work as well. When this happens, the feedback signal will decrease, and once again will tend to improve the frequency response of the amplifier.

## IC Amplifiers

When ICs were first used in audio systems, they were used as voltage amplifiers and the output of the IC was then fed to a power amplifier. Now, ICs are available that contain

the entire audio system including the power amplifier. The one shown in Fig.17 is an example of such an IC.

This circuit is taken from an automobile receiver. In automobile receivers, compact size is very important. This particular receiver is a stereo receiver, which means there has to be two audio amplifiers. Therefore, any simplification that can be made in the amplifier helps to keep the receiver as small as possible.

In the circuit shown, the signal is taken from the volume control and fed through a  $3.3\ \mu\text{F}$  capacitor to terminal 9, which is the input to the integrated circuit. The output is taken off terminal 14 and fed through a  $1500\ \mu\text{F}$  capacitor to the speaker. The diagram shows all connections to the integrated circuits, but the manufacturer's service information does not show what is in it. As a technician, you will run into circuits of this type. If the amplifier fails to work, all you can do is check for the input

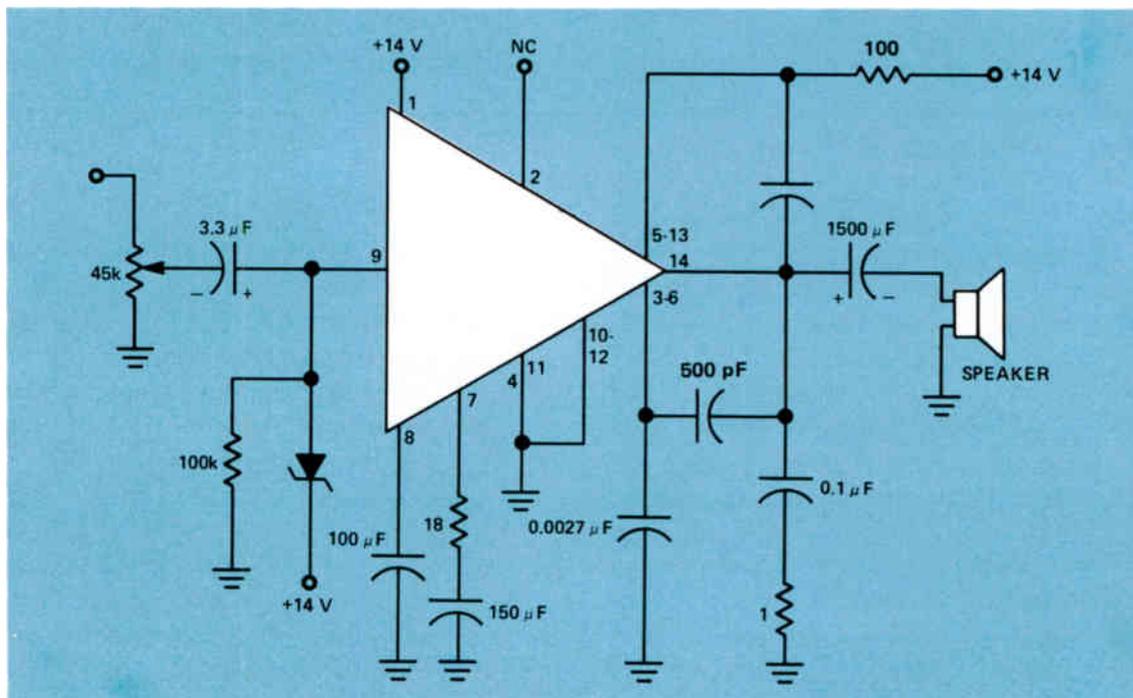


Figure 17. IC voltage amplifier and power amplifier.

signal to terminal 9. If it is normal, then check the components associated with the integrated circuit. If they are all good, you have to assume that the integrated circuit is defective and replace it.

In this particular integrated circuit, there are two differential amplifiers used as voltage am-

plifiers, and the output from the last one is fed to a power amplifier made up of an npn and a pnp transistor connected as shown in Fig.14. All of this circuitry is inside the IC. If anything goes wrong with one of the components or transistors inside the IC, there is nothing you can do except replace the entire unit.

## Summary

Single-ended power amplifiers are all Class A power amplifiers. They are used in applications where good quality is satisfactory, and economy is most important.

Push-pull audio amplifiers may be either Class A or Class B amplifiers. A push-pull amplifier has the advantage over a single-ended amplifier in that the distortion is lower. Even order harmonic distortion is canceled in push-pull amplifiers. A Class B push-pull amplifier draws little or no current under zero signal conditions. Thus it is more efficient than a push-pull Class A

power amplifier. This is particularly advantageous in portable equipment.

IC amplifiers that contain entire audio systems are made up of voltage amplifiers and a power amplifier. When a defect develops in part of an IC amplifier, all you can do is replace the unit.

Inverse feedback is used to reduce distortion and improve the frequency response of an amplifier. With inverse feedback, part of the amplified output signal is fed back to the input to oppose or reduce the effective input signal.

## Self-Test Questions

- 10 In Figs.9 and 10, is T1 a step-up or a step-down transformer?
- 11 Is the signal current in the secondary of T1 in Fig.9 greater or less than the primary signal current?
- 12 When a signal is applied to Q1 and Q2 in the circuit shown in Fig.12, what happens to the current through R2?
- 13 What is the advantage of using a Class B push-pull power amplifier such as shown in Fig.13 in a portable transistor receiver?
- 14 What are two advantages of eliminating the input and output audio transformers shown in Fig.13?
- 15 In Fig.14, if the input signal causes the current through Q1 to increase and the current through Q2 to decrease, where does the extra current required by Q1 come from?
- 16 In Fig.15, if the input signal causes the current through Q5 to increase, what is the polarity of the feedback signal back to the emitter of Q2?
- 17 If you have normal input to an IC amplifier such as shown in Fig.17, all operating voltages are normal, and the parts are good, but there is no output from the speaker, what should you do?

## RADIO FREQUENCY AMPLIFIERS

Radio frequency amplifiers are generally referred to as rf amplifiers. RF amplifiers can be divided into two types: voltage amplifiers and power amplifiers. The rf amplifiers in radio and television receivers will all be voltage amplifiers, whereas the rf amplifiers found in radio and TV transmitters will be power amplifiers.

In the amplifiers that you studied in the preceding sections, we found that we had a load in the output circuit of each stage. The load was in the collector circuit of the amplifiers using transistors and in the drain circuit of the amplifiers using FETs. In the case of voltage amplifiers, the load is usually a resistor, whereas in the case of power amplifiers, the load is usually either the output transformer or the speaker. You will find a load in the output

circuit of rf amplifiers, but in this case, the load is usually a resonant circuit. Most often, the resonant circuit will be a parallel-resonant circuit.

Four basic loads that you might run into in rf amplifiers are shown in Fig.18. In the one shown at (A), the load is a parallel-resonant circuit made up of L1 and C1. L1 is inductively coupled to L2 in order to feed the signal to the next stage.

In the circuit shown at (B), the load is L1. In this case it is not a resonant circuit but an inductance. However, L1 is inductively coupled to L2, which along with C1 makes up a resonant circuit.

In the circuit shown in Fig.18(C), we have two resonant circuits. L1 and C1 will be in the output circuit of the rf amplifier, and they form a parallel-resonant circuit. L1 is inductively coupled to L2 so that voltage is induced in series with each turn of L2. Since the voltage is

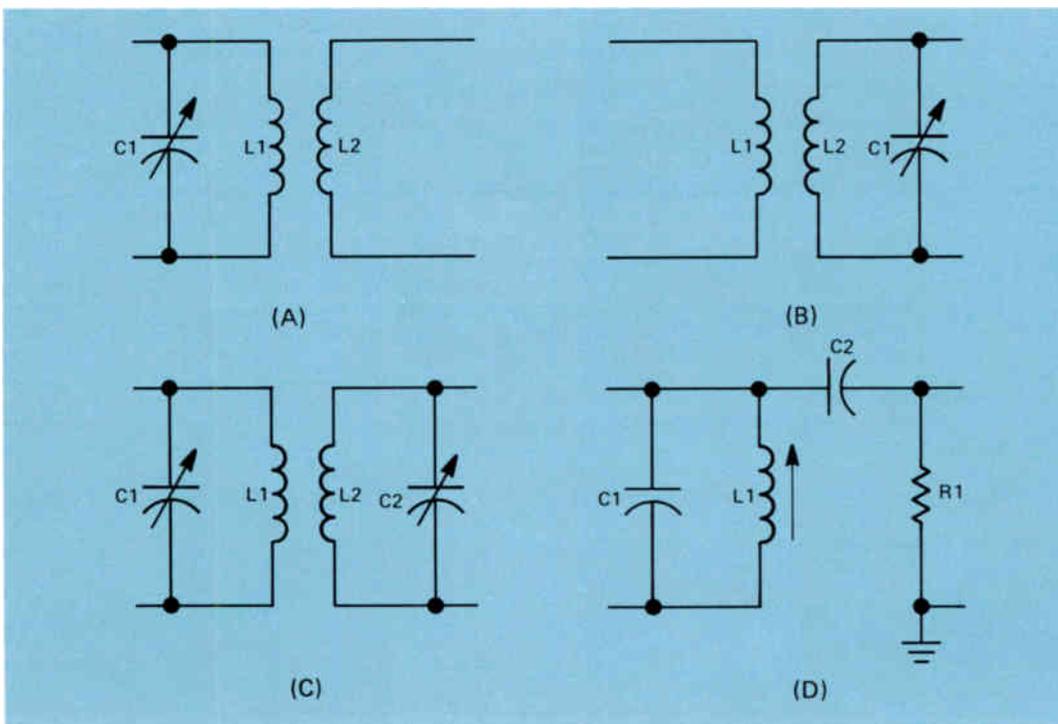


Figure 18. Four basic loads that might be found in rf amplifiers.

induced in series with the various turns of the coil, L2 and C2 form a series-resonant circuit. At first glance, you might think the circuit is a parallel-resonant circuit because it looks like the circuit made up of L1 and C1. Remember that the determining factor, whether the circuit is series-resonant or parallel-resonant, is how the voltage is applied to the circuit. The voltage is applied in parallel across L1 and C1, but it is induced in series with the turns of L2, which makes the circuit L2-C2 a series-resonant circuit.

In the circuit in Fig.18(D), we have a parallel-resonant circuit made up of C1 and L1 as the load. The parallel-resonant circuit will act as a high resistance so that considerable signal voltage will be developed across it. This voltage is coupled through C2 to the following stage. You will run into all four types of loads shown in Fig.18 in rf amplifiers and related circuits.

Some rf amplifiers are designed to operate over a band of frequencies. For example, the rf

amplifier in the input of a radio receiver must be able to amplify signals over the entire AM broadcast band from 550 kHz to 1600 kHz. As you tune the radio across the band, the rf amplifier is tuned to operate at the frequency of the broadcast stations you wish to receive.

Some rf amplifiers, on the other hand, are designed to operate at only one frequency. Before studying rf amplifiers in detail, let's learn a little more about resonant circuits.

## Resonant Circuits

When we say a circuit is resonant, we mean that the inductive reactance in the circuit is exactly equal to and canceled by the capacitive reactance in the circuit. In the case of a parallel-resonant circuit, the tank current will be at a maximum but the circuit itself will act like a high resistance. As a result, the current supplied

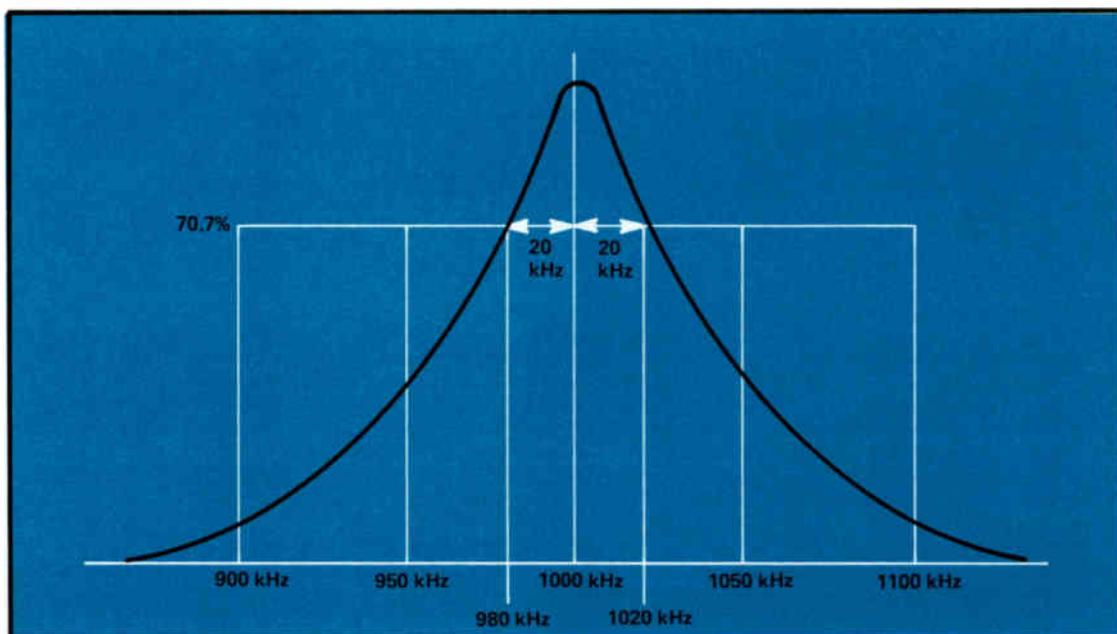


Figure 19. A response curve showing the two 70.7% points. The bandwidth extends 20 kHz on each side of the resonant frequency.

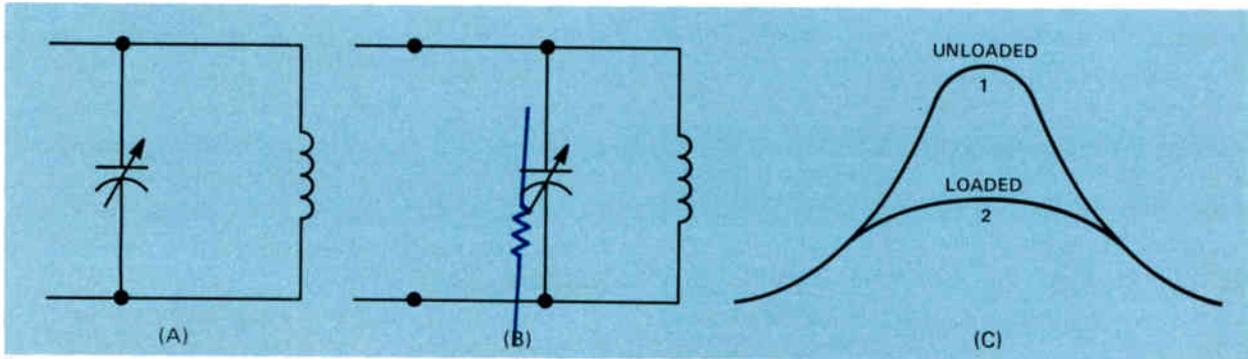


Figure 20. The response curves at (C) show the effect of loading a parallel resonant circuit as at (B).

to the resonant circuit by a generator connected across it will be at a minimum.

In the case of a series-resonant circuit, the resistance of the circuit will be at a minimum so that the current flow through it will be at a maximum. Current flow in a resonant circuit does not drop to zero immediately above and below the resonant point, but rather declines slowly as shown in Fig.19. Here we have a circuit that is resonant at 1000 kHz. Below the resonant point, the current drops off until at 900 kHz it is almost zero. Above resonance, it also drops off so that at 1100 kHz it is almost zero. Since a resonant circuit responds to a band of frequencies around the resonant point, we say that this circuit has a bandwidth. Engineers have arbitrarily fixed the bandwidth of the circuit as the point where the voltage and current drop to 70.7% of the value at resonance. This is called the *half-power point*. In the response curve shown in Fig.19, the half-power points are 980 kHz and 1020 kHz. The bandwidth of the circuit on each side of resonance is 20 kHz, so the total bandwidth of the circuit is 40 kHz.

You might wonder how this gets the name half-power point. At resonance, the power is equal to  $E \times I$ . At the 70.7% point the power is equal to:

$$P = 0.707 E \times 0.707 I$$

since,

$$0.707 \times 0.707 = 0.5$$

then

$$\begin{aligned} P &= 0.707 \times 0.707 \times E \times I \\ &= 0.5 \times E \times I = 0.5 \times P \end{aligned}$$

where P is the power at resonance.

We can change the bandwidth of a resonant circuit by loading the circuit. This is usually done by connecting a resistor across the circuit. In Fig.20(A), we have shown a resonant circuit and curve 1 of Fig.20(C) represents the response curve of the circuit. In Fig.20(B), we've shown the same resonant circuit with a resistor connected across it and curve 2 of Fig.20(C) shows the response curve of the circuit with the resistor in parallel with it. The resistor lowers the peak of the response curve, and broadens the band of frequencies over which the response will be at least 70.7% of that at resonance.

In some applications, we may want a sharp response and a narrow bandwidth. In most communications receivers, we need a sharp, narrow response curve in order to separate stations operating close together. However, in TV, the response curves must be designed to pass a band of frequencies several MHz wide.

The coupling between resonant circuits will affect the response of the circuit. For example,

in Fig.21 we have shown two resonant circuits. The resonant circuit made up of C1 and L1 is a parallel-resonant circuit. However, L2 and C2 form a series-resonant circuit, since L2 is inductively coupled to L1 so that the voltage is induced in series with the turns of the coil. The voltage is induced in L2 by placing it near L1 so that the magnetic lines of force set up around L1 cut the turns of L2. If L2 is some distance from L1, so that only some of the magnetic lines of force set up by L1 cut L2, we say that the circuits are undercoupled or loosely coupled. This will produce a response curve in the output like the one shown in Fig.22(A). If we bring L2 closer to L1, so that eventually we reach a point that all of the flux from L1 is cutting the turns of L2, we get a response curve like the one shown in Fig.22(B). We call this point critical coupling. At critical coupling, all the lines of flux produced by L1 are cutting L2.

If we bring the coils still closer together, we reach a point that is called *overcoupled*. By this we mean that the coupling is tighter than critical coupling and we'll get the double hump response curve shown in Fig.22(C). It is readily apparent that the bandwidth of the curve at (C) is wider than the bandwidth of the curve at (B).

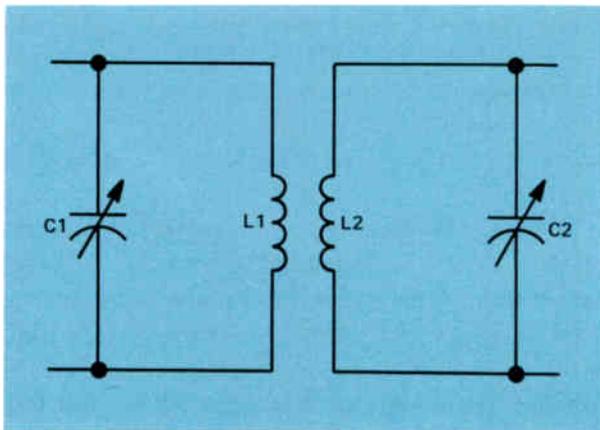


Figure 21. A schematic diagram of a double-tuned rf transformer.

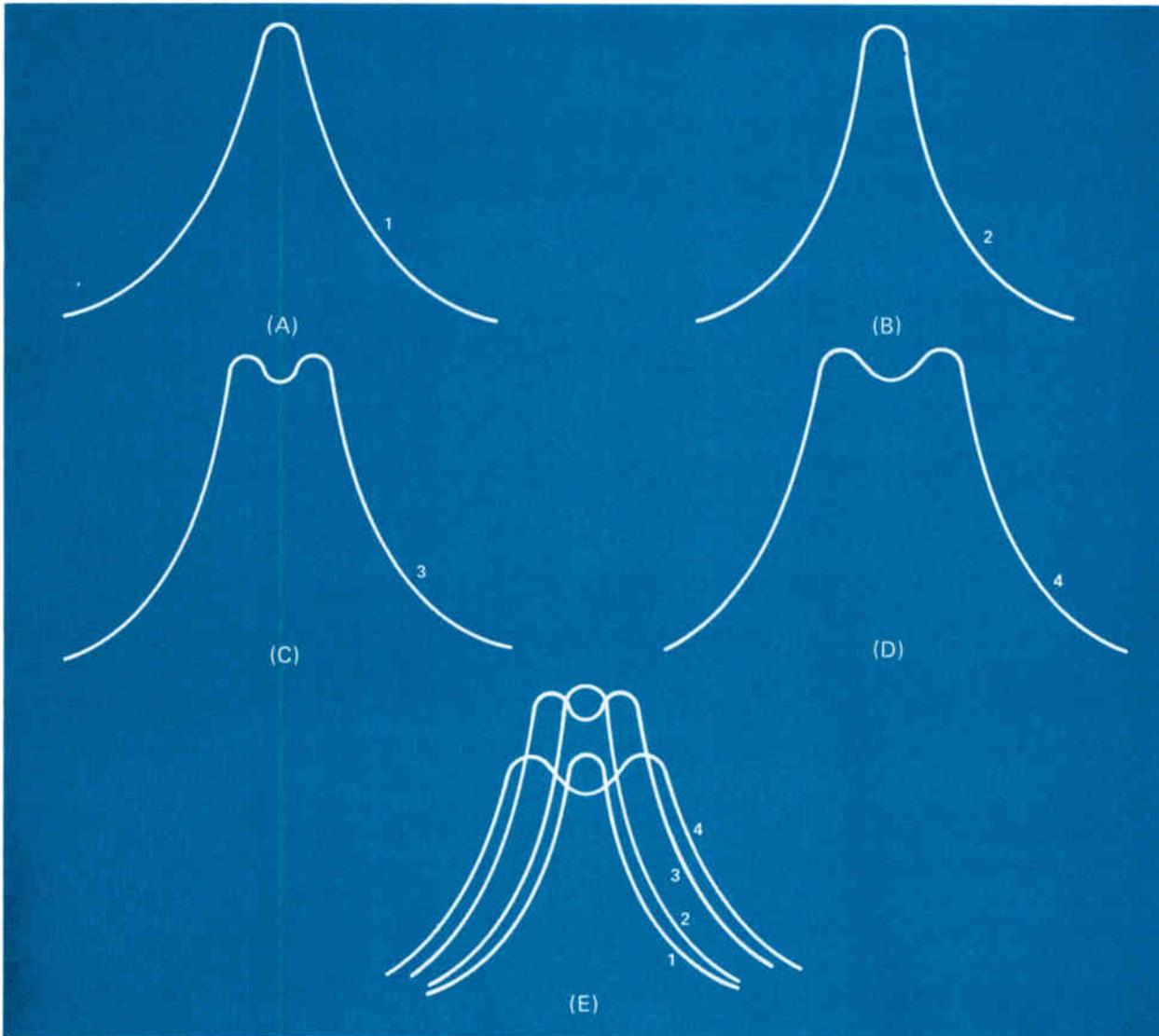
If we want a still wider bandwidth, we can push the coils still closer together and then adjust one resonant circuit until it is resonant slightly below the original resonant point, and adjust the other resonant circuit so that it is resonant slightly above the original resonant point. This will give us a response curve like the one shown in Fig.22(D).

In Fig.22(E), we have superimposed the four response curves so you can see what they look like in relation to each other. Notice that curve 1 is quite sharp, but its amplitude is less than curve 2. There are applications where it is worthwhile to take this drop in output to get a sharp response curve.

Normally the coils will be adjusted at least to critical coupling as shown by curve 2, and in several cases overcoupled as in curve 3. As an example, the response curve 2 might be adequate for AM broadcasting, but overcoupled coils like that shown at 3 might be required for FM because the FM signal requires a wider bandwidth than an AM signal.

In TV applications where an even wider bandwidth is needed, overcoupling and detuning the two circuits is used to get the wide bandwidth that is needed. Even though this results in a lower output as shown by curve 4 in Fig.22(E), we must resort to this technique in order to amplify all of the frequencies in the TV signal. We then make up for the drop in output by using additional amplifier stages.

As a technician, you will not have to be concerned about the coupling between coils in resonant circuits. The engineers that designed the set will take care of this in the design. However, if you have to replace an rf transformer such as the one shown in Fig.21, it is important that you get either an exact duplicate replacement or a replacement that has the same characteristics as the original transformer. Otherwise, you'll change the bandwidth and gain of the amplifier.



**Figure 22.** (A) An example of undercoupling, (B) critical coupling, (C) and (D) overcoupling, and (E) a superimposition of the curves.

### Transistor RF Amplifiers

A typical rf amplifier that might be found in a radio receiver is shown in Fig.23. The circuit uses an npn transistor in a common-emitter circuit.

L1 is a coil wound on a ferrite rod. A ferrite rod is a rod made of a powdered iron-type material held together by a suitable binder. L2

is wound on the same rod and is inductively coupled to L1. This particular part is called a *loopstick*. In the first radios built with an inside antenna, the coil in the input to the rf amplifier stage was wound in the form of a loop. The passing signal from the broadcast station cut the turns of the loop and induced a voltage in each turn. This voltage was then fed to the rf amplifier. The antenna was called a loop antenna.

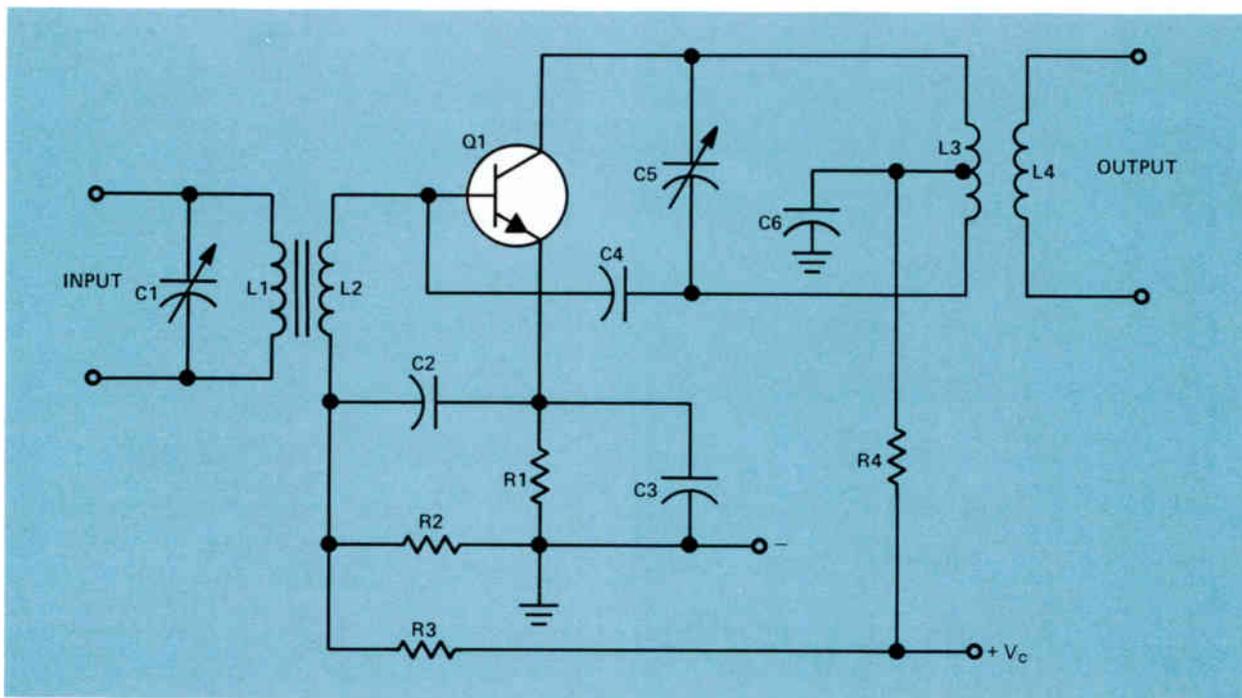


Figure 23. A transistor rf amplifier.

The ferrite rod with the two coils wound on it replaced the loop antenna. Since this device looked like a stick and replaced the loop, the name loopstick came into use.

In the loopstick, the passing radio signals induced a voltage in the turns of L1. L1 is tuned to resonance by C1 so that the voltage induced at the resonant frequency will cause a much higher current to flow in the resonant circuit than other frequencies. This in turn will mean that maximum signal voltage at the resonant frequency will be induced into L2.

L2 is inductively coupled to L1. L2 has fewer turns than L1 so there will be a current step-up, meaning that the current flowing in L2 will be higher than the current flowing in L1. This serves two useful purposes, it provides a higher current for the emitter-base circuit of the transistor Q1, and it prevents the transistor from

loading the resonant circuit. If current through Q1 did load the resonant circuit excessively, it would lower the Q, broadening the circuit's response curve and reducing the selectivity.

The signal induced in L2 is applied to the base of the transistor and to the emitter through C2. C2 is selected to have a low reactance at the signal frequency. The varying emitter-base current produced by the signal produces a high signal collector current, which is fed to the parallel-resonant circuit consisting of L3 and C5.

Notice that the collector voltage is applied to a tap on L3 through R4. C6 is connected between the tap and ground which holds the tap at signal ground potential. There will be a small voltage induced in the lower half of the coil which will be 180° out of phase with the signal voltage at the collector. This voltage is fed

through C4 and back to the base. This is a neutralizing voltage and C4 is called a neutralizing capacitor.

We feed this signal back through C4 to prevent Q1 from oscillating. When a transistor oscillates, it begins generating a signal of its own. Q1 will oscillate because there is a high signal voltage developed across L3 between the collector and ground. There is a certain capacitance between the collector and base of the transistor. Some of this signal will be fed back into the base. The signal will be strong enough to develop a signal of its own. Thus, the signal fed from the collector to the base causes the base-emitter circuit to generate a signal, which in turn is fed to the collector and from the collector back to the base. Thus, the stage begins to oscillate and produces its own signal. To prevent this, we feed a signal that is 180° out of phase with the signal at the collector through C4 and back into the base. This cancels or neutralizes the signal being fed from the collector to the base through the internal collector-base capacitance of Q1.

L4 is inductively coupled to L3 so that the amplified output from the rf amplifier is fed on to the next stage.

Figure 24 is a schematic diagram of an rf amplifier using a junction field-effect transistor. Notice that the signal is picked up by the antenna and fed to L1, which is inductively coupled to L2. L2 and C1 form a series-resonant circuit. C1 is adjusted so that the combination is resonant at the frequency of the desired station. The capacitance of C2 is so large that as far as the rf is concerned, it can be ignored. It is used to block the agc (automatic gain control) voltage from ground so that it will not be shorted out. The agc voltage is a negative voltage that is applied to the gate of the transistor. This voltage will vary to control the gain of the transistor, becoming more negative on strong signals and less negative on weak signals.

The varying signal applied between the gate and ground causes the current flow from the source to the drain of the transistor to vary. This small varying signal fed to the gate con-

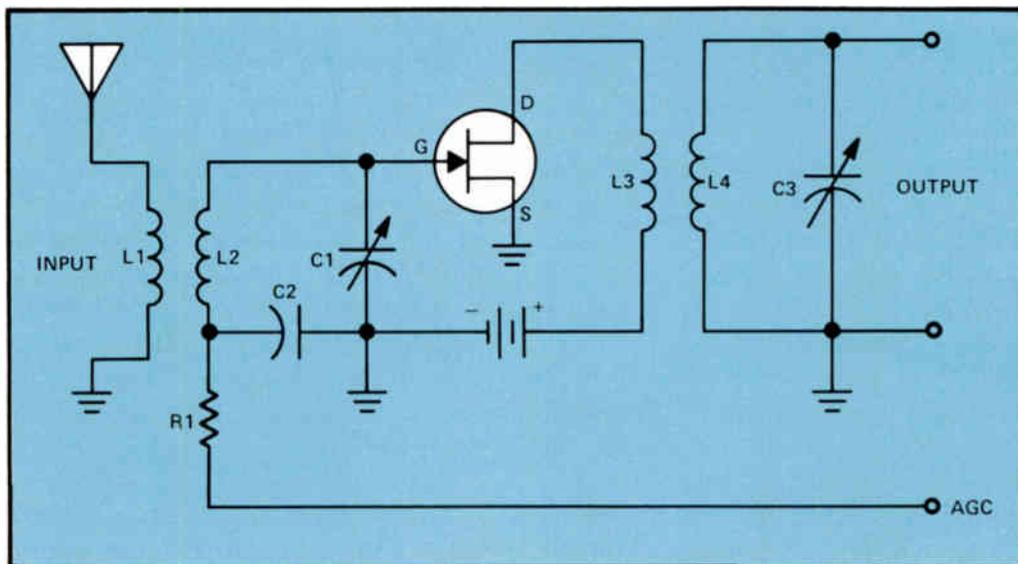


Figure 24. An rf amplifier using a junction field-effect transistor.

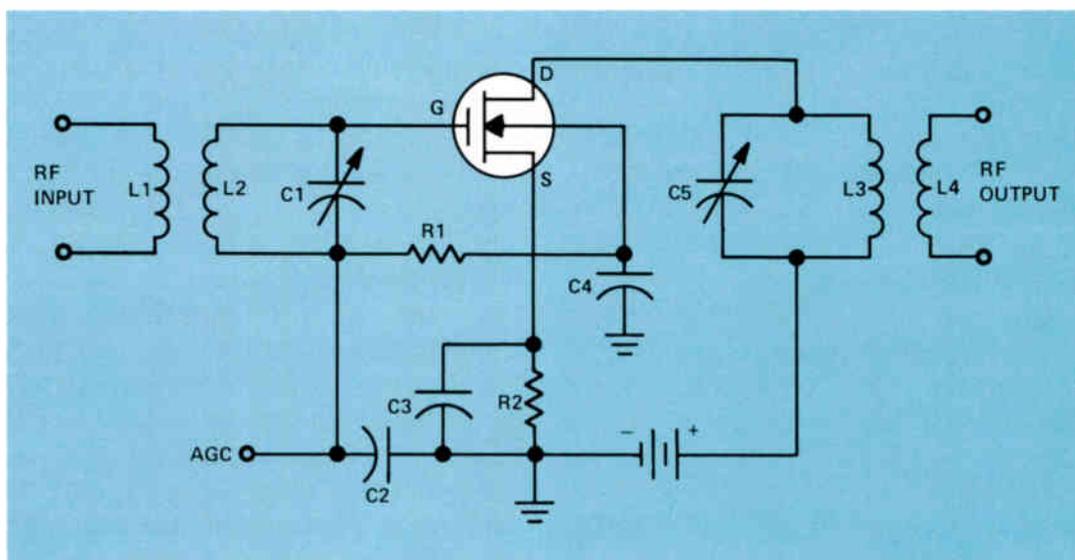


Figure 25. An rf amplifier using an insulated-gate field-effect transistor.

trols a large varying current flow from source to drain, and this current in turn flows through L3. L3 is inductively coupled to L4 which is tuned to resonance by C3. The amplified signal voltage appearing at the output is then fed on to the next stage.

In the circuit shown in Fig.24, there will be some reverse current flow across the junction of the transistor. This will have the effect of lowering the input resistance of the transistor, which in turn will lower the Q of the resonant circuit. This can be overcome by using an insulated-gate field-effect transistor in the circuit such as shown in Fig.25. The circuit here shows an n-channel depletion-type, insulated-gate, field-effect transistor.

In the circuit shown, current flows from the negative side of the power supply, through R2 to the source of the transistor. It flows through the transistor to the drain, and then through L3 back to the positive side of the voltage source. The gate is connected to the negative automatic gain control voltage through L2. The negative voltage applied to the gate will limit the width

of the channel and control the resistance of the channel.

In operation, the rf signal is applied to L1. This may be from another rf amplifier or directly from the antenna. The signal current flowing through L1 induces a voltage in series with L2. L2 and C1 form a series-resonant circuit. The resonant signal voltage is applied to the gate of the transistor and this voltage is applied in series with the negative agc voltage so it varies the negative voltage on the gate at an rf rate. The varying signal voltage causes the resistance of the channel to vary, causing the current flowing from the source through the transistor to the drain to vary. L3 and C5 form a parallel-resonant circuit. This high-impedance circuit develops a high signal voltage due to the varying current flowing through it. L3 is inductively coupled to L4, and the output from L4 is fed to the following stage.

A p-channel transistor can be used as well as an n-channel transistor in a circuit of this type. Also the enhancement type of insulated-gate transistor could be used. However, it is likely

that most rf amplifiers using an insulated-gate field-effect transistor will be depletion-type n-channel transistors. Dual gate IGFETs are widely used as rf amplifiers. The signal is fed to one gate and the agc voltage to the other.

One of the disadvantages of the insulated-gate transistor is that it is easily damaged. Simply removing or inserting the transistor in the circuit when the voltages are applied could destroy the transistor. High peak voltages build up in the gate circuit due to the very high resistance of the gate. Since the gate is actually insulated from the drain source by means of a layer of insulation, the input resistance of the gate is very high. Pickup from a nearby power line can induce a high enough voltage in a gate to destroy the transistor if the circuit is open.

### I-F Amplifiers

Modern radio and television receivers are called *superheterodyne* receivers. In a superheterodyne receiver, the incoming signal is fed to an rf amplifier such as shown in the block diagram in Fig.26. The signal is amplified and fed to a mixer stage where it is mixed with a locally generated signal. This produces two new signals, one equal to the sum of the frequencies of the two signals and one equal to the

difference. The difference frequency is fed to an amplifier called an *intermediate frequency amplifier* which is abbreviated i-f amplifier. The signal is still a radio frequency signal, but it has a lower frequency than the actual received signal. The signal is then fed to a detector, which separates the audio signal from the rf carrier. The detector gets its name, second detector, because in the early days of radio, the mixer was called the first detector. The audio signal from the second detector is then fed to low-frequency voltage amplifiers and finally to a power amplifier.

The reason for converting the incoming signal to a low-frequency signal is to improve the receiver selectivity. Consider two stations, one operating on 1500 kHz and the other on 1450 kHz. The frequency difference is 50 kHz, which is just a little more than 3% of 1500 kHz. After the two signals have been converted to a lower rf frequency (455 kHz is a common i-f frequency), the 50 kHz separation between the two stations represents a frequency difference of almost 11%. The i-f amplifier can separate the two signals, whereas an rf amplifier operating at 1500 kHz would not be able to do so.

All modern receivers are superheterodyne receivers. AM broadcast receivers today use an i-f of 455 kHz. Automobile receivers frequently

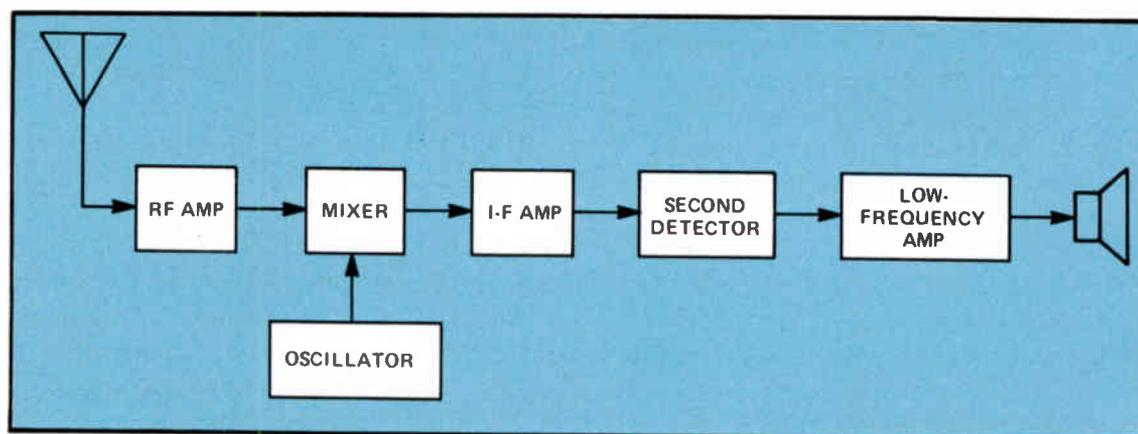


Figure 26. A block diagram of a typical super-heterodyne receiver.



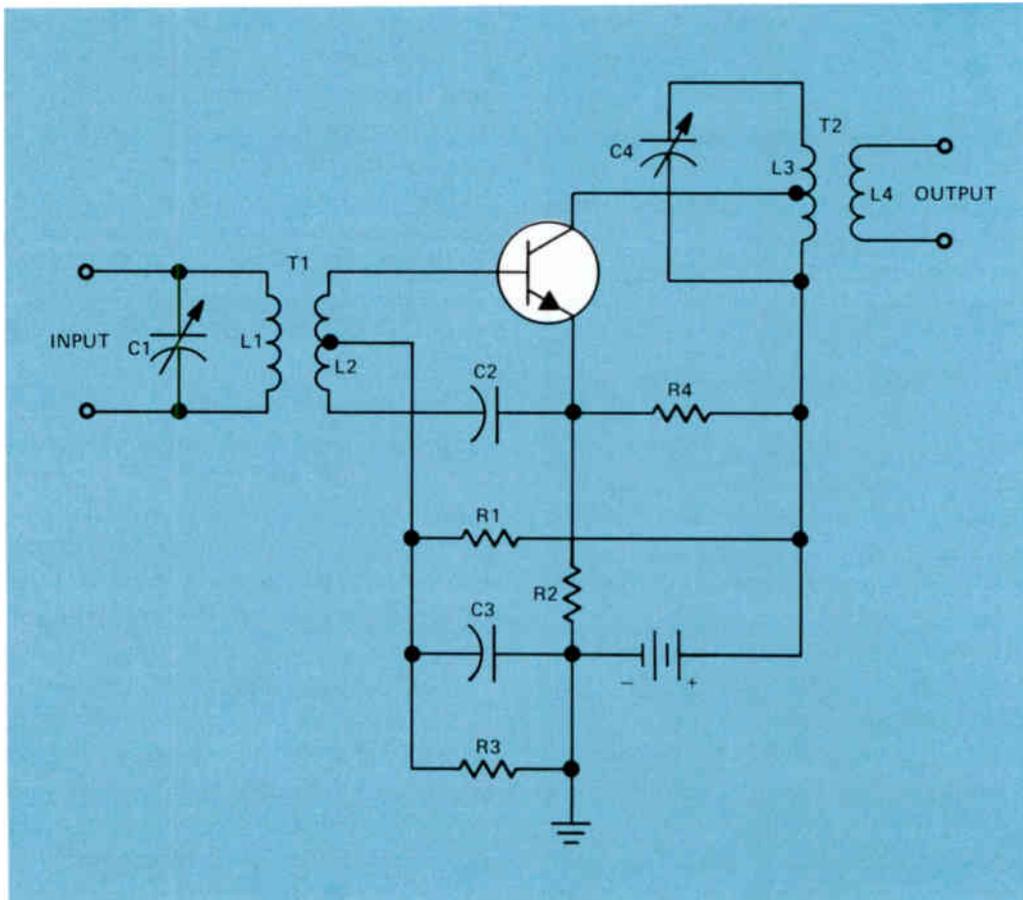


Figure 28. Transistor i-f amplifier using an npn transistor.

and R2 through L2 so the base will be negative with respect to the emitter, which places a forward bias across the emitter-base junction of the transistor.

Another transistor i-f amplifier is shown in Fig.28. This amplifier uses an npn transistor whereas the one shown in Fig.27 uses a pnp transistor. In addition to the different transistor types, the method of obtaining neutralization is somewhat different. Notice the resistor in the emitter circuit, R2. This resistor is not bypassed; therefore, a signal voltage will be developed across it. The signal voltage is fed through C2 into the lower end of the coil L2. The center tap of L2 is at signal ground potential because

C3 has a low reactance at signal frequency. The lower end of L2 is inductively coupled to the upper end so that a voltage is induced in the upper end of the coil  $180^\circ$  out of phase with the signal fed into the lower end through C2. This voltage is fed to the base, neutralizing any signal voltage fed from the collector back to the base through the transistor itself.

Notice that the collector is connected to a tap on coil L3. The output resistance of the transistor is comparatively low, and by feeding the collector into a tap in the coil in this manner, we prevent loading of the parallel-resonant circuit made up of L3 and C4. Loading would reduce the selectivity of the circuit.

## IC Amplifiers

You might wonder if integrated circuits are used as rf and i-f amplifiers. The answer to this is yes. As a matter of fact, they are widely used in both radio and TV receivers.

In Fig.29 we show what can be accomplished with a single integrated circuit. Here, we have a 14-pin IC that is used as the rf amplifier, the mixer-oscillator, the i-f amplifier, the agc detector, and the agc amplifier. In fact, this IC could be used along with a diode as a detector and the IC shown in Fig.17 to form a complete receiver.

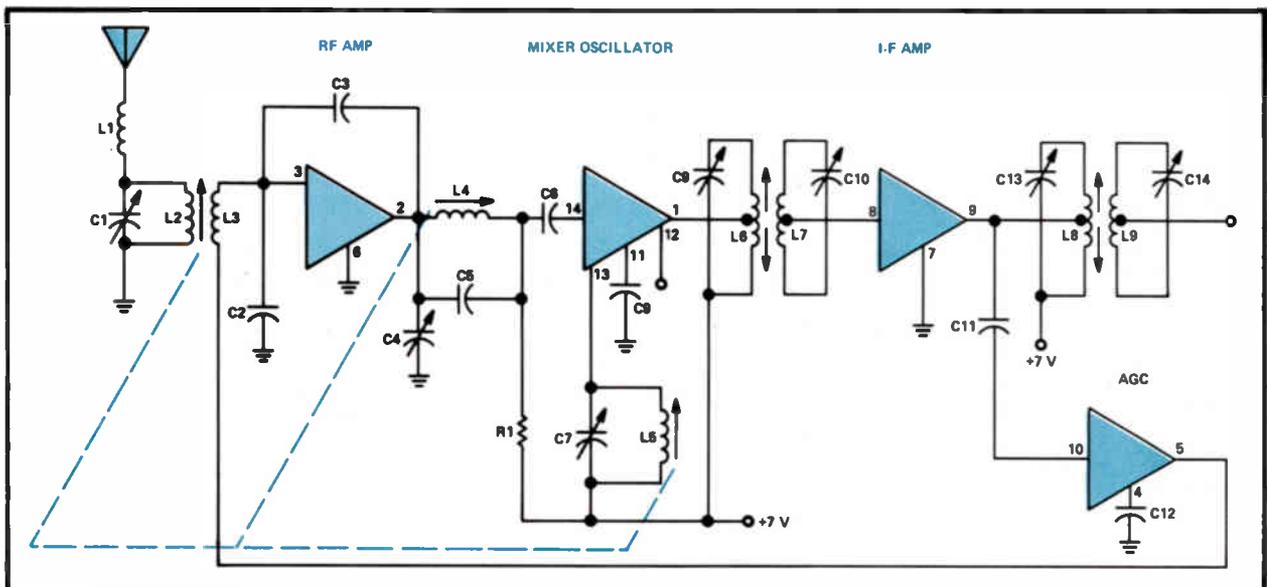
The coils L2-L3, L4, and L5 are all adjustable by a single adjustment. Changing these coils tunes the receiver across the standard AM broadcast band.

The signal picked up by the antenna is fed to the parallel-resonant circuit consisting of L2 and C1. The high circulating current in L2 induces a voltage in L3, which is fed to terminal 3 of the rf amplifier. The signal is amplified and fed through L4 to terminal 14 of the mixer oscillator. Also notice that a signal from the

output of the rf amplifier is fed through C3 back to the input to neutralize the rf amplifier. In the mixer stage, the incoming signal is converted to 455 kHz, which is the i-f. The i-f signal is fed to pin 8 of the IC, where it is amplified and fed to the parallel-resonant circuit made up of C13 and L8. L9 is inductively coupled to L8, so a strong circulating signal is induced in the series-resonant circuit made up of L9 and C14. This signal can then be fed to the second detector.

Part of the signal from the output of the i-f amplifier is fed from pin 9 through C11 to the agc detector and amplifier. In this stage a negative signal voltage, which depends upon the strength of the incoming signal, is developed, amplified, and fed back to the rf amplifier to control the gain of it. The stronger the signal, the greater the negative voltage developed and the more the gain of the rf amplifier is reduced.

ICs such as the one shown in Fig.29 are widely used because they are relatively inexpensive to manufacture. The assembly of the equipment is simple because the one part replaces a number of discrete parts.



**Figure 29.** In the circuit shown, a single IC contains the rf amplifier, the mixer-oscillator, the i-f amplifier, and the agc.

## Summary

The rf amplifiers we discussed in this section are all voltage amplifiers. They are designed to take a weak radio frequency signal and amplify it into a stronger signal. RF amplifiers have a load in the output circuit. In most cases, the loads will be some form of resonant circuit. An i-f amplifier is an intermediate frequency amplifier. It is an amplifier that operates at a relatively low radio frequency. In addition, since all incoming signals picked up by the radio are converted to the same intermediate frequency, the i-f amplifier is designed to operate at a fixed frequency. Its purpose is to improve the selectivity of the receiver. Selectivity is the ability of the receiver to separate signals operating on frequencies relatively close together.

## Self-Test Questions

- 18 What do we mean by the bandwidth of a circuit?
- 19 Name two methods that can be used to increase the bandwidth of the circuit.
- 20 What do we mean by critical coupling?
- 21 What is the name given to C4 in the circuit shown in Fig.23?
- 22 Why is C4 necessary in the circuit shown in Fig.23?
- 23 What do the letters agc in the circuit shown in Fig.24 stand for?
- 24 What is the advantage of using an insulated-gate field-effect transistor as an rf amplifier when compared to a junction field-effect transistor?
- 25 What is the i-f frequency used in the modern AM broadcast receiver?
- 26 What is the i-f used in many automobile receivers?
- 27 In the circuit shown in Fig.27, what purpose does C4 serve?
- 28 In the circuit shown in Fig.28, why is the collector fed to a tap on L3?
- 29 How many integrated circuits are used in the circuit shown in Fig.29?

## LOGARITHMS AND DECIBELS

If we feed a signal of 1 microvolt into an amplifier stage and we have a signal of 100 microvolts in the output, the gain of the stage is 100 divided by 1 = 100. This is one way of measuring the gain of a stage. Another method is to measure it in units called the decibel. The decibel is a logarithmic ratio. It is a ratio that is based on logarithms. Therefore, before we can understand what a decibel is, we must first learn something about logarithms.

There are two important types of logarithms in use today. One is called a common logarithm and the other a natural logarithm. Common logarithms are based on the number 10. This is the type of logarithms that you will study and use now.

### The Theory of Logarithms

The basic idea of logarithms come from the fact that any number can be expressed as the power of another number. The power of a number is the product of a number multiplied by itself a given number of times. The first power of a number is the number itself; the second power is the number multiplied by itself; the third power is the number multiplied by itself twice, and so forth.

This is easiest to understand by taking an example. In the system of common logarithms, we express all numbers as a power of ten. Therefore, we will use 10 as our example. The number 10 itself is equal to 10 to the first power. This can be written  $10^1$ . The number 100 is equal to  $10 \times 10$ . This is 10 to the second power and can be written  $10^2$ . Similarly, 1000 is equal to  $10 \times 10 \times 10$ , which is 10 to the third power and can be written  $10^3$ . The number 10,000 is  $10^4$ . Since  $10 \times 10 \times 10 \times 10$  is equal to 10,000, or  $10^4$ .

Now, as we have said, 100 is 10 to the second power. The logarithm of 100 is simply the power to which 10 must be raised to give us 100. The number 10 must be raised to the second power ( $10^2$ ) to give us 100. Therefore, the logarithm of 100 is 2. Similarly, the logarithm of 1000 is 3, and the logarithm of 10,000 is 4. The logarithm of 10 is 1.

This is not very complicated when the number is an exact power of 10. But let us consider the numbers between 10 and 100. It is a little more difficult to see how a number between 10 and 100 can be expressed as a power of 10. Actually, this is quite difficult to work out mathematically, but it can be done. Fortunately, all these values have been worked out and are available in tables called logarithm or log tables. If you want to know the logarithm of a number, you simply refer to the table. For example, the logarithm of the number 2 is 0.301. This means that if it were possible to multiply the number 10 by itself 0.301 times, the product would be 2. This can be written  $10^{0.301}$ . The exponent (or power) 0.301 is called the logarithm.

Now let's take the numbers 20 and 200. The logarithm of 20 is 1.301 and the logarithm of 200 is 2.301. Notice that in the three logarithms for 2, 20, and 200, the figures to the right of the decimal point remain the same. The figures to the left change. The logarithm can be divided into two parts. The part to the left of the decimal point is called the characteristic, and the part to the right of the decimal point is called the mantissa.

For any number having the same digits, the mantissa does not change. For example, the mantissa of 2, 20, 200, 2000, 20,000, and 200,000 is always 0.301. However, the characteristic changes. The characteristic for 2 is 0, for 20 is 1, for 200 is 2, for 2000 is 3, and for 20,000 is 4. Notice that the characteristic is always one number smaller than there are whole numbers in the original number. For example, in the

For numbers from:	Characteristic
1 to 9	0.
10 to 99	1. ( $10^1$ )
100 to 999	2. ( $10^2$ )
1,000 to 9,999	3. ( $10^3$ )
10,000 to 99,999	4. ( $10^4$ )
100,000 to 999,999	5. ( $10^5$ )

Figure 30. The characteristics of numbers from 1 to 999,999.

number 2000 there are four numbers and the characteristic is 3.

The chart given in Fig.30 gives you the characteristics of the numbers you are likely to encounter.

We mentioned earlier that you can find the logarithm of a number by looking it up in a table of logarithms. You will find a table of logarithms in any good math reference book. A log table generally lists the numbers from 10 to 99 in the left column, which is usually headed with the letter N. To the right, there will be 10 additional columns with headings from 0 to 9. If you want to look up the logarithm of the number 25, you find the number 25 in the N column and then look in the first column which will be headed 0 and find that the logarithm is 0.3979. If you want to look up the logarithm of the number 255, you find the number 25 in the N column, and then move over to the column under the heading 5, and find that the logarithm is 0.4065. Notice that the log table gives only the mantissa of the number. You have to determine the correct characteristic yourself. This is easy to do because the characteristic is always one less than the number of whole numbers in the number. Also, the table given in Fig.30 will tell you that for numbers from 100 to 999, the characteristic is 2. Therefore, the characteristic for the number 255 is 2.

You can also find the logarithm of a number using a slide rule that has an L scale. However,

this is not as accurate as using a log table, but often it is satisfactory. Today, with the availability of low-cost hand-held scientific calculators, both the log table and the slide rule are obsolete. Most scientific calculators have provisions for giving you the logarithm of a number rapidly and more accurately than you can get it from a log table.

### The Decibel

Many years ago, engineers working on telephone installations introduced the unit of power measurement called the *bel*. This unit of measurement is named for Alexander Graham Bell, the inventor of the telephone. The bel was introduced as a unit of measurement because engineers and scientists discovered that the human ear responds to variations of loudness in a logarithmic manner. Therefore, it is convenient to have a unit that can be used to express the ratio between the power of two signals in a logarithmic manner. The bel is simply the logarithm of the ratio of the power of two signals. For example, if we have a signal power of 100 watts and another signal power of 10 watts, and we wish to express the ratio of these two signals in bels, we would use the formula:

$$\text{bels} = \log \frac{P_1}{P_2}$$

Substituting 100 watts for  $P_1$  and 10 watts for  $P_2$ , we would get:

$$\begin{aligned} \text{bels} &= \log \frac{100}{10} \\ &= \log 10 \end{aligned}$$

Now, the log of 10 is 1, so this power ratio is equal to 1 bel. In other words, a power ratio of

100 watts to 10 watts, which is a ratio of 10 to 1, is equivalent to 1 bel. Thus, the power ratios of 10 watts to 1 watt and 1000 watts to 100 watts are both power ratios of 10 to 1, so they also represent a change in power of 1 bel.

The bel proved to be too large a unit to handle easily, so another unit, 1/10 the size of the bel, was introduced. This unit is called the decibel, which is abbreviated dB. Thus, the commonly used measuring unit is the decibel; the prefix deci means 1/10. A power ratio in decibels is defined as:

$$\text{dB} = 10 \log \frac{P_1}{P_2}$$

which simply means that the ratio of two powers expressed in decibels is equal to 10 times the logarithm of the ratio of the two powers.

You will notice that the above relationship refers to power ratios only. It is common in electronic work to use voltage ratios, especially when calculating or discussing the gain of amplifiers. When the ratio between two voltages is calculated in decibels, we must modify the decibel equation to take care of the fact that the power ratios are proportional to the squares of the voltage ratios, since  $P = E^2 \div R$ . The formula to express voltage ratios in decibels is:

$$\text{dB} = 20 \log \frac{E_1}{E_2}$$

It is important to keep in mind that the voltage formula can be used only when the resistances of the two circuits being compared are equal. If we are trying to compare voltages developed across resistors of unequal value, we must convert the voltages to the power developed across the resistor and then use the power formula.

## Using the Decibel

It so happens that the smallest amount of change in sound level that can be distinguished by the average human ear is 1 dB with a sine wave input or 3 dB on complex waves such as the average human voice.

Because the decibel is such a convenient unit for expressing changes in sound level, manufacturers of audio equipment have for some time used it in describing the response of their amplifiers. This practice has generally spread into describing the performance of many amplifiers.

Let us see how the decibel can be used to describe the response of an amplifier. You will remember that we said that engineers arbitrarily selected the 0.707 voltage points, or the half-power points, to describe the bandwidth of an amplifier. At the half-power point, we have a ratio of 1 to 0.5 because 0.5 is half of 1. In dB this is:

$$\text{dB} = 10 \log \frac{1}{0.5} = 10 \log 2$$

The log of 2 is 0.301; thus, the power ratio is:

$$\text{dB} = 10 \times 0.301 = 3 \text{ (approximately)}$$

Thus, at the half-power point, the power in the circuit is down 3 dB from what it is at the maximum power or resonant point.

Another way in which the decibel is used is in expressing attenuation of certain signals. For example, we mentioned that amplifiers frequently generate harmonics. While this is a problem in audio amplifiers because it introduces distortion, it is an even greater problem in radio frequency transmitters because it results in an extra or spurious signal being transmitted. For example, suppose a radio station transmitting in the standard broadcast band has a power output of 1000 watts. Suppose further

that the second harmonic radiation is down 30 dB. This means that the second harmonic radiation is 30 dB less than the fundamental radiation. But just how much is 30 dB? It actually represents the power ratio of 1000 to 1. This means that if the power output on the fundamental is 1000 watts, the power output in the second harmonic is actually only 1 watt.

The table in Fig.31 gives the decibel values corresponding to voltage and power ratios. From this you can see that if an amplifier has a voltage gain of 40 dB, the output signal will be 100 times the input signal.

If your primary intention is to go into radio-TV servicing, you will seldom, if ever, have to calculate decibel values corresponding to voltage or power ratios. However, if you intend to go into communications or industry as an electronics technician, you should be able to calculate both voltage gain and power ratios in decibels.

Voltage Ratio	dB	Power Ratio	dB
1	0	1	0
2	6.0	2	3.0
3	9.6	3	4.8
4	12.0	4	6.0
5	14.0	5	7.0
6	15.6	6	7.8
7	16.8	7	8.4
8	18.0	8	9.0
9	19.2	9	9.6
10	20.0	10	10.0
20	26.0	20	13.0
30	29.6	30	14.8
40	32.0	40	16.0
50	34.0	50	17.0
60	35.6	60	17.8
70	36.8	70	18.4
80	38.0	80	19.0
90	39.0	90	19.6
100	40.0	100	20.0
1,000	60.0	1,000	30.0
10,000	80.0	10,000	40.0

**Figure 31.** Decibel values corresponding to voltage and power ratios.

## Summary

A common logarithm is the power to which 10 must be raised to equal a number. For example,  $10^2 = 100$  and  $10^3 = 1000$ .

A logarithm is made up of two numbers, a whole number to the left of the decimal point which is called characteristic and a decimal number to the right which is called a mantissa. The characteristic is always one less than the total number of digits in the number. For example, the characteristic of all numbers between 10 and 99 is 1, the characteristics of all numbers between 100 and 999 is 2 and the characteristics of all numbers between 1000 and 9999 is 3.

The mantissa of the logarithm of a number can be found by looking it up in the log table. For example, a log table will give the mantissa of the number 2 as 0.301. The logarithm of 2 is 0.301. The number 20 has the same mantissa as 2, but the character-

istic is 1, so the log is 1.301. The logarithm of 200 is 2.301.

An easier way to find the logarithm of a number is with a pocket calculator. The calculator will give you both the characteristic and the mantissa of the number with better accuracy than you can obtain with most log tables.

The decibel is a logarithmic ratio that was originally developed to express the ratio between two powers. The power ratio in decibels is:

$$\text{dB} = 10 \log \frac{P_1}{P_2}$$

The ratio between two voltages can also be expressed in decibels when the resistances of the two circuits being compared are equal. The formula is:

$$\text{dB} = 20 \log \frac{E_1}{E_2}$$

## Self-Test Questions

- 30 What is a common logarithm?
- 31 What is the part of the logarithm to the left of the decimal point called?
- 32 What is the part of the logarithm to the right of the decimal point called?
- 33 What is the characteristic of numbers from 100 to 999?
- 34 If the logarithm of 7 is 0.8451, what is the logarithm of 700?
- 35 What is the decibel?
- 36 If the power output from an amplifier drops from 1000 watts to 100 watts, what is the change in decibels?

## ANSWERS TO SELF-TEST QUESTIONS

- 1 They are in phase. The signal undergoes a  $180^\circ$  phase shift in each stage so the total phase shift is  $360^\circ$ , resulting in the output signal being in phase with the input signal.
- 2 It will swing in the negative direction. There will be a  $180^\circ$  phase shift in Q1.
- 3 R5 is used to develop a reverse bias between the gate and the channel. The current flowing through R5 will develop a voltage having a polarity such that the source end is positive. This means the entire channel will be positive with respect to ground. The gate connects to ground through R4 and there is no current flow through R4 and no voltage drop. This means the channel will be positive with respect to the gate, or in other words, the gate will be negative with respect to the channel.
- 4 Replace the IC.
- 5 The + sign indicates a noninverting input. That means the signal fed into this input will produce an output signal that is in phase with it. The - sign indicates an inverting input. The output signal will be  $180^\circ$  out of phase with the input signal fed into this input.
- 6 Q3 is an emitter follower.
- 7 The letter A indicates the gain of the amplifier.
- 8 The gain of the circuit is determined by the ratio of R2 to R1.
- 9 Two. Q1 and Q2 form one differential amplifier and Q4 and Q5 form a second.
- 10 Step-down transformers. Step-down transformers are used to match the high impedance of the output stage to the low impedance of the speaker voice coil.
- 11 In a step-down transformer the secondary current is always greater than the primary current.
- 12 It remains constant. If the current through Q1 increases, the current through Q2 will decrease an equal amount so that the current through R2 remains essentially constant.
- 13 When the input signal is zero, the transistors Q1 and Q2 draw little or no power. This will result in improved battery life.
- 14 The frequency response of the amplifier will be improved and the cost will be reduced by the elimination of the two transformers.
- 15 From C1. C1 simply charges to a higher voltage and supplies the extra electrons needed by Q1.
- 16 Negative. If the current through Q5 increases, the electrons must come from the  $1000\ \mu\text{F}$  capacitor, which will tend to discharge the capacitor and produce a negative signal, which is fed back to the emitter of Q2.
- 17 Replace it. If the input signal is normal and all parts and operating voltages are correct, the IC must be defective.
- 18 The bandwidth of the circuit is generally defined as the frequency between which the output voltage is 0.707 or

# HOW AMPLIFIERS WORK

48

- 70.7% of the maximum voltage obtained at resonance.
- 19** The bandwidth can be increased by overcoupling and by loading the resonant circuits.
- 20** Critical coupling is that point where the lines of flux produced in the primary winding of the transformer cut the turns of the secondary winding of the transformer.
- 21** C4 is a neutralizing capacitor.
- 22** Energy from the collector of Q1 will be fed back to the base through the collector-to-base capacity. This signal could cause Q1 to begin generating its own signal, which we call oscillating. The signal fed through C4 has the opposite polarity to the signal fed from the collector to the base of Q2 through the collector-to-base capacity and cancels it.
- 23** AGC stands for automatic gain control.
- 24** There is no current flow through the gate of the insulated-gate field-effect transistor, and therefore, it does not load the resonant input circuit. There is some current flow to the gate of a junction field-effect transistor, which will have some loading effect on the resonant circuit, which will reduce the selectivity of the circuit.
- 25** 455 kHz.
- 26** 262 kHz.
- 27** C4 is a neutralizing capacitor.
- 28** To reduce the loading on the resonant circuit.
- 29** 1.
- 30** A logarithm is the power to which 10 must be raised to express another number.
- 31** The part of the logarithm to the left of the decimal point is called the characteristic.
- 32** The part of the logarithm to the right of the decimal point is called the mantissa.
- 33** Two. The characteristic of a number is one less than the total digits in the number.
- 34** 2.8451. Both 7 and 700 will have the same mantissa in their logarithm. The difference is in the characteristic. Since 700 has three digits, the characteristic must be 2.
- 35** The decibel is 1/10th of a bel. A bel is the logarithm of the ratio between two numbers.
- 36** The ratio of 1000 watts to 100 watts is 10 to 1. Thus,  $1000 \div 100$  is 10. The logarithm of 10 is 1; therefore, this change represents a change of 10 decibels.

## LESSON QUESTIONS

This is Lesson Number 2230.

Make sure you print your name, student number, and lesson number in the spaces provided on the Lesson Answer Form. Be sure to fill in the circles beneath your student number and lesson number.

**Reminder:** A properly completed Lesson Answer Form allows us to evaluate your answers and speed the results and additional study material to you as soon as possible. Do not hold your Lesson Answer Forms to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

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- During the negative half-cycle of a sine wave signal fed to the amplifier in Fig.1, which way will the collector voltage of Q1 and Q2 swing?
  - Q1 negative, Q2 negative.
  - Q1 positive, Q2 positive.
  - Q1 negative, Q2 positive.
  - Q1 positive, Q2 negative.
- During the negative half-cycle of a sine wave signal fed to the amplifier in Fig.2, which way will the collector voltage of Q1 and Q2 swing?
  - Q1 negative, Q2 negative.
  - Q1 positive, Q2 positive.
  - Q1 negative, Q2 positive.
  - Q1 positive, Q2 negative.
- If in the operational amplifier circuit shown in Fig.7(A), A equals 1000, R1 equals 5000 ohms, and R2 equals 50,000 ohms, the gain of the amplifier is:
  - 10.
  - 100.
  - 1000.
  - 10,000.
- When a signal is applied to a class A power amplifier such as shown in Fig.9, the average collector current:
  - Increases.
  - Decreases.
  - Remains the same.
  - Drops to zero.

# HOW AMPLIFIERS WORK

50

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5. What is the advantage of the class B push-pull amplifier shown in Fig.13 over the class A push-pull amplifier shown in Fig.12?
  - a. Has higher power output.
  - b. Uses pnp transistors.
  - c. Has lower distortion.
  - d. Has lower power consumption.
6. A positive-going signal fed to the input of the circuit shown in Fig.14 will cause the current through:
  - a. Q1 and Q2 to increase.
  - b. Q1 and Q2 to decrease.
  - c. Q1 to increase, Q2 to decrease.
  - d. Q1 to decrease, Q2 to increase.
7. The most important effect noticed when the coupling between the coils of an rf transformer is increased beyond critical coupling is that:
  - a. The output will increase.
  - b. The output will decrease.
  - c. The bandwidth will decrease.
  - d. The bandwidth will increase.
8. Transistor rf amplifiers are usually neutralized to:
  - a. Increase the gain.
  - b. Decrease the gain.
  - c. Prevent oscillation.
  - d. Reduce power consumption.
9. In the circuit shown in Fig.29, which stage is neutralized?
  - a. The rf amplifier.
  - b. The mixer-oscillator.
  - c. The i-f amplifier.
  - d. The agc detector amplifier.
10. The input and output impedance of a certain amplifier are both 500 ohms, and the gain of the amplifier is 20 dB. If an input signal of 1 volt is fed into the input, what would you expect to find in the output?
  - a. 1 volt.
  - b. 10 volts.
  - c. 20 volts.
  - d. 100 volts.

# NOTES

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you may want to review during your studies.*

# NOTES

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# NOTES

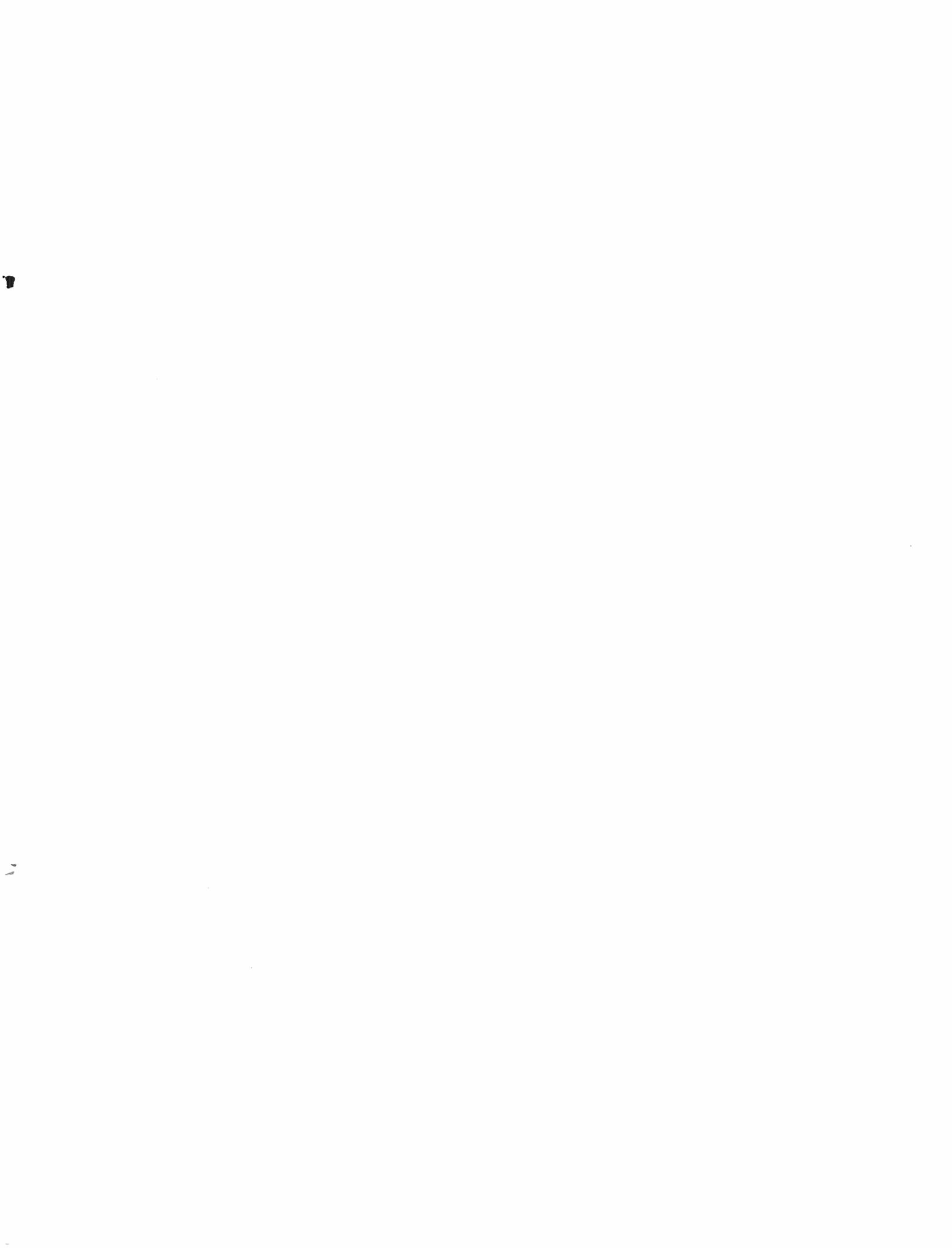
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# NOTES

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## THE ERROR OF HASTE

The fable of the hare and the tortoise is more than an interesting childhood story — it carries an important message we sometimes forget in this age of speed.

The hare, you will recall, started off in great haste. Soon it was so far ahead of the slow-plodding tortoise that it became overconfident and took a nap. The tortoise kept going steadily and won the race.

Haste does not always mean progress. Too often it leads instead to errors, to actual waste of time and energy, and even to complete failure, as in the case of the hare.

We must learn to work and wait. Take time for all things, because time often achieves results that are obtainable no other way. Shakespeare expressed it thus: "Wisely and slow; they stumble who run fast." More emphatic still was Benjamin Franklin, who said: "Great haste makes great waste."

Don't risk the dangers of haste. Keep going steadily like the tortoise, and you'll approach your goal steadily, inevitably.





# How Oscillators Work

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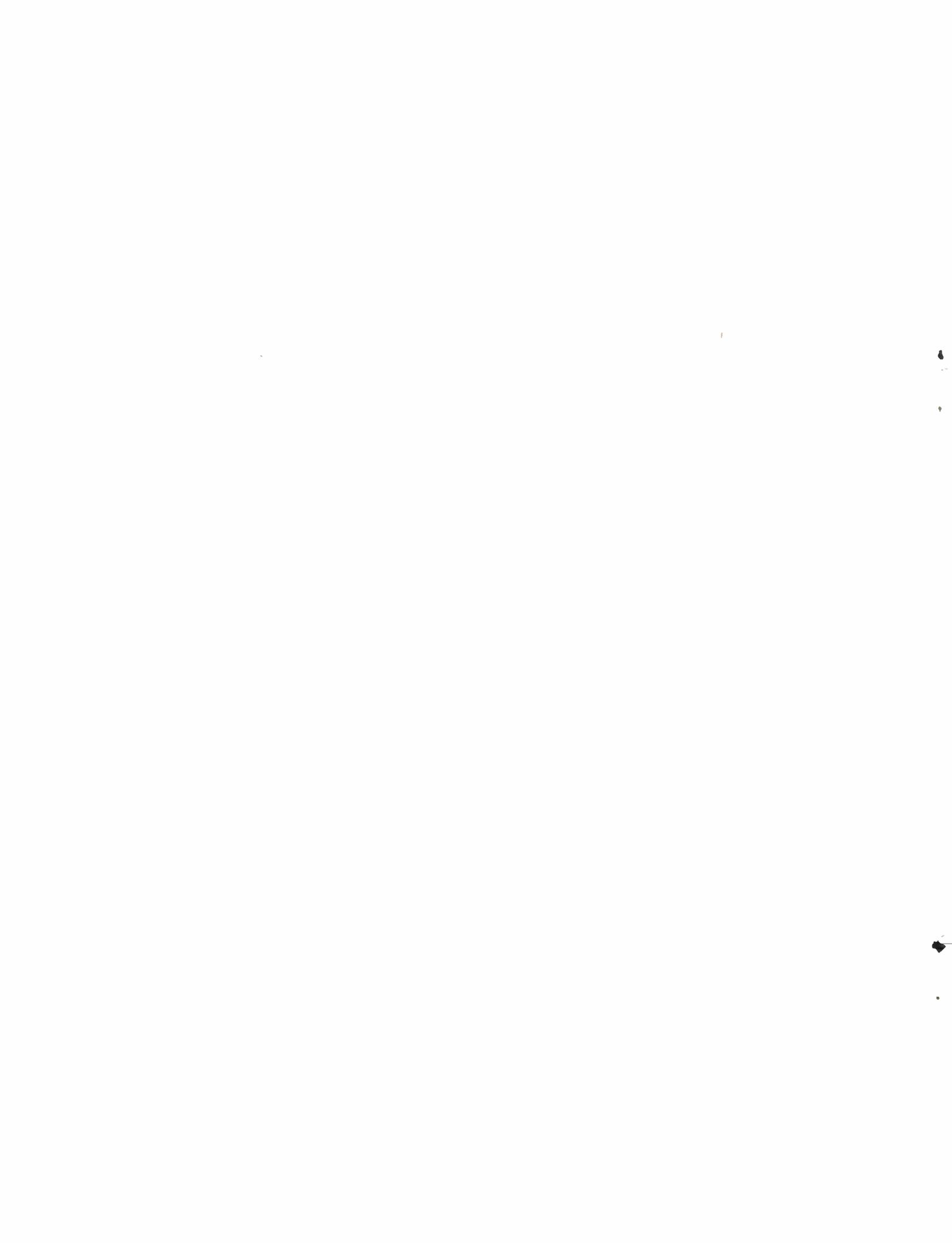


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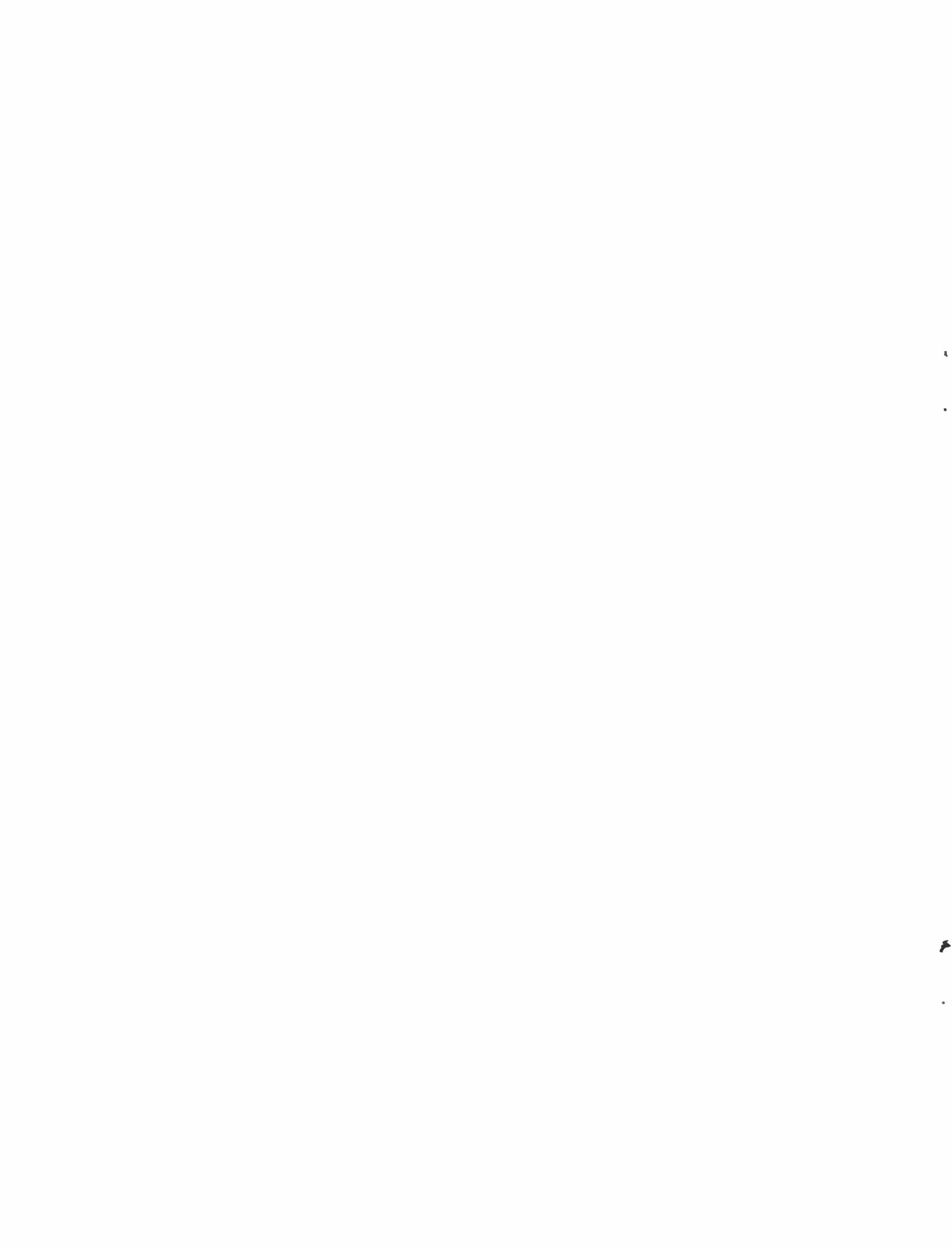
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# How Oscillators Work

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## TABLE OF CONTENTS

<b>Introduction</b> .....	1
<b>Resonant Circuits</b> .....	1
Damped Waves .....	1
Factors Affecting Resonant Circuits .....	3
Summary .....	5
Self-Test Questions .....	5
<b>LC Oscillators</b> .....	6
Oscillators Using Inductive Feedback .....	6
Oscillators Using Capacitive Feedback .....	9
Summary .....	13
Self-Test Questions .....	13
<b>Crystal Oscillators</b> .....	14
The Piezoelectric Effect .....	14
Simple Crystal Oscillators .....	16
Problems in Servicing Crystal Oscillators .....	18
Summary .....	19
Self-Test Questions .....	19
<b>RC Coupled Oscillators</b> .....	20
A Collector-Coupled Multivibrator .....	20
An Emitter-Coupled Multivibrator .....	21
Multivibrator Output Signals .....	23
Summary .....	24
Self-Test Questions .....	24
<b>Answers to Self-Test Questions</b> .....	25
<b>Lesson Questions</b> .....	26



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An oscillator circuit is used to generate an ac signal. It takes the dc from the power supply and converts it to ac. The frequency of the ac signal may be anywhere from a few hertz to thousands or even millions of hertz. The exact frequency at which the oscillator operates will depend upon the oscillator circuit and the values of the parts used in the circuit.

Oscillators can be divided into two types: LC and RC. LC oscillators use inductance and capacitance in the frequency-determining circuits. RC oscillators use resistance and capacitance in the frequency-determining network.

Both LC and RC oscillators work on the same basic principle, that of feeding some of the signal from the output circuit back into the input circuit. This signal is called the feedback signal and enables the oscillator to go on generating its own signal. The amount of signal that must be fed back into the input depends upon a number things, but it must always be strong enough to enable the oscillator to produce a signal that can overcome the losses in the oscillator circuit.

In addition to feeding enough energy from the output circuit back into the input circuit of the oscillator, the feedback signal must also be of the correct phase. This will enable the oscillator to produce a signal that will reinforce the signal in the oscillator output. If the feedback signal is not of the correct phase, it will oppose the signal in the output instead of aiding it, and the oscillator will stop oscillating.

## RESONANT CIRCUITS

LC oscillators are used to generate high-frequency signals. Perhaps the most important part of an LC oscillator is its resonant circuit. Before we start studying LC oscillators, let's briefly review resonant circuits and learn some more important facts about them.

### Damped Waves

If we connect a battery across a capacitor, the capacitor will charge to the battery voltage. If we disconnect the battery from the capacitor, the capacitor will remain charged until we provide a circuit through which it can discharge.

If we connect a coil across the charged capacitor, at the instant we connect the coil, the voltage across it will be equal to the capacitor voltage, but the current flow in the circuit will be zero as shown in Fig.1(A). Immediately after the coil is connected across the capacitor,

the capacitor will begin to discharge through the coil. The excess of electrons on side A of the capacitor will attempt to flow through the coil to get to side B. As a result, a current flow will be set up in the circuit, as shown in Fig.1(B).

Remember that a coil opposes a change in the current flowing through it. So the capacitor cannot discharge instantly through the coil, but rather must build up a current in the coil, which in turn builds up a magnetic field around the coil. Eventually, the capacitor will build up a current flow in the coil and enough electrons will leave plate A and get to plate B to discharge the capacitor.

The instant the capacitor is completely discharged, the current does not stop flowing. This is due to the inductance of the coil. Remember, inductance is the quality of a coil that opposes any change in the current flowing through it. The capacitor has built up a current flow in the coil in an effort to discharge.

The current flowing in the circuit not only discharges the capacitor, but continues flowing

# HOW OSCILLATORS WORK

2

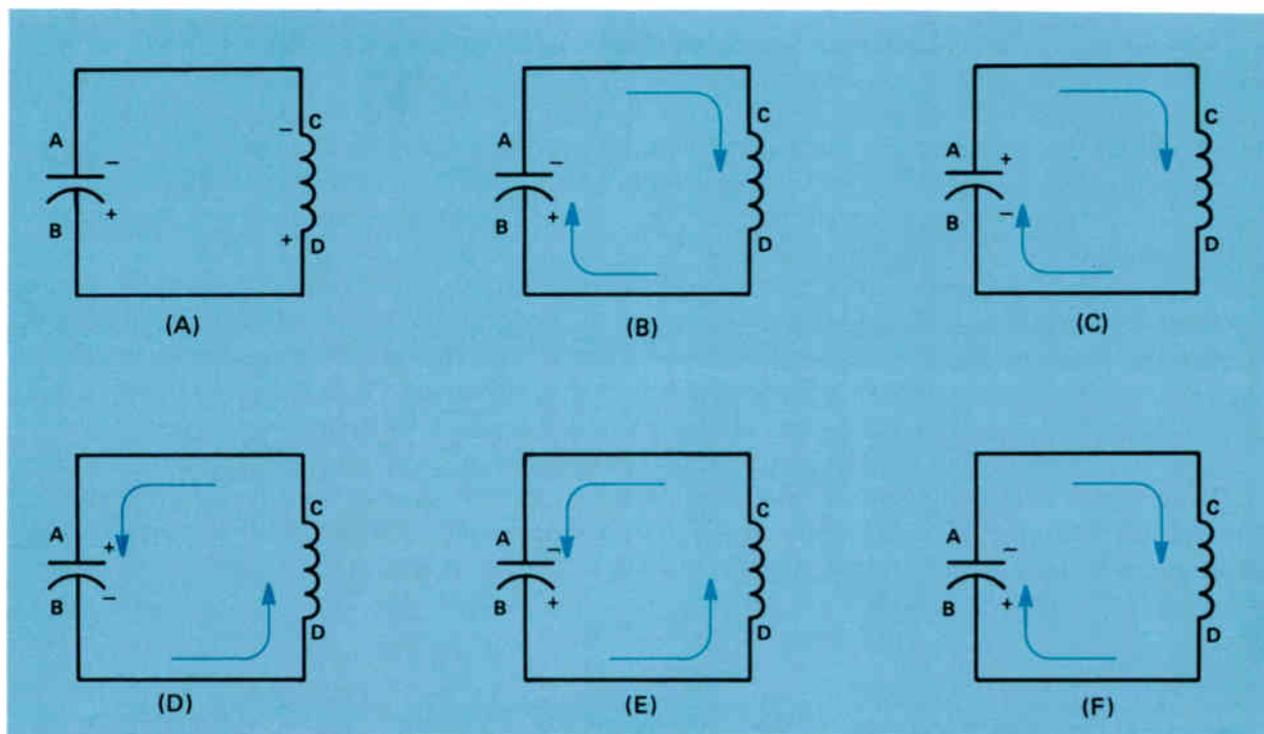


Figure 1. How oscillation takes place in a resonant circuit.

in the same direction, charging the capacitor with the opposite polarity, as shown in Fig.1(C). Here you see the current flowing through the coil in the same direction as it was in Fig.1(B). Now plate B of the capacitor is building up a surplus of electrons, and hence a negative charge. Electrons are being pulled out of plate A of the capacitor, which produces a shortage of electrons in this side of the capacitor, and hence a positive charge.

Of course, the charge that is being placed on the capacitor eventually builds up to a point where it can stop the current flowing through the coil. When the current flow through the coil drops to zero, the capacitor begins to discharge through the coil in the opposite direction as shown in Fig.1(D). Now electrons are leaving plate B of the capacitor and flowing through the coil in the opposite direction to get to plate A, which has a shortage of electrons.

Once again, when the capacitor is discharged, the coil current does not stop flowing instantly, so the capacitor is charged with the original polarity, as shown in Fig.1(E). Here we have electrons flowing out of plate B of the capacitor, resulting in a shortage of electrons on this plate, and into plate A, producing a surplus of electrons on this plate. Again, the current will eventually drop to zero and the capacitor will once again begin discharging through the coil in the opposite direction, this time with electrons flowing from plate A to plate B, as shown in Fig.1(F).

Notice that in Fig.1(F), we have the same situation as in Fig.1(B). In other words, we have gone through a complete cycle of events. The capacitor is charged with one polarity. This produces a current flow through the coil, which eventually charges the capacitor with the opposite polarity. The capacitor then begins to

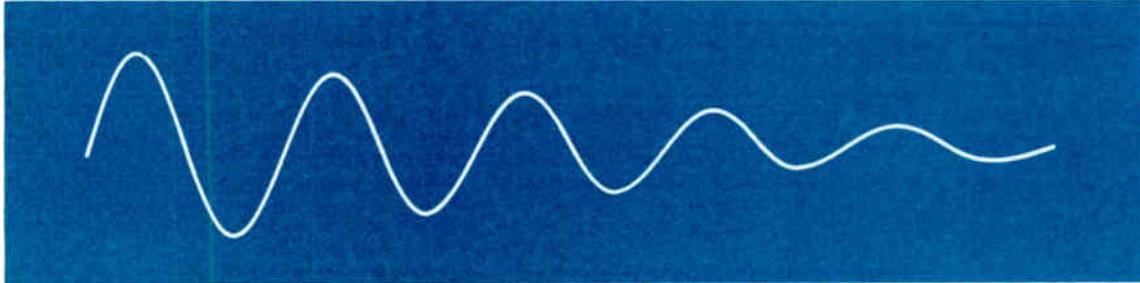


Figure 2. A damped wave.

discharge through the coil in the opposite direction, which builds up a charge on it having the same polarity as the original charge placed on the capacitor. This charge on the capacitor begins the cycle of events all over again by attempting to discharge through the coil.

If we had a perfect coil and a perfect capacitor, this oscillation or current flow back and forth would continue indefinitely once it started. But since there are losses both in the coil and in the capacitor, instead of a continuous oscillation, we would get a *damped wave*, which is sometimes called a *wave train*, as shown in Fig.2. The amplitude of each cycle of the wave is a little less than the amplitude of the preceding cycle. Eventually, due to the losses in the tank circuit, the oscillation will stop. But if we were able to momentarily connect the battery across the capacitor at the peak of each cycle, we could keep the oscillation going indefinitely. We do this electronically in an oscillator circuit.

### Factors Affecting Resonant Circuits

There are several other things we should know about resonant circuits. For example, we should know the frequency at which oscillation takes place. We should also know how many cycles there will be in a damped wave. We should also know what is meant by the *period* of a resonant circuit.

**Frequency.** We already know that resonance occurs when the inductive reactance of the coil is equal to and canceled by the capacitive reactance of the capacitor. Thus, at resonance:

$$X_L = X_C$$

We know that the inductive reactance of a coil  $X_L$  is given by the formula:

$$X_L = 6.28 \times f \times L$$

and the capacitive reactance of a capacitor is given by the formula:

$$X_C = \frac{1}{6.28 \times f \times C}$$

Now, since resonance occurs when  $X_L$  equals  $X_C$ , we have:

$$6.28 \times f \times L = \frac{1}{6.28 \times f \times C}$$

This can be manipulated to give us:

$$f^2 = \frac{1}{(6.28)^2 \times L \times C}$$

Now, if we take the square root of both sides of the equation we get:

$$f = \frac{1}{6.28 \times \sqrt{L \times C}}$$

# HOW OSCILLATORS WORK

4

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In this formula the times sign is usually omitted so you will usually see it written as:

$$f = \frac{1}{6.28 \sqrt{LC}}$$

It is a good idea to memorize this formula because it tells you a great deal about the frequency of a resonant circuit. The formula says that the frequency of a resonant circuit varies *inversely* as the square root of the LC product. When one factor varies inversely with the other, we have a situation where making one bigger makes the other smaller. This means that increasing the size of either L or C will reduce the frequency at which the resonant circuit oscillates, and reducing the size of either L or C will increase the frequency at which the resonant circuit oscillates. We can express this simply by saying: *larger L or C, lower frequency; smaller L or C, higher frequency.*

In using this formula, the frequency of oscillation will be given in hertz and the value of L and C used must be in henrys and farads, respectively.

When dealing with radio-frequency signals, the inductors used will be measured in microhenrys rather than in henrys and the capacitors in microfarads or picofarads. We can simplify the basic formula for the frequency of a resonant circuit to

$$f = \frac{159,000}{\sqrt{LC}}$$

This formula can be used to find the frequency of a resonant circuit with the inductances given in microhenrys and capacitances in microfarads.

**Period.** The period of a resonant circuit is the time it takes the resonant circuit to go through one complete oscillation. Thus, if we

have a circuit that is resonant at a frequency of 1000 hertz, its period would be 1/1000 of a second.

The period of a resonant circuit is given by the formula:

$$P = \frac{1}{f}$$

where P represents the period of a resonant circuit in seconds, and f is the frequency in hertz.

Since in electronics we are usually dealing with comparatively high frequencies, the period of most resonant circuits will be only a very small fraction of a second. As a matter of fact, the period of many resonant circuits will be only a small fraction of a microsecond.

To simplify things, the microsecond is used in electronics work as the unit of time. The microsecond, abbreviated  $\mu$ second or  $\mu$ s, is one millionth of a second. Thus, if a resonant circuit has a period of five millionths of a second, we would say it has a period of 5 microseconds, or 5  $\mu$ s.

**The Q Factor.** The number of cycles that will occur when the resonant circuit is shock-excited depends almost entirely upon the Q of the coil. The higher the Q, the more cycles that will occur.

The Q of a coil tells us how good a coil we have. A coil that has a high Q has a high inductive reactance compared to the resistance of the coil. A coil with a low Q has a high resistance compared with the inductive reactance. You will remember that the Q of a coil is expressed by the formula:

$$Q = \frac{X_L}{R}$$

If we examine this formula and remember that  $X_L$  varies directly as the frequency and the inductance, we see that Q will vary directly as

the frequency and the inductance. You might think that increasing the frequency of a resonant circuit by using a smaller capacitor in combination with a larger coil will result in a higher  $Q$ . This will often happen, but the increase in  $Q$  is not as great as might be expected because the resistance of the coil is determined by the ac resistance rather than the dc resistance. The ac resistance of a coil actually represent ac losses in the coil, which varies directly as the frequency varies. Increasing the frequency of a resonant circuit increases the inductive reactance of the coil, but at the same time it increases the losses, so that  $Q$  normally does not increase as fast as you might expect.

In a resonant circuit with a high- $Q$  coil, there will be a large number of cycles of a damped wave train set up by shock-exciting the reso-

nant circuit. In other words, the amplitude of one cycle will be almost equal to the amplitude of the preceding cycle. But if the  $Q$  of the coil is low, the losses in the coil will be high so that the amplitude of each cycle will be substantially less than the amplitude of the preceding cycle. This means that the oscillation will be damped out quite rapidly, and the number of cycles that will occur when the circuit is shock-excited will be limited.

In most oscillator circuits, a high- $Q$  coil is used. This means that only a small amount of energy must be supplied to the resonant circuit in order to sustain oscillation. On the other hand, if the coil has a low  $Q$ , the losses in the resonant circuit will be high, with the result that a large amount of energy must be supplied to keep the oscillation going.

### Summary

When a tank circuit is shock-excited, an oscillation will be built up in the tank circuit. The frequency of the oscillation will depend on the inductance of the coil and the capacity of the capacitor in the circuit. A resonant circuit with a high  $Q$  will have almost no losses, so very little energy must be supplied to the circuit to keep the oscillation going. On the other hand, a resonant circuit with a low- $Q$  coil will have high losses so that much more energy is required to keep the oscillation going. A wave train is a series of cycles from an oscillator. A damped wave train is a wave train in which the amplitude of each cycle is less than the amplitude of the preceding cycle. The period of a resonant circuit is the length of time it takes for one full cycle to occur.

### Self-Test Questions

*Please check your answers on page 25.*

- 1 When a capacitor in a tank circuit is charged, what will cause the current to continue flowing in the tank circuit after the capacitor has discharged?
- 2 Write the formula for the frequency of a resonant circuit with the inductance in microhenrys and the capacity in microfarads.
- 3 Write the formula for the period of a resonant circuit.
- 4 What is a high- $Q$  coil?

# HOW OSCILLATORS WORK

6

## LC OSCILLATORS

If a tank circuit such as shown in Fig.1 is shock-excited by momentarily connecting a battery across it, a damped wave such as shown in Fig.2 will be produced. The number of cycles in the wave train will depend upon the  $Q$  of the coil. The higher the  $Q$ , the more cycles we get.

If, instead of allowing the wave train to damp out as in Fig.2, once each cycle we supply a pulse that is timed to occur at the peak of the oscillation, as shown in Fig.3, we can reinforce the wave train and maintain the oscillation indefinitely.

In an oscillator circuit, this is exactly what we do. We use a transistor to supply a burst of energy at the correct time to make up for losses in the tank circuit so that the oscillation will continue.

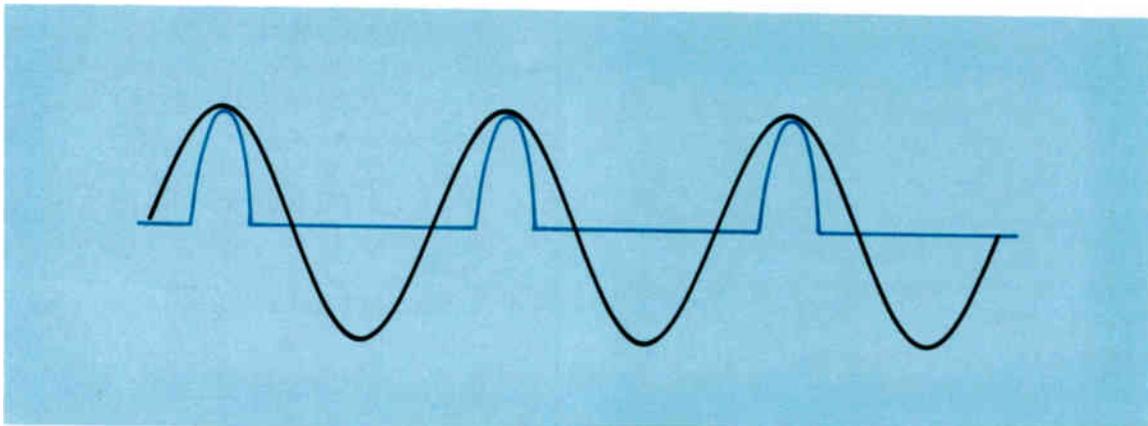
In an oscillator circuit some energy is fed from the output back into the input to make up for losses that occur in the circuit. We call the energy fed from the output back to the input *feedback*, and since it is timed to aid the oscillation, it is called *regenerative feedback*. There are two basic types of feedback used in oscillator circuits: inductive and capacitive. Let's look at inductive feedback first.

## Oscillators Using Inductive Feedback

One of the most important and widely used inductive feedback oscillators is the Hartley oscillator. It gets its name from the man who invented the circuit. The original Hartley oscillator circuit was developed for use with a vacuum tube, but an almost identical circuit, which bears the same name, is now used with transistors.

A typical Hartley oscillator is shown in Fig.4. Notice the oscillator coil  $L1$ . The entire coil is wound on a single form with a tap at terminal 2. Since the turns of the coil are on the same form and close together, the portion of the coil between terminals 1 and 2 is inductively coupled to the portion of the coil between terminals 2 and 3.

Resistor  $R2$  places a positive voltage on the base of  $Q1$  so that, when the oscillator is turned on, current will begin to flow through the transistor and through the part of the coil between terminals 1 and 2. The changing magnetic field produced by the current between terminals 1 and 2 of  $L1$  will set up the field that cuts the turns of the coil between terminals 2 and 3 and induces a voltage in this part of the coil. The voltage will have a polarity such that



**Figure 3.** The oscillator pulse is timed to occur at the peak of the oscillation in the tank circuit to reinforce the oscillation.

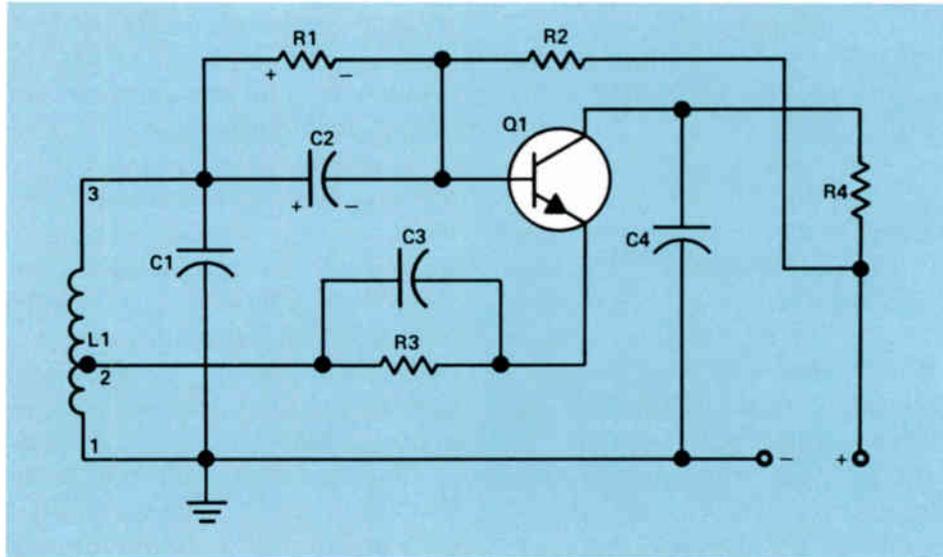


Figure 4. A typical Hartley oscillator.

terminal 3 of the coil is positive with respect to terminal 1. Thus capacitor C1 will be charged so that the plate connected to the R1/C2 junction of the coil will be positive and the other plate negative. The value of C2 is chosen so that its reactance is practically zero at the oscillation frequency; therefore, the base of the transistor is in effect connected directly to C1. Similarly, the positive voltage on the plate of C1 is in effect applied directly to the base of Q1. This causes the current through the transistor to increase still further, causing the positive potential of terminal 3 of the coil and on the plate of C1 to increase still more. This in turn makes the base of Q1 still more positive.

While the base of Q1 is positive, some of the electrons crossing the emitter-base junction will leave the transistor at the base and flow into C2, charging it with the polarity shown. As the base is driven further positive, the base current increases until eventually there is a substantial charge on C2.

Eventually a point is reached where the positive voltage on the top plate of C1 cannot cause any further increase in the transistor

collector current. When this happens, the current flowing through the coil between terminals 1 and 2 will no longer be changing; therefore, there will be no further voltage induced in the coil between terminals 2 and 3. When this happens, the voltage across the coil will begin to decrease and the capacitor C1 will begin to discharge. Now the negative voltage on C2 cuts off the transistor so there is no current flowing through it. C1 continues to discharge until it is completely discharged, but by this time there is a high current flowing in the tank circuit consisting of L1 and C1. This current doesn't drop to zero the instant C1 is discharged, but continues to flow to charge C1 with the opposite polarity. The current will eventually drop to zero, but C1 will be charged and now must discharge. In doing so, it will swing past the point where it is completely discharged and the upper plate will once again start to become positive. Eventually a point is reached where the positive voltage is great enough to overcome the negative voltage across C2. This will cause the transistor to start conducting and once again we get a burst of current through

# HOW OSCILLATORS WORK

8

the coil between terminals 1 and 2, which will once again make terminal 3 of the coil still more positive and cause a sharp burst of current through the transistor.

The transistor will conduct in bursts like this once every cycle. The burst of energy, supplied to the tank circuit by the transistor, is timed correctly to overcome the losses in the tank circuit, so the oscillation will continue indefinitely.

When the transistor is not conducting, C2 discharges through R1. This maintains a negative bias across the emitter-base junction. The sole purpose of R2 is to start the oscillator oscillating. When the oscillator is first turned on, R2 places a small positive voltage on the base of the transistor so that there will be a forward bias across the emitter-base junction. This causes the current to start flowing from ground, through the lower portion of the coil, through R3 to the emitter, and then across the emitter-base junction, where a few electrons leave the base, but the majority flow on to the collector. Once the oscillation starts, this resis-

tor is no longer necessary because the voltage built up across C1 is sufficient to drive the base positive, making the transistor conduct at the correct time during each cycle.

We mentioned earlier that the Hartley oscillator was originally developed for use with vacuum tubes. One of the big differences between a transistor and a vacuum tube is that a transistor is a low-impedance device, whereas a vacuum tube is a high-impedance device. Thus, sometimes the transistor may load the tank circuit so heavily that the losses become excessively high, and the Q is lowered so that the stability of the oscillator is affected. In some applications, you will find that the base of the transistor is connected to a tap on the oscillator coil as shown in Fig.5. The purpose of connecting the base to the tap is to reduce the loading effect of the transistor on the tuned circuit. The operation of this circuit is essentially the same as the circuit shown in Fig.4.

The problem of overloading the resonant circuit can be overcome by the field-effect transistor. A Hartley oscillator using a junction-

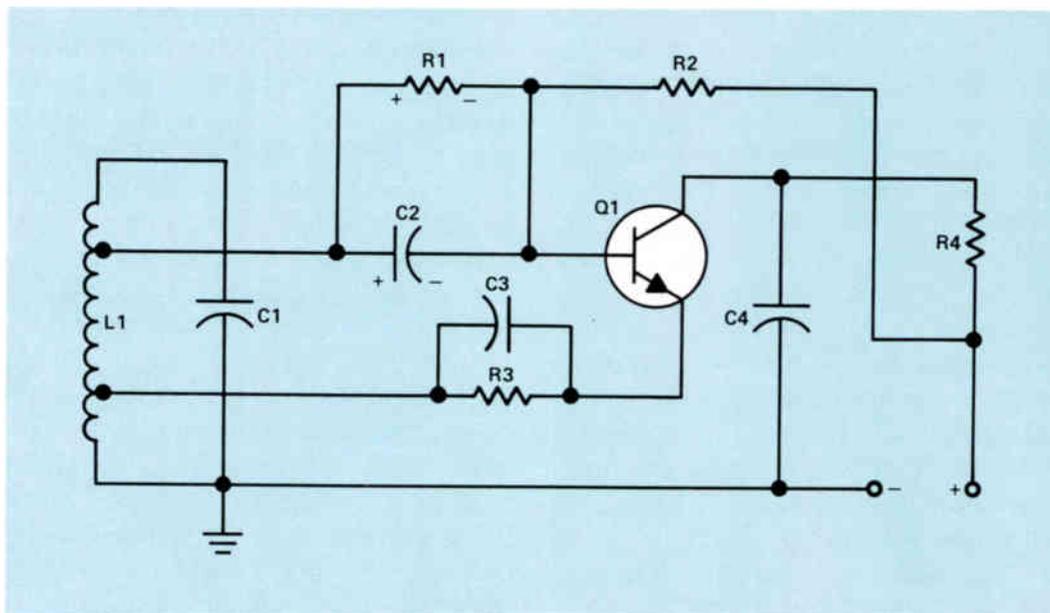
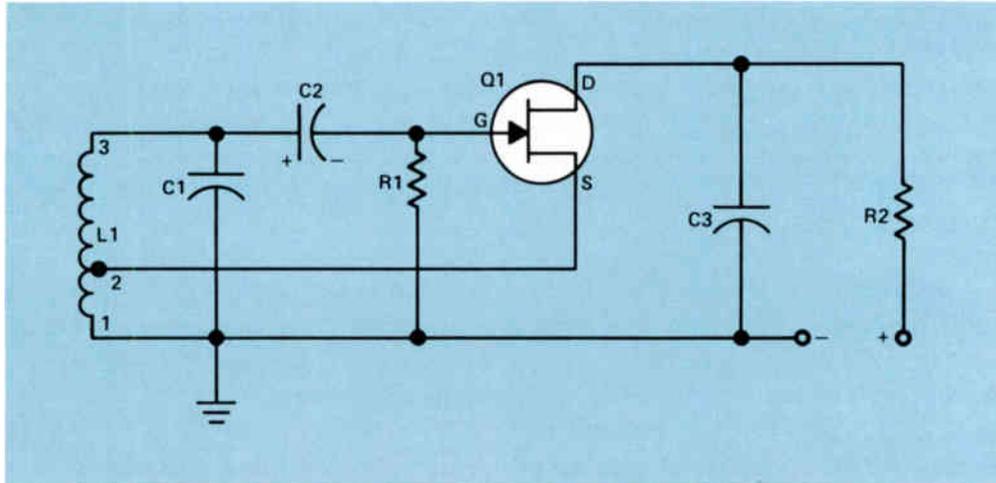


Figure 5. Connecting the base to a tap on the oscillator coil will reduce the loading effects of the transistor.



**Figure 6.** A Hartley oscillator using a junction-type, n-channel field-effect transistor.

type, n-channel field-effect transistor is shown in Fig.6.

When the equipment is first turned on, current begins to flow from the negative side of the power supply to terminal 1 of the oscillator coil L1, through the lower part of the coil to terminal 2, and then to the source of the transistor. It will flow through the n-channel to the drain and then through R2 back to the positive side of the power supply.

The current flowing through the lower portion of L1 will induce a voltage in the upper part such that terminal 3 of the coil will be positive with respect to terminal 1. The voltage across L1 will charge C1 so the grounded plate will be negative and the upper plate positive. C2 is a large-capacity capacitor, so it has a low reactance at the oscillator frequency; thus the positive pulse on the upper plate of C1 is fed through C2 to the gate of the transistor. This positive pulse has two effects. It attracts electrons across the gate junction and charges the capacitor C2 with the polarity shown. At the same time, it reduces the resistance of the channel, allowing a higher current to flow through the channel from the source to the drain.

The positive pulse fed to the gate of Q1 will appear for only a short portion of the cycle. When the positive pulse disappears, the negative voltage on C2 will be applied directly to the gate, and will cut off the flow of current through the channel of the transistor. Meanwhile, C2 will begin discharging through R1 and L1. The time constant of C2 and R1 is long enough so that C2 discharges very little before the next positive pulse comes along and recharges C2, at the same time it allows a burst of current to flow through the transistor. This burst of current supplies sufficient energy to the tank circuit to make up for any losses, and thus oscillation is maintained.

### Oscillators Using Capacitive Feedback

There are a number of different oscillator circuits that use capacitive feedback instead of inductive feedback to sustain oscillation. Let's look at some of them now.

**The Colpitts Oscillator.** The most important of the oscillators using capacitive feedback is the Colpitts oscillator shown in Fig.7. When the equipment is first turned on, current flows

# HOW OSCILLATORS WORK

10

through L2, which is a small rf choke used to complete the emitter circuit. R3 is used to place a small positive voltage on the base of the transistor, forward biasing it in order to start it conducting when the equipment is first turned on.

Current flowing through L2 develops a voltage drop across the coil which charges capacitor C2. The charge on the capacitor C2 will start an oscillation in the tank circuit, which consists of L1 and capacitors C1 and C2. Remember that when we have two capacitors connected in series they will act like one capacitor as far as the coil is concerned, and the circuit will start to oscillate. The voltage developed across C1 is the feedback voltage. It is applied between the base and emitter of the transistor.

When the voltage across C1 swings in a positive direction, it makes the end of C1 connected to C3 positive and the other end negative. This will increase the current flow through the transistor, causing an increase in current flow through L2, which charges C2 still further. This in turn causes the current flow through L1 to increase, charging C1 still further and driving the base of the transistor still further positive, building up the oscillation.

At the same time, the positive voltage applied to the base of the transistor through C3 causes base current to flow in the transistor. This charges C3 with the polarity shown. Eventually a point is reached where there is no further increase in current through the transistor. When this happens, C1 and C2 begin discharging and current begins flowing through L1 in the opposite direction. Meanwhile, the charge built up on C3 places a reverse bias across the emitter-base junction of the transistor so that it stops conducting.

The transistor will be cut off during the remainder of the cycle, and will remain cut off until the next cycle begins. When the voltage on C1 builds sufficiently in a positive direction to overcome the negative voltage across C3, the transistor will start conducting once again. When this happens, the burst of current through the transistor will build up a voltage across L2, which will recharge C1 and make up for any losses in the circuit.

Notice that during the entire half-cycle when the voltage across C1 has a negative polarity so that a negative voltage is fed to the transistor, the transistor will be cut off. Also, during a portion of the other half-cycle, when the

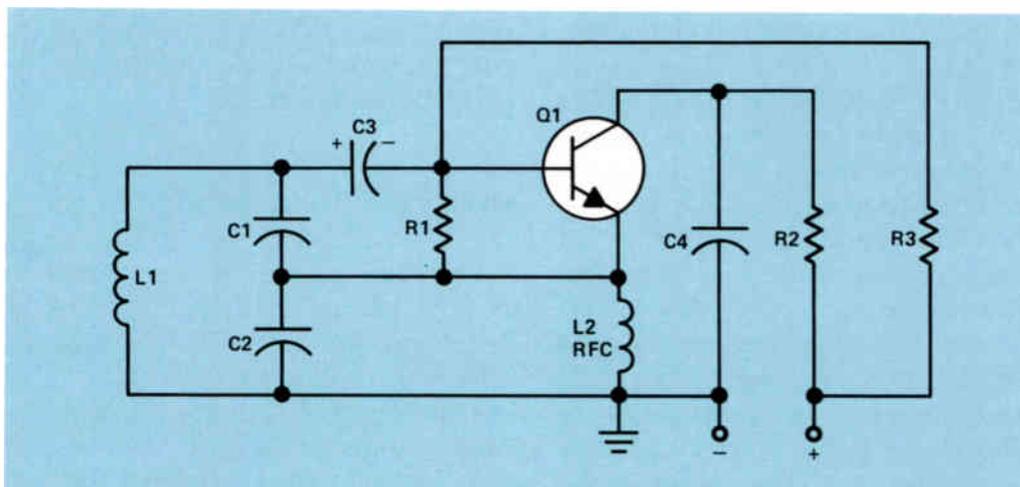


Figure 7. A Colpitts oscillator.

voltage on C1 is positive, the transistor will not conduct until the voltage is sufficiently high to overcome the negative bias voltage across C3. Thus the transistor is conducting for considerably less than one-half cycle. It is operating as a Class C amplifier. Current flows through it only during a small portion of each cycle. However, this burst of current supplies enough energy to the tank circuit to make up for any losses in the tank circuit so that the oscillation will continue.

The amount of feedback voltage supplied to the transistor depends upon the ratio of C1 to C2. If C1 is large compared to C2, the reactance of C1 will be low and the reactance of C2 will be high. Most of the voltage developed across the two capacitors will be developed across the higher reactance, which in this case is C2. This means that the feedback voltage applied to the input of the transistor will be low. However, if C1 is small compared to C2, the reactance of C1 will be high compared to the reactance of C2, and the feedback voltage applied to the input of the circuit will be high.

The ratio of C1 and C2 can be altered to provide the required feedback to the input

circuit to sustain oscillation. If the value of C1 is increased and the value of C2 decreased by the correct amount, the total capacitance in the circuit formed as a result of the two capacitors in series remains the same, and hence the resonant frequency of the oscillator does not change.

In some Colpitts oscillators, an additional capacitor is connected directly across L1. This is done to provide some convenient means of changing the resonant frequency so we can vary the frequency at which the oscillator operates. It isn't practical to try to vary both C1 and C2 at the same time and maintain the same voltage division across them. However, a separate capacitor placed across the coil can be varied, which will change the resonant frequency of the oscillator without changing the feedback. This is due to the fact that the values of C1 and C2 remain constant and they will still form a voltage divider. Part of the total voltage developed across the two capacitors in series will be fed back to the input of the circuit.

Again, resistor R3 in the circuit shown in Fig.7 is used to place a small starting bias

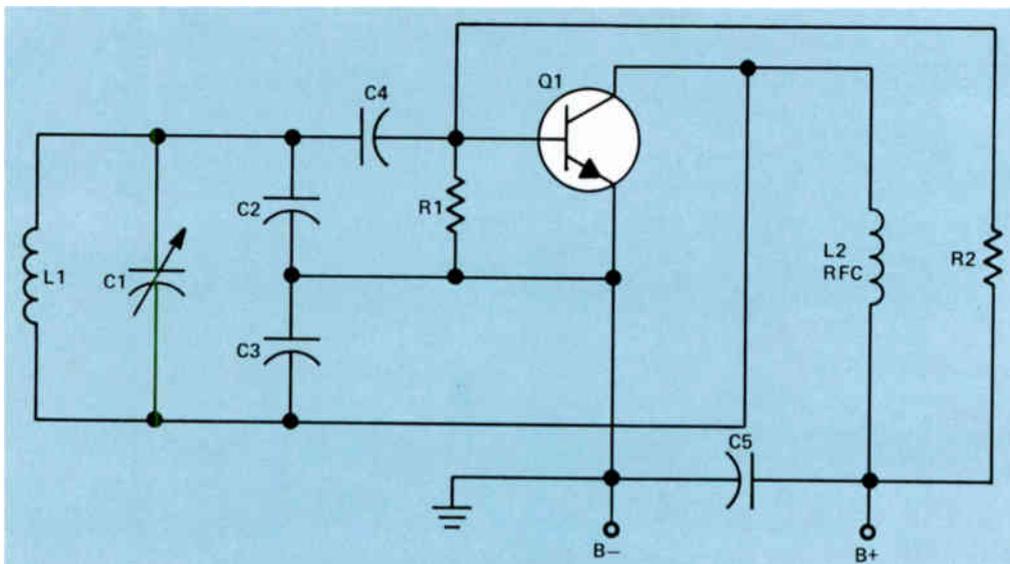


Figure 8. A variation of the Colpitts oscillator.

# HOW OSCILLATORS WORK

12

across the emitter-base junction of Q1 to get the current flow through the transistor started. Once the oscillation begins, R3 could be removed from the circuit and the oscillation would continue.

There are a number of variations of the Colpitts oscillator circuit. Any time you run into an oscillator where the feedback is controlled by a capacitive voltage divider, such as C1 and C2 in the circuit shown in Fig.7, you can be sure that it is some form of Colpitts oscillator. The Colpitts oscillator can be designed with excellent frequency stability. By this we mean that once the oscillator is adjusted to operate at a

certain frequency, it will not drift from that frequency very much. Some oscillators, on the other hand, do not have good frequency stability and will drift appreciably.

One variation of the Colpitts oscillator is shown in Fig.8. Here we have capacitor C1 connected across L1, in addition to the voltage divider capacitors C2 and C3. Notice that in the circuit, the collector of the transistor is fed back directly to L1, C1, and C3. The choke coil has been removed from the emitter circuit and the emitter is connected directly to ground.

In the circuit when current begins flowing through the transistor, there will be a voltage

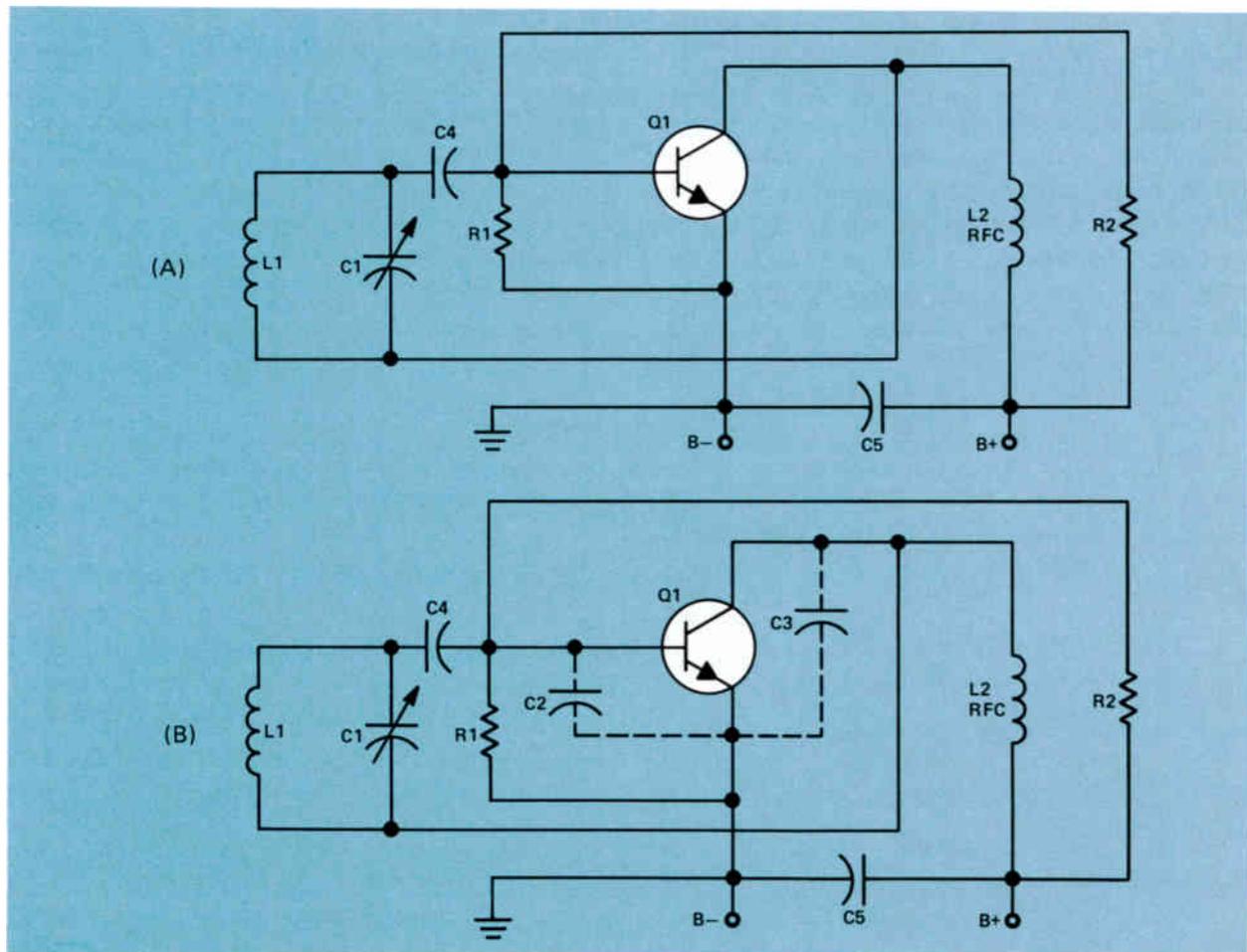


Figure 9. (A) The ultra-audion circuit. (B) The same circuit with internal transistor capacities added.

developed across the rf choke, L2, and this voltage will charge C3. Once the capacitor is charged, oscillation starts in the circuit just as in the Colpitts oscillator shown in Fig.7.

**The Ultra-Audion Oscillator.** A modified form of the Colpitts oscillator that is frequently used in the vhf region is shown in Fig.9. This circuit is called the ultra-audion oscillator. When the circuit was first developed, it was thought to be a new type of oscillator. However, careful analysis shows that it is really a Colpitts oscillator similar to the one shown in Fig.8.

Figure 9(A) is the schematic diagram of an ultra-audion oscillator and Fig.9(B) shows the ultra-audion oscillator with the transistor capacitances, drawn in dashed lines, that exist between the collector and emitter, and between

the base and emitter. We have used the same designations to identify the parts in the circuit shown in Fig.8 and Fig.9(A) so that you can see the similarity between the two circuits. The capacitors represented by the dashed line connections in Fig.9(B) are the internal capacities of the transistor which are not added into the circuit as external parts. However, in the vhf region, these capacitances are large enough to take the place of the actual capacitors used in the low-frequency oscillator shown in Fig.8. You should learn to recognize this circuit as a form of the Colpitts oscillator because it is widely used at high frequencies. Of course, manufacturers do not draw the internal transistor capacitors on schematic diagrams, so the circuit looks like Fig.9(A) rather than Fig.9(B).

### Summary

An oscillator is a circuit used to develop an ac signal. It takes dc from the power supply and changes it into ac.

There are two basic types of LC oscillators, one uses inductive feedback and the other uses capacitive feedback. In both types current flows through the transistor in bursts that last for less than one-half cycle so they are in effect Class C amplifiers. In the Colpitt's oscillator the amount of feedback can be varied by varying the size of the voltage divider capacitors across the tank coil.

Both types are self regulating: the energy supplied to the tank circuit makes up for losses in the tank circuit.

The ultra-audion oscillator is a modified Colpitts oscillator. In this circuit, the external voltage-divider capacitors connected across the coil are omitted. These are not needed because in the vhf region where the circuit is used the capacity between the collector and emitter takes the place of one capacitor and the capacity between the base and the emitter of the transistor replaces the other capacitor.

### Self-Test Questions

- 5 What do we mean when we refer to an oscillator as a "self-regulating oscillator?"
- 6 What two types of feedback are used in LC oscillators?
- 7 What type of feedback is used in the Hartley oscillator?
- 8 What type of feedback is used in the Colpitts oscillator?
- 9 What type of oscillator is the ultra-audion oscillator?

# HOW OSCILLATORS WORK

14

## CRYSTAL OSCILLATORS

The oscillator in a radio or TV broadcast station, the color oscillator in a TV receiver, various oscillators in video cassette recorders, and other oscillators in critical applications must be held to a very close frequency tolerance. LC oscillators can be designed with very good frequency stability but their frequency stability is not good enough for many applications. Usually, crystal oscillators are used in applications where the frequency must be held to a very close tolerance. In this section of the lesson, you will study crystal oscillator circuits and learn how they work.

### The Piezoelectric Effect

The operation of a crystal oscillator depends on a peculiar effect shown by quartz crystals that is known as the *piezoelectric effect*. Because of this effect, a crystal that has been suitably cut from a piece of quartz and placed in a suitable holder can be substituted in place of an LC resonant circuit. Now let's see what the piezoelectric effect is and how the crystal oscillator works.

In its natural state, a quartz crystal has a hexagonal cross section and pointed ends like the one shown in Fig.10. An imaginary line drawn between the two apexes is called the Z axis. The axis is shown in Fig.10. There are two other sets of axes labeled the X axis and the Y axis. Notice that there are three X axes and three Y axes. Both the X axes and the Y axes are perpendicular to the Z axis. The X axes pass through the corner of the crystal, whereas the Y axes are perpendicular to the face of the crystal.

Small pieces of crystal, usually about  $\frac{1}{2}$ " square and of varying thicknesses, can be cut from a natural quartz crystal. If the crystal is cut perpendicular to the Y axis, it is called a Y-cut crystal, and if it is cut perpendicular to the

X axis, it is called an X-cut crystal. These are shown shaded in Fig.10.

X-cut crystals have been widely used in crystal oscillators, but other cuts are also used. Two of these are the AT cut and the BT cut, both of which are cut perpendicular to the Y axis, but at an angle to the Z axis.

It is the peculiar property of a crystal that if an electric stress is applied in the direction of the X axis, a mechanical stress is produced in the direction of the Y axis, and if a mechanical stress is placed along the Y axis, it will cause an electrical stress on the X axis. The electrical stress produced by mechanical force is termed the *piezoelectric effect*.

For use in crystal oscillators, crystals are cut into small squares of varying thicknesses. The

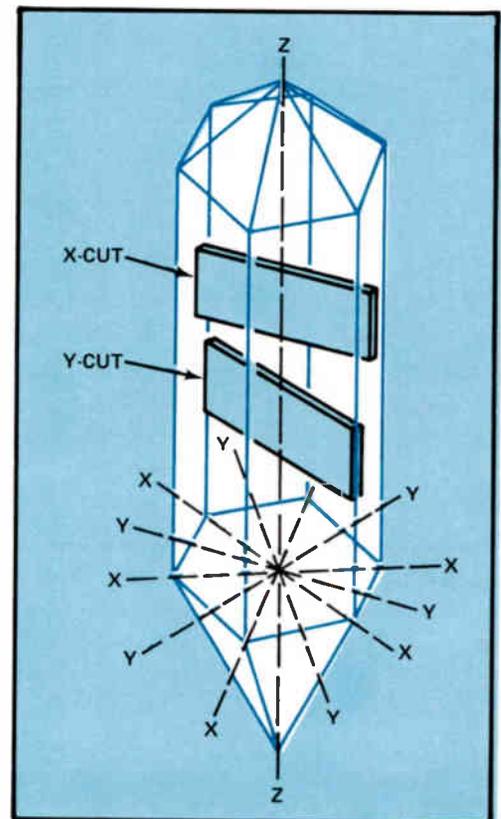


Figure 10. Major axes in a quartz crystal.

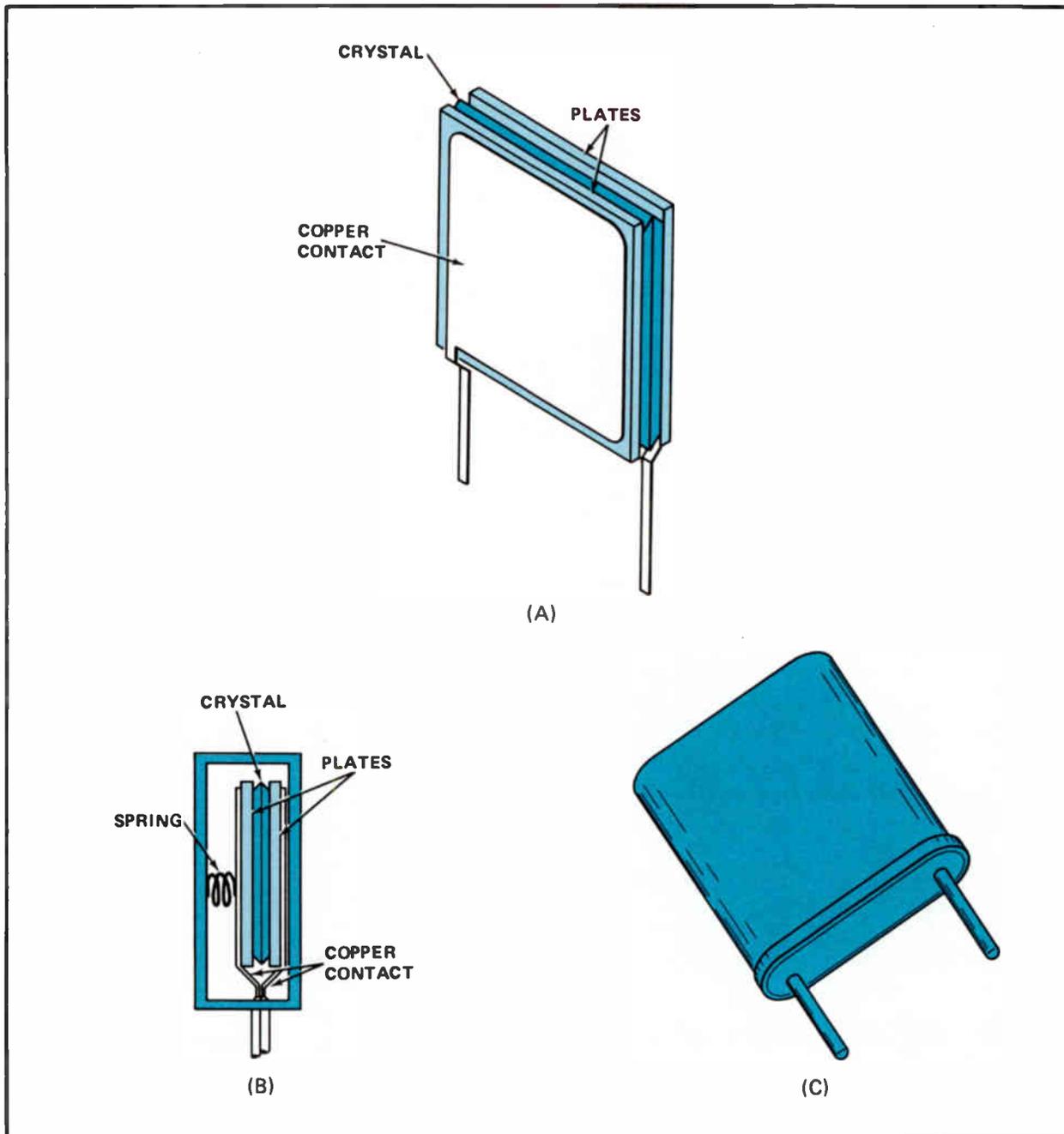


Figure 11. A crystal and its holder.

crystal is then mounted between two metal plates which will make contact with the two large surfaces of the crystal. The plates are usually held in contact at the surface by

springs. The entire assembly is put in a container and hermetically sealed to prevent changes in humidity from affecting the frequency of the crystal. A drawing of the crystal is shown in

Fig.11(A), and the side view of the crystal is shown in Fig.11(B). The complete crystal inside of the hermetically sealed holder is shown in Fig.11(C).

When an ac voltage is applied between the plates and across the quartz crystal, the crystal can be made to vibrate. When a crystal is ground to the proper thickness so that mechanical resonance exists at the frequency of the ac voltage, the amplitude of the vibrations will be quite large.

The equivalent electrical circuit of the crystal is shown in Fig.12. C1 represents the capacitance formed by the plates. The crystal itself is represented by L1, C2, and R1. The crystal may be operated as either a series- or a parallel-resonant circuit. When operated as a series-resonant circuit, the resonant frequency of the circuit is then determined only by L1 and C2. The impedance of the crystal will be lowest at the series-resonant frequency. When operated as a parallel-resonant circuit, the combination of L1 and C2 has the net effect of an inductance because the inductive reactance of L1 is much larger than the capacitive reactance of C2. The resonant frequency of a parallel circuit is determined by C1 and the net inductance of the series combination of L1 and C2. The imped-

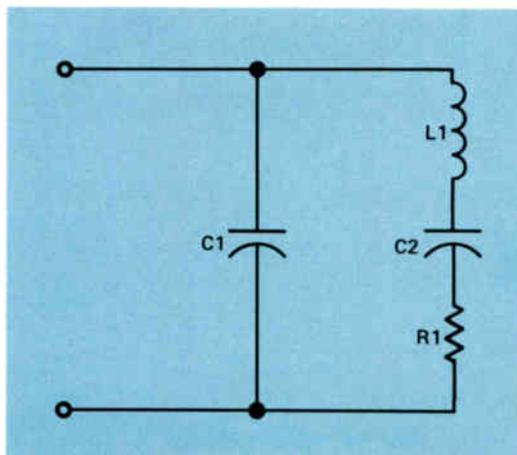


Figure 12. The equivalent electrical circuit of a crystal and its holder.

ance of the crystal is highest at the parallel-resonant frequency. In a parallel-resonant configuration, the resonant frequency of the circuit is determined by both the crystal and the externally connected circuit components. Crystals are manufactured for use either as a series-resonant or a parallel-resonant circuit. A crystal that has been manufactured for a series-resonant application normally cannot be used in parallel-resonant applications.

## Simple Crystal Oscillators

To help see how a crystal oscillator works, look at the LC oscillator shown in Fig.13. This oscillator is called a tuned-base, tuned-collector oscillator. It is easy to see where it gets its name, since there are resonant circuits in both the base and the collector circuits.

The oscillator works because of the transistor's collector-base capacitance between the output circuit and the input circuit. When a resonant circuit in the output is tuned to a frequency slightly lower than the operating frequency, it will act like an inductance. Under these conditions, the phase of the signal that is fed from the output back to the input is correct to aid the voltage in the input tank circuit consisting of L1 and C1, and thus oscillation occurs.

The crystal oscillator shown in Fig.14 is a simple modification of the oscillator shown in Fig.13. Here the crystal has been substituted for the resonant circuit in the input circuit of the oscillator. The crystal acting as a parallel-resonant circuit is the equivalent of the circuit that has been removed. Therefore, the crystal oscillator operates in exactly the same way as the oscillator shown in Fig.13. The crystal oscillator has the advantage of excellent stability over the LC oscillator. The stability of the oscillator can be further improved by keeping the temperature of the crystal constant at all times. In

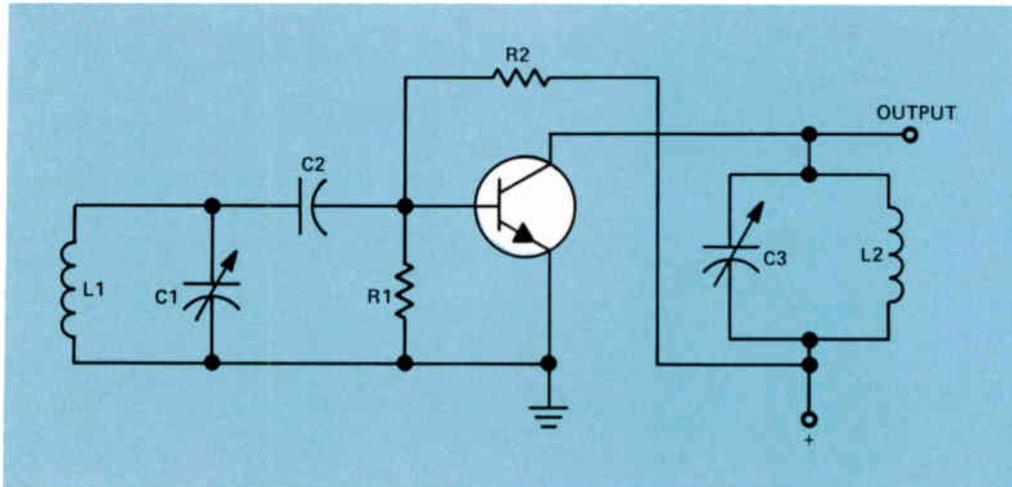


Figure 13. A tuned-base, tuned-collector oscillator.

broadcast transmitters, the crystal is placed inside an oven that is kept at a constant temperature.

Another example of a crystal oscillator is shown in Fig.15. In this application, the crystal is used as a series-resonant circuit; it is in the path between the collector circuit of the transistor and the base. The crystal provides a low

impedance at the resonant frequency so that energy at this frequency is readily fed through the crystal from the collector and back to the base. At frequencies above and below the frequency of the crystal, the impedance of the crystal increases so that energy cannot be fed back at these frequencies. Thus the crystal basically controls the frequency at which the

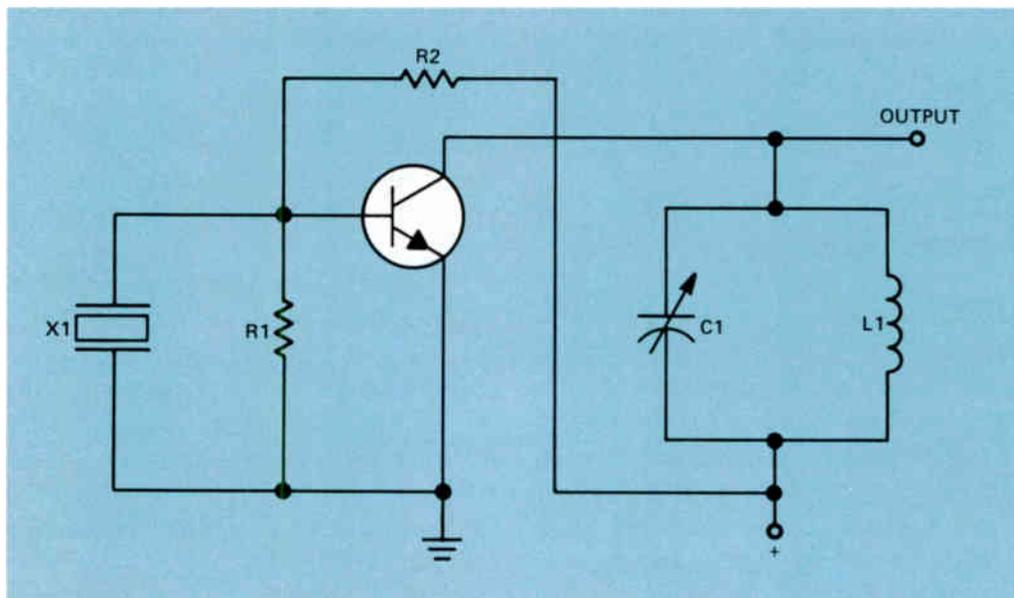


Figure 14. A simple crystal oscillator.

# HOW OSCILLATORS WORK

18

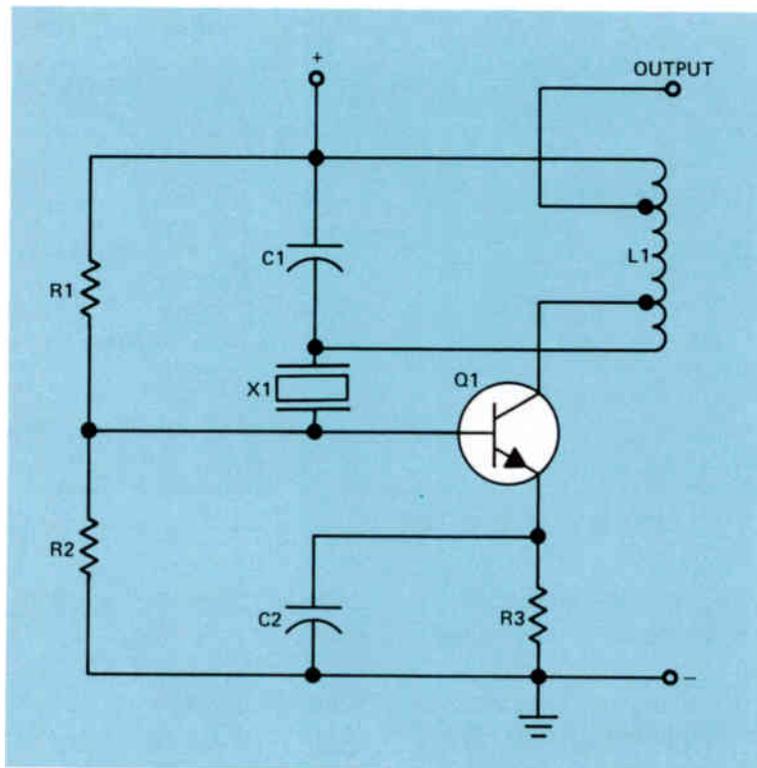


Figure 15. Transistor crystal-controlled oscillator using a series-resonant crystal.

oscillator operates. You will find crystal oscillators used in both parallel applications, as shown in Fig.14, and series applications, as shown in Fig.15.

## Problems in Servicing Crystal Oscillators

Crystal oscillators present some special servicing problems. Sometimes the crystal simply won't oscillate. Most of the crystals you are likely to encounter will be hermetically sealed units; and if the crystal fails to oscillate, there is nothing you can do but replace it, providing everything in the circuit checks satisfactorily. If the crystal is the type that can be dismantled, sometimes you can dismantle it and inspect the crystal to find the trouble. You may find that

there is a corner chipped or the crystal has been cracked. In either case the crystal should be replaced.

But often there is no apparent defect. This is one of the peculiarities of crystals; sometimes they simply fail to oscillate. Usually when you encounter this, the only thing you can do is replace the crystal.

Sometimes the operation of the crystal becomes erratic. When the power is applied to the oscillator, it may start oscillating one time and another time it will not oscillate. This may be due to dirt in the crystal or to a cracked crystal. Again, in the case of a hermetically sealed unit, which is the type you will encounter most frequently, there is nothing you can do with the unit but replace it.

Another problem often encountered with crystals is that the frequency at which they

oscillate becomes erratic. You may turn on the crystal-controlled oscillator and find that it is operating at some frequency other than the frequency for which it has been ground. The

next time you turn on the equipment, it might oscillate at the correct frequency. When you encounter this problem in the crystal, the only thing you can do is discard it.

### Summary

Crystal oscillators are used in applications where better frequency stability is needed than can be obtained with an LC oscillator. The frequency of crystal oscillators is controlled by a quartz crystal that has been cut to the thickness that provides the required operating frequency. There are three major axes of a quartz crystal: the Z axis, the X axis, and the Y axis. An effect known as the piezoelectric effect makes the use of crystals possible in a resonant circuit. This is the electrical stress produced in the crystal along one axis when a mechanical stress is placed along another axis.

Crystals can be used both as parallel-resonant circuits or as series-resonant circuits. Crystals made for use in parallel-resonant circuits have a high impedance, whereas crystals used in series-resonant applications have a low impedance. Usually a crystal cut for one mode of operation cannot be used in the other.

### Self-Test Questions

- 10 What are the three major axes of a quartz crystal?
- 11 What is the piezoelectric effect?
- 12 What two types of circuits may a crystal form?
- 13 What is the chief advantage of a crystal oscillator over an LC oscillator?
- 14 If a hermetically sealed crystal starts oscillating sometimes when the equipment is turned on, but fails to oscillate at other times, how is the problem remedied?

## RC COUPLED OSCILLATORS

The oscillators that we have studied so far have been LC oscillators. Now we will study RC oscillators, so called because they use resistance and capacitance.

The most common RC oscillator is the multivibrator. It is a two-stage oscillator. During the first half-cycle, one stage is turned full on — it is passing maximum current. The other stage is cut off. During the other half-cycle, the status of the two stages reverses. The stage that was cut off goes into maximum conduction and the stage that was conducting during the first half-cycle is now cut off.

You have already studied the multivibrator known as a flip-flop. The flip-flop is a *bistable* multivibrator. Bistable means it has two stable states. It rests in one of the states until it receives a trigger pulse. When triggered, the flip-flop changes state and remains in the new condition until triggered again.

Another type of multivibrator is the *monostable* multivibrator. This multivibrator has one stable state. When it receives a trigger pulse, it generates a single output pulse. One output pulse is produced for each trigger pulse. Upon receiving a trigger input, it switches to the semi-stable state for a fixed period of time and then returns to its stable condition to wait for another trigger pulse.

A third type of multivibrator is the *astable*, or free-running, multivibrator. This type of multivibrator is also an oscillator; once it starts running, it continues to run. In this section of the lesson, we are going to deal with the free-running multivibrator.

### A Collector-Coupled Multivibrator

A schematic diagram of a collector-coupled multivibrator is shown in Fig.16. The multivi-

brator gets its name from the fact that the output signal from Q1 is coupled from the collector through C1 to the base of Q2, and the output from Q2 is coupled from the collector to the base of Q1 through C2.

In the circuit shown in Fig.16, one of the transistors will start conducting first or slightly faster than the other. Let's assume that Q1 starts conducting first. As the current through Q1 increases, the voltage drop across R1 will increase. This will cause the voltage at the collector of Q1 to swing in a negative direction. Electrons will flow through the transistor Q1 to the one plate of C1, charging it with the polarity shown. At the same time, electrons leave the positive plate and flow through R3 back to B+. In flowing through R3 they set up a voltage drop across the resistor having a polarity such that the base end is negative. The negative voltage across R3 drives the base of the transistor Q2 negative with respect to the emitter of Q2 so Q2 will be cut off. The transistor will be cut off as long as C1 is charging through R3. It will be developing a voltage across R3 great enough to overcome the forward bias that the power supply is applying through R3 to the base of the transistor.

Eventually C1 will be charged and the current flow from it through R3 will stop. Now the power supply voltage is fed through R3 to the base of Q2, turning this transistor on. When this happens, current will begin to flow through Q2 and R4, causing the voltage on the collector of Q2 to drop. Now C2 will charge with the polarity shown, causing electrons to leave the positive plate of C2 and flow through R2. This will develop a voltage drop across this resistor having a polarity such that the base end is negative. This will completely cut off Q1. Once Q1 is cut off, there will be no current flow through R1 and no voltage drop across it.

Meanwhile, the positive plate of C1 is connected to the base of Q2. With Q2 conducting, the resistance between the emitter and base is

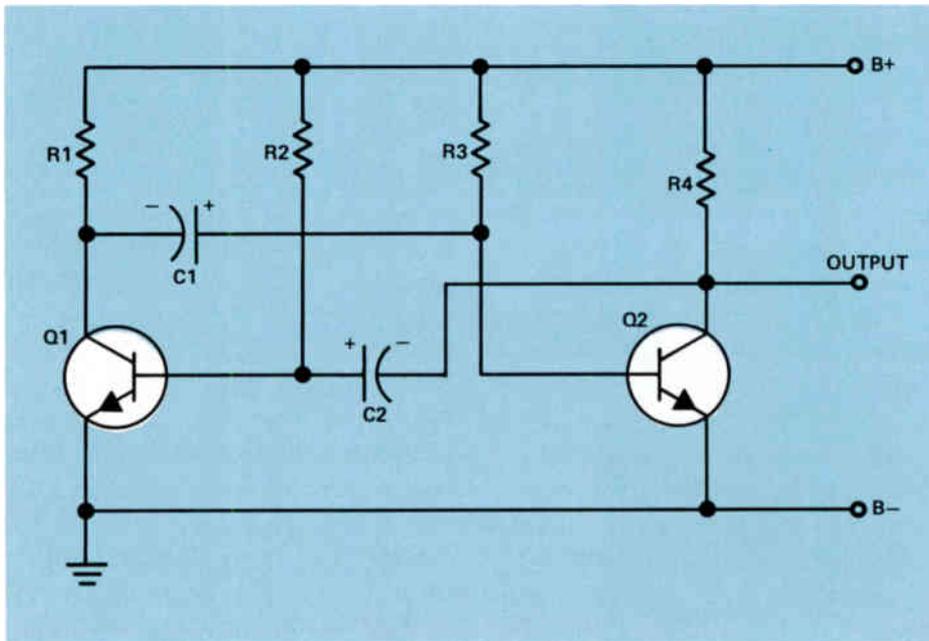


Figure 16. A collector-coupled multivibrator.

low so that C1, which is charged with the polarity shown, is connected directly from B- to B+. The capacitor must discharge and charge with the opposite polarity. Electrons will flow from B- to the emitter of Q2 across the emitter-base junction, out of the base, into the plate of C1 marked with a + sign and out of the plate marked with a - sign through R1 to B+. Since practically all of the electrons flowing to the base of Q2 are being used to charge C1, there will be little or no voltage drop across R3. Thus the potential on the base of Q2 will attempt to swing highly positive, driving this transistor into saturation. The transistor remains in this condition until C2 is completely charged, at which time Q1 will begin conducting again.

When this happens, the voltage at the collector of Q1 drops, and C1 begins discharging and charging with the polarity shown. To do this, electrons will flow out of the positive plate of C1 through R3, developing a potential such that

the base end of R3 is negative. This will cut off Q2 and cause the collector voltage to rise to the B+ value. Now C2 must discharge and charge with the opposite polarity; in doing so, it will tend to pull the base of Q1 highly positive, causing Q1 to saturate almost instantly. This action of first one transistor conducting and then the other, will go on indefinitely. Thus the multivibrator is free-running.

Transistors are particularly well-suited for this type of application because they can be switched from saturation, or maximum current condition, to cutoff very rapidly. In many applications, this rapid change from one state to the other is desirable.

### An Emitter-Coupled Multivibrator

Another widely used multivibrator is the emitter-coupled multivibrator. A schematic diagram of this type of multivibrator is shown in

# HOW OSCILLATORS WORK

Fig.17. The operation of this multivibrator is somewhat different from the operation of the collector-coupled multivibrator.

Resistors R1 and R2 place a forward bias across the emitter-base junction of Q1 and resistors R4 and R5 place a forward bias across the emitter-base junction of Q2. When the equipment is first turned on and both transistors start to conduct, the capacitor C1 must charge. To charge the capacitor, electrons will flow from ground through R5, R7, and the emitter-base circuit of Q2, into one plate of C1 and out of the other, and then through R3 to B+. The electrons flowing through R5 set up a voltage drop across this resistor having a polarity such that the base end of the resistor is positive. This causes Q2 to conduct heavily and develop a voltage drop across R7 such that the emitter end is positive. This positive voltage will overcome the forward bias on Q1 and cut Q1 off. Once this happens, there will be no current flow through R3 from Q1 so that C1 must charge to almost the full supply voltage. This causes additional electrons to flow

through R5 in parallel with R7 and the emitter-base circuit Q2. Q2 goes into saturation, creating a high positive voltage across R7.

As long as C1 is charging, Q2 will be conducting heavily. But as soon as C1 is charged, the bias across the emitter-base junction of Q2 will drop, causing the current flow through the transistor to drop. When this happens, the voltage across R7 will drop and Q1 will begin to conduct. Once Q1 starts to conduct, there will be a voltage drop across R3, and C1 must discharge. When C1 discharges, electrons will flow through R4, developing a voltage across this resistor with a polarity such that the base end is negative. This will cut off Q2 so that current flow through R7 from Q2 will drop to zero. When this happens, the forward bias across the emitter-base junction of Q1 will increase, causing it to conduct more heavily. The voltage drop across R3 will increase, causing C1 to discharge further. Eventually a point is reached where C1 is discharged, the negative voltage on the base of Q2 due to the voltage drop on R4 will disappear and Q2 will start

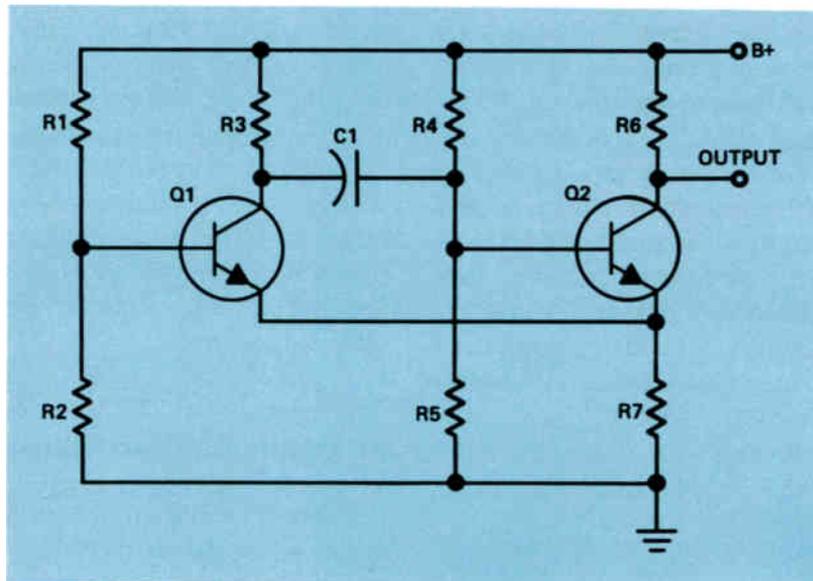


Figure 17. An emitter-coupled multivibrator.

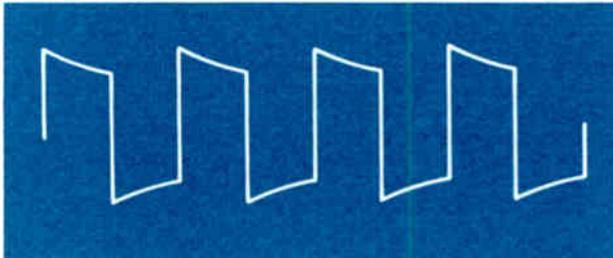


Figure 18. Output from a symmetrical multivibrator.

across  $R_7$  which will cut off  $Q_1$ , and  $C_1$  will once again charge through  $R_5$  and  $R_3$ , driving  $Q_2$  into saturation. This oscillation of first  $Q_1$  and then  $Q_2$  conducting will continue indefinitely.

### Multivibrator Output Signals

Multivibrators are called *symmetrical multivibrators* when each transistor conducts for the same length of time. In the circuit shown in Fig.16, this is what happens if  $C_1$  is equal to  $C_2$  and  $R_2$  is equal to  $R_3$ . Under these conditions,  $Q_1$  will conduct for a certain period of time and then be cut off.  $Q_2$  will conduct for an equal period of time while  $Q_1$  is cut off. Under these circumstances, the output from the multivibrator will resemble a waveform shown in Fig.18.

In the circuit shown in Fig.16,  $C_2$  discharging through  $R_2$  keeps  $Q_1$  cut off for a certain period. Similarly,  $C_1$  discharging through  $R_3$  keeps  $Q_2$  cut off. As long as the time constant of  $C_2$  and  $R_2$  is equal to the time constant of  $C_1$  and  $R_3$ , the output from the multivibrator will be symmetrical. However, by changing the time constants of these two networks we can obtain an asymmetrical output as shown in Fig.19. In the circuit shown in Fig.16, if  $Q_2$  conducts longer than  $Q_1$ , we'll have an output like the one shown in Fig.19(A). On the other hand, if  $Q_1$  conducts longer than  $Q_2$ , we can get an output as shown in Fig.19(B).

The value of the RC network used in coupling the transistors in Fig.16 will not only determine the waveshape of the output of the circuit; it will also affect the frequency at which the oscillator operates. For example, if the time constant of  $C_1$  and  $R_3$  or the time constant of  $C_2$  and  $R_2$  is decreased, the frequency at which the oscillator operates will increase. Similarly, if the time constant of the network is increased, the frequency at which the oscillator will operate is decreased. This type of multivibrator can be made to operate over a wide range of frequencies by selecting the time constant of the RC coupled networks.

In the multivibrator shown in Fig.17,  $Q_2$  conducts when  $C_1$  is charging and  $Q_1$  conducts when it is discharging. The charging path for  $C_1$  is through  $R_5$  in parallel with  $R_7$  and the emitter-base junction of  $Q_2$  and  $R_3$ . The resistance of  $R_5$  in parallel with  $R_7$  and the emitter-base junction of  $Q_2$  is so low when compared to the resistance of  $R_3$  that it can be ignored. Therefore, the time constant of the charging network is primarily the time constant of  $C_1$  and  $R_3$ .

$C_1$  discharges through  $R_7$ ,  $Q_1$ , and  $R_4$ . The resistance of  $R_7$  in series with  $Q_1$  is so low

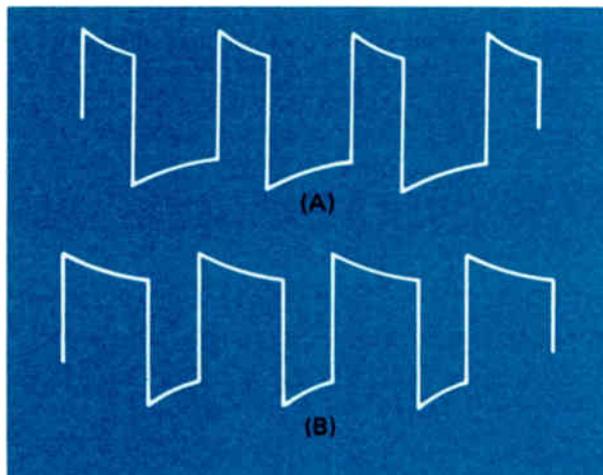


Figure 19. Output from an asymmetrical multivibrator with (A) having a shorter pulse width than (B).

# HOW OSCILLATORS WORK

when compared to the resistance of R4, they can be ignored. Therefore the discharge time is primarily the time constant of C1 and R4. Thus, if we make R3 equal to R4, the output from the multivibrator will be symmetrical.

But in most cases R4 is much larger than R3. This means that the discharge time of C1 will be much longer than the charge time. Therefore, Q2 will be cut off for a period greater than the

time it is conducting, and the output will be like Fig.19(B).

Again, the time constant of C1 and R3 and the time constant of C1 and R4 determine the frequency at which the multivibrator operates. To increase the frequency of the multivibrator operation, we can decrease the value of C1. To decrease the multivibrator frequency, we can increase the capacity of C1.

## Summary

The most common RC oscillator is the multivibrator. There are three types of multivibrators. The *monostable* multivibrator has one stable state. The *bistable* multivibrator, often called a flip-flop, has two stable states. The *astable* multivibrator is a free-running multivibrator.

There are two basic types of astable multivibrators, the collector-coupled multivibrator and the emitter-coupled multivibrator. The shape of the output signal and the frequency at which the multivibrator operates can be controlled by controlling the RC time constant of the coupling networks.

## Self-Test Questions

- 15 Which components primarily determine the frequency at which the multivibrator shown in Fig.16 operates?
- 16 If C1 equals C2 and R2 equals R3 in the circuit shown in Fig.16, will the output from the multivibrator be symmetrical or asymmetrical?
- 17 In the circuit shown in Fig.16, if the value of C2 and R2 is decreased, how will the frequency of the multivibrator be affected?
- 18 In the circuit shown in Fig.17, if R3 is equal to R4, will the output be symmetrical or asymmetrical?
- 19 What is a bistable multivibrator?
- 20 What is a monostable multivibrator?

## ANSWERS TO SELF-TEST QUESTIONS

- 1 The inductance of the coil causes the current to continue flowing after the capacitor has discharged. Inductance is the quality of a coil that opposes any change in the current flowing through it.
- 2  $f = \frac{159,000}{\sqrt{LC}}$
- 3  $P = \frac{1}{f}$
- 4 A high-Q coil is a coil in which the ratio of the inductive reactance of the coil to the resistance of the coil is high.
- 5 When we say that an oscillator is self-regulating, we mean that the energy supplied to the tank circuit is just what is needed to make up for losses in the tank circuit.
- 6 Inductive feedback and capacitive feedback.
- 7 The Hartley oscillator uses inductive feedback.
- 8 The Colpitts oscillator uses capacitive feedback.
- 9 The ultra-audion is a form of the Colpitts oscillator that is used at very high frequencies.
- 10 The three major axes of a quartz crystal are the X axis, the Y axis, and the Z axis.
- 11 The piezoelectric effect is the peculiar property of a crystal whereby, if an electrical stress is applied in the direction of the X axis, a mechanical stress will be produced in the direction of the Y axis. If a mechanical stress is placed along the Y axis, it will cause an electrical stress on the X axis.
- 12 Crystals may be used in series-resonant or parallel-resonant circuits.
- 13 The chief advantage of a crystal oscillator over an LC oscillator is excellent frequency stability.
- 14 When the performance of the crystal is erratic, the only solution is to replace the crystal.
- 15 The frequency at which the oscillator shown in Fig.16 operates is determined by C2-R2 and C1-R3.
- 16 The output will be symmetrical.
- 17 The frequency of the multivibrator will increase.
- 18 The output will be symmetrical.
- 19 A bistable multivibrator is a multivibrator with two stable states. A flip-flop is a bistable multivibrator.
- 20 A monostable multivibrator is a multivibrator with only one stable state. A pulse may cause it to change to the unstable state, but it will return to the stable state, and remain there until another pulse occurs.



- 
9. An astable multivibrator is a multivibrator that:
- Has one stable state.
  - Has two stable states.
  - Is free-running.
  - Is none of the above.
10. In the circuit in Fig.16, which part affects the frequency of the multivibrator?
- Q1.
  - Q2.
  - R1.
  - C1.

## NOTES

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*Please use this page to record any notes  
you may want to review during your studies.*



## **BELIEVE IN YOURSELF**

Here are a some statements made by famous, successful people on the subject of believing in yourself. I quote them just to show you how important self-confidence really is:

“Anything that you have a real desire to do, you have the capacity to do. Believe that and act upon your belief. There are no dreams that can’t come true.”

“Believe in yourself. Believe in humanity. Believe in the success of your undertakings. Fear nothing and no one. This way, you cannot fail.”

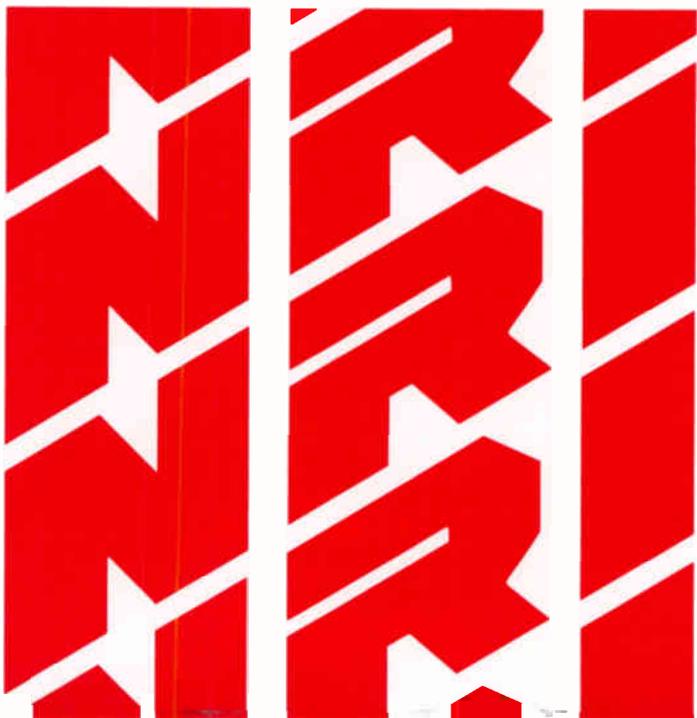
“I CAN IF I THINK I CAN! Write these words in letters an inch high and put them where you can see them every day. Memorize and repeat them — aloud and to yourself — a dozen times a day.”





# Analog Electronics

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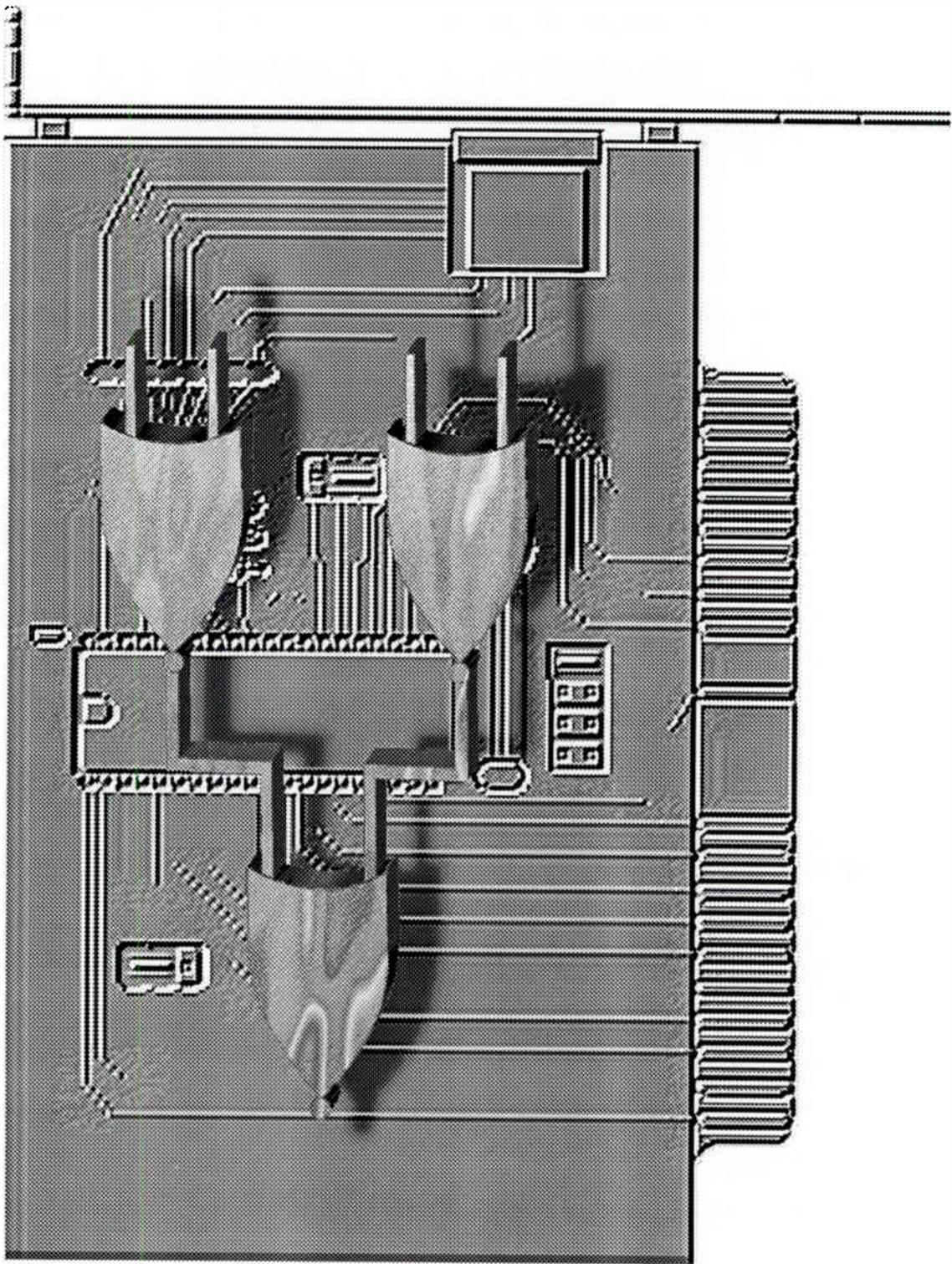
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# Analog Electronics



# Table of Contents

<b>Overview</b> .....	<b>1</b>
<b>Experiment 1: Transformer Operation</b> .....	<b>2</b>
<b>Experiment 2: Rectifier Operation</b> .....	<b>4</b>
<b>Experiment 3: Filter Operation</b> .....	<b>6</b>
<b>Experiment 4: Increasing Circuit Voltage</b> .....	<b>8</b>
<b>Experiment 5: Shunt Regulation with a Zener Diode</b> .....	<b>10</b>
<b>Experiment 6: IC Series Regulator</b> .....	<b>13</b>
<b>Experiment 7: NPN Transistor Voltage Amplifier</b> .....	<b>16</b>
<b>Experiment 8: IC Operational Amplifier</b> .....	<b>19</b>
<b>Experiment 9: NPN Transistor Multivibrator</b> .....	<b>22</b>
<b>Experiment 10: IC Function Generator</b> .....	<b>25</b>
<b>Examination Questions</b> .....	<b>29</b>



## Objectives

*In this training manual, you will use your Digital Multimeter to...*

- Connect and test a power transformer secondary circuit.
- Construct and test a full-wave bridge rectifier.
- Add a ripple filter and observe its action.
- Construct and test a shunt Zener regulator.
- Construct and test an IC series regulator.
- Construct and test a common-emitter amplifier.
- Construct and test a two-stage IC amplifier.

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# Overview

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In this training manual, you will put your knowledge of analog electronics to work. You will construct several circuits on your Discovery Lab and verify their operation. By identifying, handling, connecting, and testing real electronic components, you will make circuit theory come to life.

In each of the following sections, you will be instructed to wire a circuit, using both schematic and pictorial diagrams. After you finish connecting each circuit, you will apply power and make some measurements with your digital multimeter. You will deduce from these measurements how the circuit performs.

At the end of this training manual, on page 29, is an examination consisting of 10 multiple-choice questions. Each of the questions pertains to one of the following experiments. The questions are in the same order as the experiments. There are four questions about basic power supplies and two questions each about voltage regulators, amplifiers, and oscillators. As you perform each of the experiments, you will be instructed to turn to the examination and answer the relevant question. When you are finished with all 10 questions, follow the instructions at the beginning of the examination to fill in your answer card for this training unit.

# Experiment 1: Transformer Operation

---

## Introduction

Almost all electronic circuits and equipment need to operate from a low voltage dc source. Electrical power is distributed in the form of a relatively high ac voltage, so a power supply section or module is used to change the voltage level and convert from ac to dc. In this section, you will construct and test a power supply similar to that used in most modern electronic equipment.

If you were constructing a complete power supply, one of the first things you would do would be to arrange the wiring between the power transformer's primary winding and the ac power line. Your Discovery Lab already has the primary connections in place, both for convenience and to prevent you from having to deal with the dangerous ac power line.

## Materials Needed

For this experiment, you'll need your Discovery Lab, Digital Multimeter, and a length of hook-up wire.

## Procedure

Using your Discovery Lab as a base, connect the center-tapped transformer secondary leads to the breadboard strip as shown in Figure 1-1.

**Step 1.** For your personal safety and that of the equipment, unplug the Discovery Lab's power cord before you make these connections.

**Step 2.** Prepare three 6" lengths of solid hook-up wire by removing  $\frac{1}{4}$ " of insulation from each end of each wire.

**Step 3.** Connect the leftmost terminal of the power transformer secondary (marked 15VAC) to point C on the breadboard strip, as shown in Figure 1-1.

When you insert the wire ends into the breadboard strip's holes, stop just short of full insertion so that enough bare wire is exposed for your meter lead to make good contact.

**Step 4.** Connect the center terminal of the power transformer secondary (marked with a ground symbol) to point B on the breadboard strip.

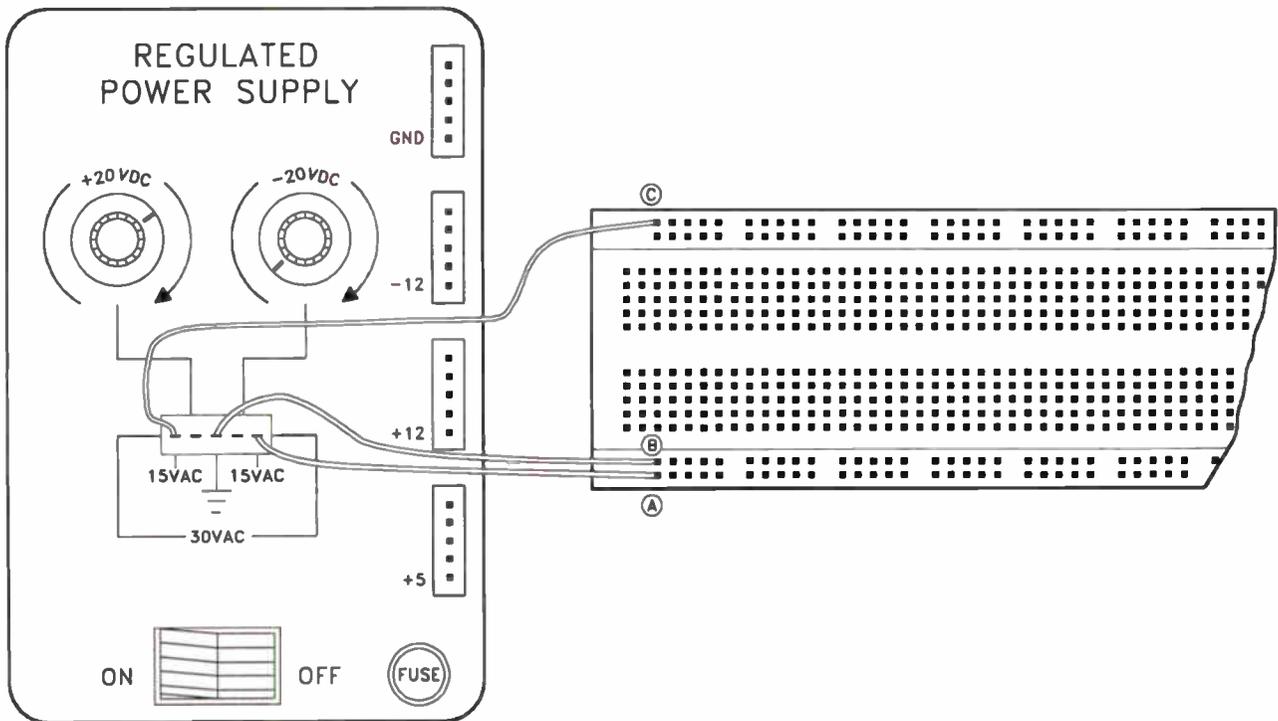


Figure 1-1. Connecting the power transformer secondary leads.

**Step 5.** Connect the rightmost terminal of the power transformer secondary (marked 15VAC) to point A on the breadboard strip.

**Step 6.** Check your wiring to make sure it is correct and then apply power and turn on the Discovery Lab's power switch.

**Step 7.** Set your digital multimeter to measure about 50 Vac and measure the transformer's output voltages. Use point B as a common point; you should find about 15 volts ac at either point A or point C. Now shift the common lead to point A and measure the voltage at point C. Use this measurement to answer Examination Question 1.

**Step 8.** After you take your measurements, remove the wire connecting point C to the transformer secondary.

## Results

You verified the operation of the power transformer; you found that half of the secondary winding can be used to provide one voltage, or the entire winding can be used to provide twice as much voltage to circuits that need that much.

# Experiment 2: Rectifier Operation

## Introduction

Now you will add a full-wave bridge rectifier to the power transformer. This will convert the ac voltage from the transformer into dc voltage.

## Materials Needed

For this experiment, you'll need your Discovery Lab with the wiring in place from the previous experiment, your digital multimeter, four 1N4002 diodes, and one 10k resistor.

## Procedure

Add a full-wave bridge rectifier to the power transformer as Figure 2-1 shows in schematic form. All rectifier diodes are 1N4002 or equivalent and are rated at 1 amp (A), 100 volts (V) piv. Place the components as shown pictorially in Figure 2-2.

**Step 1.** For your personal safety and that of the equipment, again unplug the Discovery

Lab's power cord before you make these connections.

**Step 2.** Connect a rectifier diode as D1 from point A to point -.

**Step 3.** Connect a rectifier diode as D2 from point B to point -.

**Step 4.** Connect a rectifier diode as D3 from point B to point +.

**Step 5.** Connect a rectifier diode as D4 from point A to point +.

**Step 6.** Connect a 10k (brown-black-orange) resistor as the load ( $R_L$ ) from point - to point +.

**Step 7.** Check your wiring to make sure it is correct and then apply power and turn on the Discovery Lab's power switch.

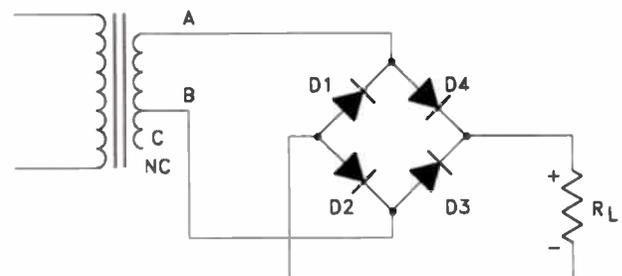


Figure 2-1. Schematic of the full-wave bridge rectifier.

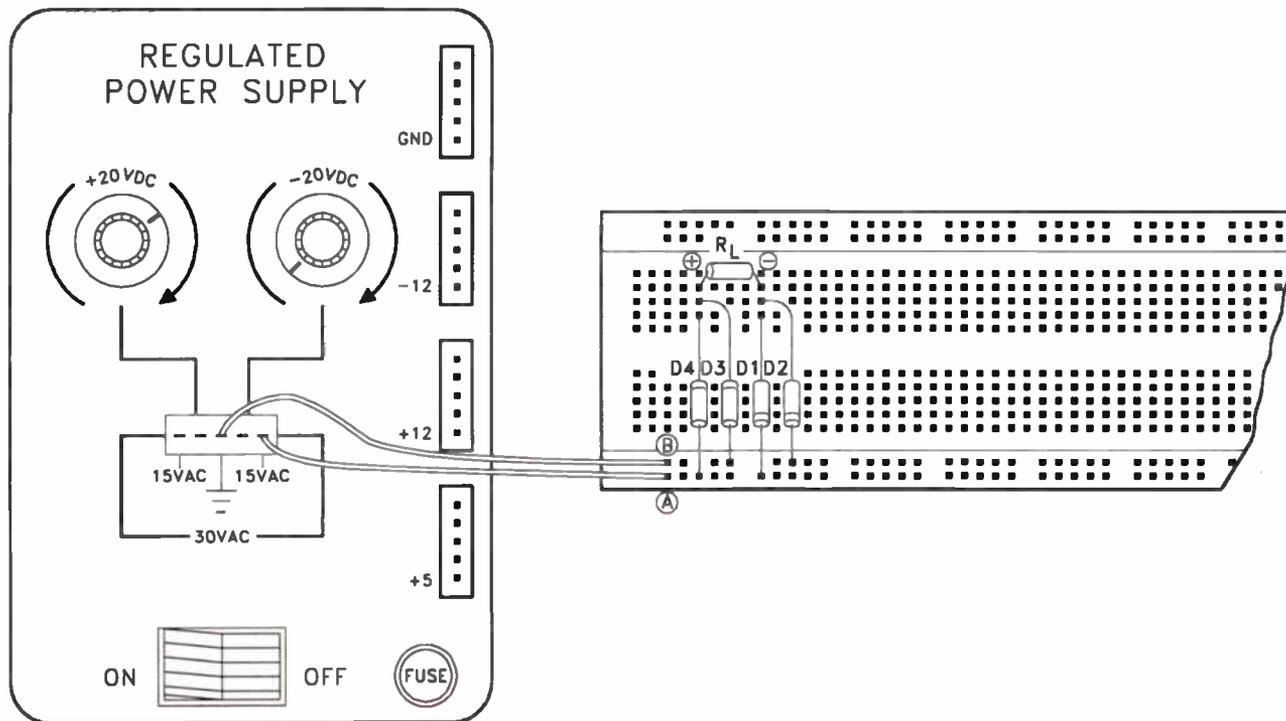


Figure 2-2. Wiring the full-wave bridge rectifier.

**Step 8.** Set your digital multimeter to its 50-V scale and measure the dc voltage at the rectifier's output. Connect the digital multimeter's minus (-) jack to point - as a common point. Record your reading in the upper-left space of Figure 2-3.

**Step 9.** Set your digital multimeter to measure about 50 Vac and measure the ac ripple voltage at the rectifier's output. Connect the digital multimeter's minus (-) jack to point - as a common point. Record your reading in the upper-right space of Figure 2-3. Use these measurements to answer Examination Question 2.

## Results

You constructed a full-wave bridge rectifier circuit and observed its operation without

any ripple filter. You should have observed that, while dc output voltage is present, there is also a large ac component at the output.

DC VOLTS	AC VOLTS	WITHOUT FILTER
EXP. 2, STEP 8	EXP. 2, STEP 9	
EXP. 3, STEP 4	EXP. 3, STEP 5	WITH C1 ADDED
EXP. 4, STEP 5	EXP. 4, STEP 6	WITH FULL AC INPUT

Figure 2-3. For the full-wave bridge rectifier experiment, enter your measured values in this voltage chart.

# Experiment 3: Filter Operation

## Introduction

Now you will add a filter capacitor to the power supply circuit. This will smooth the ripple from the pulsating dc voltage and produce one more pure dc output voltage.

## Materials Needed

For this experiment, you'll need your Discovery Lab with the wiring in place from the previous experiment, your digital multimeter, and one 100-microfarad ( $\mu\text{F}$ ), 50-V electrolytic capacitor.

## Procedure

Now add a 100- $\mu\text{F}$ , 50-V electrolytic capacitor to the circuit as Figure 3-1 shows in schematic form. Orient the capacitor as shown pictorially in Figure 3-2.

**Step 1.** For your personal safety and that of the equipment, again unplug the Discovery

Lab's power cord before you make these connections.

**Step 2.** Connect the filter capacitor from point – to point +. Note that the + end of the capacitor must be on point +, and vice versa. Electrolytic capacitors like this are polarity-sensitive and will not work if connected backwards!

**Step 3.** Check your wiring to make sure it is correct and then apply power and turn on the Discovery Lab's power switch.

**Step 4.** Set your digital multimeter to measure about 50 V and measure the dc voltage at the rectifier's output. Connect the digital multimeter's minus (–) jack to point – as a common point. Record your reading in the center-left corner of Figure 2-3.

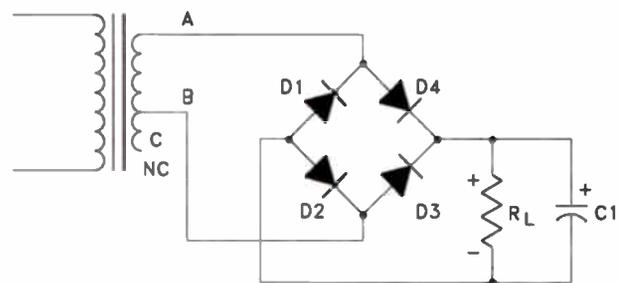


Figure 3-1. How a filter capacitor is added to the circuit.

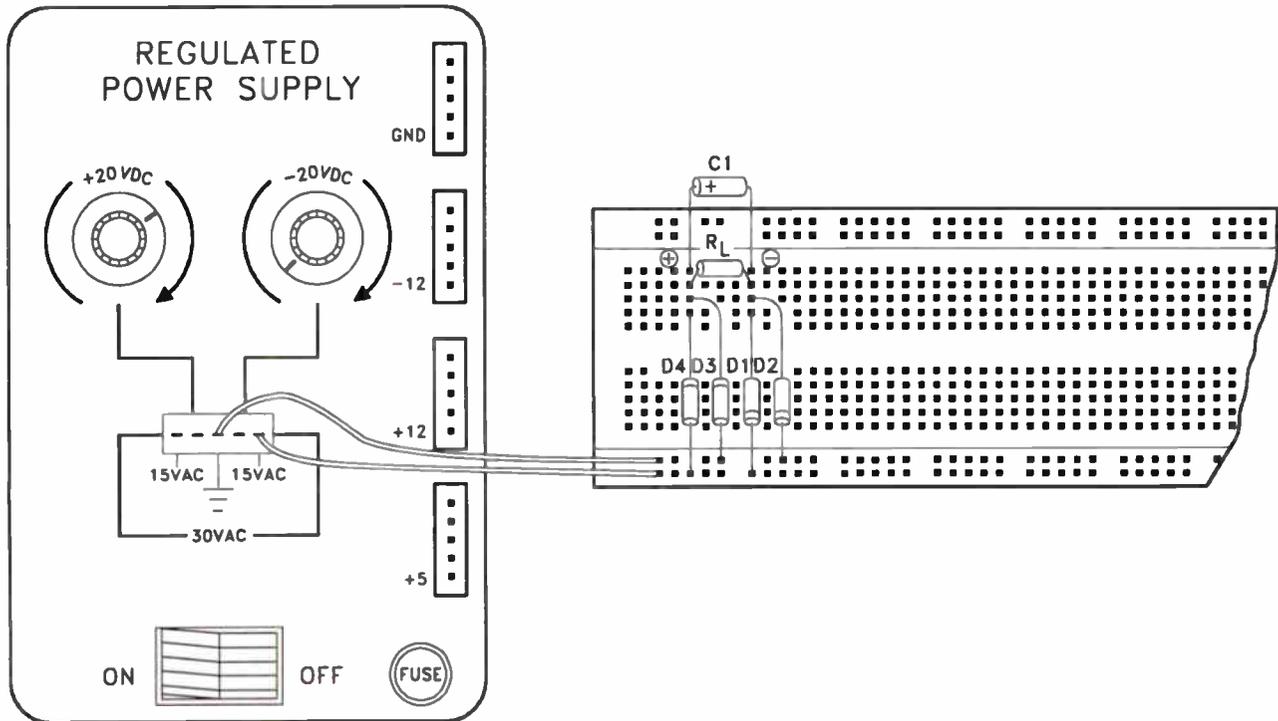


Figure 3-2. While connecting the filter capacitor, observe polarity.

**Step 5.** Set your digital multimeter to measure a low ac voltage and measure the ac ripple voltage at the rectifier's output. Connect the digital multimeter's minus (-) jack to point - as a common point. Record your reading in the center-right corner of Figure 2-3. Use these readings to answer Examination Question 3.

## Results

You added a filter capacitor at the output of the full-wave bridge rectifier circuit and observed its effect on dc and ac output voltage. You should have noticed a dramatic decrease in the ac ripple voltage when you installed the filter capacitor.

## Experiment 4: Increasing Circuit Voltage

---

### Introduction

Now you will increase the ac voltage applied to the rectifier circuit by using the entire transformer secondary winding rather than just half of the winding, as before.

### Materials Needed

For this experiment, you'll need your Discovery Lab with the wiring in place from the previous experiment and your digital multimeter.

### Procedure

Now connect the power transformer to the rectifier circuit to use the entire secondary winding instead of only half.

**Step 1.** For your personal safety and that of the equipment, again unplug the Discovery Lab's power cord before you make these connections.

**Step 2.** Disconnect the wire connecting point B with the Discovery Lab's center power transformer terminal.

**Step 3.** Connect point B instead to the leftmost transformer terminal (marked 15VAC).

**Step 4.** Check your wiring to make sure it is correct and then apply power and turn on the Discovery Lab's power switch.

**Step 5.** Set your digital multimeter to measure about 50 V and measure the dc voltage at the rectifier's output. Connect the digital multimeter's minus (-) jack to point - as a common point. *Keep your fingers away from the circuit conductors to avoid getting a shock.* Record your reading in the bottom-left corner of Figure 2-3.

**Step 6.** Set your digital multimeter to measure a low ac voltage and measure the ac ripple voltage at the rectifier's output. Connect the digital multimeter's minus (-) jack to point - as a common point. *Again, keep your fingers away from the circuit conductors to avoid getting a shock.* Record your reading in the bottom-right corner of Figure 2-3. Use these readings to answer Examination Question 4.

---

**Step 7.** If you are finished with the power supply experiments, unplug the Discovery Lab's ac power cord and remove the wires and components you added for these experiments. Save them for later use in other experiments.

## **Results**

In this experiment, you doubled the amount of ac voltage applied to the input of the full-wave bridge rectifier circuit. You should have observed that the dc output voltage was doubled as a result.

# Experiment 5: Shunt Regulation with a Zener Diode

## Introduction

In this experiment, you will use one of your Discovery Lab's variable dc outputs to demonstrate the operation of a simple shunt Zener diode voltage regulator.

## Materials Needed

For this experiment, you'll need your Discovery Lab, your digital multimeter, one 100-ohm ( $\Omega$ ), 1-W (W) resistor, two 1k resistors, one 6-V,  $\frac{1}{2}$ -watt (W) Zener diode, and a length of hook-up wire.

## Procedure

Using your Discovery Lab as a base, construct the circuit that is shown in schematic form in Figure 5-1. Wire the components as shown in Figure 5-2:

**Step 1.** For your personal safety and that of the equipment, unplug the Discovery Lab's power cord before you make these connections.

**Step 2.** Prepare two 6" lengths of solid hook-up wire by removing  $\frac{1}{4}$ " of insulation from each end of each wire.

**Step 3.** With one of the wires, connect the Discovery Lab's +20-V output to point A on the breadboard strip.

**Step 4.** Use the other wire to connect the Discovery Lab's ground to point B on the breadboard strip.

**Step 5.** Connect a 100  $\Omega$ , 1-W resistor (R1) from point A to point C on the breadboard strip.

**Step 6.** Connect a 6-V,  $\frac{1}{2}$ -W Zener diode from point C to point B on the breadboard strip. Make sure that the Zener's cathode (striped end) is connected to point C.

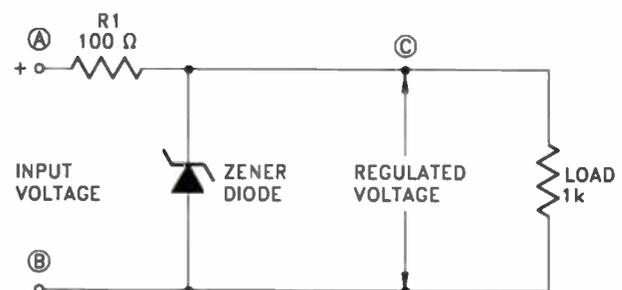


Figure 5-1. The Zener diode shunt regulator circuit.

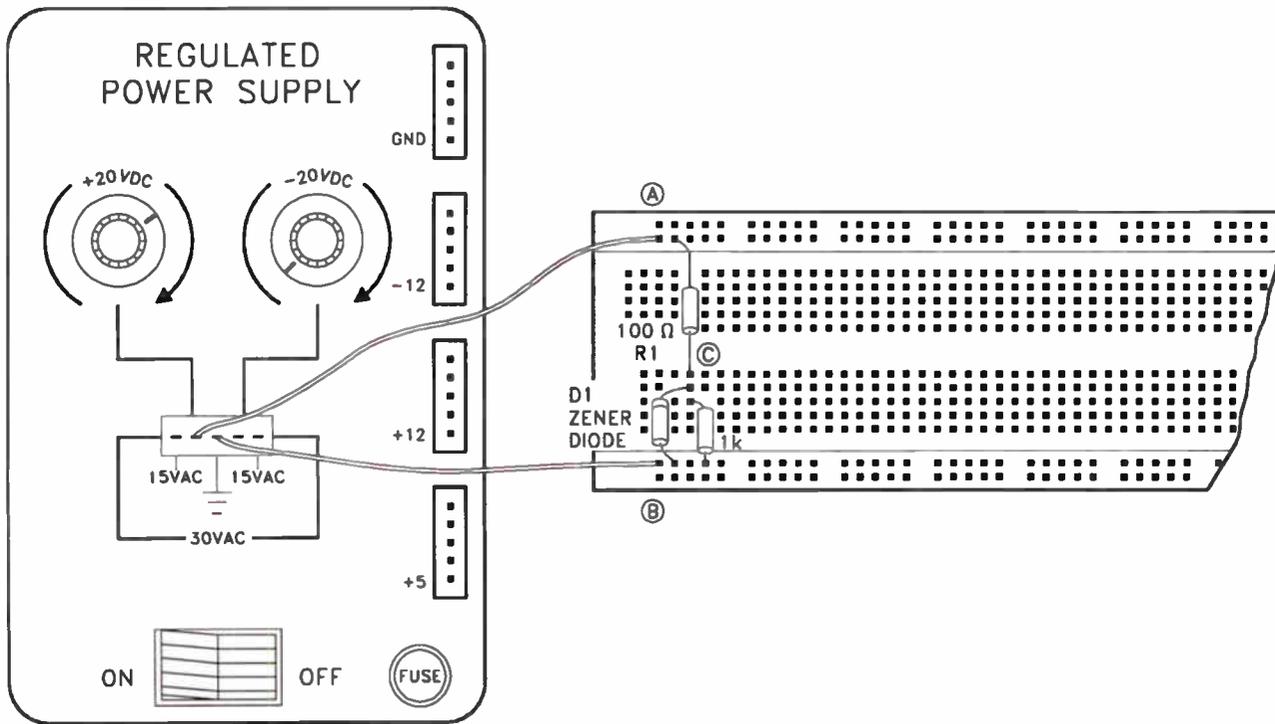


Figure 5-2. Wiring the Zener diode shunt regulator circuit.

**Step 7.** Connect a 1k, 1/4-W resistor from point C to point B on the breadboard strip. This resistor is the load ( $R_L$ ) and is connected in parallel with the Zener shunt regulator.

**Step 8.** Check your wiring to make sure it is correct and then apply power and turn on the Discovery Lab's power switch.

**Step 9.** Connect your digital multimeter's negative lead (the black probe) to point B (ground) on the breadboard strip. Leave this connection in place for all of the following steps.

**Step 10.** Set your digital multimeter to measure about 50 V and measure the voltage at point A. This is the input to the regulator circuit. Note that you can vary this voltage from less than 2 V to about 20 volts. For now, set it to about 15 V and leave it there. Record your reading in the top-left corner of Figure 5-3.

**Step 11.** Set your digital multimeter to measure about 10-V scale and measure the voltage at point C. This is the input to the regulator circuit. Since the regulator circuit uses a 6-V Zener, you should find a regulated voltage at point C. Record your reading in the top-right corner of Figure 5-3.

INPUT (A)	OUTPUT (C)
	1 k LOAD
	500 Ω LOAD

Figure 5-3. For the Zener diode shunt regulator experiment, enter your measured values in this voltage chart.

**Step 12.** Now connect another 1k,  $\frac{1}{4}$ -W resistor from point C to point B on the breadboard strip. This resistor is in parallel with the existing load and will double the load current, since it's the same value as the original load resistor. Again measure the voltage at point C and record your reading in the bottom-right corner of Figure 5-3. If the regulator is working, the voltage won't change much when you add the extra load. This shows that the regulator has excellent load regulation. Use these measurements to answer Examination Question 5.

**Step 13.** Measure the input voltage at point A and record your reading in the bottom-left corner of Figure 5-3. Since the Discovery Lab's adjustable dc outputs are regulated, you shouldn't notice much difference with or without the extra load resistor.

**Step 14.** While the extra load resistor is connected, run the input voltage up and down and notice that it has little, if any, effect on the output voltage, until you turn it down to about half of your preset +15 volts. This shows that the regulator has excellent line regulation.

**Step 15.** When you finish checking your results, turn off the Discovery Lab and remove the components you installed in steps 5–12 above.

## Results

You constructed and analyzed a Zener diode shunt regulator. You checked for load regulation by changing the amount of load resistance applied to the circuit. You also checked for line regulation by changing the input voltage with the Discovery Lab's variable output power supply.

---

# Experiment 6: IC Series Regulator

---

## Introduction

In this experiment, you will use one of your Discovery Lab's variable dc outputs to demonstrate the operation of a three-terminal IC series voltage regulator.

## Materials Needed

For this experiment, you'll need your Discovery Lab with the wires left in place from the previous experiment, your digital multimeter, one 7805 voltage regulator IC, two  $1\ \mu\text{F}$  capacitors, two  $100\ \Omega$  resistors, and a length of hook-up wire.

## Procedure

Again, using your Discovery Lab as a base, construct the circuit shown in schematic form in Figure 6-1. Wire the components as shown in Figure 6-2, on the next page.

**Step 1.** For your personal safety and that of the equipment, unplug the Discovery Lab's power cord before you make these connections.

**Step 2.** Prepare a 2" length of solid hook-up wire by removing  $\frac{1}{4}$ " of insulation from each end.

**Step 3.** Connect this wire from point A to point D on the breadboard strip.

**Step 4.** Bend the leads of a 7805 voltage regulator IC, as shown in Figure 6-3, on the next page. Bend the center (ground) lead toward the front (marked side) of the IC, and bend the outer leads toward the back of the IC.

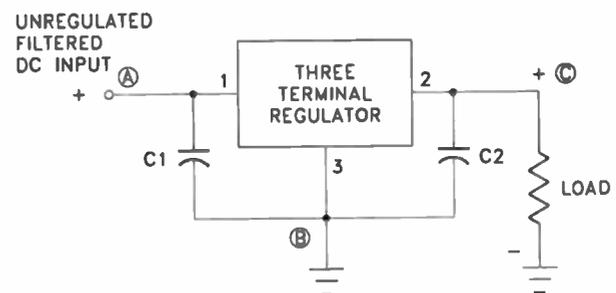


Figure 6-1. The three-terminal IC series regulator circuit.

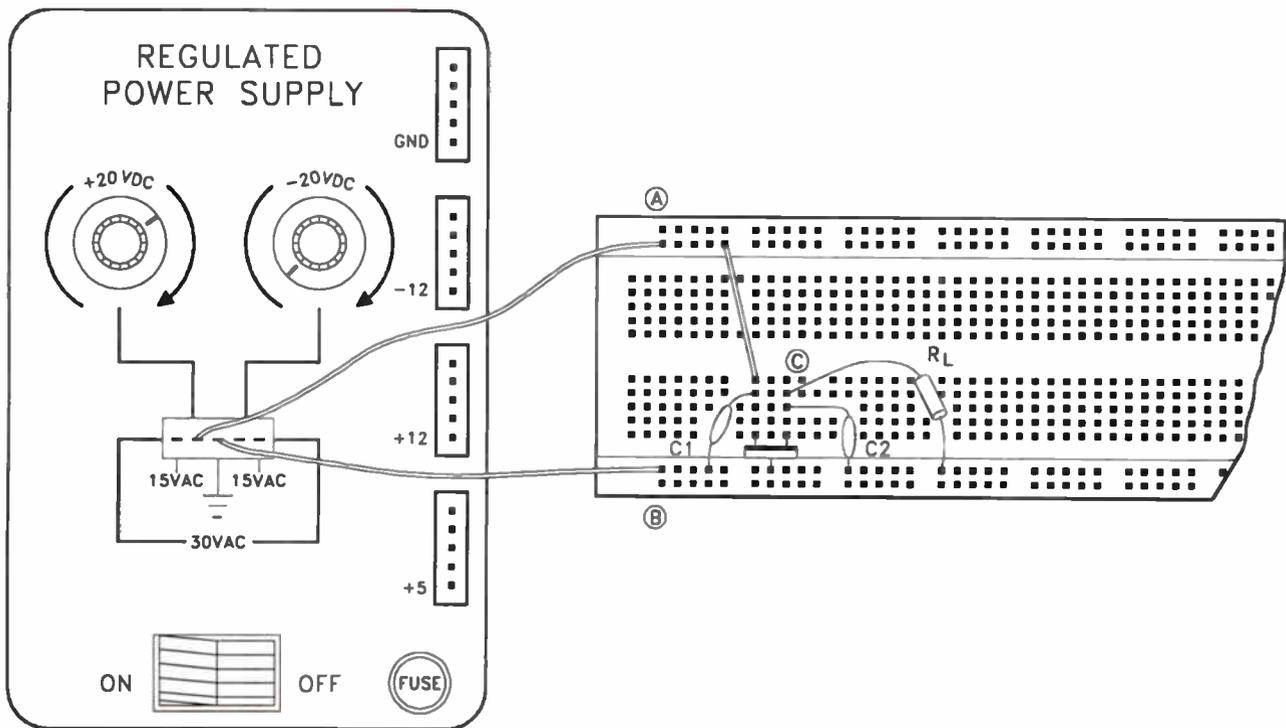


Figure 6-2. Wire the three-terminal IC voltage regulator.

**Step 5.** Carefully insert the three leads of the 7805 IC into the breadboard so that the center lead contacts point B, the left (IN) lead contacts point D, and the right (OUT) lead contacts point C. You may find it helpful to use a pair of longnose pliers to insert the leads into the socket.

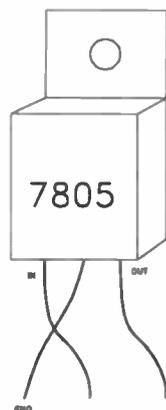


Figure 6-3. Bend the leads of the 7805 voltage regulator IC as shown.

**Step 6.** Connect a  $1\ \mu\text{F}$  capacitor from point A to point B on the breadboard socket. Make sure the positive (+) lead of the capacitor is connected to point A.

**Step 7.** Connect another  $1\ \mu\text{F}$  capacitor from point C to point B on the breadboard socket. Make sure the positive (+) lead of the capacitor is connected to point C.

**Step 8.** Connect a  $100\ \Omega$ , 1-W resistor ( $R_L$ ) from point C to point B on the breadboard socket.

**Step 9.** Once again connect your digital multimeter's negative lead (the black probe) to point B (ground) on the breadboard strip. Leave this connection in place for all of the following steps.

**Step 10.** Set your digital multimeter to measure about 50 V and measure the voltage at point A. This is the input to the regulator circuit. Note that you can vary this voltage from less than 2 V to about 20 volts. For now, set it to about 15 V and leave it there. Record your reading in the top-left corner of Figure 6-4.

**Step 11.** Set your digital multimeter to measure about 10 V and measure the voltage at point C. This is the input to the regulator circuit. Since the regulator circuit uses a 7805 IC, you should find nearly a regulated voltage at point C. Record your reading in the top-right corner of Figure 6-4. Use this reading to answer Examination Question 6.

**Step 12.** Now connect another 100  $\Omega$ , 1-W resistor from point C to point B on the breadboard strip. This resistor is in parallel with the existing load and will double the load

current, since it's the same value as the original load resistor. Again, measure the voltage at point C and record your reading in the bottom-right corner of Figure 6-4. If the regulator is working, the voltage won't change much when you add the extra load.

**Step 13.** Measure the input voltage at point A and record your reading in the bottom-left corner of Figure 6-4. Since the Discovery Lab's adjustable dc outputs are regulated, you shouldn't notice any difference with or without the extra load resistor. This shows that the regulator has excellent load regulation.

**Step 14.** While the extra load resistor is connected, run the input voltage up and down and notice that it has little, if any, effect on the output voltage, until you turn it down to about half of your preset +15 volts. This shows that the regulator has excellent line regulation.

**Step 15.** When you finish checking your results, turn off the Discovery Lab and remove the components you installed in steps 2–12 above.

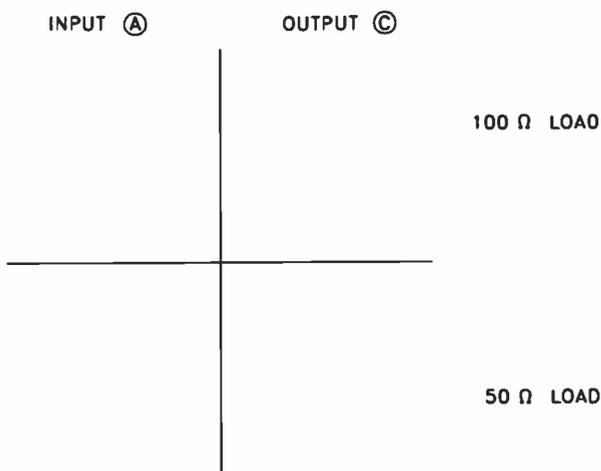


Figure 6-4. For the IC series regulator experiment, enter your measured values in this voltage chart.

## Results

You constructed and analyzed an IC series regulator. You checked for load regulation by changing the amount of load resistance applied to the circuit. You also checked for line regulation by changing the input voltage with the Discovery Lab's variable output power supply.

# Experiment 7: NPN Transistor Voltage Amplifier

## Introduction

In this experiment, you will construct a common-emitter amplifier stage using an npn transistor and analyze its dc operation.

## Materials Needed

For this experiment, you'll need your Discovery Lab, your digital multimeter, one 2N3904 transistor, two 100  $\Omega$  resistors, two 1k resistors, and a length of hook-up wire.

## Procedure

Using your Discovery Lab as a base, construct the circuit shown in schematic form in Figure 7-1. Wire the components as shown in Figure 7-2.

**Step 1.** For your personal safety and that of the equipment, unplug the Discovery Lab's power cord before you make these connections.

**Step 2.** Prepare three 6" lengths of solid hook-up wire by removing  $\frac{1}{4}$ " of insulation from each end of each wire.

**Step 3.** With one of the three 6" wires, connect the Discovery Lab's GND point to point A on the breadboard strip.

**Step 4.** With another of the three 6" wires, connect the Discovery Lab's +12-V output to point B on the breadboard strip.

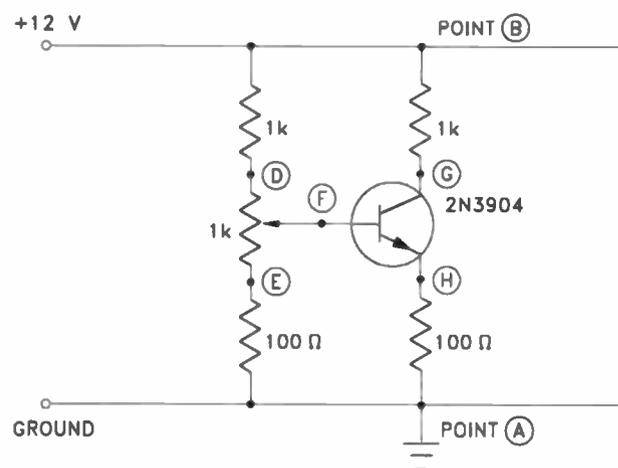


Figure 7-1. An NPN transistor connected in a common-emitter amplifier circuit.

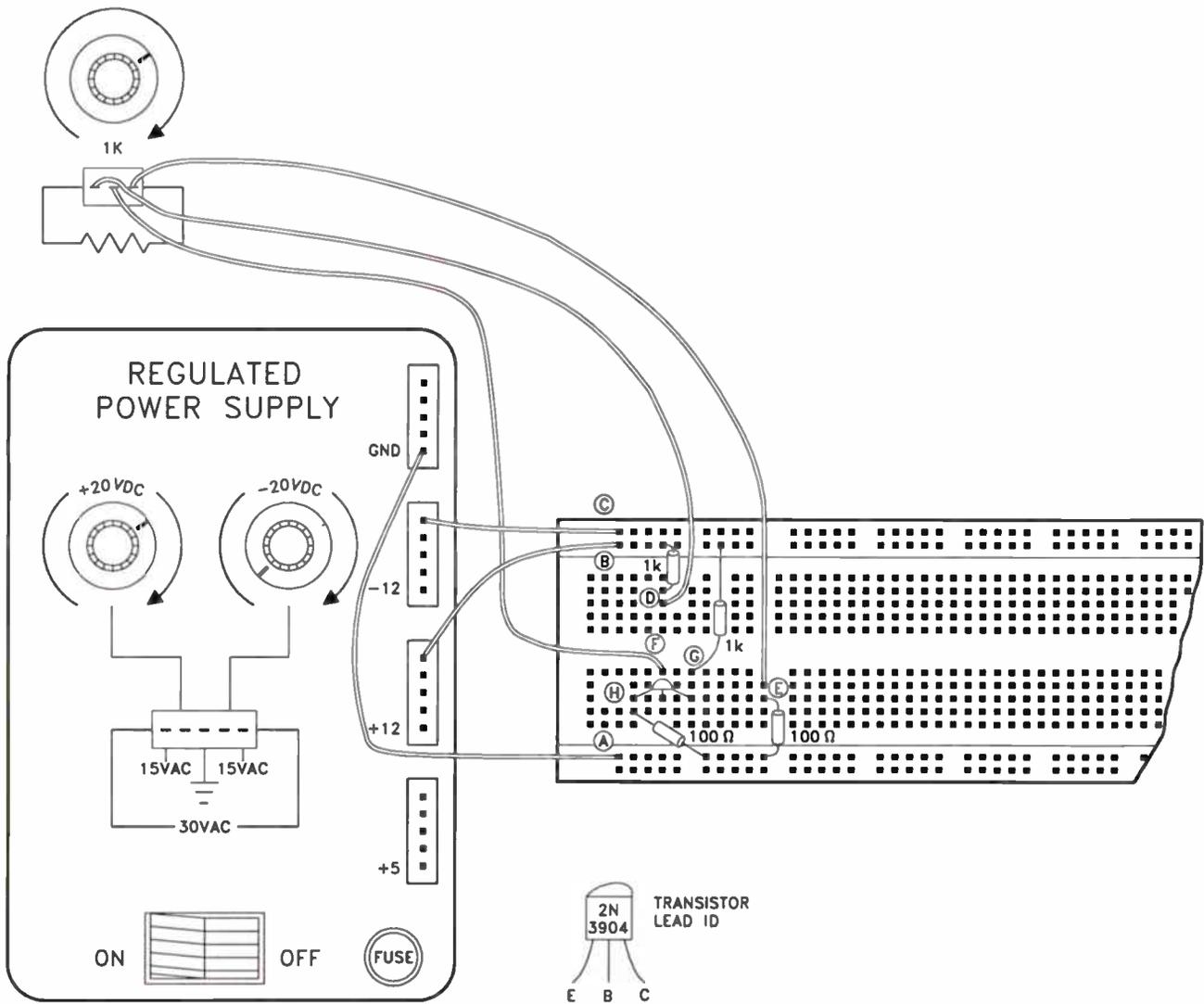


Figure 7-2. Wiring the common-emitter amplifier.

**Step 5.** With the last of the three 6" wires, connect the Discovery Lab's -12 V output to point C on the breadboard strip.

**Step 6.** Prepare three 9" lengths of solid hookup wire by removing  $\frac{1}{4}$ " of insulation from each end of each wire.

**Step 7.** With one of the three 9" wires, connect the left terminal of the Discovery Lab's 1k pot to point D on the breadboard strip.

**Step 8.** With another of the three 9" wires, connect the right terminal of the Discovery Lab's 1k pot to point E on the breadboard strip.

**Step 9.** With the last of the three 9" wires, connect the center terminal of the Discovery Lab's 1k pot to point F on the breadboard strip.

**Step 10.** Connect a 1k resistor from point B to point D on the breadboard strip.

**Step 11.** Connect a 100  $\Omega$  resistor from point E to point A on the breadboard strip.

**Step 12.** Connect a 1k resistor from point B to point G on the breadboard strip.

**Step 13.** Connect a 100  $\Omega$  resistor from point H to point A on the breadboard strip.

**Step 14.** Install the 2N3904 NPN transistor on the breadboard strip. Connect the collector to point G, the base to point F, and the emitter to point A of the breadboard strip.

**Step 15.** Connect the negative (-) lead of your digital multimeter to point A of the breadboard strip.

**Step 16.** Connect the positive (+) lead of your digital multimeter to point B of the breadboard strip.

**Step 17.** Set the digital multimeter to its 50-V range.

**Step 18.** Check your wiring to make sure it is correct and then apply power to the Discovery Lab and turn on its power switch. The digital multimeter should immediately register about 12 V. If there is no reading, quickly turn off the power and recheck your connections.

**Step 19.** Assuming the +12-V power supply is working properly, make the following tests with the power on.

**Step 20.** Read the dc voltage at points F (input) and G (output) of the breadboard strip. Take each reading with the 1k pot fully clockwise, centered, and fully counterclockwise. Record your readings in the table in Figure 7-3.

**Step 21.** Turn the 1k pot fully clockwise and again read the voltage at point G (the collector of the transistor). Use this measurement to answer Examination Question 7.

**Step 22.** When you finish checking your results, turn off the Discovery Lab and remove the components you installed in steps 10–14 above. Leave in place the six wires you installed in steps 3–9.

## Results

You constructed a typical amplifier circuit and analyzed its operation under static (dc) conditions. You built and tested a common-emitter npn transistor voltage amplifier and checked it for normal operation. You should have observed that the output voltage swings were opposite in direction to those at the input, since this is an inverting amplifier circuit.

	BASE Ⓕ	COLLECTOR Ⓖ
POT CW		
POT CENTERED		
POT CCW		

**Figure 7-3.** For the common-emitter amplifier experiment, enter your measured values in this voltage chart.

---

# Experiment 8: IC Operational Amplifier

---

## Introduction

In this experiment, you will construct a two-stage amplifier using an IC dual op amp. You will configure one of the two op amp circuits as an inverting amplifier and the other op amp as a voltage follower. You will then analyze the dc operation of the two-stage amplifier.

## Materials Needed

For this experiment, you'll need your Discovery Lab with the wires left in place from the previous experiment, your digital multimeter, one 1458 dual op amp IC, one 10k resistor, one 100k resistor, and a length of hook-up wire.

## Procedure

Using your Discovery Lab as a base, construct the circuit shown in schematic form in Figure 8-1, on the next page. Wire the components as shown in Figure 8-2, on the next page.

**Step 1.** For your personal safety and that of the equipment, unplug the Discovery Lab's power cord before you make these connections.

**Step 2.** Make sure the six wires installed in steps 3–9 of the previous experiment are still in place.

**Step 3.** Install the 1458 dual op amp IC on the breadboard strip as shown. Be careful to avoid bending any of the eight leads under the chip.

**Step 4.** Prepare six 1" and two 3" lengths of solid hook-up wire by removing  $\frac{1}{4}$ " of insulation from each end of each wire.

**Step 5.** Connect one of the 3" wires from Pin 8 of the 1458 IC to point B on the breadboard strip.

**Step 6.** Connect another of the 3" wires from Pin 4 of the 1458 IC to point C on the breadboard strip.

**Step 7.** Connect one of the 1" wires from Pin 3 of the 1458 IC to point A on the breadboard strip.

# ANALOG ELECTRONICS

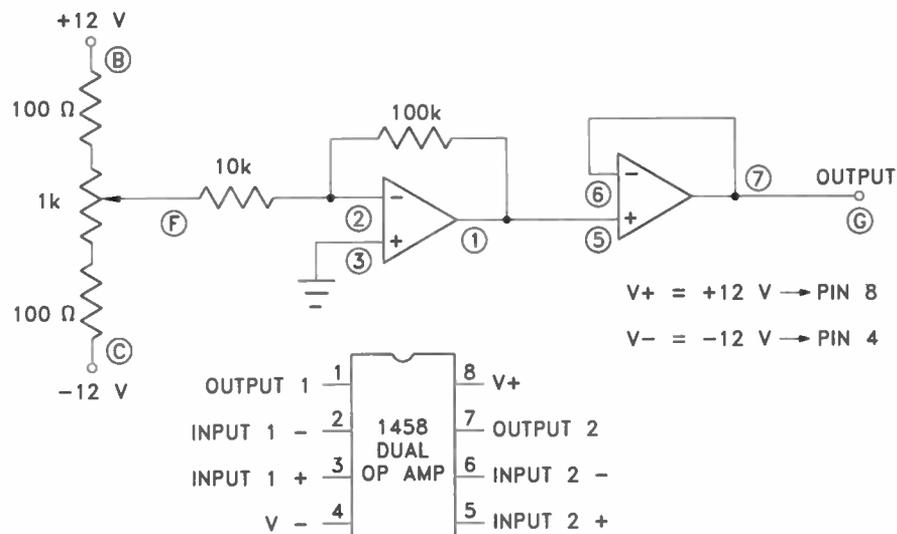


Figure 8-1. A 1458 dual op amp IC used as a two-stage amplifier. The first stage has a gain of 10; the second stage is a voltage follower, which provides a low impedance output.

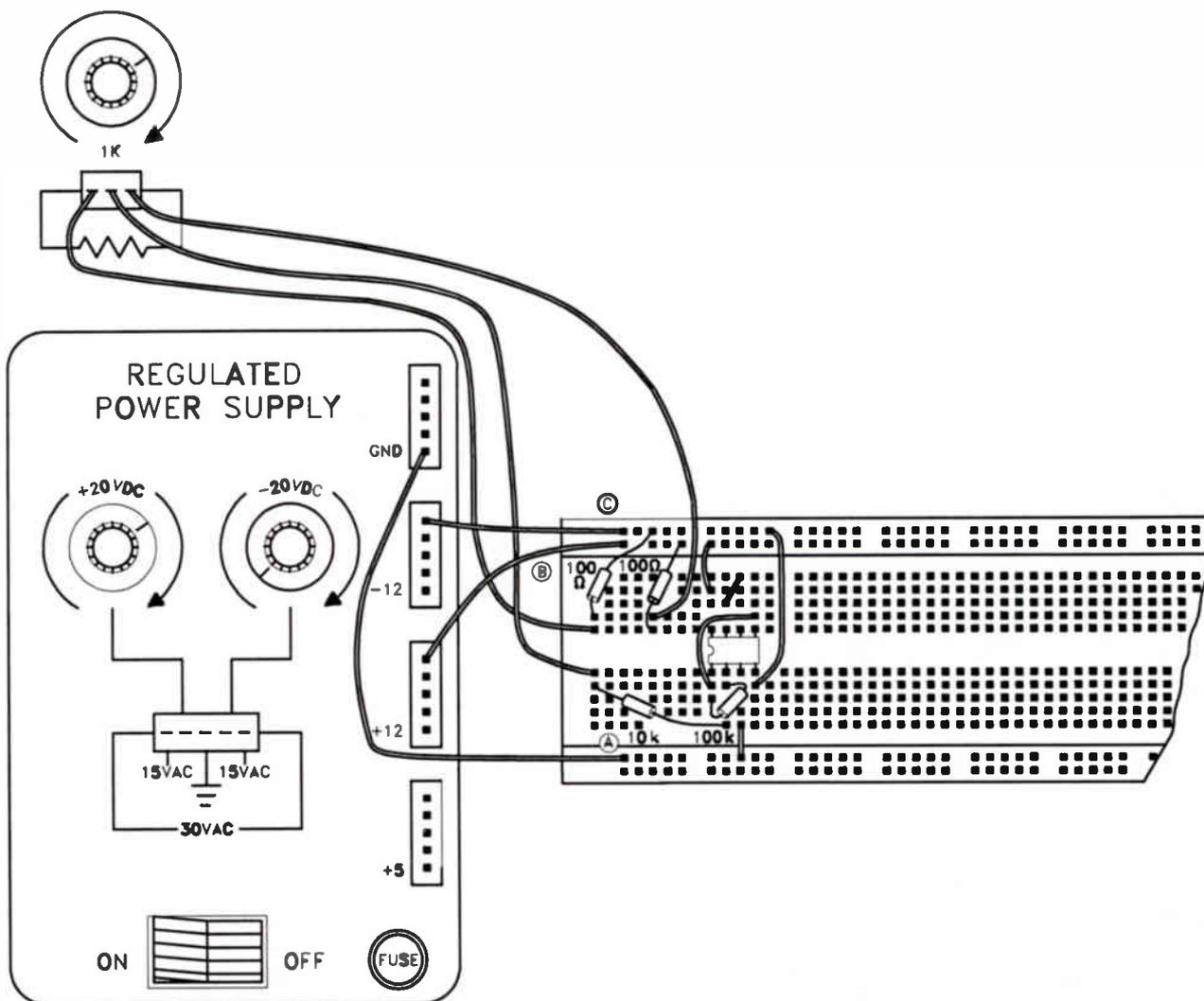


Figure 8-2. Wiring the two-stage IC amplifier circuit.

**Step 8.** Connect another of the 1" wires from Pin 6 to Pin 7 of the 1458 IC.

**Step 9.** Connect another of the 1" wires from Pin 1 to Pin 5 of the 1458 IC.

**Step 10.** Connect a 10k resistor from point F to Pin 2 of the 1458 IC.

**Step 11.** Connect a 100k resistor from Pin 2 to Pin 1 of the 1458 IC.

**Step 12.** Connect the negative (-) lead of your digital multimeter to point A of the breadboard strip.

**Step 13.** Connect the positive (+) lead of your digital multimeter to point B of the breadboard strip.

**Step 14.** Set the digital multimeter to read about 50 V.

**Step 15.** Check your wiring to make sure it is correct and then apply power to the Discovery Lab and turn on its power switch. The digital multimeter should immediately register about 12 V. If there is no reading, quickly turn off the power and recheck your connections.

**Step 16.** Assuming the +12-V power supply is working properly, make the following tests with the power on. Measure the input (point F) and output (point G) voltages with the 1k pot turned fully clockwise, centered, and fully counterclockwise. Remember to reverse the leads for negative voltages when using an analog meter. Record your readings in the table in Figure 8-3.

**Step 17.** Again measure the output voltage at point G with the 1k pot turned fully counterclockwise. Use this reading to answer Examination Question 8.

**Step 18.** When you finish checking your results, turn off the Discovery Lab and remove all the wires and components from the breadboard strip.

## Results

You constructed a typical two-stage IC amplifier circuit and analyzed its operation under static (DC) conditions.

You built and tested an inverting amplifier and a voltage follower, each implemented with half of a dual op amp IC. You programmed the inverting amplifier for a voltage gain of 10 with the resistor values you used. The two amplifiers were cascaded so that the output of the x10 inverting amplifier fed the input of the voltage follower. As was also the case with the transistor amplifier, you should have observed that the output voltage swings were opposite in direction to those at the input, since this is an inverting amplifier circuit.

	INPUT ⓕ	OUTPUT ⓖ
POT CW		
POT CENTERED		
POT CCW		

**Figure 8-3.** For the two-stage IC amplifier experiment, enter your measured values in this voltage chart.

# Experiment 9: NPN Transistor Multivibrator

## Introduction

In this experiment, you will construct a type of oscillator circuit called a *multivibrator*. You will build this circuit around two npn transistors and study its operation.

## Materials Needed

For this experiment, you'll need your Discovery Lab, two 2N3904 transistors, two 1k resistors, two 10k resistors, two 100  $\mu\text{F}$  capacitors, two LEDs, and a length of hook-up wire.

## Procedure

Using your Discovery Lab as a base, construct the circuit shown in schematic form in Figure 9-1. Wire the components as shown in Figure 9-2.

**Step 1.** For your personal safety and that of the equipment, unplug the Discovery Lab's power cord before you make these connections.

**Step 2.** Make sure all wires and components are removed from the breadboard strip. As needed, re-use the cut lengths of solid hook-up wire from previous experiments.

**Step 3.** Connect a 6" piece of hook-up wire from the Discovery Lab's +5 terminal to point A on the breadboard strip.

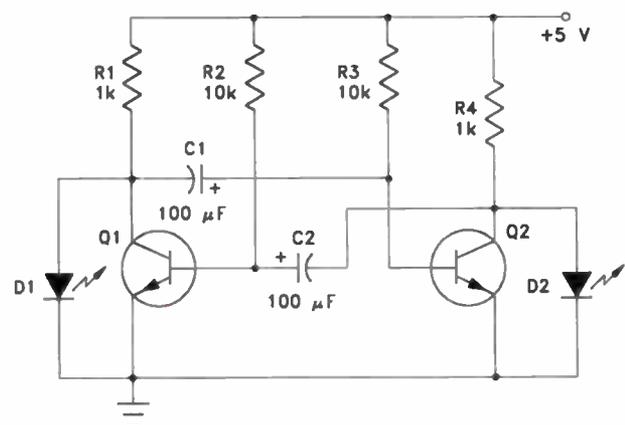


Figure 9-1. Two npn transistors connected as an astable multivibrator.

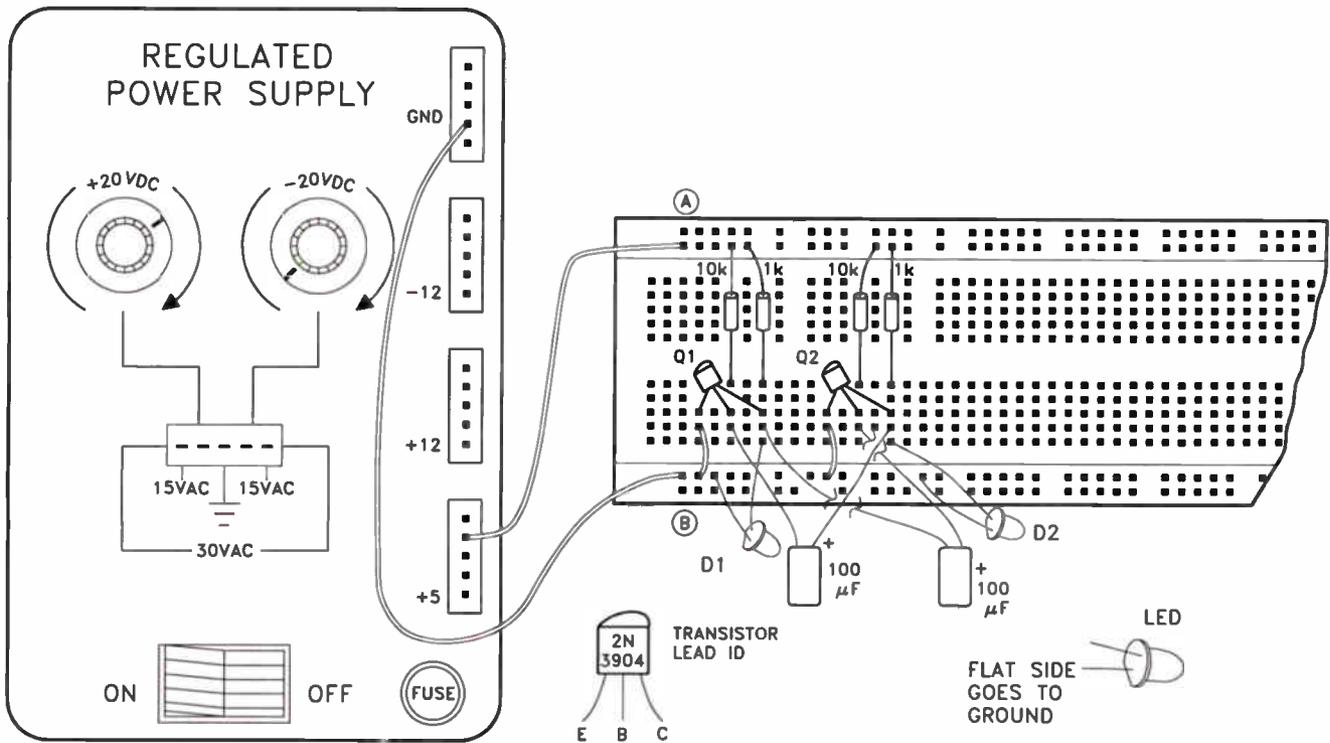


Figure 9-2. Wiring the astable multivibrator circuit.

**Step 4.** Connect another 6" piece of hook-up wire from the Discovery Lab's GND terminal to point B on the breadboard strip.

**Step 5.** Insert two 2N3904 transistors and orient them as shown. We will call the transistor on the left Q1 and the one on the right Q2.

**Step 6.** Connect a 1" piece of hook-up wire from the emitter (left lead) of Q1 to ground point B.

**Step 7.** Connect another 1" piece of hook-up wire from the emitter (left lead) of Q2 to ground point B.

**Step 8.** Connect a 10k resistor from the base (center lead) of Q1 to +5 point A.

**Step 9.** Connect another 10k resistor from the base (center lead) of Q2 to +5 point A.

**Step 10.** Connect a 1k resistor from the collector (right lead) of Q1 to +5 point A.

**Step 11.** Connect another 1k resistor from the collector (right lead) of Q2 to +5 point A.

**Step 12.** Connect a 100 µF capacitor from the collector of Q1 to the base of Q2. The plus (+) lead goes to the base of Q2.

**Step 13.** Connect another 100 µF capacitor from the collector of Q2 to the base of Q1. The plus (+) lead goes to the base of Q1.

**Step 14.** Connect an LED as D1 from the collector of Q1 to ground. The cathode (flat) side goes to ground.

**Step 15.** Connect an LED as D2 from the collector of Q2 to ground. The cathode (flat) side goes to ground.

**Step 16.** Check your wiring to make sure it is correct and then apply power to the Discovery Lab and turn on its power switch. LEDs D1 and D2 should begin flashing immediately. If they don't, quickly turn off the Discovery Lab and check your wiring.

**Step 17.** Observe the operation of the flashing lights. Each one is displaying the state of one of the two transistors. When Q1 is conducting, its collector voltage is very low, so LED D1 is dark. When Q1 is cut off, its collector voltage increases, and so LED D1 is lit. Use your observations to answer Examination Question 9.

**Step 18.** When you finish checking your results, turn off the Discovery Lab and remove all the wires and components from the breadboard strip.

## Results

Using two npn transistors, you constructed and tested an astable multivibrator, which generates complementary (equal, but opposite) square wave outputs. Since the oscillation frequency is very low, you were able to see the oscillator's complimentary outputs driving the two LEDs.

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# Experiment 10: IC Function Generator

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## Introduction

In this experiment, you will construct a function generator using an IC dual op amp. You will configure one of the two op amp circuits as an integrator and the other op amp as a voltage comparator. You will connect these circuits so that each one's output feeds the other's input. You then will observe the output of this oscillator circuit.

## Materials Needed

For this experiment, you'll need your Discovery Lab with all the wires from previous experiments removed, one 1458 dual op-amp IC, one 1k resistor, one 4.7k resistor, four 10k resistors, one 47k resistor, one 10  $\mu$ F capacitor, an LED, and a length of hook-up wire.

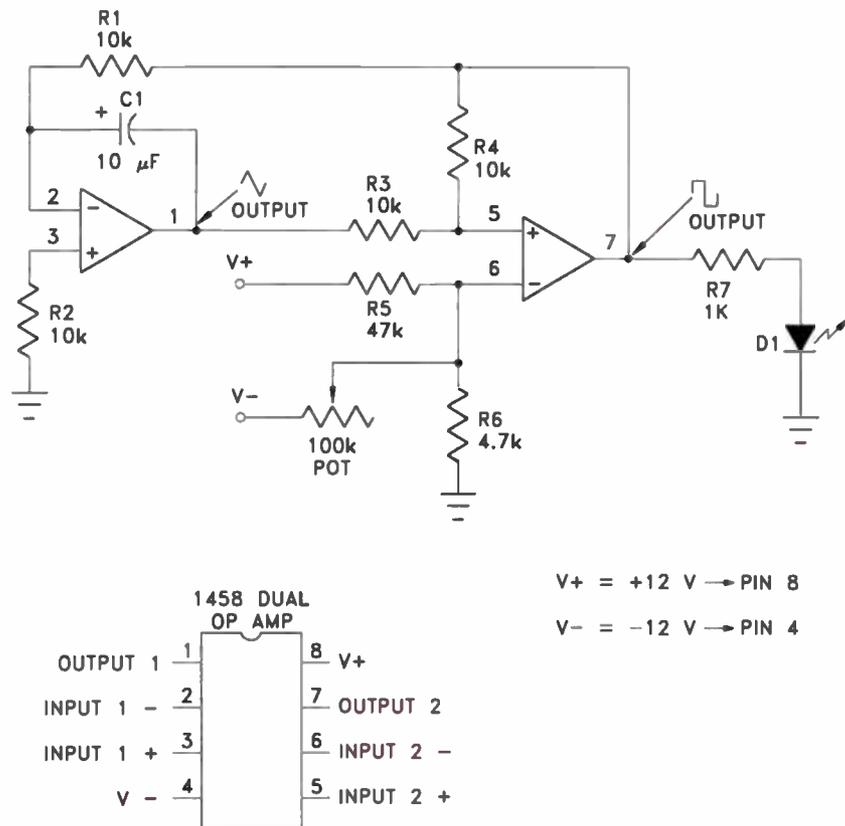
## Procedure

Using your Discovery Lab as a base, construct the circuit shown in schematic form in Figure 10-1, on the next page. This circuit is quite a bit more complex than others you have built so far. Be very careful to make the connections exactly as shown and position the wiring, especially the resistor leads, to avoid short circuits. Wire the components as shown in Figure 10-2, on page 27.

**Step 1.** For your personal safety and that of the equipment, unplug the Discovery Lab's power cord before you make these connections.

**Step 2.** Make sure all wires and components are removed from the breadboard strip. As needed, re-use the cut lengths of solid hook-up wire from previous experiments.

**Step 3.** Connect a 6" piece of hook-up wire from the Discovery Lab's GND terminal to ground point A on the breadboard strip.



**Figure 10-1.** A 1458 dual op amp IC used as a function generator. The integrator is on the left, and the comparator is on the right.

**Step 4.** Connect another 6" piece of hook-up wire from the Discovery Lab's +12 terminal to point B on the breadboard strip.

**Step 5.** Connect another 6" piece of hook-up wire from the Discovery Lab's -12 terminal to point C on the breadboard strip.

**Step 6.** Install the 1458 dual op amp IC on the breadboard strip as shown. Be careful to avoid bending any of the eight leads under the chip.

**Step 7.** Connect a 3" piece of hook-up wire from point B on the breadboard strip to Pin 8 of the 1458 IC.

**Step 8.** Connect another 3" piece of hook-up wire from point C on the breadboard strip to Pin 4 of the 1458 IC.

**Step 9.** Connect a 10k resistor from ground point A on the breadboard strip to Pin 3 of the 1458 IC.

**Step 10.** Connect a 4.7k resistor from ground point A on the breadboard strip to Pin 6 of the 1458 IC.

**Step 11.** Connect a 10k resistor between pins 2 and 7 of the 1458 IC.

**Step 12.** Connect another 10k resistor between pins 5 and 7 of the 1458 IC.

**Step 13.** Connect another 10k resistor between pins 1 and 5 of the 1458 IC.

**Step 14.** Connect a 47k resistor from point B on the breadboard strip to Pin 6 of the 1458 IC.

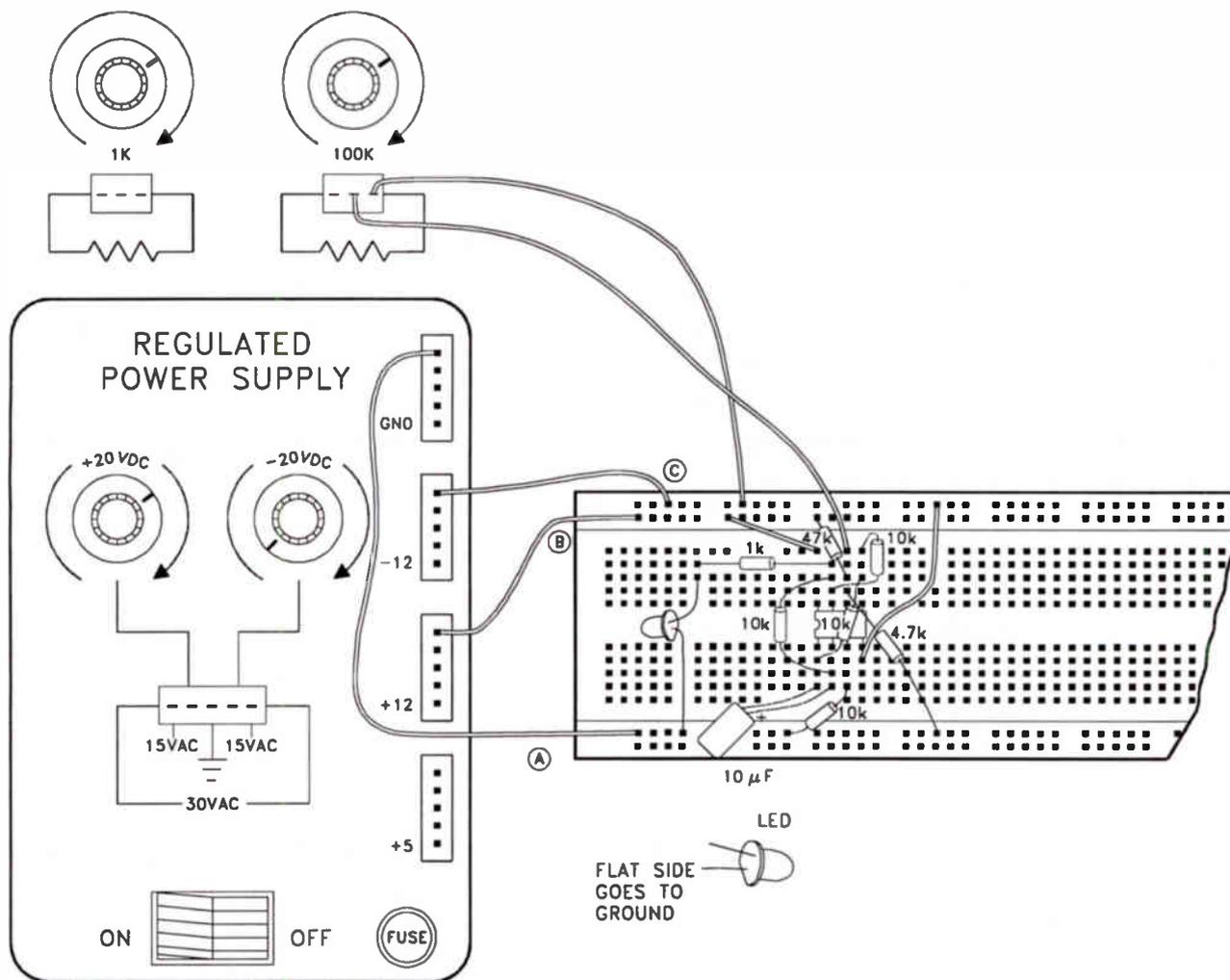


Figure 10-2. Wiring the function generator circuit.

**Step 15.** Connect a 1k resistor from Pin 7 of the 1458 IC to the anode of the LED. Connect the cathode (flat) side of the LED to ground.

**Step 16.** Connect a 10  $\mu$ F capacitor from Pin 1 to Pin 2 of the 1458 IC. The positive (+) lead should connect to Pin 2.

**Step 17.** Connect the center terminal of the 100k pot to Pin 6 of the 1458 IC.

**Step 18.** Connect the right terminal of the 100k pot to point C on the breadboard strip.

**Step 19.** Check your wiring to make sure it is correct and then apply power to the Discovery Lab and turn on its power switch. Rotate the 100k pot from one extreme to another. LED D1 should begin flashing and remain flashing over much of the pot's range. If it doesn't, quickly turn off the Discovery Lab and check your wiring.

**Step 20.** Observe the operation of the flashing LED. The lamp is connected to the function generator's square wave output. Rotate the 100k pot from one extreme to the other and note its effect on the flashing LED. Use your observations to answer Examination Question 10.

**Step 21.** When you finish checking your results, turn off the Discovery Lab and remove the all the wires and components from the breadboard strip.

## Results

You built and tested a basic function generator circuit around a 1458 dual op amp IC. You connected one half of the IC (one complete op amp) as an integrator and the

other half as a comparator. By connecting these two circuits back-to-back, so that the output of each one feeds the input of the other, you formed a function generator circuit.

The output of the integrator circuit is a triangle waveshape, while the output of the comparator is a square wave. The frequency of both outputs is the same. You used an LED indicator to observe the square wave output and to study the result of changing the value of one of the circuit's resistors.



# ANALOG ELECTRONICS

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3. In Step 5 of Experiment 3, when I measured the voltage across  $R_L$  with the filter capacitor connected, I found about:
  - a. +20 V and 0 Vac.
  - b. +20 V and 15 Vac.
  - c. +40 V and 0 Vac.
  - d. +40 V and 30 Vac.
4. In Step 6 of Experiment 4, when I measured the voltage across  $R_L$  with increased input voltage, and with the filter capacitor still connected, I found about:
  - a. +20 V and 0 Vac.
  - b. +20 V and 15 Vac.
  - c. +40 V and 0 Vac.
  - d. +40 V and 30 Vac.
5. In Step 12 of Experiment 5, when I measured the Zener-regulated voltage across the load resistor, I found about:
  - a. +0.7 V.
  - b. +6 V.
  - c. +25 V.
  - d. +50 V.
6. In Step 11 of experiment 6, when I measured the IC-regulated voltage across the load resistor, I found about:
  - a. +0.7 V.
  - b. +5 V.
  - c. +6 V.
  - d. +25 V.
7. In Step 21 of Experiment 7, when I measured the transistor amplifier's output voltage with the 100k pot turned fully clockwise, I found about:
  - a. +1 V.
  - b. +2 V.
  - c. +10 V.
  - d. +20 V.
8. In Step 17 of Experiment 8, when I measured the IC voltage follower's output voltage with the 1k pot turned fully counterclockwise, I found about:
  - a. -12 V.
  - b. 0 V.
  - c. +12 V.
  - d. +20 V.
9. In Step 17 of Experiment 9, when I observed the operation of the two LEDs driven by the multivibrator, I saw that:
  - a. LED D1 was lit when LED D2 was dark, and vice versa.
  - b. Both LEDs flashed on and off together.
  - c. Only LED D1 flashed.
  - d. Only LED D2 flashed.
10. In Step 20 of Experiment 10, when I observed the operation of the LED driven by the function generator, I saw that I could:
  - a. Change the LED's brightness by adjusting the 100k pot.
  - b. Start and stop the oscillation of the function generator by adjusting the 100k pot.
  - c. Not change the oscillator's operation by adjusting the 100k pot.
  - d. Change both the brightness and blinking rate by adjusting the 100k pot.

*Please use this page to record any notes  
you may want to review during your studies.*

# NOTES

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## **NRI** Graduates Say. . .

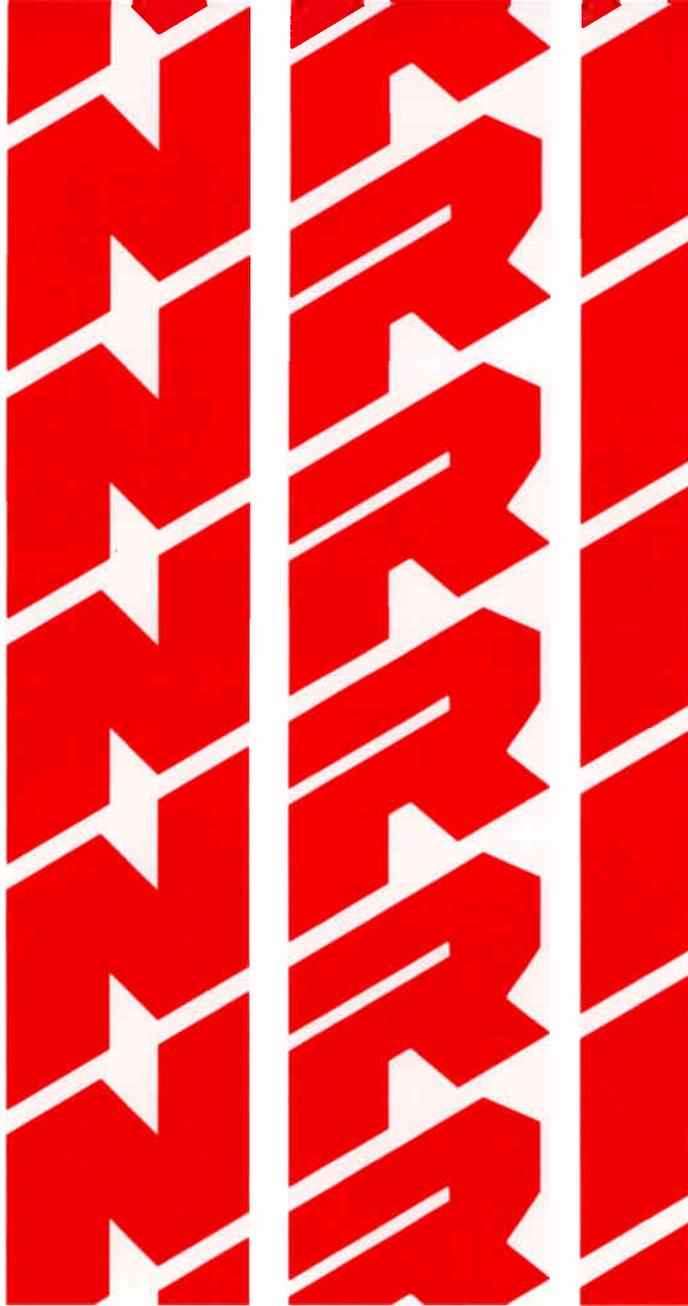
"Through NRI I not only received the experience I was looking for, I also gained the confidence I sought to return to college and upgrade my skills and further my career ambitions. I particularly enjoyed the way you structure the course into smaller sections; it provided me the opportunity to move through the lessons at my own pace without fear of missing something important.

I chose NRI because right from your first correspondence with me I felt as though I had to mail out my application right away. It sounded so exciting, I couldn't wait to get started, which is what I did. I looked forward to each new lesson because it felt so good to read and comprehend almost immediately, and those times I didn't understand, after one or two re-reads, I got it. I only needed the help of an instructor once, but his reply was prompt and clear. I was almost sorry once I had completed the course, but I've since enrolled in college and my studies continue. Would I recommend NRI to others? I already have! I sing your praises often to workmates and I think a couple of them have applied.

So all I can say is thanks to you I am far better off than I was three years ago, and my future looks bright. I'm sure there are many others who feel as I do."

Tyrone J. Leslie  
Groton, Connecticut





# Basic Electronics Experiments

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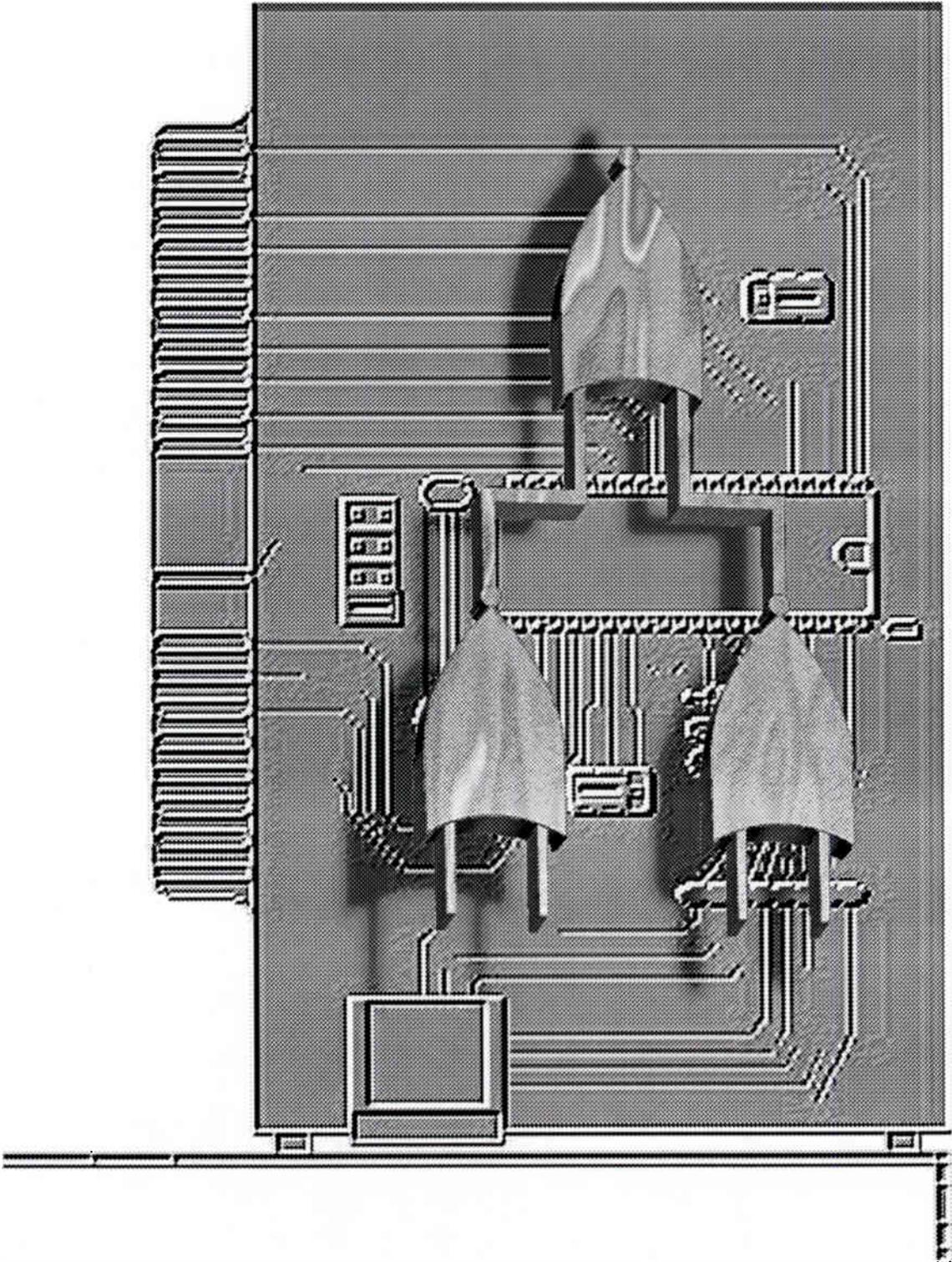
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# Basic Electronics Experiments





# Table of Contents

<b>Overview</b> . . . . .	<b>1</b>
<b>Experiment 1: Kirchhoff's Voltage Law</b> . . . . .	<b>6</b>
<b>Experiment 2: Voltage in a Series-Connected Circuit</b> . . . . .	<b>11</b>
<b>Experiment 3: Voltage Polarity</b> . . . . .	<b>16</b>
<b>Experiment 4: Measuring Voltage to Determine Current</b> . . . . .	<b>20</b>
<b>Experiment 5: Series Voltage Dividers</b> . . . . .	<b>24</b>
<b>Experiment 6: Electrical Power</b> . . . . .	<b>28</b>
<b>Preparing for Experiments 7–9</b> . . . . .	<b>32</b>
<b>Experiment 7: Using an Ohmmeter</b> . . . . .	<b>34</b>
<b>Experiment 8: Circuit Continuity</b> . . . . .	<b>36</b>
<b>Experiment 9: Parallel Resistance</b> . . . . .	<b>39</b>
<b>Experiment 10: Charging and Discharging Capacitors</b> . . . . .	<b>42</b>
<b>Experiment 11: Basic Coil Action</b> . . . . .	<b>45</b>
<b>Experiment 12 : Transistor Operation</b> . . . . .	<b>48</b>
<b>Examination Questions</b> . . . . .	<b>53</b>



## Objectives

*Upon completion of this lesson you will:*

- Configure components using schematic diagrams and measure the voltage, resistance, and current within the circuits.
- Determine open and shorted components using a multimeter.
- Configure components in a circuit to observe effects of a bleeder resistor.
- Determine the power factors of a circuit by taking appropriate measurements throughout the circuit.
- Determine best range to use when measuring resistance with an ohmmeter.
- Determine the status of a transistor as it operates within a circuit.

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# Overview

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This training manual contains your digital multimeter, complete with test leads, operating manual, and electronic parts to be used in the experiments. Your first step in performing the experiments is to study the section in this manual on using the digital multimeter. If you are already familiar with digital multimeters, the information and instructions provided will serve as a review.

This training manual features practical experiments that demonstrate some of the electronic fundamentals discussed in your lessons. Each experiment is an actual working demonstration. The principal objective of this training manual is to provide you with hands-on experience that illustrates basic electronic concepts. Another goal is to develop your ability to visualize a circuit and wire it using only a schematic diagram as your guide.

As you perform each experiment, try to understand what happens in the circuit. For example, if an LED (light-emitting diode) glows brighter when you change the amount of resistance in a circuit, what basic circuit characteristic changed and why? Did the applied voltage change? Did the current change? Does the circuit configuration also affect the result? If you learn to ask yourself these types of analytical questions, you can

gain a better understanding of electronics and electronics troubleshooting.

The best way to complete this training manual is to perform each experiment in sequence. Don't hurry to finish any experiment, even if you feel you already know what the results will be. We also encourage you to review your regular lesson materials for additional information on each subject discussed in this manual.

This training manual also contains a soldering project, the purpose of which is to provide you with soldering practice. You may assemble your soldering project whenever you like. However, most students prefer to wait until they have completed all of the experiments in this training manual before they work on the soldering project.

## Preparing for the Experiments

You will build circuits with resistors, capacitors, a transistor, LEDs, and a coil. Nine-volt batteries (included) supply power for the breadboard on which you will connect the circuits. The battery clip leads and the coil leads are stranded wire. They don't plug into the breadboard easily. To make attaching the

# BASIC ELECTRONICS EXPERIMENTS

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stranded-wire leads easier, solder a length of hook-up wire to them. Since hook-up wire is solid, it can be inserted easily into the holes of the breadboard socket.

Cut three pieces of white hook-up wire and three pieces of black hook-up wire in 3" lengths. Strip  $\frac{1}{4}$ " of insulation from the ends of these wires. Also strip  $\frac{1}{4}$ " of insulation from the battery clip and coil leads. Splice the black hook-up wire pieces with the black leads of the battery clips and the white hook-up wire to the red leads. Solder these joints together as shown in Figure 1.

Solder the remaining black and white wire pieces to the leads of the coil. Since the coil is not polarized, it makes no difference what color hook-up wire you use for each lead.

## Using the Breadboard Socket

You will build the experimental circuits on a breadboard that is similar to the breadboard shown in Figure 2 on the next page. A breadboard provides a large number of multipin wire-sockets that allow you to connect

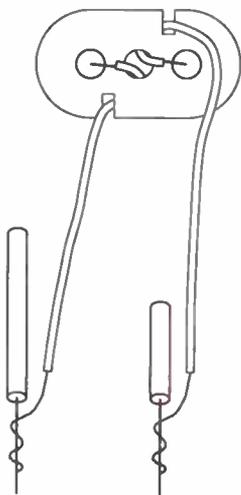


Figure 1. Splice hook-up wire to the leads of the battery clip.

electronic circuit components together without using solder. The design of the breadboard also lets you add or change components easily.

On the breadboard, notice the two rows at the top and bottom labeled with a + and - sign. The wire-sockets in each of these four rows are connected. This type of connection is called a bus, and it comes in handy for convenient connections to power supply voltages. Each hole in the top row (blue) is connected to every other hole in the row. Likewise, all the holes in the second row (red) are connected to each other. The red and blue rows, however, are not connected to each other. You could, for example, connect the positive and negative leads from a battery to the red and blue rows and have access to voltage along the length of the breadboard.

Refer to Figure 3 on the next page. The center section of the breadboard holds 126 five-slot connectors, arranged in two rows of 63 connectors each. Each of the five-hole columns is separate from the others, but the five holes in each one are connected. In fact, the back side of the breadboard is a collection of slots, each filled with a conductive spring-clip that covers five holes. Most of your experiments will use the center section of the breadboard, while power supply (battery) connections typically insert into the blue and red buses.

## Using Your Digital Multimeter (DMM)

Your DMM has multiple functions, plus a diode test position. It can measure AC and DC voltages and AC and DC current, as well as resistance. The rotary switch in the center of the DMM selects all functions and ranges.

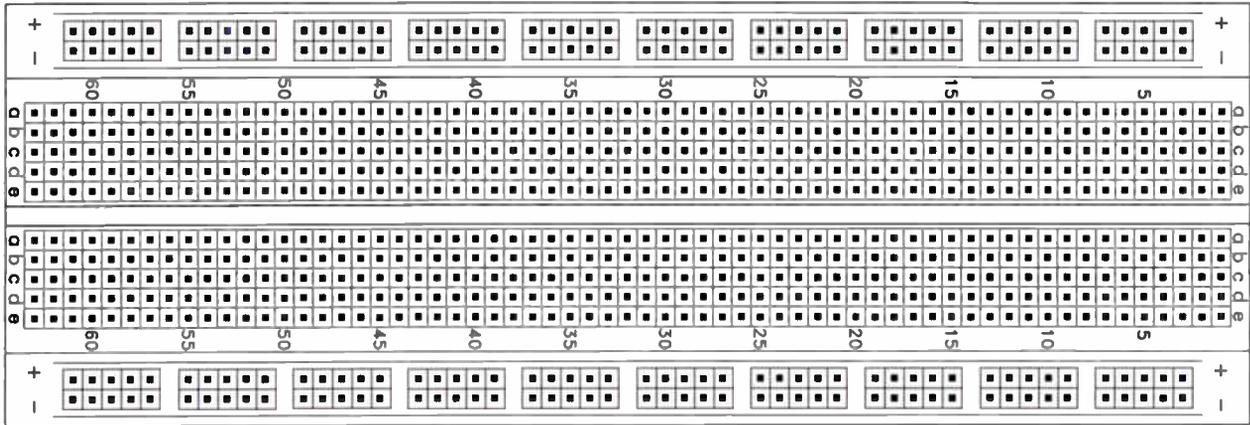


Figure 2. The breadboard socket used during these experiments.

Typically, when the rotary function switch is pointing in the vertical position (or 12 o'clock), the DMM is in the OFF position.

In a clockwise direction from the OFF position (roughly 12 to 5 o'clock) are the voltage functions. Moving in a counterclockwise direction are the resistance and diode test functions (roughly 9 to 12 o'clock). The current functions are found between the other two function areas (approximately 5 to 9 o'clock). On some models a separate switch might be used to select the proper AC or DC function.

However, the rotary switch is used to select AC or DC functions on this model. Each function may have three to five ranges, depending upon the meter design.

Some multimeters have a capacitance function, but it is not included with this particular model. One of the unique features is being able to test NPN and PNP transistors using an visual indication or audible tone to indicate a good test.

Test lead jacks are usually are located on the bottom of the DMM. One jack is marked

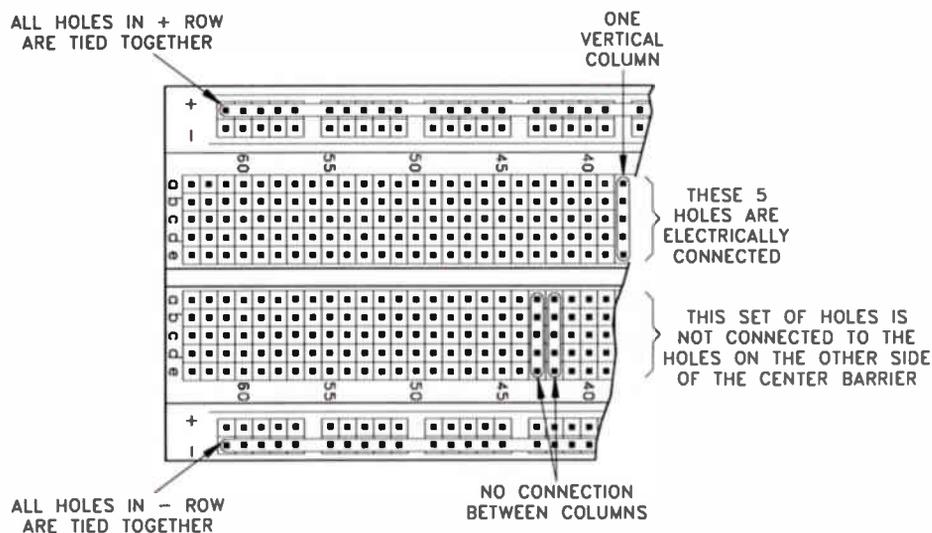


Figure 3. The breadboard socket is designed to provide a method of connecting components without soldering.

# BASIC ELECTRONICS EXPERIMENTS

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COM. This is the common jack; it is used for all types of measurements. This jack is often referred to as the ground or negative jack. Normally, you will plug the black test lead into this jack. The black test lead remains in this jack when taking voltage, current, and resistance measurements.

A jack marked  $V/\Omega$  is used for both DC and AC voltage measurements and resistance measurements. The V represents voltage, and the  $\Omega$  represents resistance. When the voltage and resistance measurement functions are used, the red test lead is plugged into this jack.

The jack marked mA is used for both DC and AC current measurements between 0 and 200 milliamps (mA). There is also a jack marked A which is used for both DC and AC current measurements between 200 milliamps (mA) and 20 amps (20 A). When you are going to use the DMM to measure current, initially you should keep the black lead in the COM jack and plug the red lead into the A jack. This is a safety precaution when measuring current, especially when it is unknown. Thereafter, to measure current that is known to be lower than 200 mA, plug the red test lead into the mA jack.

The best way to become familiar with your DMM is by using it. In this training manual, you will be instructed to take DC voltage and DC current measurements. You also will take resistance measurements. In the next training manual, you will learn how to use the AC voltage ranges of the DMM. The procedures for measuring AC current are rarely used, and will not be covered in this course. However, please note that current measurement procedures are the same for both AC and DC. In the early experiments, as you are learning how to use your DMM, you will be informed

of how to set the range switch for voltage and/or current measurements. With practice, you should be able to determine for yourself the proper range to use.

There is one safety procedure that must be followed when measuring unknown voltages or currents. *You should always start with the highest range to avoid damage to the meter.* The meter has a built-in fuse that is designed to protect it, but it is possible to damage the meter before this fuse blows.

For example, suppose you want to measure an unknown dc voltage. You should set the range switch to the highest volt range on the DCV function. Let's say that the highest range is 1,000 volts. If the reading you get on the meter indicates that the voltage is substantially less than 1,000 V, then you can switch to the next lowest position that does not cause an overload indication. By using this procedure, you will avoid the possibility of damaging the meter. If you start out measuring the voltage on the 200 V position, for example, and the voltage is very high perhaps 700 or 800 V you could damage the meter. But if you start off on the highest DCV position, you'll see that the voltage is high and know that you should not switch the range switch to a lower voltage position.

The same is true when taking current measurements. Start in the highest current position and switch to a lower range if you see that the current is much lower than the range selected.

This is only preliminary information on your DMM. You will learn more about your DMM and how to use each function as you perform the experiments. We recommend that you do not use the DMM for any measurements other than those in the experiments until after

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you have completed this training manual. By that time, you will have had sufficient instruction on how to use each function of the meter. These instructions will reduce the possibility of accidental damage to the meter due to incorrect use.

## Performing the Experiments

In performing your experiments, be sure to follow these steps:

**Step 1.** Read the entire experiment and pay particular attention to the discussion of the experiment.

**Step 2.** Perform the experimental procedure and each step of the experiment exactly as directed. Record your results in the charts or tables provided for that purpose.

**Step 3.** Study the discussion of the experiment and analyze your results. If they do not seem to be right, repeat the measurements to make sure that you did not make a mistake. Do not move on to the next experiment until you get the desired results.

**Step 4.** You will notice instructions to turn off the DMM at the end of many of the experiments. However, it is not necessary to turn off the instrument if you are going to perform more than one experiment without stopping. The DMM draws so little current that the battery usually will last a year or more before

needing replacement. These instructions are given as a reminder. Turn off the DMM after you have performed all of the experiments that you are planning to do at one time.

The experiments in this manual will familiarize you with the operation of your digital multimeter (DMM). At the same time, you will learn the causes of incorrect voltage and resistance measurements in electronic circuits.

You are now ready to begin learning how to troubleshoot with a DMM. Keep in mind that taking measurements is only the beginning. What you can do with the results of your measurements is what really counts.

The DMM supplied in this kit is a very reliable and accurate servicing instrument. It was designed by service engineers for the service expert. Learn to use it properly, and it will be your most powerful tool. It will give you information quickly and accurately. Your regular lessons in conjunction with these experiments will teach you how to apply this information.

**Caution:** Your DMM has a fuse that provides built-in protection against an accidental overload. However, it is still possible to damage your meter. Be sure that you read the instructions carefully and fully understand them before proceeding with the experiments. These precautions will eliminate the possibility of an accident that could result in serious damage or injury.

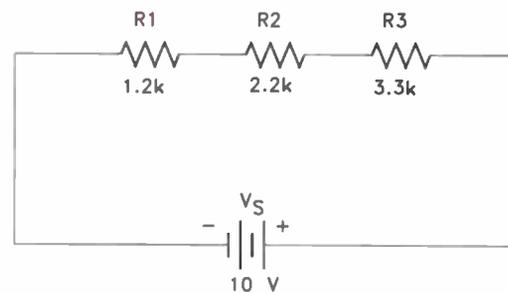
# Experiment 1: Kirchhoff's Voltage Law

## Introduction

The source voltage across a series of resistors causes current to flow through the resistors. This current produces a voltage drop across each resistor. Regardless of how many resistors are used in the circuit, each one will have a voltage drop across it that is related to the current and resistance. The higher the resistance, the more voltage is required to push current through it.

In your regular lessons, you learned about Kirchhoff's voltage law. This law states that the sum of the voltage drops around any closed circuit equals the source voltage. Consider the circuit shown in Figure 1-1. By dividing the source voltage (10 V) by the total circuit resistance (6.7k), we find that the current flow in this circuit is 1.49 milliamps. Once we determine the current, we can prove Kirchhoff's voltage law by calculating the voltage across each resistor and then adding these values together. The total should equal the source voltage.

Modern digital multimeters have a very high and constant input resistance. This high



$$R_T = R_1 + R_2 + R_3 = 6.7k$$

$$I_T = \frac{V_S}{R_T} = 1.49 \text{ mA}$$

$$V_{R1} = I_T \times R_1 = 1.79 \text{ V}$$

$$V_{R2} = I_T \times R_2 = 3.28 \text{ V}$$

$$V_{R3} = I_T \times R_3 = 4.93 \text{ V}$$

$$V_S = V_{R1} + V_{R2} + V_{R3} = 10 \text{ V}$$

Figure 1-1. Applying Kirchhoff's law to a simple series circuit.

input resistance means that the total resistance you are connecting across the circuit will not affect the circuit, regardless of the meter range you are using. Thus, voltage readings in low-voltage circuits are much more accurate. However, even this meter can upset the voltage distribution in very high-resistance circuits.

## Materials Needed

In this experiment, you will need:

Breadboarding socket

Digital multimeter

- 1 9 V battery with the battery clip attached
- 1 10k resistor
- 1 100k resistor
- 1 470k resistor
- 1 1M resistor
- 2 10M resistors

## Procedure

If you need to do so, install the battery that was supplied with the DMM. Also, plug the black meter lead into the jack marked COM and the red lead into the jack marked V.

In this experiment, you will breadboard a simple series circuit and use your DMM to measure the voltages in the circuit. Begin by wiring the circuit in Figure 1-2. A pictorial of how the circuit might be arranged is shown in Figure 1-3, on the next page. When you have finished, turn the DMM selector switch to 20-V DC.

**Step 1.** To measure the source voltage, touch the black lead of your meter to the junction of R1 and the negative lead of the battery. Touch the red lead to the junction of R3 and the positive lead of the battery. Record your reading for Step 1 in Table 1-1, on the next page.

**Step 2.** Measure the voltage drop across R1 (10k) by touching the black lead of your DMM to the end of R1 that connects to the negative terminal of the battery and the red lead to the junction between R1 and R2. Record your reading for Step 2 in Table 1-1.

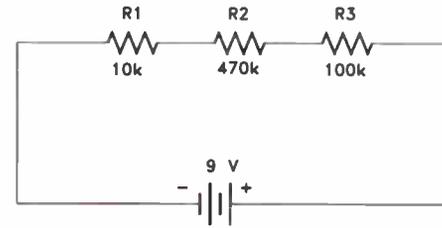


Figure 1-2. Schematic of the series circuit for Experiment 1.

**Step 3.** Measure the voltage drops across R2 (470k). Reposition the black lead of your DMM to the junction of R1 and R2 and touch the red lead to the junction between R2 and R3. Record your reading for the voltage across R2 in Table 1-1.

**Step 4.** Lastly, you will measure the voltage drop across R3 (100k). Move the black lead to the junction of R2 and R3 and touch the red lead to the junction between R3 and the positive terminal of the battery. Record your measurement in Table 1-1. Now, Total the voltage drops you measured across R1, R2, and R3 and compare this value to the source voltage you recorded in Table 1-1. How does the sum of the voltage drops compare to the source voltage you measured in Step 1?

**Step 5.** Wire the circuit shown in Figures 1-4, on the next page, on your breadboard socket. Be sure to connect R2 in parallel with R3, and one end of R1 to the junction of R2 and R3. A pictorial is provided in Figure 1-5, on page 9.

**Step 6.** Measure the source voltage by touching the black lead of your DMM to the negative terminal of the battery and the red lead to the positive terminal of the battery. Record your measurement in Table 1-2.

**Step 7.** Measure and record the voltage drops across each resistor like you did in Steps 2–4. Notice that the voltage drop across R2 and R3 is the same, even though the

# BASIC ELECTRONICS EXPERIMENTS

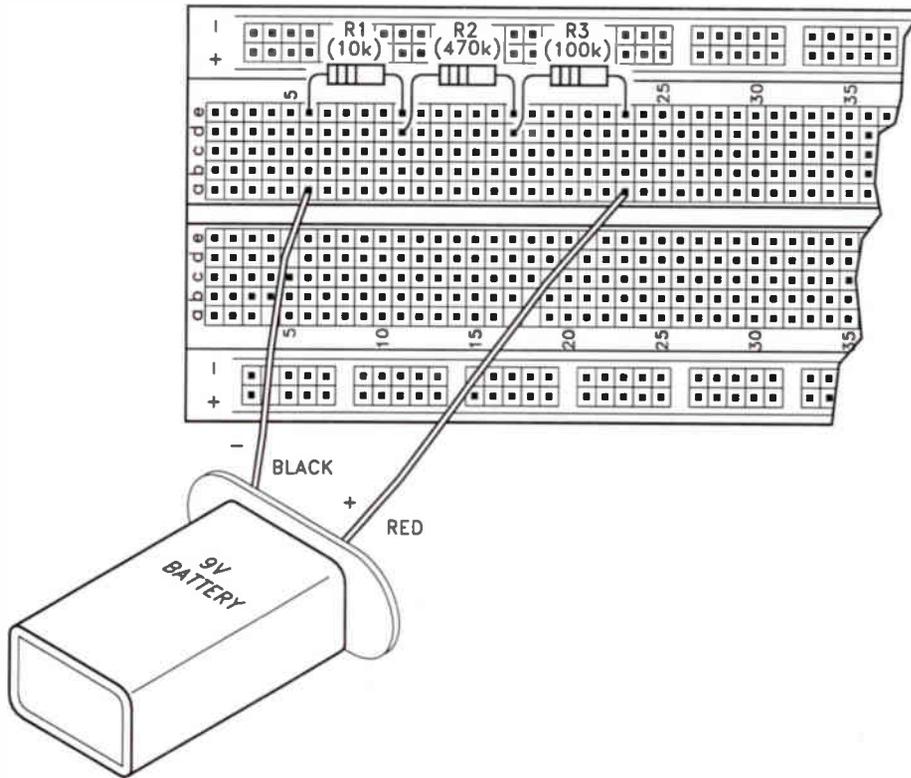


Figure 1-3. An illustration of the circuit for Steps 1 and 2.

resistance of R2 is different from R3. When a voltage source is equally applied across two or more electronic components, the components are said to be in parallel.

Also, notice that the voltage across R1 is greater in this experiment than it was in the series circuit using the same resistors. Unlike a series circuit, the more components we add to a parallel circuit, the more source current will flow in the circuit. That's because

in a parallel circuit, the total resistance decreases as you add more components to the parallel network. The higher voltage across R1 is an indication that the total source current is higher.

When you measure the voltage across a component, the meter's internal resistance is placed in parallel with it. Like any other parallel combination, the combined resistance

Step 1	Source Voltage	
Step 2	Voltage Drop Across R1	
Step 3	Voltage Drop Across R2	
Step 4	Voltage Drop Across R3	
Sum of Voltage Drops		

Table 1-1. Record your readings for the circuit in Figure 1-1 here.

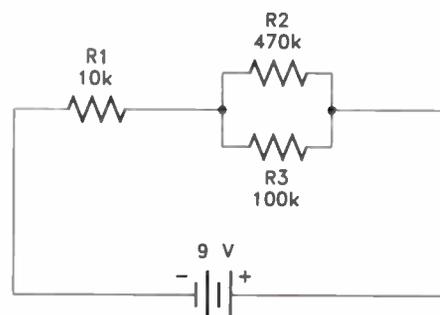


Figure 1-4. Kirchhoff's voltage law also applies to combinational-combinational circuits.

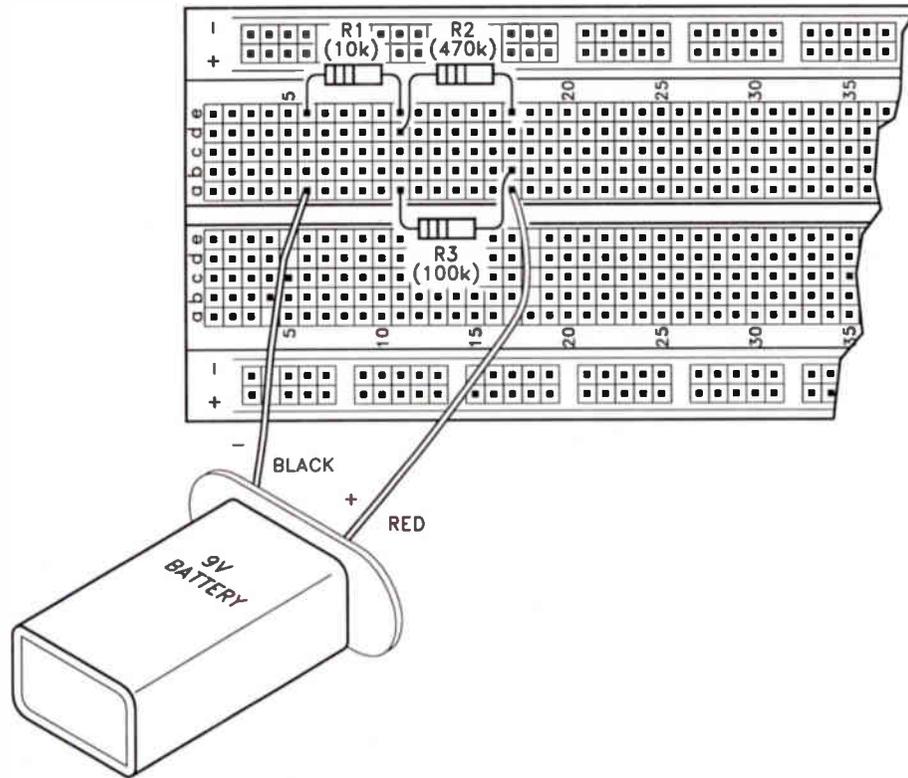


Figure 1-5. An illustration of the circuit for Step 3.

is less than the internal resistance of the meter or the resistance of the component. As long as the resistance of the component is substantially smaller than the internal resistance of the meter, you'll get accurate readings. But, if the resistance of the component is extremely high, the combined internal resistance of the meter and the resistance of the component could cause an inaccurate reading. In this case, we say that the meter loads down the component. To demonstrate,

reconstruct the circuit shown in Figure 1-2 on page 7, using two 10M resistors and one 1M resistor.

Repeat steps 1 through 4 and notice that the sum of the individual voltage drops does not equal the source voltage. This proves that measurement errors can occur in very-high-resistance circuits. Fortunately, circuits with this much resistance are rare, but they do exist. Disconnect the battery from your circuit.

Step 6	Source Voltage	
Step 7	Voltage Drop Across R1	
	Voltage Drop Across R2	
	Voltage Drop Across R3	
	Sum of Voltage Drops ( $V_1 + V_2$ or $V_3$ )	

Table 1-2. Record your results for Step 3 here.

## Results

In this experiment, you proved that in a series circuit the sum of the voltage drops across the individual components is equal to the source voltage.

# BASIC ELECTRONICS EXPERIMENTS

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When you connect your meter across a resistor, you are adding the resistance of the meter in parallel with the resistance of the resistor. This changes the resistance in the circuit slightly. Your meter has an internal resistance of around 22 megohms. When you connected it across the 100k resistor, the resistance of the parallel combination became 99,548 ohms. You saw that the change is small it was less than 500 ohms, which is less than 0.5 percent. This small change means that the voltage reading you'll get will be quite accurate.

Years ago, service technicians used meters that had a sensitivity of 20,000 ohms per

volt. Thus, on a 5 V range, a meter of this type will have a total resistance of 100,000 ohms. If you use this type of meter and connect it across the 100k resistors in this experiment, you would change the resistance to 50k. The resulting voltage reading you would get would be quite inaccurate.

This experiment demonstrates the value of a high-resistance meter in voltage measurements, particularly in low-voltage circuits. However, even this meter can cause erroneous measurements in high-resistance circuits.

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# Experiment 2: Voltage in a Series-Connected Circuit

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## Introduction

You know from the experiments you have already performed that when current flows through a resistance, there is always a voltage drop across the resistance. You also know that current flows only in a circuit with continuity.

*Continuity*, as used in electronics, refers to the completeness of the path through which current flows. If there is no continuity, or, in other words, if the path is broken at some point, current cannot flow. These facts are of great importance to the technician. They are used constantly in troubleshooting.

A complete circuit has a voltage source, one or more parts through which current can flow, and wires or leads that connect parts together and to the voltage source. The parts in the circuit do not necessarily have to be resistors. However, all parts through which current is able to flow have some resistance. Examples of other parts are coils, transformers, and transistors. The fact that such parts have some resistance means that there will be a voltage drop across each part when it is connected in a circuit with a voltage source.

Certain defects are evident when the voltage drop at some point in a circuit is either

too high or too low. You can get a fairly good idea of what the voltage drop in each part of the circuit should be by looking at the schematic diagram. For example, if there are three resistors having the same resistance in a series circuit, you should find that the voltage drop across each of the resistors is equal to about one-third of the source voltage. On the other hand, if one very high resistance is in series with one or more low resistances, then the voltage drop across the high resistance will be very nearly equal to the source voltage, and the voltage drop across the low resistance will be almost zero.

If there is no voltage drop across one part in a circuit but there is a voltage drop across the other parts, there must be a short circuit, or a path with no resistance, across the part with no voltage drop. Thus, the current flows through the short circuit rather than through the part. Because the resistance is essentially zero through the short, there is no voltage drop across it.

If you measure the whole source voltage across a part in a series circuit, you can assume that the part is open (will not pass current). The full source voltage across the part indicates that there is no voltage across the other parts in the circuit and therefore no

# BASIC ELECTRONICS EXPERIMENTS

current flowing through them. The break is in the part across which you measured the source voltage. You will investigate these conditions in this experiment so that when you come across them in service work, you will know what to expect.

## Materials Needed

To perform this experiment you will need:

- Breadboarding socket
- Digital multimeter
- 1 9 V battery with the battery clip attached
- 2 1k resistors
- 1 2.2k resistor
- 1 10k resistor
- Hook-up wire

## Procedure

Begin by cutting two pieces of wire about 2" long and removing about  $\frac{1}{2}$ " of the insulation from both ends of each wire. Twist the two wires together as shown in Figure 2-1. When the top portion is connected as shown, the twisted pair will be used to simulate a shorted resistor. When the top is untwisted, the twisted pair will be used to simulate an open resistor.

Now construct the circuit shown in Figure 2-2. Your wiring should look something like the illustration in Figure 2-3.

**Step 1.** Examine Figure 2-2. Notice that R1, R2, and R3 form a series circuit and are connected across the 9 V battery. R4 is *not* in the circuit.

Put the DMM on the 20 V DC range and measure the source voltage. The black lead

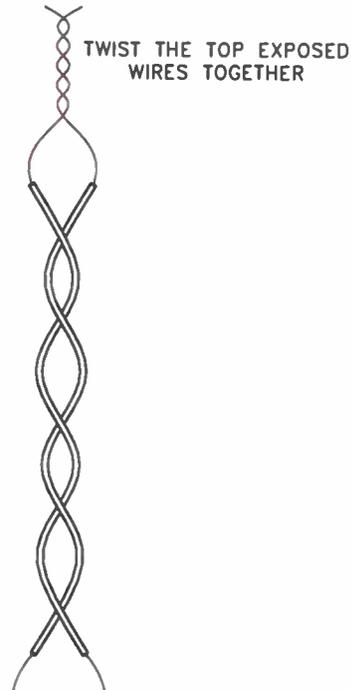


Figure 2-1. Illustration of a twisted pair of wires.

from your DMM should connect to the negative terminal of the battery, and the red meter lead should connect to the positive battery terminal. Record your reading in the Normal Resistance column of Table 2-1.

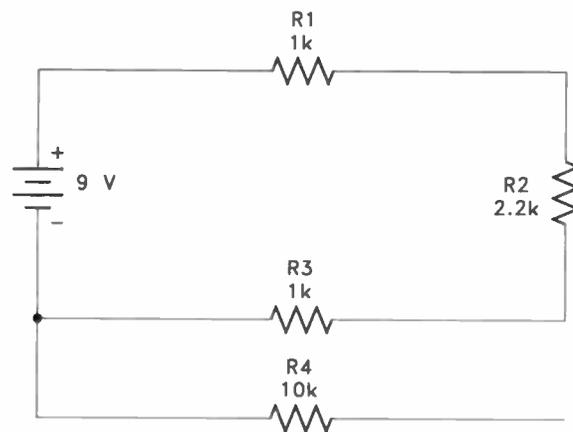


Figure 2-2. Schematic of the circuit for Experiment 2.

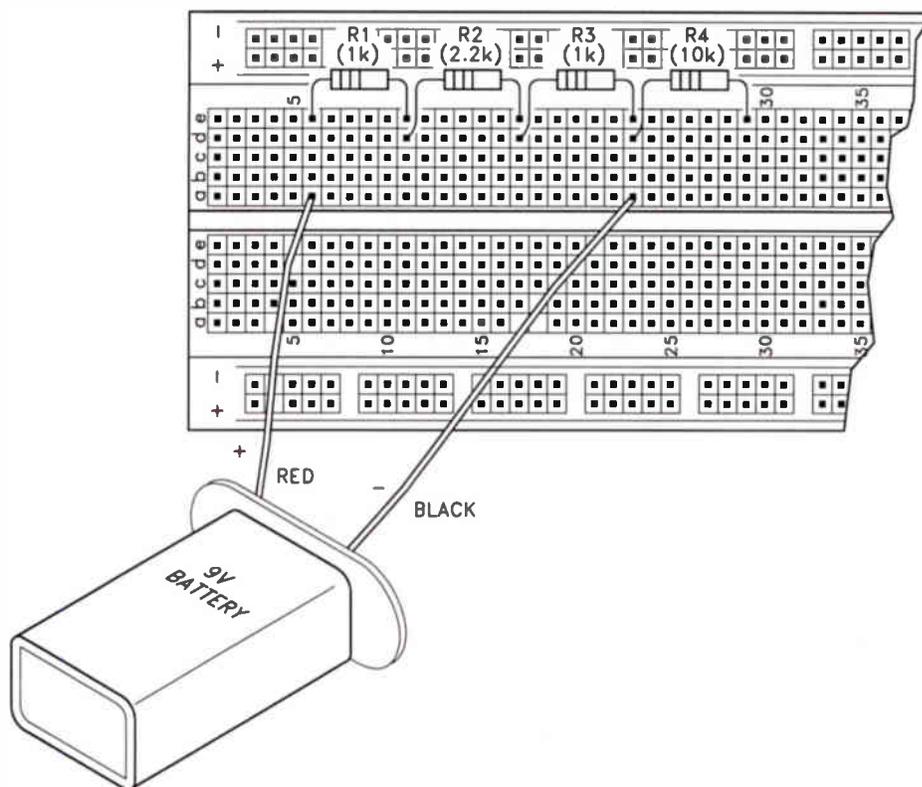


Figure 2-3. Pictorial of the circuit for Experiment 2.

**Step 2.** Next, measure the voltage drop across R1, R2, and R3 and record these voltages in Table 2-1. Remember, the end of a resistor where electrons enter will be negative with respect to the other end of the same resistor. For example, to measure the voltage across R2, touch the black lead of your DMM to the end of R2 that is closest to the negative terminal of the battery, and touch the red lead to the other end of R2.

Voltage Measured	Normal Resistance	R2 Shorted	R2 Open
Across R1			
Across R2			
Across R3			

Table 2-1. Record your results for Experiment 2 here.

**Step 3.** Notice that a voltage drop developed across R1, R2, and R3. These voltages indicate that current is flowing through each part. Now measure the voltage across R4. You'll get a 0 V reading indicating that there is no current flowing through this part.

**Step 4.** Remove R2 and replace it with the twisted wire pair which you prepared earlier. The twisted pair simulates a shorted-out resistor. Now measure the voltage drop across R1, R2, and R3 and record your reading in Table 2-1 under R2 Shorted. You should discover that there are voltage drops across R1 and R3, with 0 volts across R2. This indicates that R2 is shorted out of the circuit.

Short circuits usually increase the current flow in a circuit. This is why you should have noticed an increase in the voltage drops across R1 and R3. The power sources in most equipment are protected so that when

# BASIC ELECTRONICS EXPERIMENTS

the current exceeds a predetermined level, the power source shuts off, thereby protecting the equipment from further damage.

**Step 5.** With the twisted pair still connected to the breadboard socket, untwist the top portion as shown in Figure 2-4. The twisted pair now simulates a burned-out resistor. Again, measure the voltage across R1, R2, and R3. Record your readings in Table 2-1 under R2 Open.

For this step, you should get 0 V readings across R1 and R3 and the full source voltage across R2. Can you explain why? Remove the simulated burned-out resistor and save it for later use. Reconnect the 2.2k resistor back in the circuit for R2.

**Step 6.** In Step 3 of this experiment, you found that there was no voltage drop across resistor R4. Notice that one end of R3 and one end of R4 connect to the negative terminal of

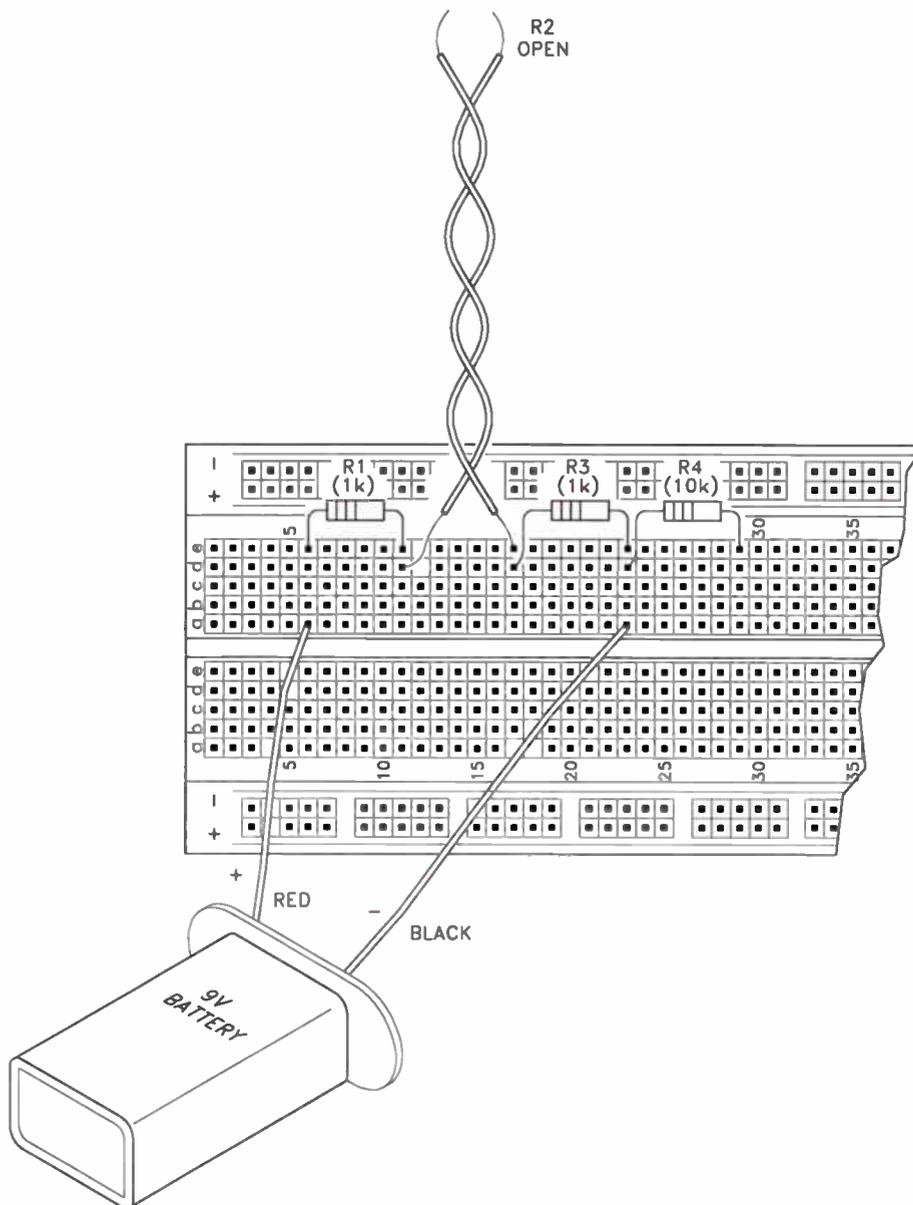


Figure 2-4. A circuit using the simulated “open” resistor.

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the battery. Thus, the ends of these two resistors are at the same potential. Connect the black lead of your DMM to the end of R3 that is connected to the negative terminal of the battery. This connection also connects the black lead from the DMM to one end of R4.

Touch the red lead of the meter to the free end of R4. Once again, you should get a 0 V reading. Now connect the red lead to the end of R3 that is connected to R2. Make a mental note of the voltage reading. Leaving the red lead still connected to the junction of R2 and R3, connect the black meter lead to the free end of R4 and observe what happens. You should measure the same voltage. Disconnect the battery from the circuit.

This experiment shows that there is no voltage drop across R4, but there is continuity through it. If there had been no continuity, with the black lead connected to the free end of R4, you would have measured 0 V at the junction of R2 and R3.

## Results

This experiment demonstrates four important facts:

1. If current flows through a circuit, there will be a voltage drop across all parts not shorted in the circuit.
2. If one part in a complete circuit has no voltage drop across it, but there are voltage drops across all other parts, the part with no voltage drop is shorted. The short may be in the part itself or in some other parallel part.
3. If in a circuit that should be complete, you find full source voltage across one part and no voltage across the other part, the part with full source voltage across it is open.
4. If there is no voltage drop across a part, but one lead of the part connects to an operating circuit, both ends of the part will be at the same potential with respect to all other parts in the circuit.

## Experiment 3: Voltage Polarity

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### Introduction

Many of the expressions used in electronics servicing do not make sense to beginners until they are used in practical work. One expression that often causes confusion is positive or negative with respect to. This expression means that a point in a circuit is at a positive or negative potential compared to the potential at some other point in the circuit. For example, we may say that the drain of a field-effect transistor is 10 V positive. This statement has no real meaning because a point by itself cannot have a voltage.

*Voltage* is defined as a potential difference between two points. Thus, when we say that there are 10 V at the drain of an FET, we mean that there is a potential difference of 10 V between the drain and a reference point.

Using Figure 3-1, let's suppose that the source of the FET is the reference point. Thus, you can say that the drain is positive with respect to the source. If the drain is your reference point, then you would label the source as negative with respect to the drain. At the same time, the gate is negative with respect to the source, and the source is positive with respect to the gate. Thus, depending on

the reference points we select, the source can be seen as positive or negative.

In this experiment you will use resistors and a 9 V battery supply to determine polarity.

Another term that often causes confusion is ground. In most circuits, ground is simply a common reference point. Thus, in Figure 3-1, we say that the drain is positive with respect to ground. Schematic symbols used for ground connections are shown in Figure 3-2. Very often, the metal chassis provides an electrical return path back to one side (usually the negative side) of the power supply. In this case, any one of the ground symbols might be used. An automobile is a good example of a

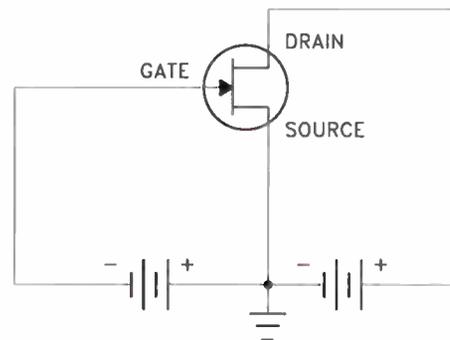


Figure 3-1. A field-effect transistor with batteries for drain-source and gate-source biasing.

chassis ground system. In most cars, all wiring is at some positive level with respect to the chassis.

An earth ground also provides a common return path back to one side of the power supply. In addition, it provides a degree of protection from shock hazards if the equipment is defective. Polarized plugs often are used to ensure the proper connection of earth-grounded equipment. A common tie point is like a chassis ground, except that terminal lugs are used in place of a metal chassis. If a metal chassis is used, only certain areas serve as return paths.

## Materials Needed

To perform this experiment, in addition to the 9 volt battery, the breadboard socket, and your DMM, you will need the following:

- 1 2.2k resistor
- 1 4.7k resistor
- 1 10k resistor

## Procedure

For this experiment, you will construct the circuit shown in Figure 3-3. An illustration of this circuit is shown in Figure 3-4, on the

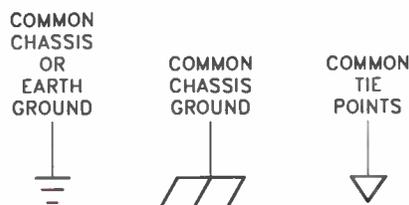


Figure 3-2. Schematic symbols for ground.

next page. For convenience, we have numbered the junction of R1 and the negative lead from the battery as Terminal 1, the junction of R1 and R2 as Terminal 2, and so on. We've also shown the negative terminal of the battery in Figure 3-4 going to ground. In an actual circuit, this might be a connection to the metal chassis or to the foil around the perimeter of a PC board.

In this experiment, the black lead from your DMM will be connected to Terminal 3, the junction of the 4.7k and 10k resistors (R2 and R3). Turn the range switch on the DMM to the 20 V DC range and proceed with the following steps.

**Step 1.** With the black lead from the DMM on Terminal 3, touch the red lead to Terminal 1. Record the polarity and the voltage in Table 3-1.

**Step 2.** With the black lead from the DMM still on Terminal 3, touch the red lead to Terminal 2. Record the polarity and voltage in Table 3-1.

**Step 3.** With the black lead still on Terminal 3, touch the red lead to Terminal 4. Record the polarity and voltage in Table 3-1.

**Step 4.** You already know the voltage and polarity of Terminal 1 with respect to Terminal 3. You determined these values in Step 1

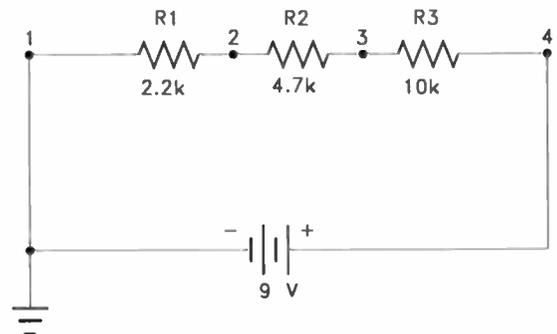


Figure 3-3. The circuit for Experiment 3.

# BASIC ELECTRONICS EXPERIMENTS

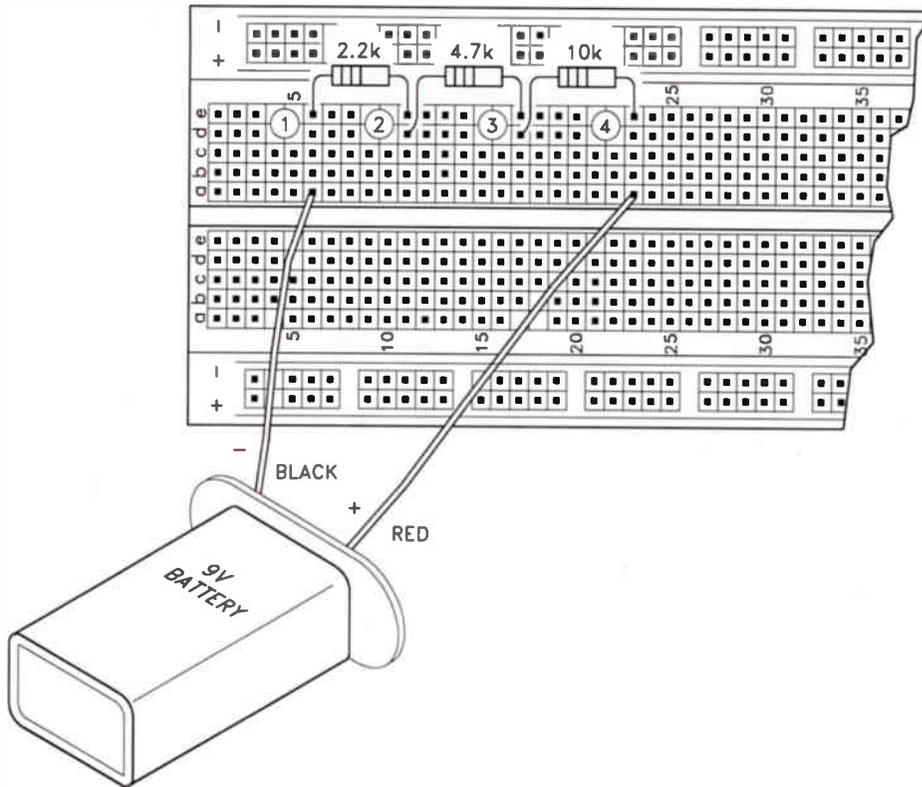


Figure 3-4. An illustration of the circuit for Experiment 3.

of the experiment. To test your understanding of this subject, fill in the following statement. Perform whatever measurements are necessary in order to complete the statement. Your response to this statement will help you to answer one of the exam questions at the end of this manual.

The voltage on Terminal 3 is \_\_\_\_\_ with respect to Terminal 1, and \_\_\_\_\_ (the same as, greater than, or less than) the voltage measured in Step 1.

Terminal	Polarity	Voltage
1		
2		
4		

Table 3-1. Record your results for Experiment 3 here.

**Step 5.** When you are finished, turn off the DMM and unplug the battery from the breadboard socket.

## Results

In Steps 1 and 2, you should have discovered that the voltages on Terminals 1 and 2 were negative with respect to Terminal 3. Your meter should have indicated a negative (-) sign in front of the voltage reading. The meter has built-in auto polarity. Thus, it automatically indicates whether the voltage being measured is positive or negative with respect to the common terminal.

In Steps 3 and 4, you should have discovered that the voltage on terminal 4 was positive with respect to Terminal 3. Depending on

---

your meter, this is indicated by the absence of any sign or by a positive (+) sign ahead of the voltage reading.

The auto polarity feature of your DMM is one of the conveniences found in this type of meter. In some voltmeters, however, you will have to reverse the leads or change the position of a switch when taking negative voltage measurements.

In Step 4, you determined the voltage and polarity of Terminal 3 with respect to Terminal 1. To do this, you simply touched the black lead of the DMM to Terminal 1 and the red lead to Terminal 3. Voltages are measured with respect to the black (common) lead of your meter.

## Experiment 4: Measuring Voltage to Determine Current

---

### Introduction

Ohm's Law tells us that current in amperes is equal to the voltage in volts, divided by the resistance in ohms. Therefore, if we measure the voltage drop across a known resistor, we can accurately determine the current through it by dividing the voltage by the resistance.

In this experiment, you will see that you can determine the current flowing in a circuit by measuring the voltage across any known resistor and by applying Ohm's Law. You will also see how you can use the voltmeter scale to indicate current directly in milliamps if there is a 1k resistor in the circuit.

### Materials Needed

For this experiment, you will need your DMM, breadboarding socket, battery with clip, and the following resistors:

- 2 1k resistors
- 1 4.7k resistor

### Procedure

**Step 1.** Build the circuit shown in Figure 4-1. The diagram for this circuit is shown in Figure 4-2, on the next page. Notice the polarity of the battery. Also, the red meter probe should be reconnected to the V input jack. Set your DMM selector switch to the 20 V range.

**Step 2.** Measure the voltage across R1 by connecting the red lead from your DMM to the end of the resistor connected to the positive terminal of the battery. Connect the black lead of your DMM to the other end of R1. Record the voltage reading in Table 4-1.

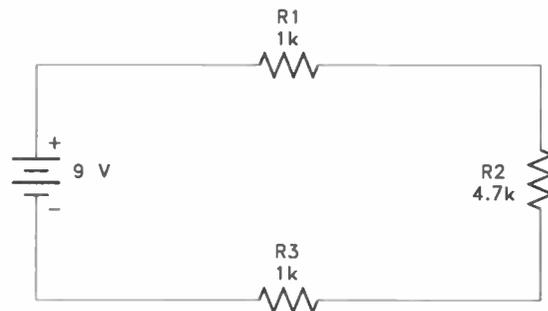


Figure 4-1. A schematic diagram of the circuit for Experiment 4.

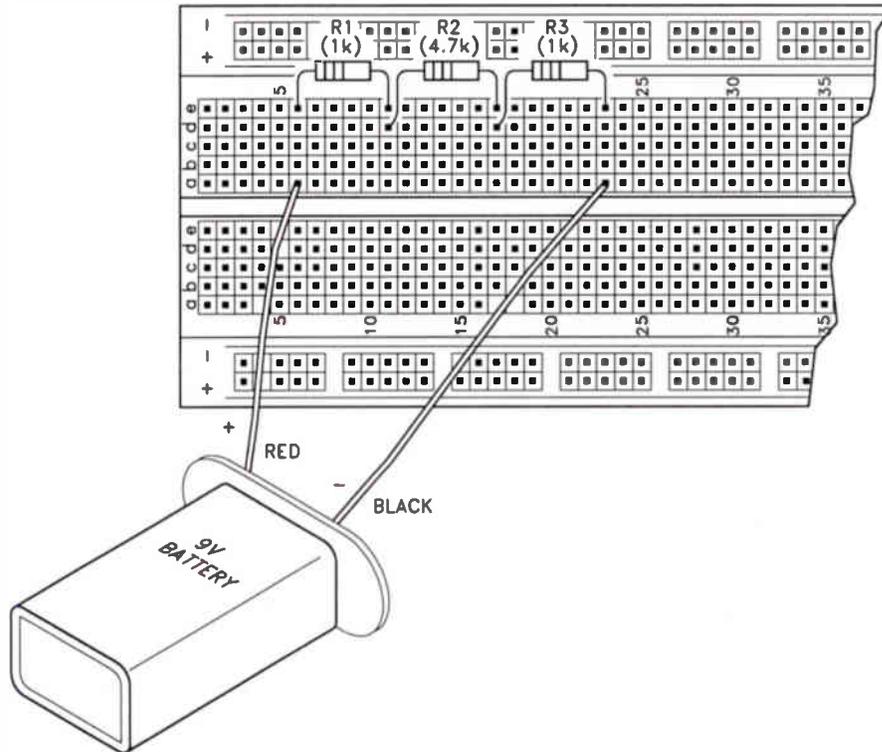


Figure 4-2. An illustration of the circuit for Experiment 4.

Now, to find the current, we use Ohm's Law, which tells us that the current in amperes is equal to the voltage in volts divided by the resistance in ohms, or  $I = E/R$ . By substituting 1,000 for R and the voltage that you have just measured and recorded for E, you can find the current in amps. To change the answer to milliamps, multiply by 1,000 (or simply move the decimal point three places to the right). For example, let's say that the source voltage was 9 V and that

we measured 1.43 V across R1. Using this figure, we get:

$$I = E/R$$

$$\frac{1.43}{1,000} = 0.00143 \text{ amp}$$

To change this to milliamps, multiply it by 1,000. This gives us:

$$0.0014 \times 1,000 = 1.43 \text{ milliamps}$$

Notice that to perform this operation we simply had to move the decimal point three places to the right.

Now, determine the current through the 1k resistor from your experimental results. Record your current in Table 4-1.

**Step 3.** Measure the voltage across R2 by connecting the DMM across it. Switch the meter to a lower range to get the most

	Voltage Reading	Current in mA
R1 1k		
R2 4.7k		
	Ammeter	
	Ammeter reading	

Table 4-1. Record your results for Experiment 4 here.

# BASIC ELECTRONICS EXPERIMENTS

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accurate measurement. Record the reading in Table 4-1.

Determine the current through R2 just as you did for R1 in Step 1. This time, substitute 4.7k for R in the formula and substitute the second voltage measurement for E. Record the current reading in Table 4-1, after multiplying the answer by 1,000 to change amps to milliamps.

You know that the current is the same in all parts of a series circuit. Therefore, the current determined in Step 3 should be the same as that obtained in Step 2. However, there may be some small variation in your results due to parts tolerances. The resistors used all have a 5% tolerance so the actual value may not be exactly the value indicated.

**Step 4.** In this step, you will use the DMM to measure the current flow in the circuit to see how close you come to the calculated value. Set your DMM to the 20 mA current range. Unplug the red lead from the V jack and plug it into the A jack. Unplug the negative lead from the battery and connect it to the black lead from the DMM. Connect the red lead to the end of R3, which was formerly connected to the negative lead of the battery. This connection puts the meter in the circuit so that it can measure the actual current flow in the circuit. Record the measured value in Table 4-1. You should find that it agrees very closely with the calculated values obtained in Steps 2 and 3.

**Step 5.** After you've completed this step, move the red lead from jack A on the DMM back to jack V again. Turn your DMM to the OFF position.

## Results

Now, let us compare your results for Steps 1, 2, and 3. The three current values should be approximately the same. Actually, the current is exactly the same anywhere in the circuit, but because of parts tolerances, your values probably show slight differences. When we performed this experiment, the actual measured and calculated values came within 0.04 milliamps. This is a variation of only 40 microamps.

Notice the voltage value that you measured across the 1k resistor (R1) and the current that you calculated for R1. The voltage across R1 and the current in milliamperes flowing through it should be the same because you divided the voltage by 1,000 to find the current and then multiplied by 1,000 to change it to milliamps. In other words, when the resistance equals 1,000 ohms, the value of the voltage across it in volts is equal to the value of the current through it in milliamps. Thus, you can read the current directly on the voltmeter scale if you are measuring across a 1k resistor. If the voltmeter indicates 0.2 V, you have 0.2 mA of current. If it indicates 1.5 V, you have 1.5 mA of current, and so on.

While your DMM can measure current directly, you do have to open the circuit and put the meter in series with the circuit. Generally, this involves unsoldering a lead or a connection. If there happens to be a 1k resistor in the circuit, you can simply measure the voltage across the resistor to determine the current. Thus, you will save the time needed to unsolder a part, take the reading, and re-solder the part.

---

Technicians seldom take current measurements or use Ohm's Law to calculate the current in the circuit. The circuit current values are not given for most electronic equipment. However, the voltage values are generally given. If the correct voltage appears across the part, you can assume that the current is correct for that circuit. As far as the current is concerned, the technician is interested in only three possibilities. These are:

1. Is the current normal?
2. Is the current too high?
3. Is the current too low?

Voltage measurements can give an indication to all three answers without the use of Ohm's Law or the necessity of unsoldering and re-soldering connections. The technician usually does not care about the actual value of the current, but rather whether it is normal.

# Experiment 5: Series Voltage Dividers

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## Introduction

As you have seen in the preceding experiments, if any resistance in a series circuit has changed in value, the voltage across each resistor will change. In some circuits, however, we want the voltage to remain fairly stable even when the resistance changes.

As you have learned previously, when a large resistor and a small resistor are in parallel, the combined resistance is approximately that of the small resistor. This means that even if the larger resistance varies somewhat, it will still be much higher than the smaller resistance. Thus, the combined resistance will remain essentially unchanged. This important fact can be put to good use when we want to stabilize the voltage across a load in which resistance varies.

For example, an amplifier is similar to a resistance connected across a power source. It converts a portion of the power supply voltage to a useful output signal. If the amplifier has to produce a higher output signal, it consumes more power from the power supply.

The power supply sees this increased demand as a decrease in load resistance. If the power supply is properly designed, it will maintain a constant voltage despite the varying load resistance.

In this experiment, you will build a circuit in which the load resistance can be varied and in which the load requires considerably less voltage than the source voltage of 9 volts. You will see how the voltage across the load changes when the load resistance is changed. Then, you will change the circuit so that the effects of variation in load resistance are reduced to a minimum.

As a technician, you may not be particularly interested in being able to design voltage dividers, but you should certainly know how they work. If you find that a particular circuit is not operating satisfactorily, you must rely on your voltage measurements to tell you what might have happened in the circuit. A knowledge of how voltage dividers operate will go a long way in helping you find the source of the trouble.

## Materials Needed

Gather the battery with clip, your DMM, and the breadboarding socket. You will also need the following parts:

- 1 1k resistor
- 1 4.7k resistor
- 1 10k resistor
- 1 10k trim potentiometer
- Hook-up wire

## Procedure

**Step 1.** Build the circuit shown in Figure 5-1. A pictorial layout of this circuit is shown in Figure 5-2, on the next page. Use the jumper cables supplied with this kit so that you can clip both leads of the meter to the circuit under test. Also make sure that the red test lead of your DMM is connected to the V jack. You are now ready to see how the circuit works.

**Step 2.** Measure the load voltage in Figure 5-1 by clipping the black lead from the DMM

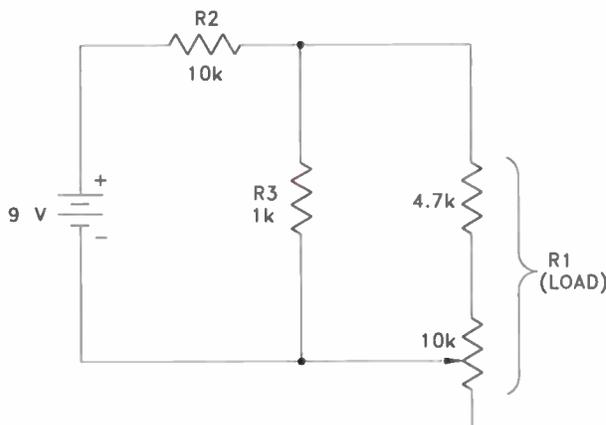


Figure 5-1. A schematic of the circuit for Step 1.

to the negative lead of the battery and the red lead to the junction of the 4.7k resistor and the 10k resistor (R2). The meter is now connected across the 4.7k resistor and part of the 10k potentiometer. These two parts make up the load resistor, R1, in Figure 5-1.

With a small screwdriver, adjust the potentiometer so that the meter reads 0.8 volts. We will consider this position to be the normal resistance of R1. Now, turn the potentiometer fully counterclockwise. This increases the resistance of R1 and thereby increases the voltage across it. From the perspective of the power source, however, the higher load resistance appears to be a smaller load since it draws less current. Now record the voltage across the load at this time in the space labeled Voltage with Minimum Load in Step 2 of Table 5-1, on the next page.

Now, rotate the potentiometer fully clockwise, reducing the resistance of the variable resistor to practically 0. The resistance of R1 now consists of only the 4.7k resistor. This decreased resistance appears to be a larger load, from the perspective of the power source, because the circuit now draws more current. Note the meter reading and record it in the space provided for Voltage with Maximum Load in Step 2 of Table 5-1.

**Step 3.** Remove the 1k resistor as shown in Figure 5-3, on the next page. The load is still made up of the combination of the 4.7k resistor and part of the potentiometer. Adjust the potentiometer fully counterclockwise. Note the voltage reading and record it as the Voltage with Minimum Load for Step 3 in Table 5-1.

# BASIC ELECTRONICS EXPERIMENTS

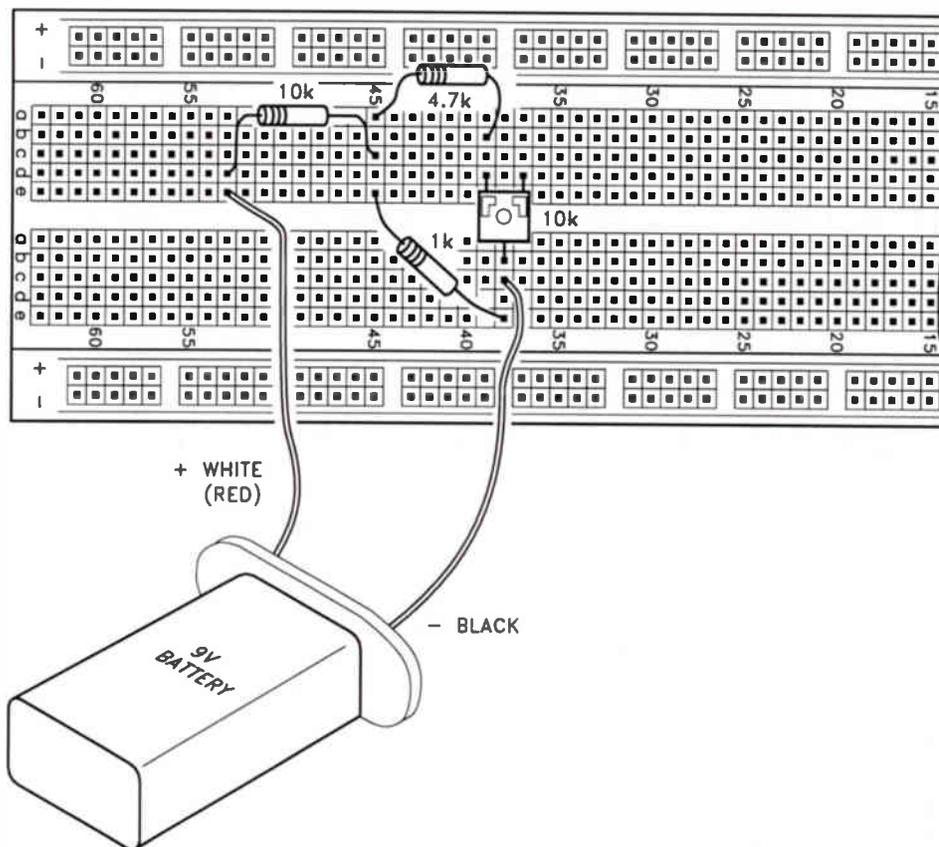


Figure 5-2. Layout of the circuit for Step 1.

Next, turn the potentiometer fully clockwise to reduce the value of R1. Record the reading as the Voltage with Maximum Load in Table 5-1. When you are finished with the experiment, unplug one lead of the battery to open the circuit and conserve battery life.

readings. In Step 2, there should be less of a difference between the maximum and minimum voltages than in Step 3.

In many voltage dividers, the source voltage divides between the circuit parts. The voltage across a part is proportional to its

## Results

Look over the figures you have recorded in Table 5-1 and compare the two sets of

	Voltage with Minimum Load	Voltage with Maximum Load
Step 2		
Step 3		

Table 5-1. Record your results for Experiment 5 here.

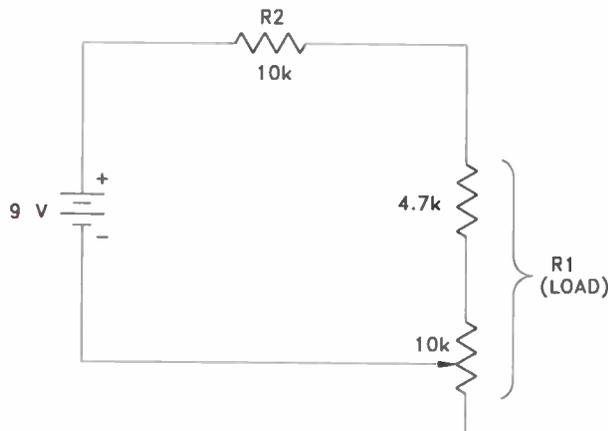


Figure 5-3. A schematic of the circuit for Step 2.

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resistance. If two parts have equal resistances, the source voltage will divide equally between them. Both will have the same voltage drop. If one part is variable, then it will have more than half of the voltage across it some of the time and it will have less than half the rest of the time.

In Step 1, you installed what is commonly called a bleeder resistor. This time, the voltage changes were much smaller. When two resistors are in parallel, the combined resistance is less than the smallest resistor. The combined resistance of R1 and the 1k bleeder resistor was between 780  $\Omega$  and 982  $\Omega$  depending on the potentiometer setting. In other words, when you added the bleeder resistor, changes in load resistance were substantially reduced. Therefore, load voltage was nearly the same (but much lower), regardless of load resistance variations.

In Step 3, you removed the bleeder resistor. With the potentiometer turned counterclockwise, the total load resistance was about 14.7 kilohms. This is nearly 1 1/2 times the resistance of R2. Thus, more than half the source voltage was dropped across R1. With the potentiometer turned fully counterclockwise, the total load resistance was only 4.7k, making R1 less than half the resistance of R2. Thus, most of the source voltage was dropped across R2.

In your work, be on the lookout for bleeder resistors. They can fail or change in value just like any other parts. You must take them into consideration when you diagnose a circuit where the components are in parallel with other electronic parts.

## Experiment 6: Electrical Power

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### Introduction

In this experiment, we will discuss the term *power*, and how it is determined in an electronic circuit. Power, whether it is electrical or mechanical, is defined as the rate at which work is being done. Work is done whenever a force causes motion to occur. When mechanical force is exerted to lift or move, work is being done. However, when force is exerted without motion, such as when the force of a compressed spring is exerted between two stationary objects, work is not taking place.

With this in mind, we already know that voltage is the electrical force that causes current to flow in a closed circuit. When a voltage exists, but its force does not produce current flow, as in an open circuit, no work is being done. Work is accomplished when applied voltage causes electrons to move. The instantaneous rate at which this work is done is called the electrical power rate, and is measured in watts.

This unit measurement of electrical power is normally measured using a device called a wattmeter, illustrated in Figure 6-1. A wattmeter combines both voltage and current, as shown in Figure 6-2, on the next page. Thus,

we can conclude that power can be initially calculated using these two factors of voltage and current. Depending on the circuit quantities known, one of the following formulas can be used to determine power:

$$P = E \times I$$

$$P = I^2 R$$

$$P = E^2 / R$$

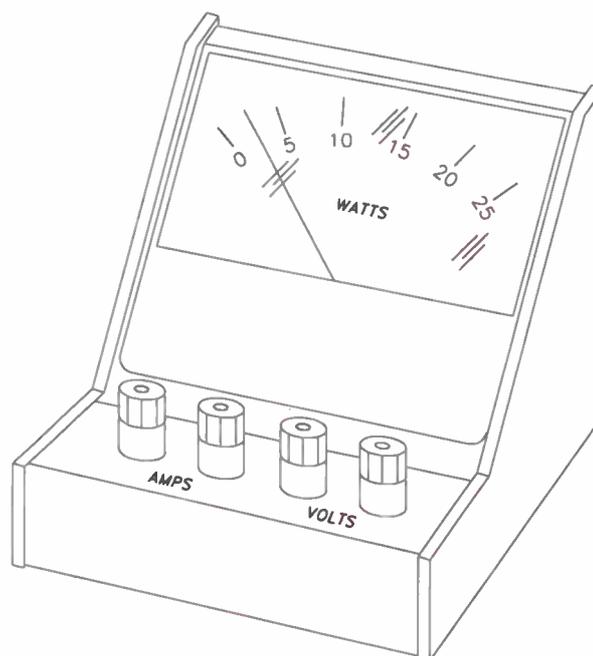


Figure 6-1. Wattmeter with a 25-watt range.

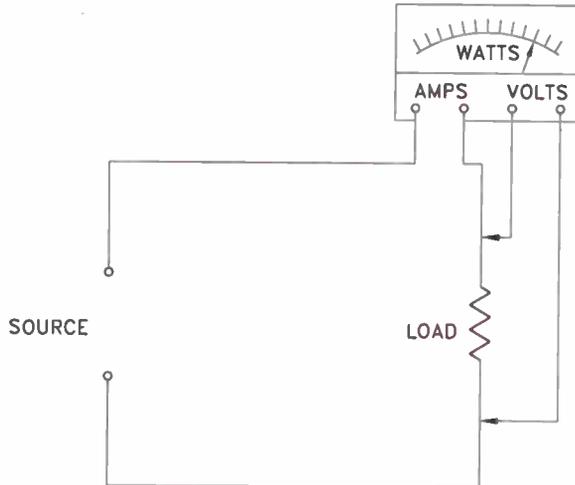


Figure 6-2. Wattmeter connections to measure power.

Where  $P$  is power in watts (W),  $E$  is in volts (V),  $I$  is in amperes (A), and  $R$  is in ohms (S).

Electrical components are usually given a power rating. This rating, in watts, indicates the rate at which the device converts electrical energy into another form of energy such as heat, light, or motion. Light bulbs are the most common devices using this type of power rating. In other electrical devices this power rating indicates the maximum power the device is designed to use rather than the normal operating power.

Knowing how to determine the power of a given electrical configuration improves your overall competence as a technician. It might also help you to evaluate the performance of a defective circuit. For example, a power source could be loaded down if a circuit connected across it consumes too much power. Knowing how to calculate power might help you locate the defective circuit.

## Materials Needed

In this experiment, you will need the battery with clip, your DMM, the breadboard socket, and the following parts:

- 2 1k resistors
- 1 2.2k resistor
- 1 4.7k resistor
- Jumper leads

## Procedure

Wire Figure 6-3 on your breadboard socket. Refer to the diagram in Figure 6-4, on the next page, to make sure you have wired it correctly. Now you are ready to measure the power consumed by the circuit.

**Step 1.** Turn on your DMM by setting it to measure DC current. Start with the 20 mA/20 A range, since the amount of current flow in the circuit is unknown. Unplug the probe

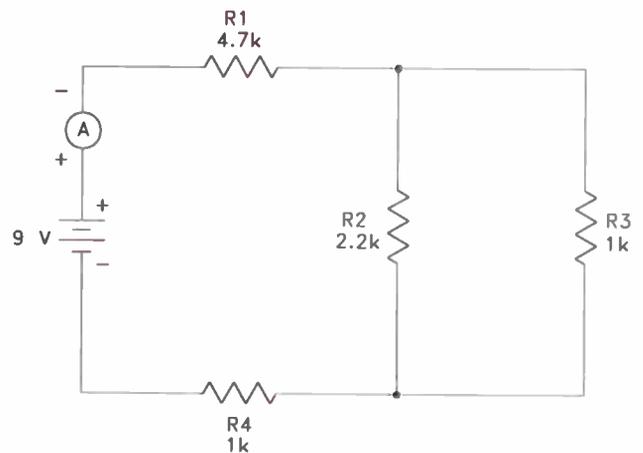


Figure 6-3. The circuit for Experiment 7.

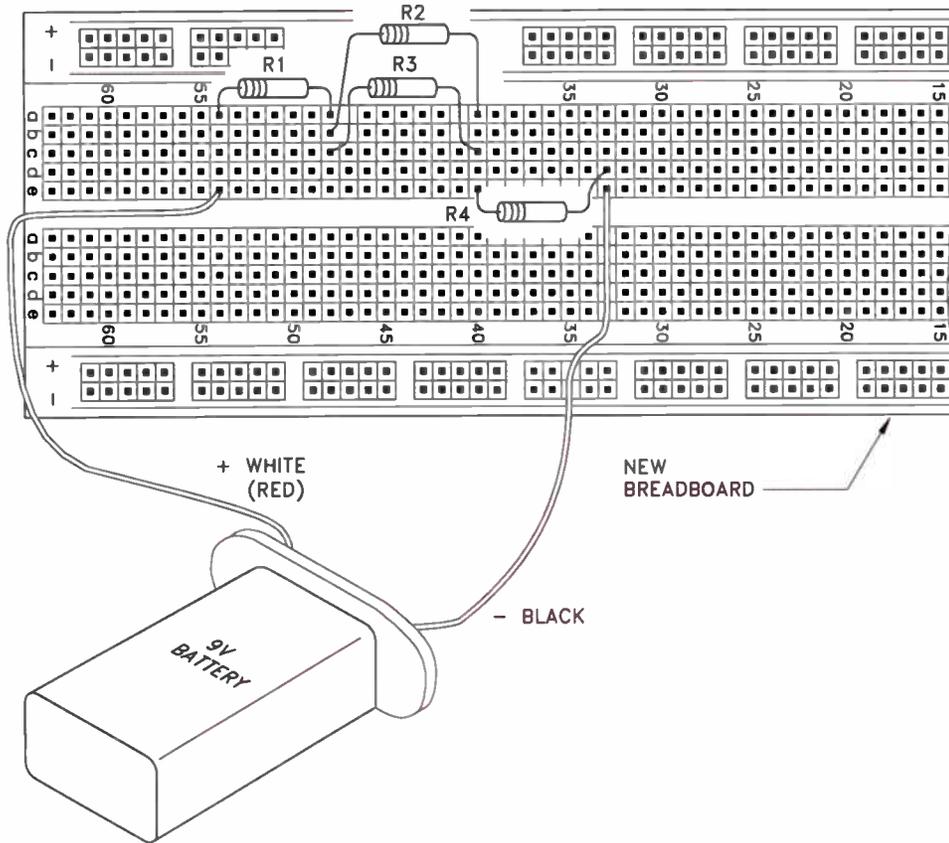


Figure 6-4. An illustration of the circuit for Experiment 6.

lead from the V input jack and connect it to the A input jack. This setup allows you to safely connect your DMM to the circuit as an ammeter.

Now, disconnect the positive lead of the 9-V battery from the breadboard socket and connect it to the positive lead of the DMM

	Part 1	Part 2
Total Current		
Source Voltage		
Total Power		
Power R1		
Power R2		
Power R3		
Power R4		

Table 6-1. Record your results for Experiment 6 here.

using one of the jumper leads. Connect the black lead to the free end of R1. Measure the total current flow in the circuit and record your measurement in Table 6-1.

**NOTE:** If necessary, switch the DMM to a lower current range to get a more accurate reading. You will do this by positioning the selector switch to the 200-mA range, and moving the red lead of the DMM from the A jack to the mA jack. You can read even lower ranges now by simply placing your selector switch to the lower ranges.

**Step 2.** Next, you will measure the loaded source voltage. First disconnect the meter and reconnect the positive lead of the battery to R1. Set your DMM to the 20 V DC range. Don't forget to unplug the red probe from the A or mA jack and connect it to the V jack.

---

Measure the loaded source voltage by connecting the black lead to the negative battery terminal and the red lead to the positive battery terminal. Record your measurement in Table 6-1.

You can now calculate total power consumption by multiplying the total circuit current by the loaded source voltage. If your current is in milliamps, you'll have to convert it to amps. Thus, if you measured 2.5 mA, divide this figure by 1,000 to convert it to amps. Record your results in Table 6-1 for total power under Part 1.

**Step 3.** To determine the power consumed by individual parts, you will need to measure the voltages across R1 and R4. Record your measurement in the margin of this page. Using the formula  $P = E \times I$ , determine the power consumed by each of these resistors. The value of I is the total current recorded in Table 6-1. Record your answers in Table 6-1 under Part 2.

**Step 4.** Next, you will determine the power used by resistors R2 and R3. The same voltage is dropped across both R2 and R3 because they are wired in parallel. However, the current is divided between them. Having determined

the voltage, use the formula  $P = E^2/R$  to find the power consumption for each resistor. Record your answers in Table 6-1 under Part 2.

**Step 5.** Add the power used by the individual parts in the circuit. Record your answer in Table 6-1 as the Total Power under Part 2. Compare the Total Power for under Part 1 in Table 6-1 with the Total Power for Part 2. Except for a small difference, due to the parts tolerances, the results should be nearly equal.

## Results

In this experiment, you calculated electrical power. You saw that power is determined by multiplying voltage by current. Total circuit power can also be determined by adding the power used by individual parts.

Technicians need to also understand that power is dissipated or converted to other forms of energy. Consequently, the fuse of a circuit responds to heat, a by-product of the power converted, by melting if the current flow exceeds the predetermined level. Some electrical parts are rated (in watts) according to their ability to dissipate heat.

# Preparing for Experiments 7-9

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## Ohmmeter Operation

In servicing electronic equipment, the technician usually relies on voltage and resistance measurements. Often, you will not be able to take voltage measurements, because a defect in the circuit overloads a fuse as soon as the equipment is turned on. Under these circumstances, the technician must rely on resistance measurements to locate the problem.

To use the ohmmeter section of your DMM, the black lead should be in the COM jack and the red lead should be in the V jack. The switch is rotated through one of the six positions. You will learn how to properly select the correct position as part of the following experiments.

In taking resistance measurements, the equipment **MUST** be turned off. As a matter of fact, it is a good idea to unplug the equipment from the power line or disconnect the batteries if the equipment is battery operated. This precaution will prevent accidental damage to the DMM. If you try to take resistance measurements with the power turned on, the resistance measurements may be inaccurate, and you run the risk of damaging the DMM.

## How Your Ohmmeter Works

Your DMM is primarily a voltage-measuring device. It does not measure the resistance of a part directly. The DMM contains six precision resistors that are used for resistance measurements. A different resistor is switched in for each range. In the 200-ohm range, a precision 200-ohm resistor is used internally. In the 2k range, a precision 2k resistor is used.

When you take a resistance measurement, a small current flows through the precision resistor inside the meter and through the resistor under test. This flow produces a voltage across the resistor that the DMM measures and converts into a resistance reading.

## Setting the Range Switch

As a general note, the objective in setting the range switch is to set the switch to the position that gives you the most significant reading. The maximum resistance that can be measured on each of the ranges is shown in the top row in Table 7-1. If you try to measure a resistance at too low a range, you will

Range							
Resistor	200	2k	20k	200k	2M	20M	Best Range
1k							
2.2k							
4.7k							
10k							
100k							
470k							
1M							
2M							

**Table 7-1. Record the reading on each range for the resistors listed and the range that gives the best reading.**

get an overload indication on the meter display. This reading tells you that the resistance is too high to be measured at that range. If you use too high a range when measuring a resistance, the meter will not give you the most accurate reading that it is capable of giving. For example, suppose you have a 47  $\Omega$  resistor, and you want to check its exact resistance. Remember that resistors have a tolerance and that a 47  $\Omega$  resistor, having a tolerance of 10%, could have a resistance anywhere between 42.3  $\Omega$  and 51.7  $\Omega$  and still be within tolerance. Because this resistance is less than 200  $\Omega$ , you would use the 200  $\Omega$  range to check the resistance.

In checking the resistance of a 47-ohm resistor in a lab, the two digits displayed on the left indicate 47. The digit on the right continually changes, sometimes displaying a 1, sometimes a 2, and sometimes a 3. This indicates that the resistance of the resistor is a little over 47  $\Omega$ . If we switch the range switch to the 2k position, the meter will display 0.047. If we switch to the 20k range, we'll get a reading of 0.04 or 0.05. If we move the switch to the 200k range, we'll get a reading of 0.00. It is obvious from this that the 200  $\Omega$  range provided us with the most accurate reading. Now it is your turn to get some practical experience measuring the resistance of resistors.

## Experiment 7: Using an Ohmmeter

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### Introduction

In checking the resistance of parts with an ohmmeter, there are three important rules to bear in mind:

1. Make sure the equipment that is being tested is turned off. If power is supplied from a power line, it is usually a good idea to remove the power line plug from the wall socket. If the equipment is battery operated, all batteries should be disconnected.
2. Use the correct range of the ohmmeter. As you will see, if you use the wrong range, the ohmmeter may indicate that a good part is open or shorted.
3. Keep your fingers off the part being tested when measuring high resistances. The resistance of your body can affect the result of your measurements. On low resistances, however, it does not matter. Do not touch the probes when measuring iron-core devices, such as transformers or chokes, because you may receive a shock. As you continue working with your ohmmeter, you will learn other valuable tricks of the trade that will enable you to get the greatest use from the ohmmeter section of your DMM.

### Materials Needed

In this experiment, in addition to your DMM, you'll need the following resistors:

- 1 1k resistor
- 1 2.2k resistor
- 1 4.7k resistor
- 1 10k resistor
- 1 100k resistor
- 1 470k resistor
- 1 1M resistor
- 1 2M resistor
- 1 10M resistor

### Procedure

**Step 1.** Connect the ohmmeter leads to the 10M resistor and rotate the switch to the 20M position. You should get a reading a little above or below 10 megohms. Now touch the two ohmmeter leads with your fingers, and you will see that the reading drops. The resistance of your body is now in parallel with the 10M resistor, and thus reduces the resistance reading.

---

**Step 2.** Disconnect your ohmmeter from the 10M resistor and connect it across a 10k resistor. Now, starting with the 200 ohm range, note the reading on the DMM. Switch to the 2k and then the 20k, 200k, 2M, and 20M ranges. You should discover that on ranges below 20k, the DMM display indicated an overload. On the 20k range, you received a reading close to 10.00 kilohms. On the 200k, 2M, and 20M range, you got readings with fewer digits. Thus, the 20k range gave you the most accurate reading.

**Step 3.** Measure the resistance of each resistor listed in Table 7-1, on page 33. Measure the resistance on each ohmmeter range.

Then, indicate the range that gave the most accurate reading. Record your results in Table 7-1.

## Results

In this experiment, you learned that you must choose a suitable ohmmeter range. The wrong range may indicate a fault when the resistor is actually good. Additionally, the appropriate range also gives you the most accurate reading for the resistor being measured.

# Experiment 8: Circuit Continuity

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## Introduction

You have seen in earlier experiments how circuit continuity can be checked with a voltmeter. Also, you have learned that when continuity is intact, the circuit is able to carry current. While parts may have shorted or changed in value, these conditions do not affect the ability of the circuit to carry current. If the circuit has continuity, it simply means that the circuit does not have an open.

Most technicians prefer using the ohmmeter for continuity testing, because it can easily be shifted to various points in the circuit to measure the actual resistance. Although the ohmmeter can display the approximate sum of the resistances, it is not designed to measure the total resistance of the circuit while making continuity checks. The true purpose of the ohmmeter is to show that the circuit is complete.

When making continuity measurements, technicians seldom bother to determine the actual resistance in the circuit. They simply check to see that there is a reading that shows continuity. When making continuity tests with your DMM, set the range switch to the 20M position. Otherwise, if you are checking a high-resistance circuit, you may get an

overload reading that may lead you to believe that the circuit is open.

In this experiment, you will demonstrate that in a circuit containing both large and small resistances, a small resistor could be shorted without materially affecting the overall resistance measurement. To find such a short requires a check of the individual resistors. Do this type of check when the symptoms of the circuit indicate that there are possible problems causing the circuit to fault out.

## Materials Needed

In this experiment, you will need your DMM, the breadboarding socket, the dummy resistor that you used in Experiment 2, and the following resistors:

- 1 1k resistor
- 1 2.2k resistor
- 1 10k resistor
- 1 100k resistor
- 1 1M resistor
- 1 10M resistor

## Procedure

You will make a voltage divider using five resistors in series and check the continuity. Using your breadboarding socket, construct the voltage divider shown in Figure 8-1 and Figure 8-2, on the next page. By now, you should be able to build simple circuits without the aid of a pictorial diagram.

**Step 1.** Measure the value of each resistor in the divider and record the resistance in ohms in the spaces provided for Step 1 in Table 8-1, on the next page. Now, add up the values of all five resistors and record this sum as the total resistance in the space provided.

**Step 2.** Connect one lead of your DMM to Terminal A and the other lead to Terminal B. Adjust the range switch to give a reasonable indication and record the value in Table 8-1. Your reading should be approximately the same as the sum of the individual resistance measurements.

**Step 3.** To simulate a short across resistors R4 and R5, take a short piece of wire and connect it between Terminals B and D. With the DMM still connected to Terminals A and B, record your reading for Step 3 in Table 8-1. The value you record should be almost the same as that obtained in Step 2, showing that the two resistors could be completely shorted without materially affecting the ohmmeter measurement.

**Step 4.** Remove the 1k resistor (R4) from the circuit and replace it with the 2.2k resistor. A change in resistance value from 1,000 ohm to 2,200 ohm is apparent when you check each individual resistor. However, see how it affects the total resistance by measuring the resistance from A to B and record your results in Table 8-1.

**Step 5.** Remove the 2.2k resistor and in its place substitute the simulated open resistor you made in Experiment 2. Now, measure the resistance between Terminals A and B. The meter will give an overload reading, indicating that the resistance between Terminals A and B is greater than 20 megohms. This certainly indicates that the circuit was open, since the original resistance was approximately 11 megohms.

**Step 6.** To find the open part in the voltage divider consisting of R1, R2, R3, the open resistor, and R5, connect the black lead from the ohmmeter to Terminal A. With the range switch in the 20M position, touch the red lead to Terminal F. You should get a reading of about 10 megohms. Now, move the red lead to Terminal E. You should get a reading of about 11M, indicating continuity between Points A and E. Now move the red lead to Point D. Again, you should get a reading indicating continuity between Points A and D. Now move the red lead to Point C. You should get an overload indication that pinpoints the open circuit as being located between Terminals C and D.



Figure 8-1. The circuit for Experiment 8.

# BASIC ELECTRONICS EXPERIMENTS

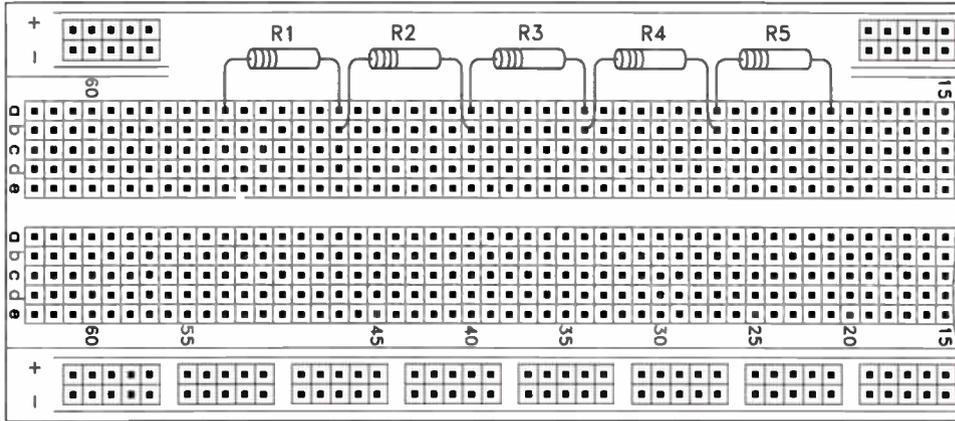


Figure 8-2. An illustration of the circuit for Experiment 8.

## Results

In this experiment, you saw that continuity can be checked with an ohmmeter. You saw that you can reduce the resistance of the divider in Figure 8-1 by completely shorting out R4 and R5 without appreciably changing the measured total resistance. Therefore, to check the condition of the individual resistors in a circuit having a high resistance, you must connect the ohmmeter directly across each resistor in question.

You also saw that an increase in resistance in one of the low-resistance parts will have no apparent effect on the total measured resistance.

These are key points to remember when troubleshooting electronic equipment. Make continuity tests when you suspect that a circuit is open, but remember that this does not show the value of the individual parts.

	Measurement	Value
Step 1	R1	
	R2	
	R3	
	R4	
	R5	
	Total	
Step 2	A to B	
Step 3	R4 and R5 Shorted	
Step 4	R4 = 2.2k	

Table 8-1. Record your results for Experiment 8 here.

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# Experiment 9: Parallel Resistance

---

## Introduction

You already know that electronic parts connected in parallel have a combined resistance lower than that of the smallest resistance of the group. However, as a service technician, you may want to know what the exact combined resistance should be. This enables you to measure the combined resistance and decide whether the parts are in good condition.

It is easy to decide what the combined resistance should be when parallel-connected parts have the same resistance. The rule is as follows:

The combined resistance of equal parts in parallel is equal to the resistance of one of the resistors divided by the number of resistors in the group.

Thus, if we connect three 1k resistors in parallel, the combined resistance is 1,000 divided by 3, or 333 ohms. Three 3.3k resistors in parallel have a resistance of 1,000 ohms; two 22k resistors in parallel have a combined resistance of about 11,000 ohms.

Parallel-connected resistors are not always equal in value. When this is the case, the combined resistance,  $R$ , can be found by using the formula:

$$R = \frac{R1 \times R2}{R1 + R2}$$

For example, if we have a 1k resistor and a 3.3k resistor in parallel:

$$\begin{aligned} R &= \frac{1,000 \times 3,300}{1,000 + 3,300} \\ &= \frac{3,300,000}{4,300} \\ &= 767 \text{ ohms} \end{aligned}$$

It is helpful, but not imperative, that you be able to make these computations on a daily basis. As a busy technician, you may not always have the time to calculate them. Instead, when you cannot readily tell the combined resistance at a glance, you may resort to simply unsoldering one end of each of the resistors and check the resistors individually.

If by chance you have the time to spare and find the calculations easy to work, then you can avoid the trouble of unsoldering a component to determine its condition and resolder the component into the circuit. It may be a good idea for you to invest in an inexpensive, hand-held calculator. With this additional tool, you can quickly work through these calculations.

# BASIC ELECTRONICS EXPERIMENTS

When resistors do not have any shunting (parallel-connected) parts, the resistance value is checked by connecting the test leads directly across the resistor. With some meters, doing this can cause erratic readings if there are transistors or diodes in the circuit. This is usually because the ohmmeter voltage is so high that the diode junction within the semiconductor may conduct and affect the measurement.

However, using the DMM issued in this kit, the voltage used in the ohmmeter section is so low that neither the diodes nor the transistors will conduct. This feature makes the DMM particularly useful in servicing solid-state equipment.

In this experiment, you will connect resistors in parallel and measure their combined resistance. You will then check the measured value with the calculated resistance value to prove that the calculated value is correct. Expect small variations between the calculated and measured values due to component tolerances.

## Materials Needed

In this experiment, you will need your DMM, the breadboard socket, and the following resistors:

- 2 1k resistors
- 1 2.2k resistor
- 1 10k resistor
- 1 100k resistor
- 1 10M resistor

## Procedure

**Step 1.** Plug one of the 1k resistors and a 2.2k resistor into the breadboard socket so that they are in parallel. Calculate the resistance with the formula:

$$R+ = \frac{R1 \times R2}{R1 + R2}$$

$$R = \frac{1,100 \times 2,200}{1,000 + 2,200} = 687.5 \Omega$$

Measure the combined resistance. To do this, simply clip one lead from your DMM to each end of a resistor. Rotate the range switch until you get a suitable reading and record the measured value in Table 9-1.

**Step 2.** Remove the 2.2k resistor and replace it with a 10 k resistor. Calculate the resistance of the combination with the formula:

$$R+ = \frac{R1 \times R2}{R1 + R2}$$

By substituting the values of the resistors, we have:

$$R = \frac{1,000 \times 10,000}{1,000 + 10,000} = 909 \text{ ohms}$$

Now, measure the resistance of the parallel combination. Record this reading in Table 9-1.

Parallel Combination	Computed Value	Measured Value
1k and 2.2k		
1k and 10k		
10k and 2.2k		
10k and 1M		
10M and 100k		

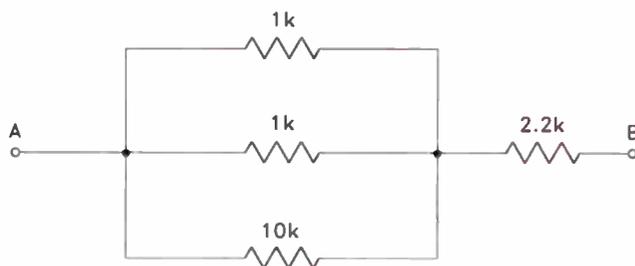
Table 9-1. Record your results for Experiment 9 here.

**Step 3.** Following the same procedure, measure the combined resistance of the other parallel combinations listed in Table 9-1. In each case, calculate the values so that you can check the measured values.

**Step 4.** Build the series-parallel circuit shown in Figure 9-1. You should be able to do this without the aid of a pictorial diagram.

Before you measure the combined resistance, examine the circuit carefully and calculate in advance what the total resistance should be. Jot down what you think it is somewhere below the schematic diagram.

**Step 5.** Now connect one lead from the DMM to Terminal A and the other lead to Terminal B. Choose the appropriate ohmmeter range on your multimeter and read the resistance value. Compare this value with the value you calculated before taking the measurement within the circuit.



**Figure 9-1.** The circuit for Step 4 of Experiment 9.

## Results

When you compared your measured values with the calculated values given in the chart, they should have been fairly close in most cases. However, because of the tolerances of the resistors, you may find that the readings differ somewhat in some cases.

When two resistors are in parallel and one is much larger, an accurate resistance check of the larger resistor cannot be performed until it is disconnected from the circuit. For example, when you measured the 10M and 100k resistors in parallel, their combined resistance should have been close to 100,000 ohms, or the resistance of the smaller resistor. Even when the 10M resistor was completely removed, the resistance remained close to the parallel value.

When there is only a slight difference in the value of the parallel resistors, or when one is disconnected or is defective, there will be a considerable change in the measured resistive value of the parallel configuration.

## Experiment 10: Charging and Discharging Capacitors

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### Introduction

As you have learned, a capacitor is an electronic component that has the ability to store an electrical charge. In most circuits, capacitors charge and discharge constantly according to dynamic circuit conditions. Rates of capacitive charge and discharge are dependent upon the circuit resistance. The time (in seconds) required for a capacitor to charge to 63% of the applied voltage is equal to the resistance value (in megohms) multiplied by the capacitance value (in microfarads). This is known as the time constant of the circuit, and it is typically expressed as  $TC = R \times C$ .

### Materials Needed

For this experiment, you will need the breadboard socket and your DMM in addition to the following parts:

- 1 9-volt battery with clips
- 1 10k resistor
- 1 100k resistor
- 2 10 microF electrolytic capacitors

If you need to do so, install the battery clips on the batteries at this time.

### Procedure

Wire the circuit shown in Figure 10-1. Do not connect the negative battery lead until you are instructed to do so. Use a 10k resistor for R, set your meter to the 2 mA position, and move the red lead to the mA socket. Figure 10-2, on the next page, shows one way to breadboard the circuit.

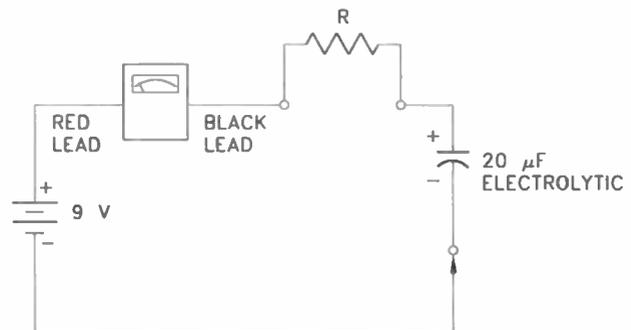


Figure 10-1. A DC voltage capacitor charging circuit.

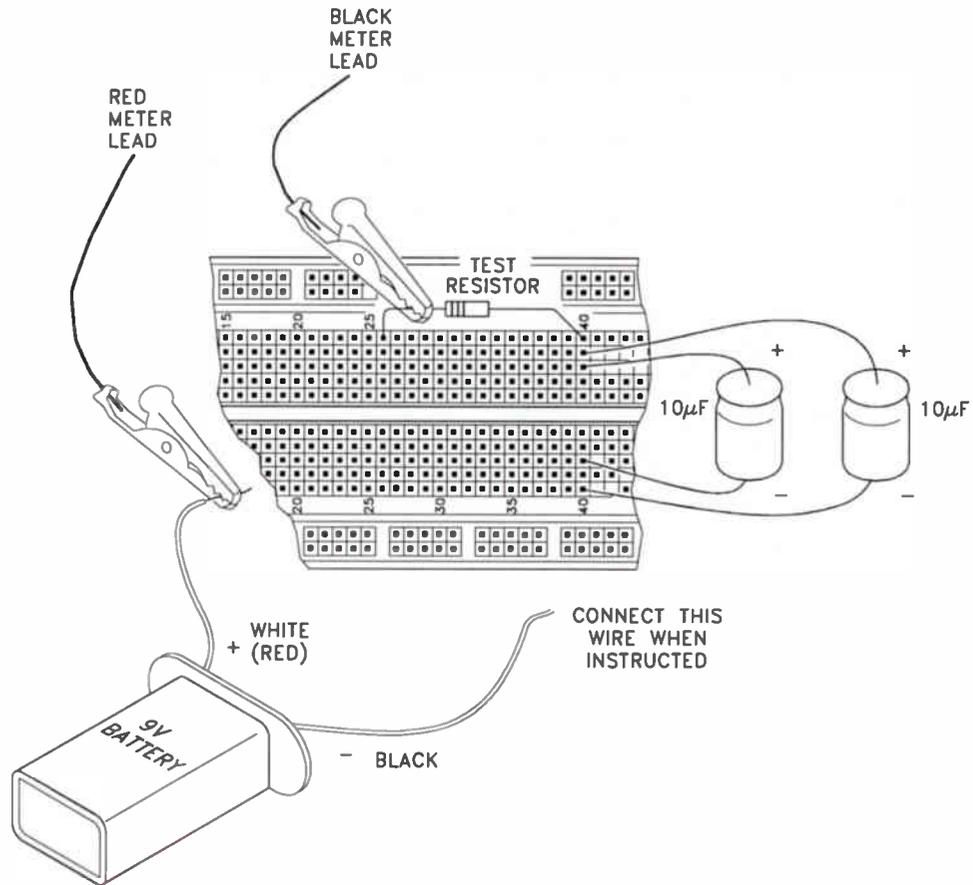


Figure 10-2. One way to breadboard the connection for Experiment 10.

To get the  $20\mu\text{F}$  capacitance shown in Figure 10-1, you'll have to connect two  $10\mu\text{F}$  electrolytic capacitors in parallel. When capacitors are connected in parallel, the total capacitance is the sum of the individual values. Remember that electrolytic capacitors should be installed with polarity positioned in the appropriate direction.

When you connect the 9-volt battery to the circuit, the voltage across the series-connected resistor and capacitor will be 9 volts. The time it takes the capacitor to charge depends on the amount of resistance and capacitance in the circuit. If either the resistance or the capacitance is increased, the amount of time it takes to charge the capacitor will increase as well.

**Step 1.** When you're ready, touch the 9-volt battery black lead to the capacitor's negative lead. As soon as you do this, the meter will indicate a charging current. When the meter display changes to 000, the capacitor has become completely charged.

**Step 2.** To repeat the experiment, you'll have to discharge the capacitors. To observe the capacitive discharge current, simply unclip the red meter lead from its current position. Move the red lead to the negative lead of a capacitor. You should see the same indication on the meter as before. This shows the capacitors discharging through the resistor and the meter in the opposite direction of current flow. You can repeat Steps 1 and 2 several times to observe the action.

# BASIC ELECTRONICS EXPERIMENTS

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**Step 3.** Increase the amount of resistance in the circuit by replacing the 10k resistor with a 100k resistor. Repeat Step 1 and Step 2 of the experiment. Notice that the current displayed on the meter display indicates 000 more slowly than it did before in both the charging and discharging cycles.

**Step 4.** Remove one of the 10 $\mu$ F capacitors and repeat Step 1. Notice that the charging rate is faster with less capacitance in the circuit. Short the leads of the capacitors by touching the leads together. By doing this you will discharge the capacitors. Now, connect the capacitors in series to reduce the capacitance further. Electrolytic capacitors are connected in series, just like two batteries connect the positive lead of one capacitor to the negative lead of the other. The circuit should charge very quickly because it has less capacitance. (If you want to repeat this step, you will have to discharge the capacitors each time.)

**Step 5.** Disconnect the battery to turn the circuit off.

## Results

In Steps 1 and 2 of this experiment, you proved that when power is applied to a capacitor, a high current initially flows and then decreases as the capacitor charges. As the current diminishes, the meter will eventually indicate zero. You also learned that a capacitive circuit discharges in the opposite direction. Lastly, you may have noticed that as long as the charge and discharge paths remained the same, the time for charging and discharging was equal.

In Steps 3 and 4, you saw that increasing the resistance in the circuit caused the time constant to increase. In this case, it should have taken 10 times as long for the capacitor to fully charge through the 100k resistor as it did through the 10k resistor. You also proved that capacitors connected in series have less capacitance than capacitors connected in parallel. Decreasing the capacitance also decreased the charge and discharge times. This is because the time constant was smaller. Similarly, increasing the capacitance in the circuit without changing the resistance increases the time constant.

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# Experiment 11: Basic Coil Action

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## Introduction

A coil is an inductive device created by a looping turn of wire around a core. The conductor is usually copper wire. The core can be made of any material that affords a path for magnetic flux lines in a coil. The DC resistance of a coil is the same as the resistance of the wire itself meaning that the form of a coil doesn't change the conductor's DC characteristics. However, it does change the way the wire responds to alternating current (AC). Because a coil of wire can oppose the starting, stopping, or changing of current, it has the characteristic of inductance.

Recall that inductance is the characteristic of a coil that enables it to induce a voltage into itself. Winding wire in the form of a coil causes a significant increase in the inductance properties. Therefore, when inductance is increased the inductive reactance increases. The opposition that the coil offers to alternating current is much greater than its opposition to direct current. This opposition to current flow is known as impedance.

You have already studied these properties in an earlier lesson. We suggest that if these factors sound vague to you, you may want to review the earlier lesson to refresh your

memory concerning the impedance, reactance, and inductance properties of coils.

## Materials Needed

For this experiment, you will need the breadboard socket, your DMM and the following parts:

- 2 9-volt batteries with clips
- 1 1k resistor
- 2 Red light-emitting diodes
- 1 Choke coil

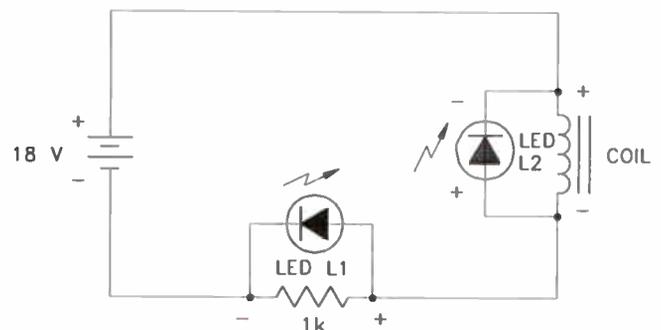


Figure 11-1. Circuit connection to demonstrate counter electromotive force (CEMF).

# BASIC ELECTRONICS EXPERIMENTS

## Procedure

A full study of inductance, inductive reactance, and many other aspects of inductors (coils) would normally require weeks of laboratory time. Therefore, this experiment will focus on the basic properties of coils. In this experiment, you'll construct a simple inductive circuit and use light emitting diodes

(LEDs) to observe the voltage changes in the circuit.

You will want to begin this experiment by constructing the circuit shown in Figure 11-1 without the LEDs. To get the 18 V supply, you'll have to connect two 9-volt batteries in series aiding. Use the diagram in Figure 11-2 if you need help. Be sure to move the red lead of your DMM back to the V socket.

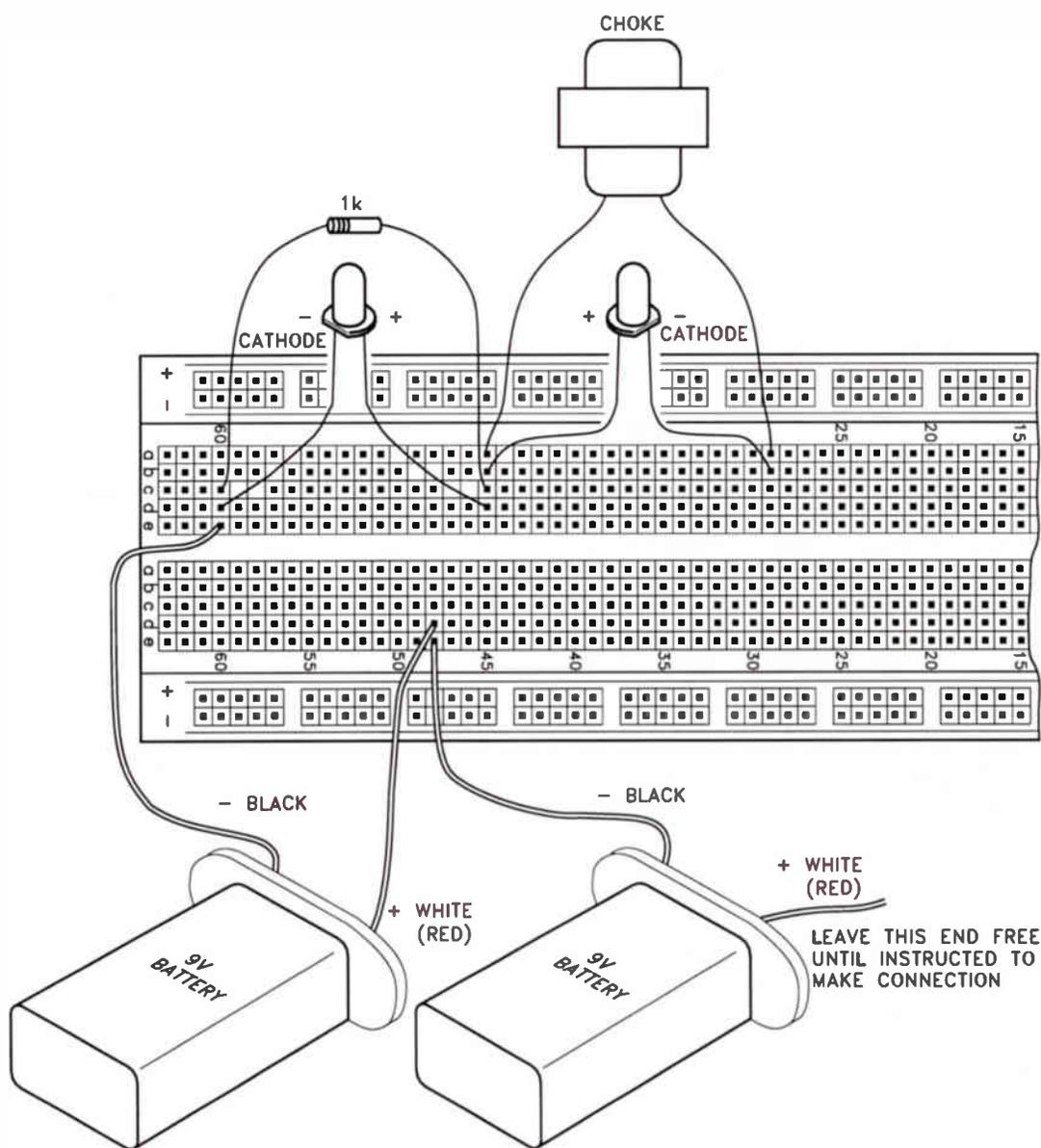


Figure 11-2. One way to connect components for coil demonstration.

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**Step 1.** Connect the negative lead of the 18 V supply to the free end of the 1k resistor and the positive lead to the free lead from the choke coil. Set your meter to the 20 V range and measure the voltage drops across the resistor and the coil. You should find that the DC voltage across the resistor is more than the DC voltage across the coil. Thus, the resistance of the coil is less than 1 kilohm. The coil's inductive properties will become evident as you connect the LEDs later in this experiment.

**Step 2.** Disconnect the battery red lead from the coil. Connect the LEDs across the 1k resistor and the coil with the polarity, as shown in the schematic. An LED lights when a negative voltage is applied to the cathode and a positive voltage is applied to the anode. Ensure that the components are installed into the circuit properly, review Figure 11-1 carefully.

The second LED (L2) should be connected with opposite polarity when compared to first LED (L1). Current should flow from the battery, through LED L1 and the 1k resistor, through the coil, and back to the battery positive. Current should not flow through LED L2 at this point.

**Step 3.** Touch the battery red lead to the free end of the coil. Current in the circuit flows through L1 and bypasses L2.

**Step 4.** Disconnect the red lead from the coil and carefully watch L2.

**Step 5.** Disconnect the battery.

## Results

When you initially connected power, LED L1 turned on, indicating current flow in the circuit. LED L2 did not light because it does not conduct (it is reverse biased). When you disconnected the battery from the circuit, you saw that LED L2 lit very briefly. Can you explain this from what you know about coils and their properties?

When you disconnected the battery, the circuit DC current stopped. The magnetic field surrounding the coil (induced by current flow) collapsed as circuit current stopped. The collapsing magnetic field induces a voltage and current into the coil in the opposite direction of the battery current. The opposite polarity of the induced voltage is of the correct polarity to light L2. The induced voltage (sometimes called CEMF, or counter electromotive force) is of very brief duration, lasting only as long as the decreasing current is changing.

# Experiment 12 : Transistor Operation

## Introduction

The two types of bipolar transistors are the NPN and the PNP transistors. Both types are used in electronic circuits. For any transistor to operate, the emitter-base junction must be forward biased and the collector-base junction must be reverse biased. Applying this requirement to the NPN transistor shown in Figure 12-1(A), this means that the base must be positive with respect to the emitter, and the collector must be positive with respect to the base.

Figure 12-1(B) shows a two-diode representation of the NPN transistor. D1 represents the base-emitter junction, while D2

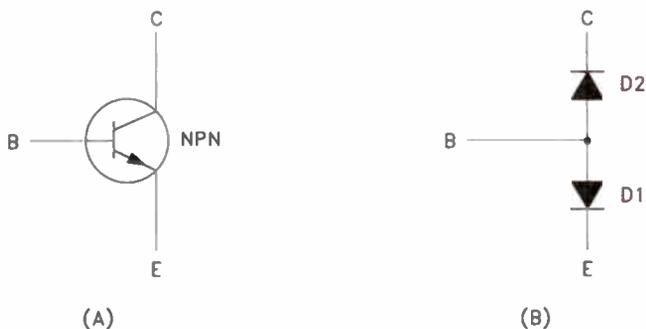


Figure 12-1. (A) An NPN transistor can be represented as (B) two back-to-back diodes.

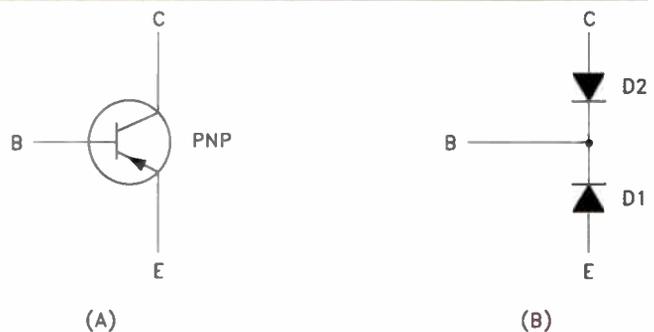


Figure 12-2. (A) A PNP transistor and (B) diode equivalent.

represents the collector-base junction. Figure 12-2 is similar to Figure 12-1, but it shows a PNP transistor symbol and its two-diode representation.

In this experiment, you are going to show that an NPN transistor can have a current gain when properly biased. That is, a small current in the input circuit can control a much higher current in the output circuit. Also, you will learn how to measure voltages to determine if a transistor is saturated (conducting hard), cut off (not conducting), or biased for linear (Class A) operation.

A transistor is a solid-state device that amplifies by controlling the flow of current carriers through its semiconductor materials. The

basic idea of current flow within a transistor is that the amount of current flowing from emitter to collector is controlled by the base current. The base current is very small compared to the collector current. Therefore, increasing or decreasing the base current will cause a much larger collector current to increase or decrease. The total current flow in a transistor flows in the emitter circuit. Approximately 95% of the emitter current reaches the collector circuit, while the remaining 5% passes through the emitter-base circuit.

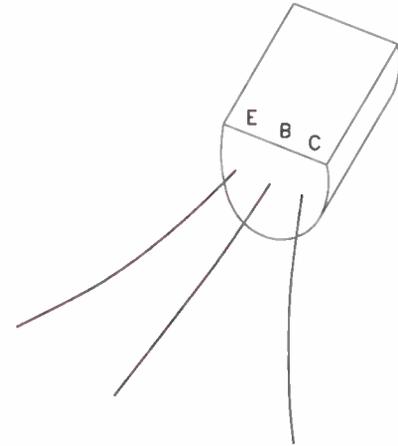


Figure 12-4. Lead identification for a typical transistor.

## Materials Needed

You will need your breadboard socket, 9-volt battery with clips, your DMM, and the following parts:

- 1 1k resistor
- 1 2.2k resistor
- 1 4.7k resistor
- 1 10k resistor
- 1 10k trim potentiometer
- 1 NPN transistor (2N3904 or equivalent)

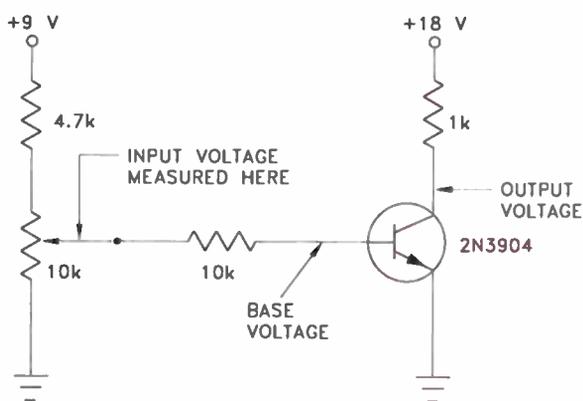


Figure 12-3. Schematic for the circuit for Experiment 12.

## Procedure

Construct the circuit shown in Figure 12-3 on your breadboard.

Figure 12-4 identifies the leads of the transistor. As in an earlier experiment, the 18 V supply is produced by connecting two 9-volt batteries in series aiding. Figure 12-5, on the next page, shows an illustration of one way to wire this circuit.

Set your meter to 20 V DC and connect the black lead to ground. For this experiment, you will measure the output voltage directly from the collector of the transistor. The input voltage will be measured at the end of the 10k base resistor that connects to the center tap of the 10k potentiometer. Base voltage will be measured directly from the base of the transistor. In a moment, you'll see why the base voltage isn't necessarily the input voltage.

**Step 1.** Connect the battery and rotate the 10k potentiometer fully in the counterclockwise direction. Measure the output voltage on the collector and record the reading in Table 12-1, on the next page. Then, measure the base voltage and record this measurement in

# BASIC ELECTRONICS EXPERIMENTS

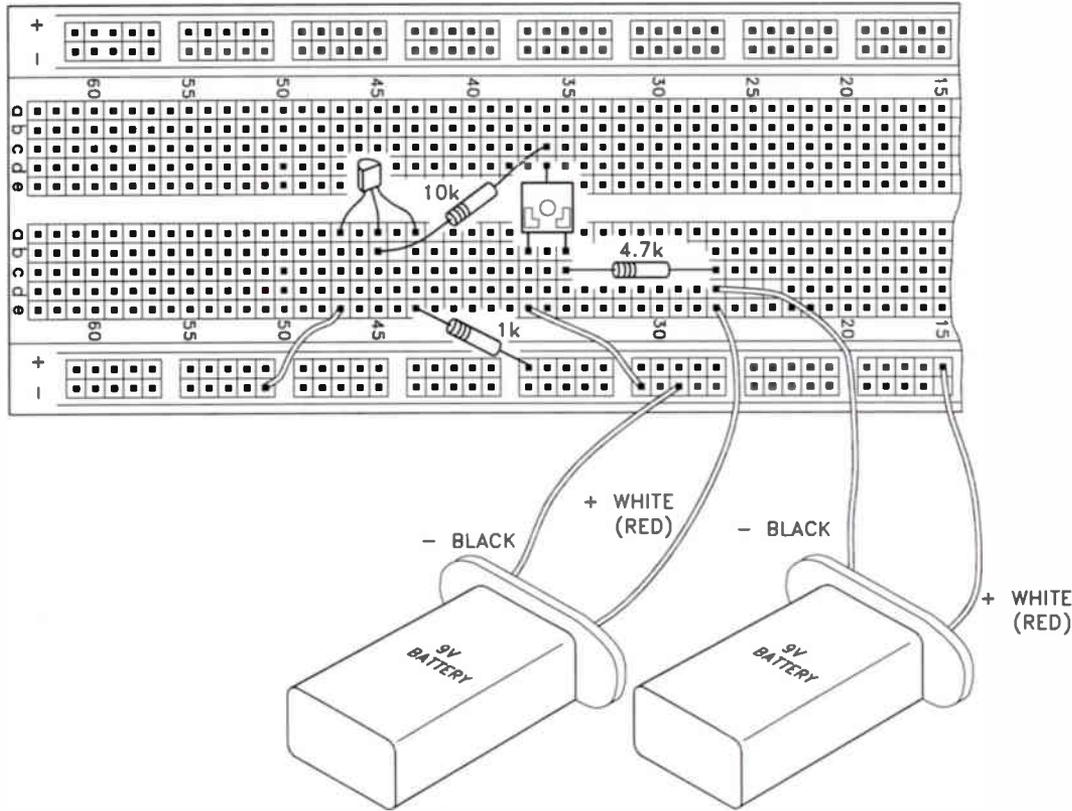


Figure 12-5. An illustration of the circuit for Experiment 12.

Table 12-1. Measure the input voltage as indicated above and record this voltage in Table 12-1, even if it's zero. Then, slowly adjust the potentiometer until you acquire a reading of 1 volt.

**Step 2.** With the input set to 1 V, measure the base voltage again. It should be about 0.7 V direct current. Record your results in Table 12-1. This means you have approximately 0.3 V dropped across the 10k resistor. Using Ohm's Law, it is easy to determine that you have approximately 30 microamps of current in the base circuit.

**Step 3.** After you record the DC voltage at the base, re-measure the output voltage and record it in Table 12-1. Now, turn the potentiometer completely clockwise and record the collector (output) voltage. Next, measure and record the input voltage once again. Then,

measure and record the voltage on the base of the transistor.

**Step 4.** Adjust the 10k control for an input of 1 volt. Remember, for this experiment, the input is measured at the center tap of the control. Do not readjust the control after setting it.

**Step 5.** Now, measure the collector supply voltage and record this voltage in Table 12-2.

Pot Position	Input	Output	Base
Fully Clockwise			
Input = 1 volt	1 volt		
Fully Counterclockwise			

Table 12-1. Record your results for Step 1 here.

Load Resistance	Output Voltage	Supply Voltage	Voltage Across Load	Collector Current
1k				
2.2k				

Figure 12-2. Record your results for Step 2 here.

Then, measure and record the collector output voltage. Subtract this voltage from the previous reading and enter your result as the voltage drop across the 1k collector load resistor. To find the collector current, divide the voltage across the collector by the resistance and enter your results.

**Step 6.** Next, remove the 1k load resistor and replace it with a 2.2k load resistor. The total resistance is now more than twice the original value. Again, measure the supply and output voltages and determine the voltage drop across the collector resistor. Then, calculate the collector current and record it in Table 12-2. When you are finished, disconnect the batteries from the circuit.

## Results

An NPN silicon transistor was used in Step 1. Until the bias pot was properly adjusted to produce the necessary base voltage, there was no current flow through the transistor. This was determined when you read the full supply voltage at the collector. The transistor was cut off (not conducting), and it appeared as an open circuit.

When the bias control was adjusted to produce 1 V DC at the 10k base resistor, you

should have measured approximately 0.7 V DC at the base. You will always measure between 0.6 and 0.7 V across the emitter-base junction of a conducting silicon transistor. With the proper bias voltage present, the transistor began conducting, and there was a voltage drop across the collector load resistor. You should have measured about 12.3 V DC at the collector of the transistor. This indicates that the transistor is no longer cut off.

From this experiment, you have proved that a transistor must be biased before it will conduct. The emitter-base junction is forward biased with a positive voltage at the base and the emitter grounded. A positive voltage at the base of an NPN transistor causes a reduction in the voltage at the collector. The collector was connected to a +18 V DC supply through a 1k resistor. The base-collector junction was therefore reverse biased.

When you increased the bias voltage to maximum, you found that the voltage across the emitter-junction remained essentially constant, while the voltage across the base resistor increased. This resulted in an increase in base current. This small change in base current was more than sufficient to saturate the transistor and cause the collector voltage to drop almost to zero.

A saturated transistor appears as a very low resistance, and it drops very little voltage. It has characteristics very similar to a turned-on switch. The majority of the voltage in this circuit is dropped across the collector resistor.

You also learned that once the transistor is saturated, further increase in base-emitter current will not affect the collector current.

# BASIC ELECTRONICS EXPERIMENTS

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When a transistor is properly biased to operate as a linear (Class A) amplifier, the collector voltage will be approximately half of the supply voltage. In the circuit that used an 18 V DC supply, the collector voltage should be adjusted for approximately 9 V to allow a maximum positive and negative swing of an input signal without distortion.

Additionally, you learned that the size of the collector resistor did not greatly affect the collector current. From this experiment, you

have determined that the base current, which you can vary by adjusting the control, actually controls the collector current; the transistor is a current-controlled device with a small base current (about 30 mA) controlling a large collector current (about 5.6 mA).

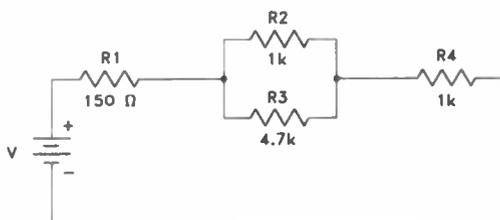


# BASIC ELECTRONICS EXPERIMENTS

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3. If the load resistance in the circuit used in Experiment 5 increases, the voltage drop across it will \_\_\_\_\_, indicating that the output current has \_\_\_\_\_.
- Increase, increased
  - Decrease, decreased
  - Increase, decreased
  - Decrease, increased

4. In the circuit shown below, the current leaving the parallel branch and flowing to the positive terminal of V is \_\_\_\_\_ the current flowing through R1.
- Usually greater than.
  - Considerably greater than.
  - Considerably less than.
  - Equal to.



5. What is the most practical and quickest way to determine total current in the circuit for Question 4?
- Create an open in the circuit and then connect an ammeter.
  - Use Ohm's Law to calculate after measuring the voltage across R1.
  - Measure the voltage across R3.
  - Use Ohm's Law to calculate after measuring the voltage across R2.

6. Using the values recorded in Table 3-1, what is the voltage on Terminal 3 of Figure 3-3 with respect to Terminal 1?
- Negative and equal to the voltage measured in Step 1.
  - Positive and equal to the voltage measured in Step 1.
  - Positive and much smaller than the voltage measured in Step 1.
  - Positive and much greater than the voltage measured in Step 1.
7. According to the information you recorded in Table 7-1, what ohmmeter range gave the most significant reading for the 2.2k resistor?
- 2k.
  - 20k.
  - 200k.
  - 2M.

8. What resistance did you measure from the circuit shown in Figure 9-1?
- Approximately 2,700 ohms.
  - Approximately 5,500 ohms.
  - Approximately 17,000 ohms.
  - Approximately 28,500 ohms.

- 
9. What change in resistance would you expect between Terminals A and B of Figure 8-1 if resistors R3, R4, and R5 were shorted?
- Increase more than 10 percent.
  - Decrease more than 10 percent.
  - Decrease less than 5 percent.
  - Increase 1 percent.
10. When you compared the base and collector currents of the conducting transistor in Experiment 12, you found that:
- No current flowed in the circuit.
  - They were about equal.
  - The base current was slightly greater than the collector current.
  - The collector current was much greater than the base current.

# NOTES

*Please use this page to record any notes you may want to review during your studies.*



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*Please use this page to record any notes you may want to review during your studies.*



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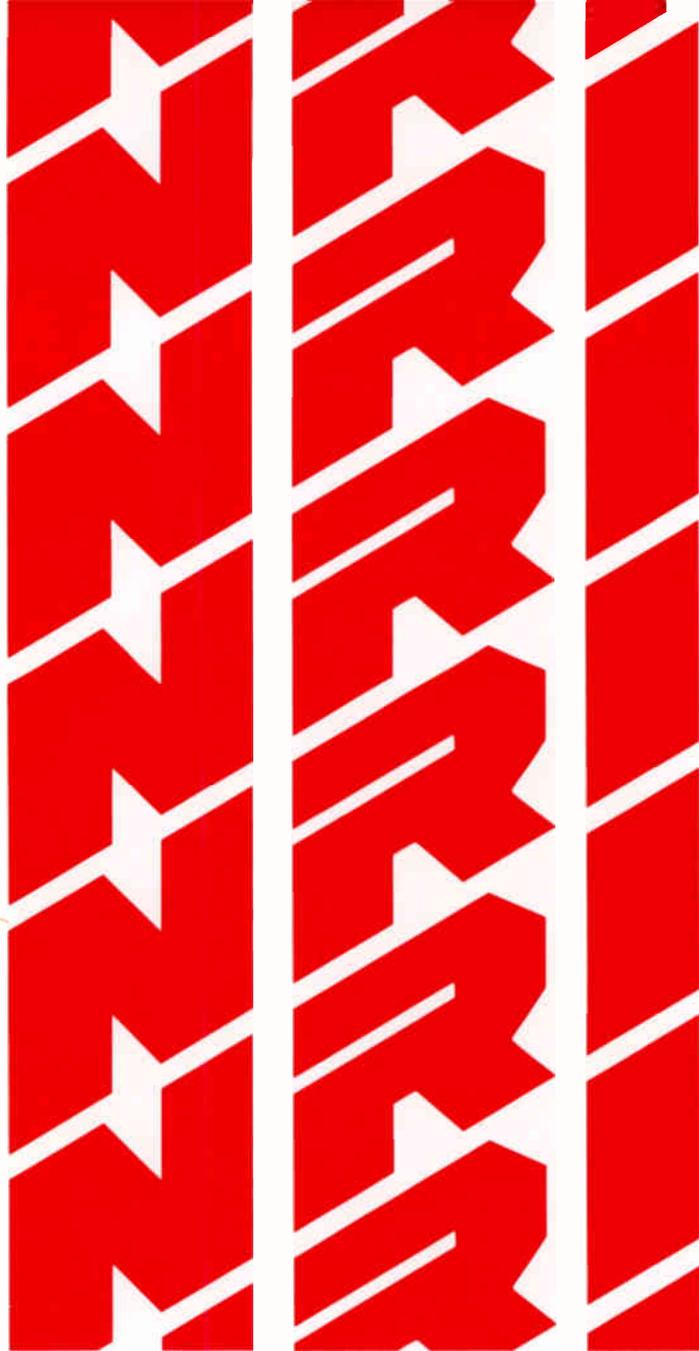
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# Voltage, Current, and Resistance



**2217**

*NRI Schools*

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Washington, DC 20008



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# **Voltage, Current, and Resistance**



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# Table of Contents

<b>Voltage</b> .....	1
DC Voltage .....	1
Voltages in Series .....	4
Voltage Units .....	5
Review .....	5
Self-Test Questions .....	6
<b>Current</b> .....	7
Current Units .....	7
Review .....	9
Self-Test Questions .....	9
<b>Resistance</b> .....	10
The Ohm .....	10
Resistance Units .....	11
Review .....	12
Self-Test Questions .....	12
<b>Ohm's Law</b> .....	13
How Voltage Affects Current .....	13
How Resistance Affects Current .....	14
Finding E .....	15
Review .....	15
Self-Test Questions .....	16
<b>Answers to Self-Test Questions</b> .....	17
<b>Lesson Questions</b> .....	19

# Lesson Objectives

In this lesson you will . . .

- Explore some practical aspects of connecting dc power sources.
- Learn about "ground."
- Discover how dc voltages connected in series add together.
- Learn how voltage, current, and resistance values are changed into smaller or larger units.
- Examine useful applications of Ohm's Law in finding the values of current and voltage in a series circuit.

## VOLTAGE

You have learned that voltage is the electrical pressure or force that sets electrons in motion. Batteries and generators are sources of voltage. The unit in which voltage is measured is the volt (V). Let's review some of the important things you learned about voltage in the first lesson, and expand that knowledge.

### DC Voltage

DC is a common abbreviation for direct current. A *dc voltage* is one that causes a direct current to flow. In the early days of electronics, equipment (usually radio equipment) was built on a metal chassis. One side of the operating voltage source was connected to this chassis. The chassis, in turn, was connected to a water pipe or other metal pipe driven into the ground. As a result, the connection to the chassis became known as the "ground connection."

With one side of the voltage source connected to the ground, dc voltage measurements are made between the ground and other points in the circuit. This is a convenient method of reading voltages found in various parts of the circuit.

A flashlight cell produces a voltage of about 1.5 volts. Higher voltages can be obtained by connecting two or more cells together, because their voltages add together. We say the cells are connected *in series*. A series connection puts the negative terminal of one cell in contact with the positive terminal of another. The two cells combine into one voltage source having a negative and a positive terminal, as shown schematically in Fig.1(A). If each cell has a voltage of 1.5 V, the total voltage available from the series-connected combination is 3 volts.

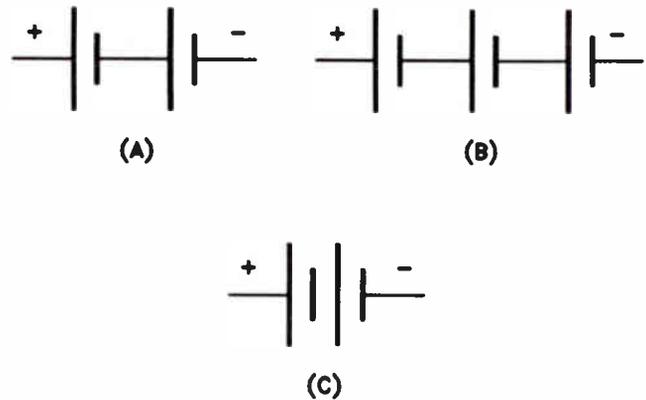


Figure 1. Battery symbols. Each cell is rated at 1.5 volts.

Most people think of a flashlight cell as a battery, but technically it is a cell. The combination of two or more cells is a *battery*. A three-cell combination, shown in Fig.1(B), has a total voltage of 4.5 volts. If we connect 15 cells as shown by Fig.1(C), we get a voltage of  $15 \times 1.5 = 22.5$  volts. Notice that we did not draw 15 cells. Usually two cells are shown, and the voltage is listed in numerals.

We can connect two 9 V batteries in series, as shown in Fig.2, to get 18 volts. There is 9 V between terminals A and B, 9 V between terminals B and C, and 18 V between terminals A and C. Sometimes we say that terminal C is 18 V positive with respect to (or compared to) terminal A; or that terminal A is 18 V negative with respect to

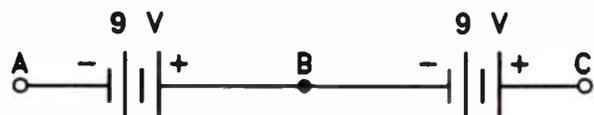


Figure 2. Two 9 V batteries connected in series.

## VOLTAGE, CURRENT, AND RESISTANCE

terminal C. If polarity is unimportant to the application, we may just say that there is 18 V between A and C.

To simplify the wiring of most electronic equipment, a common terminal of the power source is frequently used as a reference point. For example, terminal B is a common point with respect to the voltages at A and C. It is 9 V positive with respect to terminal A, and 9 V negative with respect to terminal C. This common terminal may be used as a reference point and is most frequently called *ground*, or sometimes a *common ground*. At the ground point, the voltage is considered to be zero because it is used as a reference value. When you read that some circuit point is at “ground potential,” it means that the voltage at that point is 0 V with respect to the common ground.

Usually, the negative terminal of the battery or power supply is connected to the common ground terminal as shown in Fig.3(A). Notice the symbol used to represent the ground connection. When connected in this way, terminal A is regarded as the zero reference point (the ground) for voltage in the equipment circuits. Terminal B would measure +9 V, and terminal C, +18 volts.

The common connection can also be made as shown in Fig.3(B). Here, terminal C connects to the common ground terminal, so the voltage at terminal C is 0 volts. Terminal B voltage is -9 V and terminal A has -18 volts. The net effect is the same as when terminal A is grounded; there is 18 V between terminals A and C. The difference is in the polarity of the voltage with respect to the ground reference point.

A third way of making the common or ground connection is shown in Fig.3(C), where terminal B is at ground potential. Terminal A is -9 V, and terminal C is +9 V with respect to the reference point, terminal B. There is still 18 V total between terminals A and C.

Most modern electronic equipment is made with printed circuit boards. These are thin, insulating boards to which a layer of copper conductor is glued. The copper is marked with the desired circuit pattern, then most of the copper is etched off the board by an acid solution, leaving the circuit conductor layout. Frequently, some excess copper is left on the board to form the *common connection*, also called the *ground foil*.

Using the chassis as a common connection significantly reduces the amount of necessary wiring in electronic equipment. The same technique is used on a larger scale in automobiles, where the frame of the vehicle takes the place of a wire. The negative terminal of the automotive battery is bolted to the frame or chassis of the car. Current flow in automotive electrical accessories is from the chassis ground, through the accessory, then through a wire to the positive terminal of the battery. This is why you will frequently see automotive electrical systems described as “12 V negative ground” systems.

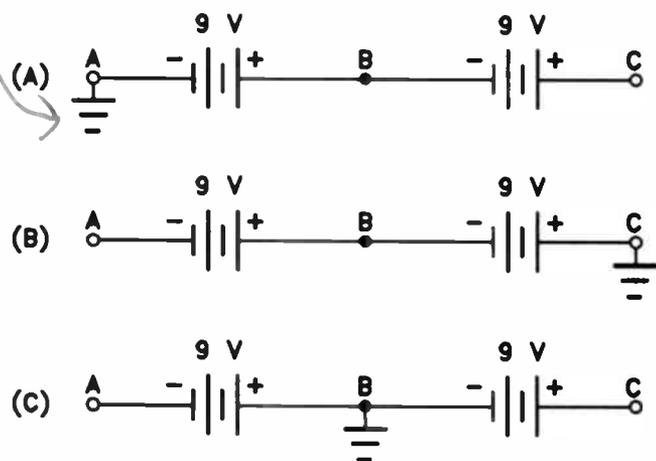


Figure 3. Three ways of adding a common or ground connection to two 9 V batteries connected in series. The voltage between the terminals is the same in all three circuits.

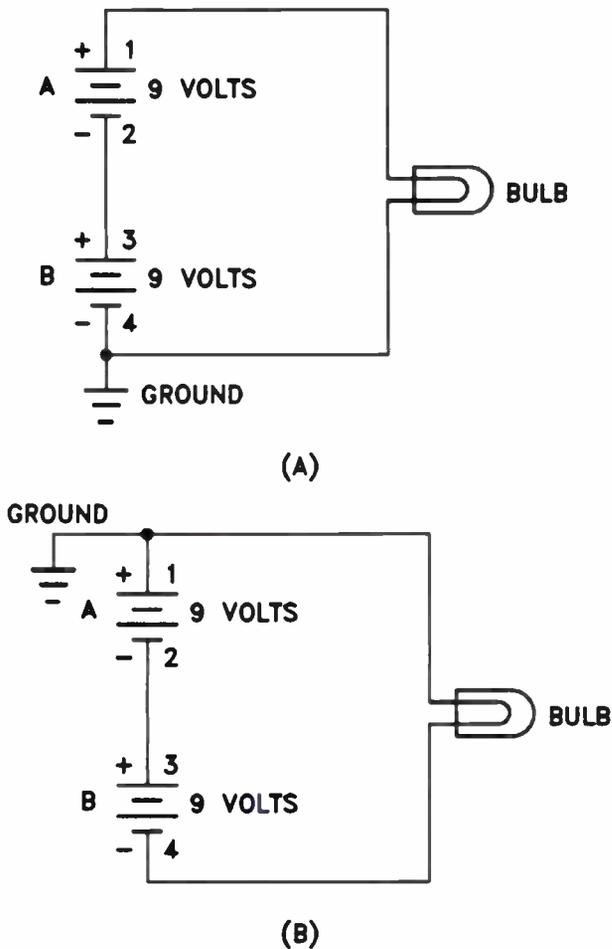


Figure 4. Simple circuits with ground connection.

In Fig.4, one battery is labeled A and the other is labeled B. The positive terminal of battery A is terminal 1, and the negative terminal is terminal 2. The positive terminal of battery B is terminal 3, and the negative terminal is terminal 4. Notice that the negative terminal of battery B in Fig.4(A) is grounded.

With the batteries connected in this way, using ground as a reference, we say that terminal 1 of battery A is +18 V with respect to ground. Also, if the negative terminal (4) of bat-

tery B is at ground or zero potential, terminal 3 of battery B will be 9 V with respect to ground.

In Fig.4(B), the ground connection is moved so that terminal 1, the positive terminal of battery A, is ground. Now we consider terminal 1 of battery A to be at zero, or ground potential, and terminal 4, the negative terminal of battery B, is -18 V with respect to ground. Remember that the total voltage is the same in both cases.

As you've seen before, we can go one step further and ground the connections between terminals 2 and 3 of the two batteries, as shown in Fig.5. Here we have both negative and positive polarities with respect to ground. Terminal 1 of battery A is positive with respect to ground, and terminal 4 of battery B is negative with respect to ground. The total voltage applied to the bulb is still 18 V because the two batteries are connected in series. The same current flows through the bulb in the two examples given in Fig.4 and the circuit shown in Fig.5. In your study of electronics, you will run into a lot of equipment where voltages may be either negative or positive with respect to ground.

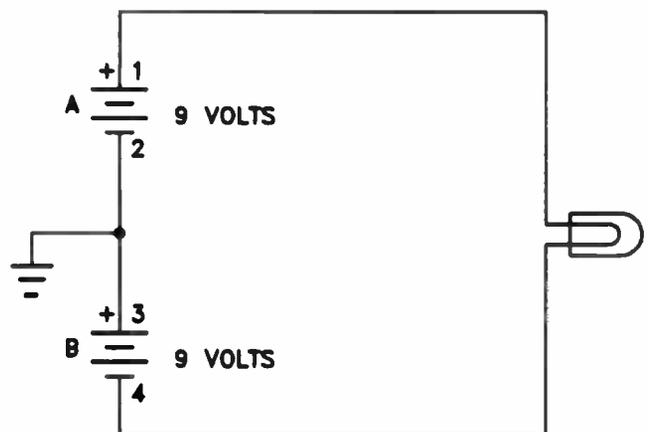


Figure 5. A simple circuit with a positive voltage with respect to ground and a negative voltage with respect to ground.

# VOLTAGE, CURRENT, AND RESISTANCE

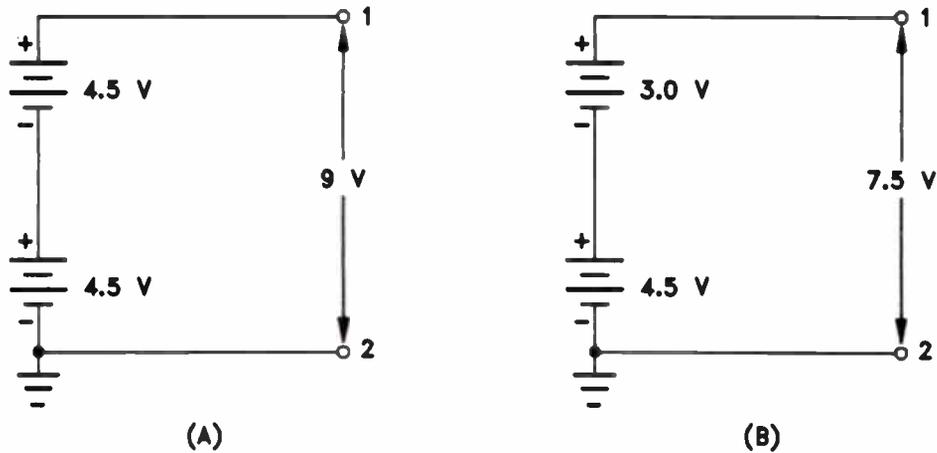


Figure 6. Batteries connected in series so their voltages add.

## Voltages in Series

Voltage sources can be connected in series. Whether they add together or subtract from each other depends on how they are connected.

In Fig.6(A) we have two 4.5 V batteries connected in series aiding. This means that the two voltages add together. Notice that the batteries are connected in the same way as the cells forming each battery are connected. We have, in effect, simply added three additional cells to one

of the 4.5 V batteries, so that the total voltage between terminals 1 and 2 is 9 volts.

In Fig.6(B), we have batteries with different voltages connected in series aiding. In effect, we have simply added two cells to the 4.5 V battery, so the total voltage is 7.5 volts.

In Fig.7, we have three examples of batteries connected in series opposing. These batteries are connected so that their voltages oppose. To find the total voltage we subtract the battery voltages.

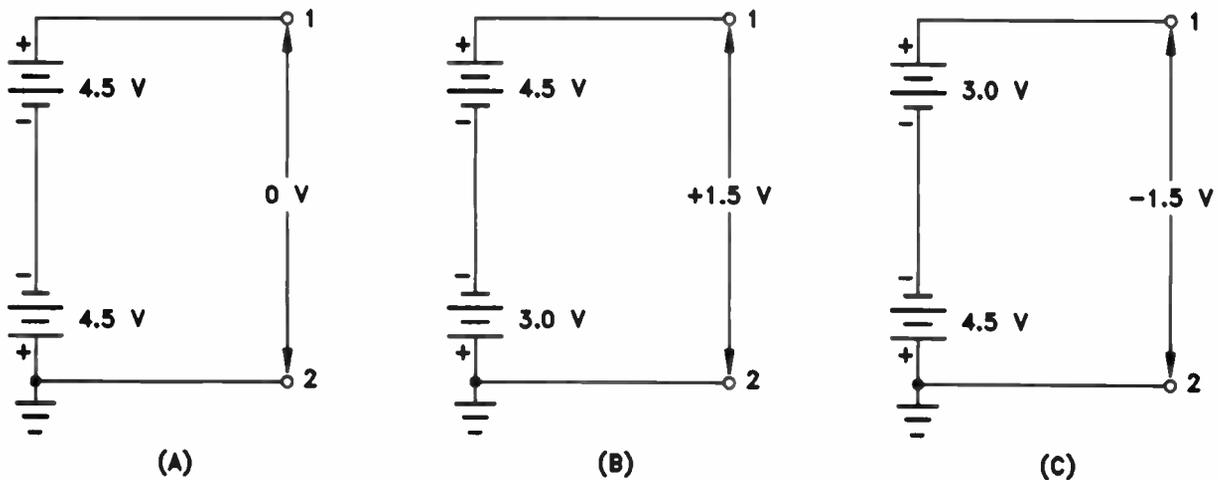


Figure 7. Batteries connected in series so their voltages subtract.

In Fig.7(A), each battery is a 4.5 V battery. When you subtract 4.5 from 4.5, the result is 0. Therefore, the potential between terminals 1 and 2 is 0 volts.

In Fig.7(B), we have batteries of unequal voltages. Subtracting the smaller voltage from the larger, we have  $4.5 - 3.0 = 1.5$  volts. Since the positive terminal of the larger battery connects to terminal 1, terminal 1 will be 1.5 V positive.

In Fig.7(C), we have the opposite situation. The positive terminal of the 4.5 V battery connects to terminal 2. Therefore, terminal 2 is positive with respect to terminal 1, or, in other words, terminal 1 is 1.5 V negative.

We can connect dc generators in series in the same way as the batteries shown in Figs.6 and 7. If they are connected in series aiding, their voltages add. If they are connected in series opposing, their voltages subtract.

## Voltage Units

In many electronic circuits, the voltage values are not expressed in volts. Some values are much smaller, and require that the voltage unit be expressed in a more convenient unit of measurement. Occasionally, larger units are needed as well. For this reason, several useful voltage units have been defined.

**The Millivolt.** When the volt is too large a unit, we use the millivolt, and sometimes the microvolt. A *millivolt*, *mV*, is one thousandth of a volt. The prefix milli means one thousandth. To convert volts to millivolts we multiply by 1000. To do this, we simply add zeros and move the decimal point three places to the right. To convert from millivolts to volts, we do the opposite: divide by 1000 and move the decimal point three places to the left. Thus,  $2.5 \text{ V} = 2.5 \times 1000 = 2500 \text{ mV}$ .

**The Microvolt.** The *microvolt*, abbreviated  $\mu\text{V}$ , is one millionth of a volt. The symbol  $\mu$  is the Greek letter mu, and is traditionally used to indicate "micro." To convert volts to microvolts, multiply by 1,000,000. Do this by moving the decimal point six places to the right. To convert from microvolts to volts, move the decimal point six places to the left.

**The Kilovolt.** Another unit used in voltage measurements is the kilovolt. The *kilovolt* is 1000 volts. Thus, 25 kilovolts, abbreviated 25 kV, is equal to 25,000 volts. Voltages are measured in kilovolts in TV receivers, in video displays used with computers and microcomputers, and in radio and TV transmitters. Remember, a kilovolt is equal to 1000 V, so to convert kilovolts to volts, we simply multiply by 1000.

## Review

A dc voltage produced by a battery or a dc generator will have a polarity that does not change. Connected to a circuit, a dc voltage source produces a current that flows in one direction. Voltage sources are frequently connected to common points called ground, and may be either positive or negative with respect to ground.

Batteries and generators can be connected in series aiding so that their voltages add, or in series opposing so that their voltages subtract. When voltage sources are connected in series between ground and another point, the polarity of the point may be positive or negative when the batteries oppose, depending on the polarity of the larger voltage source.

Some circuits you will use will have very small voltages; others will have very high voltages. Remember that the millivolt (mV) is one thousandth of a volt, the microvolt ( $\mu\text{V}$ ) is one millionth of a volt, and the kilovolt (kV) is one thousand volts.

## VOLTAGE, CURRENT, AND RESISTANCE

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Your understanding of the basic principles of electronics is essential. Advanced lessons are based on the fundamentals you learn in early lessons. If you skip over parts you do not understand, you are sure to run into problems later. If you have difficulty with some of the material, carefully reread those lesson sections. If you need additional help, take advantage of the NRI consultation service. Write and tell us exactly which section of the lesson gave you trouble, and we will give you additional assistance.

### Self-Test Questions

*Please check your answers on page 17.*

- 1 In the circuit shown in Fig.4(B), if both batteries are 6 V, what voltage is present at terminal 4 with respect to ground?
- 2 In the circuit shown in Fig.5, if each battery is a 45 V battery, what is the voltage at terminal 1 with respect to ground? What is the voltage at terminal 4 with respect to ground?
- 3 If a 15 V battery and a 45 V battery are connected in series as in Fig.6(B), what will the voltage be at terminal 1 with respect to ground?
- 4 Two batteries are connected as shown in Fig.7(B). One battery is a 45 V battery with its positive terminal connected to terminal 1, and the other battery is a 22-1/2 V battery with its positive terminal grounded. What is the voltage at terminal 1 with respect to ground?

12 V

45 + V  
45 - V

60 + V

22 1/2 + V

## CURRENT

You have learned that an electron is part of an atom and that it has a negative electrical charge. All electrons have the same negative electrical charge. Electrons repel each other because like charges repel. Electrons are repelled by negative charges, and attracted by positive charges.

**Direct Current.** When a battery is connected to an electric circuit, electrons are repelled from the negative terminal of the battery and attracted by the positive terminal. Electrons move in one direction through the circuit. This type of current flow is called *direct current*, or *dc*. Direct current is widely used in electronic equipment. Current will flow through many of the devices used in electronic equipment in only one direction, and therefore the current used to operate these devices is direct current.

In a simple circuit, such as the one shown in Fig. 8, the current flow is the same in all parts of the circuit at all times. The number of electrons leaving the negative terminal of the battery is exactly the same as the number of electrons passing point A on the wire connecting the battery to the lamp. The number of electrons flowing through the lamp is the same as the number of electrons passing point B on the other wire, and it is the same as the number of electrons moving into the positive terminal of the battery.

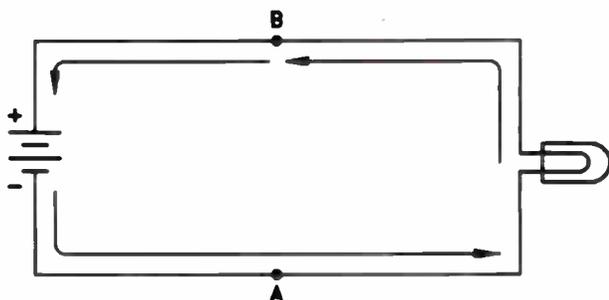


Figure 8. A simple circuit.

Another important point to remember is that electrons start moving in all parts of a circuit the instant the circuit is completed. Electrons do not leave the negative terminal, hit other electrons, and start a chain reaction of movement. All free electrons in the entire circuit start moving at the same time.

**Alternating Current.** The electric current supplied to homes for light and power is an *alternating current*, or *ac*. Alternating current flows first in one direction and then in the other direction. The current supplied by most power companies in the United States and Canada is 60-cycle current. This means that it goes through 60 cycles per second. We use the word hertz (abbreviated Hz) for cycles per second, so we say that the frequency is 60 Hz. In resistive circuits, alternating and direct current have the same relationships of current, voltage, and resistance. We will discuss alternating current more fully in another lesson.

### Current Units

The basic unit of current measurement is the *ampere* — abbreviated *A* — but in electronics this unit is often too large for convenient use. In common electronic circuits the current flow is small. It may be only a few thousandths of an ampere.

**The Milliampere.** We can express three thousandths of an ampere ( $3/1000$ ) more easily as a decimal, 0.003 ampere. But, it is more convenient to express the value in milliamperes (mA). A milliampere is one thousandth of an ampere. A current of three thousandths of an ampere is 3 milliamperes. To convert amperes to milliamperes, we simply multiply by 1000. This is done by moving the decimal point three places to the right. The process is similar to converting dollars to cents. One dollar is written in numerals as \$1.00. To convert the \$1.00 to

# VOLTAGE, CURRENT, AND RESISTANCE

cents, we move the decimal point two places to the right and we have 100¢. To convert 5 A to mA, we can write 5 A as 5.000 amperes. Move the decimal point three places to the right and we have 5000 milliamperes. Similarly, if the current is 0.05 A, we can write it as 0.050 A, and move the decimal point three places to the right to give us 50 mA. In other words, to go from the large unit to the small unit, move the decimal point to the right.

To convert milliamperes to amperes, move the decimal point three places to the left. In other words, 47 mA can be written as 0.047 amperes. Moving the decimal point three places to the left, we have 0.047 ampere.

**Note:** A standard means of expressing any number less than one in decimal form includes placing a zero to the left of the decimal point.

**The Microampere.** In some circuits even the milliamperes is too large a unit. There is a smaller

unit, (the *microampere*), abbreviated  $\mu\text{A}$ . The microampere is one millionth of an ampere, just as a microvolt is one millionth of a volt.

To convert amperes to microamperes, move the decimal point six places to the right. In fact, try to remember that the decimal point always moves to the right when converting from large units to small units. Since there are a million microamperes in one ampere, we move the decimal point six places to the right. To convert milliamperes to microamperes, we move the decimal point three places to the right.

To convert microamperes to milliamperes, move the decimal point three places to the left. To convert microamperes to amperes, move the decimal point six places to the left. In other words, 50  $\mu\text{A}$  would be 0.000050 ampere.

In Fig.9 we have several examples of conversions from one unit to another. Study this figure and the conversions. Then try to do them your-

LARGE TO SMALL	SMALL TO LARGE
<p>DOLLARS TO CENTS</p> <p>\$1 = 100¢</p> <p>WE MOVED THE DECIMAL POINT 2 PLACES TO THE RIGHT</p> <p>\$1.00 = 100¢</p>	<p>CENTS TO DOLLARS</p> <p>1000¢ = \$10</p> <p>WE MOVED THE DECIMAL POINT 2 PLACES TO THE LEFT</p> <p>1000¢ = \$10.00</p>
<p>AMPERES TO MILLIAMPERES</p> <p>1 A = 1000 mA</p> <p>WE MOVED THE DECIMAL POINT 3 PLACES TO THE RIGHT</p> <p>1 A = 1.000 A</p> <p>1.000 A = 1000 mA</p>	<p>MILLIAMPERES TO AMPERES</p> <p>10 mA = 0.010 A</p> <p>WE MOVED THE DECIMAL POINT 3 PLACES TO THE LEFT</p> <p>010. mA = 0.010 A</p> <p>10 mA = 0.01 A</p>
<p>AMPERES TO MICROAMPERES</p> <p>1 A = 1000000 <math>\mu\text{A}</math></p> <p>WE MOVED THE DECIMAL POINT 6 PLACES TO THE RIGHT</p> <p>1 A = 1.000000 A</p> <p>1.000000 A = 1000000 <math>\mu\text{A}</math></p>	<p>MICROAMPERES TO AMPERES</p> <p>1000000 <math>\mu\text{A}</math> = 1.000000 A</p> <p>WE MOVED THE DECIMAL POINT 6 PLACES TO THE LEFT</p> <p>1000000 <math>\mu\text{A}</math> = 1.000000 A</p> <p>1000000 <math>\mu\text{A}</math> = 1 A</p>

Figure 9. Examples of conversion from one unit to another.

self. This is the best way to learn how to convert from one unit to another. With a little practice, you will be able to convert from one unit to another as easily as you convert dollars to cents or cents to dollars.

## Review

We have reviewed current flow. Remember that current flow is a movement of electrons, and in a simple series circuit the current flow is the same in all parts of the circuit. When the circuit is complete, current starts to flow in all parts of the circuit at the same time.

You learned that the milliampere is one thousandth of an ampere, and the microampere is one millionth of an ampere. To convert from larger units to smaller units, move the decimal point to the right. In converting amperes to milliamperes (or milliamperes to amperes), move the decimal point three places; in converting amperes to microamperes (or microamperes to amperes), move the decimal point six places.

## Self-Test Questions

- 5 If the current flow past a point in the circuit is 1 A and it is increased so that four times the number of electrons pass the point in a second, what will the new current be? *4A*
- 6 Convert \$6.00 to cents. *600¢*
- 7 Convert 2 A to mA. *2000 mA*
- 8 Convert 0.42 A to mA. *420 mA*
- 9 Convert 0.037 A to mA. *37 mA*
- 10 Convert 0.002 A to mA. *2 mA*
- 11 Convert 46 mA to A. *.046 A*
- 12 Convert 822 mA to A. *.822 A*
- 13 Convert 2 A to  $\mu$ A. *2,000,000  $\mu$ A*
- 14 Convert 0.0017 A to  $\mu$ A. *1700  $\mu$ A*
- 15 Convert 147  $\mu$ A to A. *.000147 A*
- 16 Convert 0.031 mA to  $\mu$ A. *31  $\mu$ A*
- 17 Convert 327,000  $\mu$ A to mA, and then to A. *327 mA      .327 A*

# VOLTAGE, CURRENT, AND RESISTANCE

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## RESISTANCE

All wires and components in electronic equipment have resistance. The resistance may be so low that it has no effect on the performance of the circuit; however, almost every circuit has some resistive component that affects the way it operates. In a dc circuit, the only factor that limits the amount of current that flows is the *resistance* in the circuit.

### The Ohm

The unit of resistance is the *ohm*, named after pioneer scientist George Simon Ohm. Its symbol is the Greek letter omega ( $\Omega$ ). When an applied voltage of 1 V causes 1 A of circuit current, the circuit resistance is 1 ohm. What if an applied voltage of 2 V causes 1 A of circuit current? Since the current flow is 1 A in both cases, the circuit

in the second case has twice the resistance to current flow, or 2 ohms.

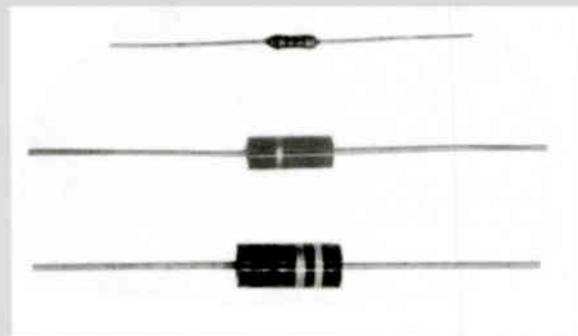
**DC Resistance.** DC resistance is the opposition offered to the flow of direct current in the circuit. If a dc voltage is applied to an electrical circuit, the dc resistance of the circuit will limit the current that will flow in the circuit. Usually, we call it resistance, rather than dc resistance.

**AC Resistance.** The ac resistance of a component may not be the same as the dc resistance. At very high frequencies, much higher than the 60 Hz used by the power companies that supply electricity to your home, ac circuits have special characteristics that change the effective resistances. We will discuss these factors in greater detail in another lesson.

**Resistors.** You know that electronic circuits use copper wire to keep resistance low, but there are many instances where specific values of resistance are needed in the circuit for various reasons. Parts designed to add resistance to the

### Carbon Resistors

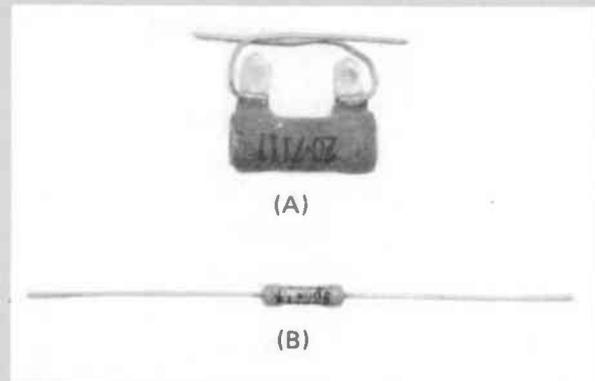
*Carbon resistors come in several different sizes and in many different resistance values. The size of the resistor tells you how much power the resistor can handle. Three different sizes of carbon resistors are shown here. Each resistor has a resistance of 1000 ohms. The resistor on the top is a 1/2-watt resistor. The one in the middle can handle twice the power without burning up, and is a 1-watt resistor. The one on the bottom is a 2-watt resistor, which can withstand four times the power of the 1/2-watt component. The watt is a unit of electrical power which we will discuss later.*



### Wire-wound and Deposited-film Resistors

*A wire-wound resistor (A) is made of wire wound on a form which is usually ceramic. The wire used to wind a resistor is called resistance wire because it has a much higher resistance than copper wire. Wire-wound resistors are used in places where they must handle a higher current than could be handled by a carbon resistor.*

*The deposited-film resistor (B) is composed of a metal oxide film deposited on a ceramic form. These resistors can handle higher currents than carbon resistors, and can be made in larger resistance values than the wire-wound type.*



circuit are called resistors. There are many different values, physical sizes, and types of resistors used in electronic equipment. The most commonly used type, the carbon resistor, is a mixture of powdered carbon and a cement-like material that bonds the carbon together. By varying the composition of the mixture, different values of resistance are obtainable, from less than an ohm up to several million ohms.

### Resistance Units

Some electronic circuits require resistances of several thousand ohms, others may use values greater than a million ohms.

**Kilohm.** For convenience, one thousand ohms are represented by the letter k (kilo), so 1k is 1 kilohm. A resistance of 2200 ohms is expressed as 2.2k. A resistor having a resistance of 100,000 ohms would be labeled 100k. A resistor with a resistance of 470,000 ohms would be labeled 470k.

**Megohm.** Megohm units (M) refer to resistors larger than one million ohms. A 2,200,000 resistor would be labeled 2.2M. Resistor values below a megohm may occasionally be expressed in megohms. For example, a 470,000 ohm resistor could be labeled 470k, or 0.47M.

Converting back and forth between ohms, kilohms, and megohms is the same process as converting between amps (amperes), milliamps, and microamps, except that the ohm is the basic unit, and we typically work with larger values than one ohm. To convert from the small unit to the larger unit, simply move the decimal point to the left, either three places for kilohms or six places for megohms. To convert from the larger unit to the smaller unit, move the decimal point in the opposite direction to the right. This may seem very complicated, but don't be concerned about it. You will see all three terms, ohms, kilohms, and megohms so often that converting from one to another will become automatic.

# VOLTAGE, CURRENT, AND RESISTANCE

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## Review

In a dc circuit the current flow is limited by the circuit resistance. The unit of resistance is the ohm. If a current of 1 A flows in a circuit when a voltage of 1 V is applied to the circuit, the resistance in the circuit is 1 ohm.

Three important types of resistors that you will encounter in electronic equipment are the carbon resistor, the wire-wound resistor, and the metal oxide film resistor. These resistors are made in various resistance values and sizes to handle different values of current.

In many electronic circuits, the resistance is so high that we use the kilohm, which is equal to 1000 ohms, and the megohm, which is equal to 1 million ohms.

## Self-Test Questions

- 18 If the current flow in a circuit is 1 A, and we double the resistance in the circuit, will the current increase, decrease, or remain the same?
- 19 Name three types of resistors commonly used in electronic equipment.
- 20 Convert 4700 ohms to k. *4.7K*
- 21 Convert 5,600,000 ohms to M. *5.6M*
- 22 Convert 0.330M to k. *330K*
- 23 Convert 2.2M to ohms. *2,200,000*
- 24 Convert 8.2k to ohms. *8200*
- 25 Convert 680k to M. *.680M*

## OHM'S LAW

Ohm's law is one of the most important laws in electronics. It tells us how the voltage, current, and resistance are related in an electrical circuit. Ohm's law states that the current flow in a circuit is equal to the voltage divided by the resistance. Rather than using words to express this law, we use symbols. We use the letter I for current, E for voltage, and R for resistance. Using these symbols, we can express Ohm's law as:

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

With this expression, if we know any two of the three values — resistance, current, or voltage — we can determine the third.

For example, we can interchange the R and I and we have the formula:

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

This formula tells us that the resistance in a circuit is equal to the voltage divided by the current. We can also express this formula as:

$$E = IR$$

This tells us that the voltage in a circuit is equal to the current flow in the circuit multiplied by the resistance in the circuit.

The importance of the three forms of Ohm's law is that they show us how the current, voltage, and resistance in a circuit are related. As we will see in the following sections, a change in either the voltage or the resistance in the circuit will result in a change in the current.

## How Voltage Affects Current

Now we are going to use Ohm's law in the form:

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

This formula shows how a change in the applied circuit voltage affects the current in the circuit.

In Fig.10 we have a simple circuit consisting of a voltage source and a resistor. Notice the schematic symbol for a resistor; this is another important symbol you should remember. The battery voltage (E) is 20 V; the resistance (R) of the resistor is 2 ohms. The unknown value is the amount of current.

We can determine the circuit current using Ohm's law. We simply substitute the numeric values of voltage and resistance for E and R in the formula, then divide to give us the value of I:

$$\begin{aligned} I &= \frac{E}{R} \\ &= \frac{20}{2} = 10 \text{ A} \end{aligned}$$

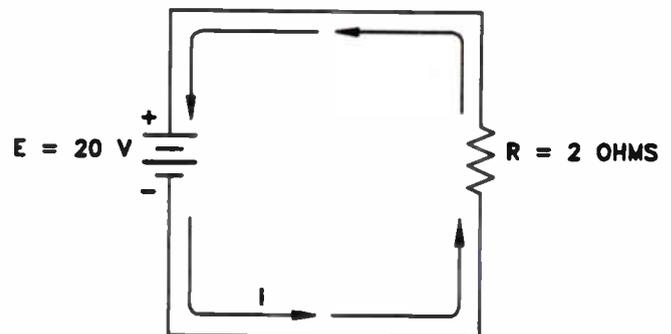


Figure 10. A simple circuit consisting of a voltage source and a resistor.

## VOLTAGE, CURRENT, AND RESISTANCE

---

In the circuit shown in Fig.10, the current flow will be equal to 10 amperes. If we increase the voltage to 40 V, the new current flow will be:

$$I = \frac{40}{2} = 20 \text{ A}$$

If we reduce the voltage to 10 V, the current flow in the circuit will be:

$$I = \frac{10}{2} = 5 \text{ A}$$

Notice in each example that the current flow is directly related to the voltage. Increasing the voltage increases the current; reducing the voltage reduces the current. In the example where the voltage doubled, the current doubled. When the voltage was cut in half, the current was cut in half. This relationship will always hold true.

If we increase the voltage to three times the original value, the current will increase to three times the original value. If we reduce the voltage to one third of its original value, the current will be reduced to one third of its original value. As long as resistance remains the same, any change in the voltage will result in a direct change in the current.

### How Resistance Affects Current

In the simple circuit shown in Fig.10, where the voltage is 20 V and the resistance 2 ohms, we found by using Ohm's law that the current flow is 10 amperes. The same circuit is shown in Fig.11, except that we have replaced the 2-ohm resistor with a 4-ohm resistor. How will this affect the value of I? Using Ohm's law, we can find the current:

$$I = \frac{E}{R} = \frac{20}{4} = 5 \text{ A}$$

Here the current is 5 A, half the value it was before. Doubling the resistance cut the current in half. Suppose that, instead of doubling the resistance from 2 ohms to 4 ohms, we cut the resistance in half, reducing it from 2 ohms to 1 ohm. Using Ohm's law, we can easily find out what happens:

$$I = \frac{20}{1} = 20 \text{ A}$$

Cutting the resistance in half doubled the current from 10 A to 20 amperes.

This relationship between current and resistance holds true regardless of how we change the resistance. If we increase the resistance to three times its original value, the current decreases to one third the original value. If we cut the resistance to one third its original value, the current increases to three times its original value. We say that current varies "inversely" with respect to resistance. If the resistance increases, the current decreases. If the resistance decreases, the current increases.

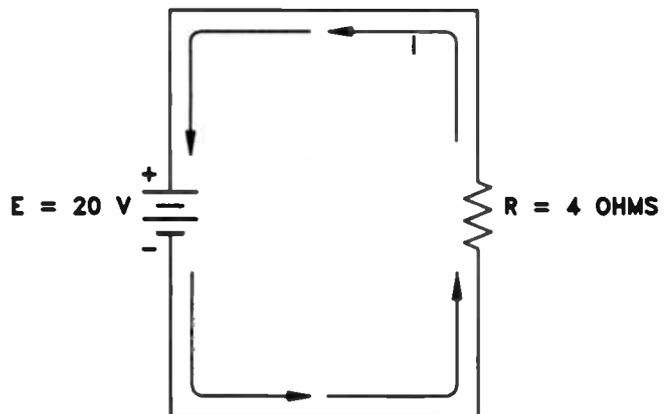


Figure 11. The 2-ohm resistor in the circuit of Fig.10 is replaced by a 4-ohm resistor.

This relationship between current and resistance is obvious if we examine Ohm's law. Look at the expression for current below:

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

If E remains constant and we increase R, it is obvious that I must become smaller, because E is divided by a larger number. If we reduce R, and keep E constant, I must get larger.

### Finding E

In some circuits, we may know the values of current and resistance, but we want to find the voltage in the circuit. An example of this type of problem is shown in Fig.12. Here the current is 2 A and the resistance 15 ohms. We want to find the value of E using Ohm's law:

$$E = IR$$

We can substitute for the values of I and R and get:

$$\begin{aligned} E &= 2 \times 15 \\ &= 30 \text{ V} \end{aligned}$$

Thus, the value of the voltage applied to the circuit must be 30 volts. If we measured a circuit current increase to 3 A, and the resistance remained 15 ohms, we would know that the voltage applied to the circuit had increased to 45 V, because:

$$\begin{aligned} E &= IR \\ E &= 3 \times 15 \\ E &= 45 \text{ V} \end{aligned}$$

Notice that in all of the examples we've given using Ohm's law, the voltage is in volts, the

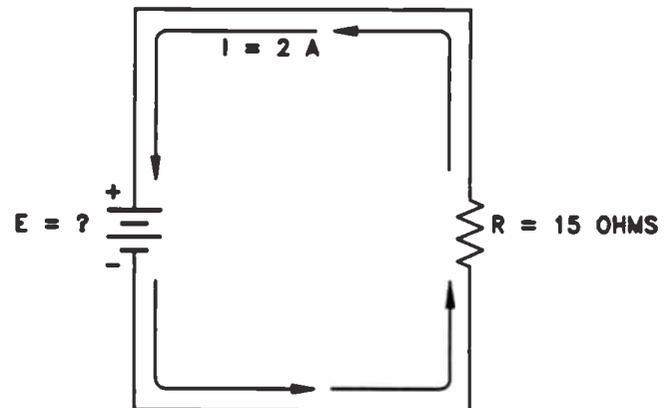


Figure 12. A simple circuit where  $I = 2$  amperes and  $R = 15$  ohms.

current is in amperes, and the resistance is in ohms. However, the current may be expressed in milliamperes or microamperes. In such a case, you must convert the value to amperes to use Ohm's law. Similarly, the resistance may be in kilohms or megohms. Again the value must be converted to ohms.

### Review

We have seen how circuit current is affected by the applied voltage and by the circuit resistance. We found that increasing the voltage increased the current, and decreasing the voltage decreased the current. We said that the current varies directly to the voltage. In the case of the resistance in the circuit, we found it had the opposite effect on the current. Increasing the resistance of the circuit decreased the current, and decreasing the resistance increased the current. The current is said to vary inversely to the resistance.

You should remember the three forms of Ohm's law so that you can see how each of the three

## VOLTAGE, CURRENT, AND RESISTANCE

---

quantities — current, voltage, and resistance, is affected by changes in the other two. The three forms of Ohm's law are:

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

*Current*      *voltage*  
*Resistance*

$$E = IR$$

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

Remember that to use Ohm's law, the voltage must be in volts, the current in amperes, and the resistance in ohms.

### Self-Test Questions

- 26 Give the form of Ohm's law that is used when you know the voltage and current, and want to find the resistance.
- 27 Write the Ohm's law formula that is used when you know the current and resistance in the circuit, and want to find the voltage.
- 28 Write the Ohm's law formula that is used when you know the voltage and resistance in the circuit, and need to find the current.
- 29 In the circuit in Fig.10, find the current if the voltage is 15 V and the resistance is 3 ohms.
- 30 If in the circuit in Fig.11, the voltage is 60 V and the resistance is 15 ohms, what is the current?
- 31 If the current in a circuit is 3 A and the resistance is 20 ohms, what is the voltage?

*R = E/I*  
*E = IR*  
*I = E/R*  
*5A*  
*4A*  
*60V*

## ANSWERS TO SELF-TEST QUESTIONS

---

### ANSWERS TO SELF-TEST QUESTIONS

- 1 -12 V.
- 2 Terminal 1 is +45 V, and terminal 4 is -45 V.
- 3 +60 V. The two batteries are connected in series aiding, and therefore their potentials will add,  $15 + 45 = 60$  V. The terminal is positive because it is connected directly to the positive terminal of one of the batteries.
- 4 +22-1/2 V. The two batteries are connected to oppose each other, and thus their voltages subtract.  $45 \text{ V} - 22\text{-}1/2 \text{ V} = 22\text{-}1/2 \text{ V}$ . The polarity will be that of the higher voltage battery, which is the 45 V battery. Since its positive terminal is connected to terminal 1, terminal 1 will be positive.
- 5 4 A. If the original current was 1 A and the number of electrons increased by four times, the new current must be 4 A.
- 6 \$6.00 = 600¢.
- 7 2 A = 2000 mA.
- 8 0.42 A = 420 mA.
- 9 0.037 A = 37 mA.
- 10 0.002 A = 2 mA.
- 11 46 mA = 0.046 A.
- 12 822 mA = 0.822 A.
- 13 2 A = 2,000,000 µA.
- 14 0.0017 A = 1700 µA.
- 15 147 µA = 0.000147 A.
- 16 0.031 mA = 31 µA.
- 17 327,000 µA = 327 mA = 0.327 A.
- 18 The current will decrease. If we double the resistance in the circuit, the current will be cut in half.
- 19 Carbon resistors, wire-wound resistors, and metal oxide film resistors.
- 20 4.7k. In order to convert 4700 ohms to kilohms, we move the decimal point three places to the left.
- 21 5.6M. In order to convert 5,600,000 ohms to megohms, we move the decimal point six places to the left.
- 22 330k. In order to convert megohms to kilohms, we move the decimal point three places to the right.
- 23 2,200,000 ohms.
- 24 8200 ohms.
- 25 0.680M. In order to convert kilohms to megohms, move the decimal point three places to the left.
- 26  $R = \frac{E}{I}$
- 27  $E = IR$
- 28  $I = \frac{E}{R}$
- 29 5 A. To solve this problem use the formula:  
$$I = \frac{E}{R}$$
Substituting 15 V for E and 3 ohms for R, we get:  
$$I = \frac{15}{3} = 5 \text{ A}$$
- 30 4 A. To solve this problem, use the formula:  
$$I = \frac{E}{R}$$
Substituting 60 V for E and 15 ohms for R, we get:  
$$I = \frac{60}{15} = 4 \text{ A}$$
- 31 60 V. To solve this problem, use the formula:  
$$E = IR$$
Substituting 3 A for I and 20 ohms for R, we get:  
$$E = 3 \times 20 = 60 \text{ V}$$

# Lesson Summary

**Some of the important facts that you should remember about this lesson are:**

- When connected to a circuit, a dc voltage source causes current flow in one direction.
- Voltage sources use common points called grounds.
- A point in a circuit may be either positive or negative with respect to ground.
- Batteries and generators connected in series aiding will add their voltages. In series opposing, their voltages subtract.
- Current flows in all parts of the circuit at the same instant when voltage is applied.
- Current, voltage, and resistance units may be conveniently expressed in smaller or larger units for ease of measurement.

## LESSON QUESTIONS

This is Lesson Number 2217.

Make sure you print your name, student number, and lesson number in the space provided on the Lesson Answer Form. Be sure to fill in the circles beneath your student number and lesson number.

**Reminder:** A properly completed Lesson Answer Form allows us to evaluate your answers and speed the results and additional study material to you as soon as possible. Do not hold your Lesson Answer Forms to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

Name <u>John Smith</u>	
Print	
Student No.	Lesson No.
XY01237894	2217
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② ○ ② ● ② ② ○ ② ②	● ● ② ②
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⑨ ○ ⑨ ○ ⑨ ○ ● ⑨	⑨ ○ ⑨ ⑨

- If a 9 V battery and a 6 V battery are connected in series aiding, the total voltage of the two batteries will be:
  - 15 volts.
  - 3 volts.
  - 9 volts.
  - 6 volts.
- If a 6 V battery and 4 V battery are connected in series opposing, the total voltage across the two will be:
  - 6 volts.
  - 4 volts.
  - 2 volts.
  - 10 volts.
- A common point on the wiring connections, tied to the negative side of the power source, is called a:
  - Lug.
  - Ground.
  - Node.
  - Chassis.
- A voltage of 20 mV is equal to how many volts?
  - 20 volts.
  - 2 volts.
  - 0.2 volts.
  - 0.02 volts.

## VOLTAGE, CURRENT, AND RESISTANCE

---

5. If the current flow in the circuit is 2 A when the voltage is 5 V, what will the current be when the voltage is raised to 20 volts?  
a. 1-1/2 amperes.  
b. 4 amperes.  
c. 8 amperes.  
d. 20 amperes.
6. If the current flow in the circuit is 4 A when the resistance is 2 ohms, what will the current be if the resistance is increased to 8 ohms?  
a. 1 ampere.  
b. 2 amperes.  
c. 4 amperes.  
d. 8 amperes.
7. If the voltage applied to a circuit is 20 V and the resistance is 4 ohms, the current will be:  
a. 20 amperes.  
b. 10 amperes.  
c. 5 amperes.  
d. 1 ampere.
8. If the current flow in a circuit is 8 A and the resistance is 2 ohms, the voltage will be:  
a. 4 volts.  
b. 8 volts.  
c. 12 volts.  
d. 16 volts.
9. If the voltage in a circuit is 100 V and the current is 1 A, then the resistance is:  
a. 1 ohm.  
b. 10 ohms.  
c. 100 ohms.  
d. 1000 ohms.
10. If the current flow in a circuit is 6 mA and the resistance is 6k, what will the current be if the resistance is changed to 3k?  
a. 3 milliamperes.  
b. 6 milliamperes.  
c. 9 milliamperes.  
d. 12 milliamperes.

$4 \times 20 = 80$   
 $80 / 10 = 8 A$

$1/4 \text{ of } 4 A = 1 A$

$\frac{6}{3} = 2 \times 6 mA = 12$

.006

Current Voltage  
 $I = \frac{E}{R}$  Resistance

$$E = IR$$

$$R = \frac{E}{I} \quad \frac{5V}{2A} \quad \frac{20V}{2A} \quad 2.5 \quad .006 A$$



## **EACH DAY COUNTS**

Each day of our life offers its own reward for work well done, its own chance for happiness. These rewards may seem small, and these chances may seem petty in comparison with the big things we see ahead.

As a result, many of us pass by these daily rewards and daily opportunities, never recognizing that the final goal, the shining prize in the distance, is just a sum of all these little rewards we must win as we go along.



# Using Your Digital Multimeter

5788



*NRI Schools*

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*Washington, DC 20008*







# Table of Contents

**Introduction . . . . . 1**

**Figure References . . . . . 3**



## Objectives

*When you have completed the experiments in this manual and listened to the accompanying audio tape you will know:*

- How to make ac and dc voltage measurements.
- How to make resistance measurements.
- How to measure circuit current.
- Which measurements are made in series and which measurements are made in parallel with the circuit.

---

# Introduction

---

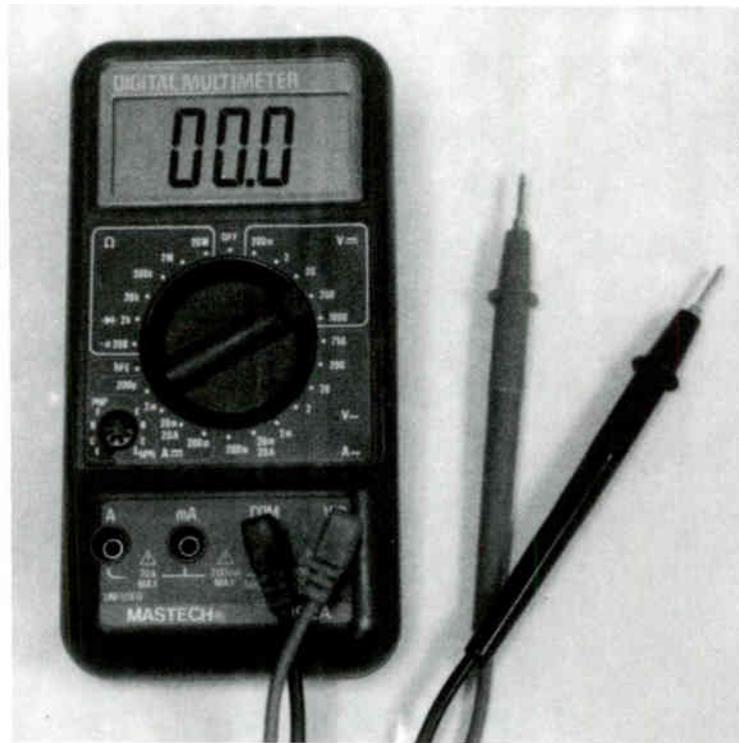
Please refer to the figures in this booklet as you listen to NRI's Action Audio Cassette, which you received as part of your training unit 4976K. Before you begin the tape, make sure you have your DMM handy.

The tape leads you step-by-step through the basic operation of your DMM. You'll be asked to perform various operations and to make visual observations with your DMM as you listen to the cassette — that's NRI's Action Audio Learning.

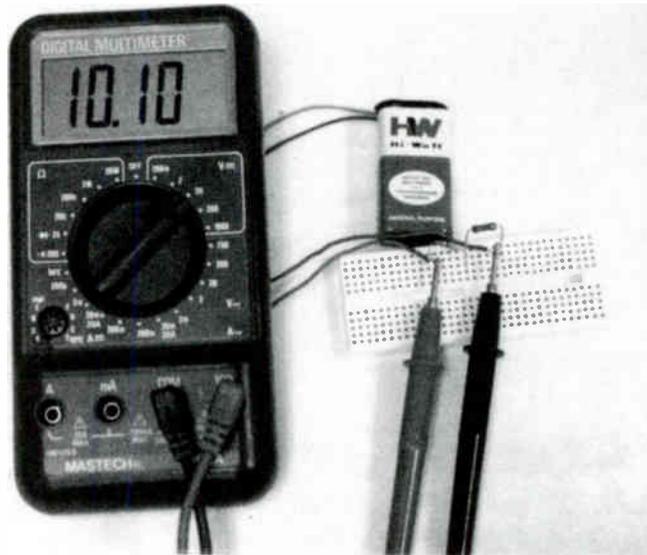
This Action Audio Learning Unit was written and produced by the NRI development staff for the exclusive use of NRI students. I think you'll find this NRI Action Audio Learning Unit an exciting way to learn electronics.

## Figure References

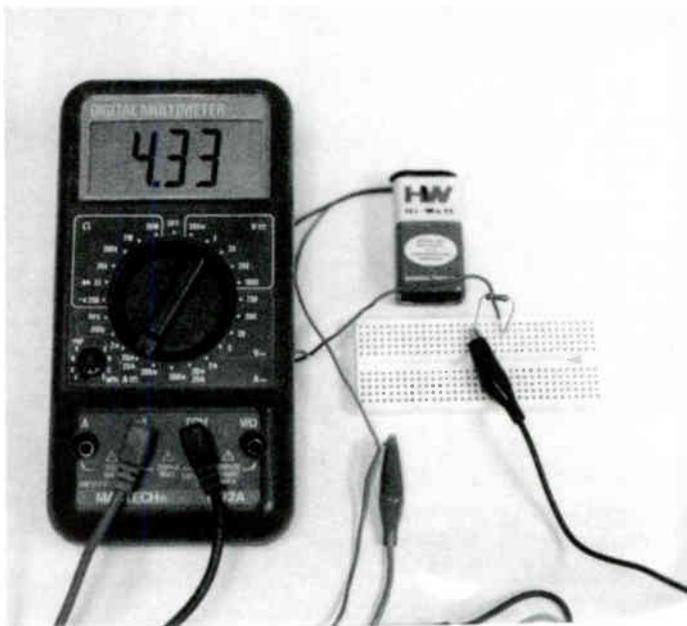
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**Figure 1. The DMM with the leads connected for voltage and resistance measurements.**



**Figure 2. The DMM should be in parallel with the voltage being measured.**



**Figure 3. Connect the meter in series for current measurements.**

# USING YOUR DIGITAL MULTIMETER

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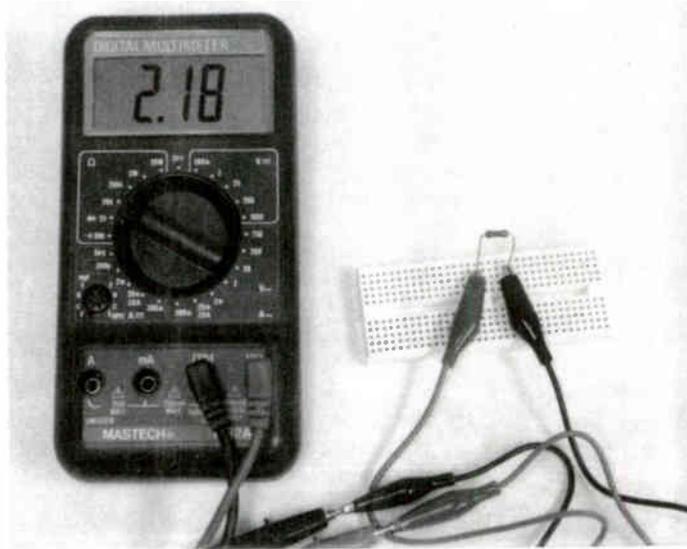


Figure 4. Resistance readings are also taken in parallel.



Figure 5. Internal view of the DMM.

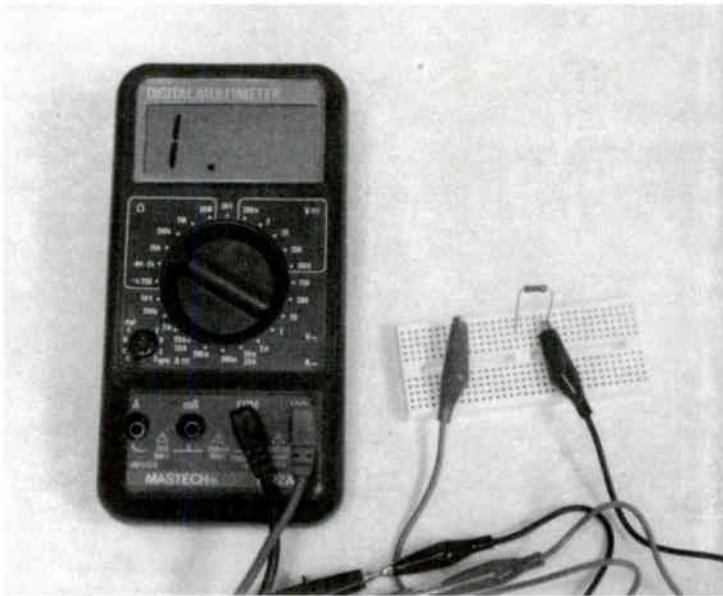


Figure 6. The overrange indicator.

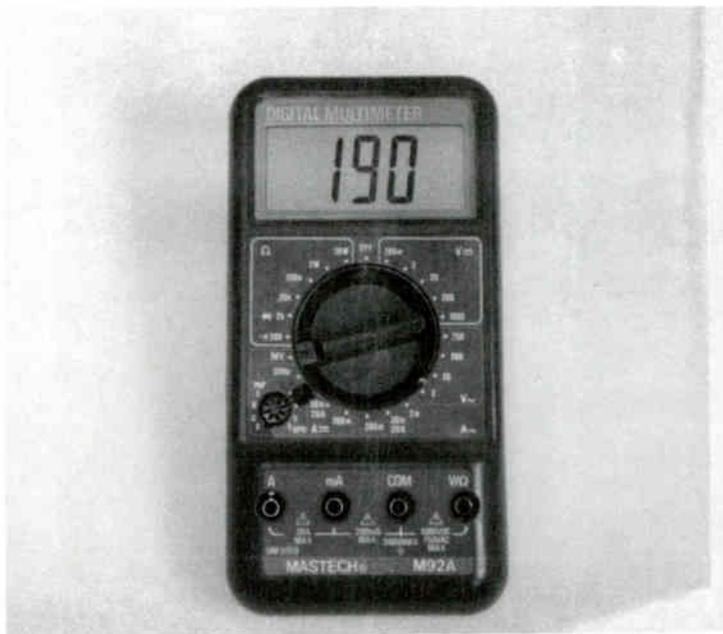


Figure 7. Current gain for a 2N4124 transistor using the special transistor-testing socket of the DMM. Note that the leads of the DMM are removed.

# NOTES

*Please use this page to record any notes  
you may want to review during your studies.*



## **NRI** Graduates Say. . .

“Through NRI I not only received the experience I was looking for, I also gained the confidence I sought to return to college and upgrade my skills and further my career ambitions. I particularly enjoyed the way you structure the course into smaller sections; it provided me the opportunity to move through the lessons at my own pace without fear of missing something important.

I chose NRI because right from your first correspondence with me I felt as though I had to mail out my application right away. It sounded so exciting, I couldn't wait to get started, which is what I did. I looked forward to each new lesson because it felt so good to read and comprehend almost immediately, and those times I didn't understand, after one or two re-reads, I got it. I only needed the help of an instructor once, but his reply was prompt and clear. I was almost sorry once I had completed the course, but I've since enrolled in college and my studies continue. Would I recommend NRI to others? I already have! I sing your praises often to workmates and I think a couple of them have applied.

So all I can say is thanks to you I am far better off than I was three years ago, and my future looks bright. I'm sure there are many others who feel as I do.”

Tyrone J. Leslie  
Groton, Connecticut



# Working with the 8085 Microprocessor



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# Working with the 8085 Microprocessor

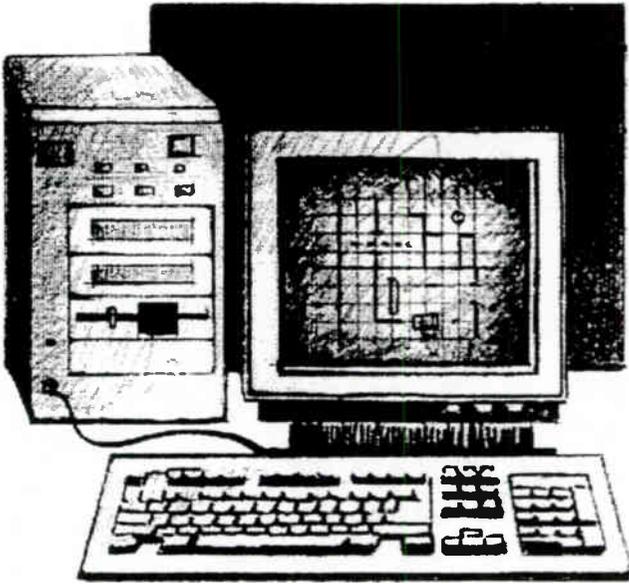
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**ISBN KM4427**



# Table of Contents

<b>Introduction</b> . . . . .	<b>1</b>
<b>Examination Questions</b> . . . . .	<b>2</b>





## Objectives

*In this training manual, you will . . .*

- Understand the instruction set for the 8085 microprocessor.
- Convert hexadecimal code into binary numbers.
- Learn to read the instruction stored at an address in ROM.
- Learn the most, and least, significant bits of a binary address.

---

# Introduction

---

In this training unit, you will build and program the 8085 microprocessor trainer. The projects in this training unit will enable you to better understand the operation of a microprocessor.

In the experiments in this unit, you will examine RAM, ROM, displays, and data entry. Your experiments will show how address, data, and control buses carry information to and from the processor and how the Arithmetic/Logic Unit (ALU) registers operate.

The assembly of the 8085 microprocessor is divided into lessons. Each lesson is designed to demonstrate a particular microprocessor function. As you go through the lesson in the assembly manual, follow the instructions carefully. Do not skip lessons. The trainer is assembled in stages, and later experiments may not work if the preceding step was skipped.

If at any time you find that the programs in the lesson do not execute properly, check the program entry using the following method:

- Set the AD0–AD7 and the A8 switches to the correct address.
- Press the ALE switch to latch the address.
- Press the RD switch to read the data stored at that address.

Remember that the ALE switch *must* be pressed every time the address switches are changed.

After you complete the assembly and programming of your microprocessor trainer, return to this manual and answer the Kit Questions.



- 
3. At what addresses in ROM is the pattern code for the display stored?
- 0030-003F.
  - 0040-004F.
  - 0050-005F.
  - 0060-006F.
4. The ROM IC of the trainer is:
- IC1.
  - IC2.
  - IC3.
  - IC4.
5. The switch which enables instruction to be written to ROM is the:
- EN RAM switch.
  - EN ROM switch.
  - WR switch.
  - WEN switch.
6. Which switch(es) set the least significant bit of the address?
- AD0-AD3.
  - AD4-AD7.
  - A8.
  - TIM.
7. What ROM addresses contain the display information?
- 0040-006A.
  - 0077-00A4.
  - 00A5-00FF.
  - 0177-01A4.
8. What is the memory location where the KEY FOUND (K FND) routine is stored?
- 00A2-00AF.
  - 00B8-00CA.
  - 00D4-00E1.
  - 00EF-00FF.
9. In the instruction set for the 8085 micro-processor, what is the hex code for a jump (JMP) command?
- 00.
  - 24.
  - C3.
  - DE.
10. What is the hex code for a move to memory command (MOV MA)?
- 00.
  - 77.
  - AA.
  - FF.
-

# NOTES

*Please use this page to record any notes you may want to review during your studies.*





## **NRI** Graduates Say. . .

"My training with NRI was very good. I like the way that you broke up the major topics into smaller, more "digestible" segments. Then all of the extra material that added support was just incredible. You did not leave any rock unturned."

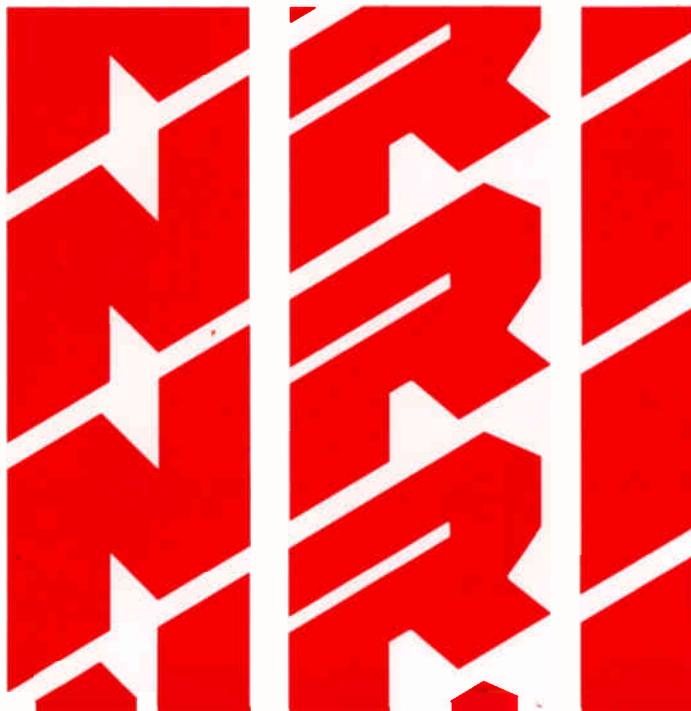
Vincent Ricciardi  
Lawrenceville, Georgia





**DC Electronics**

**6748**



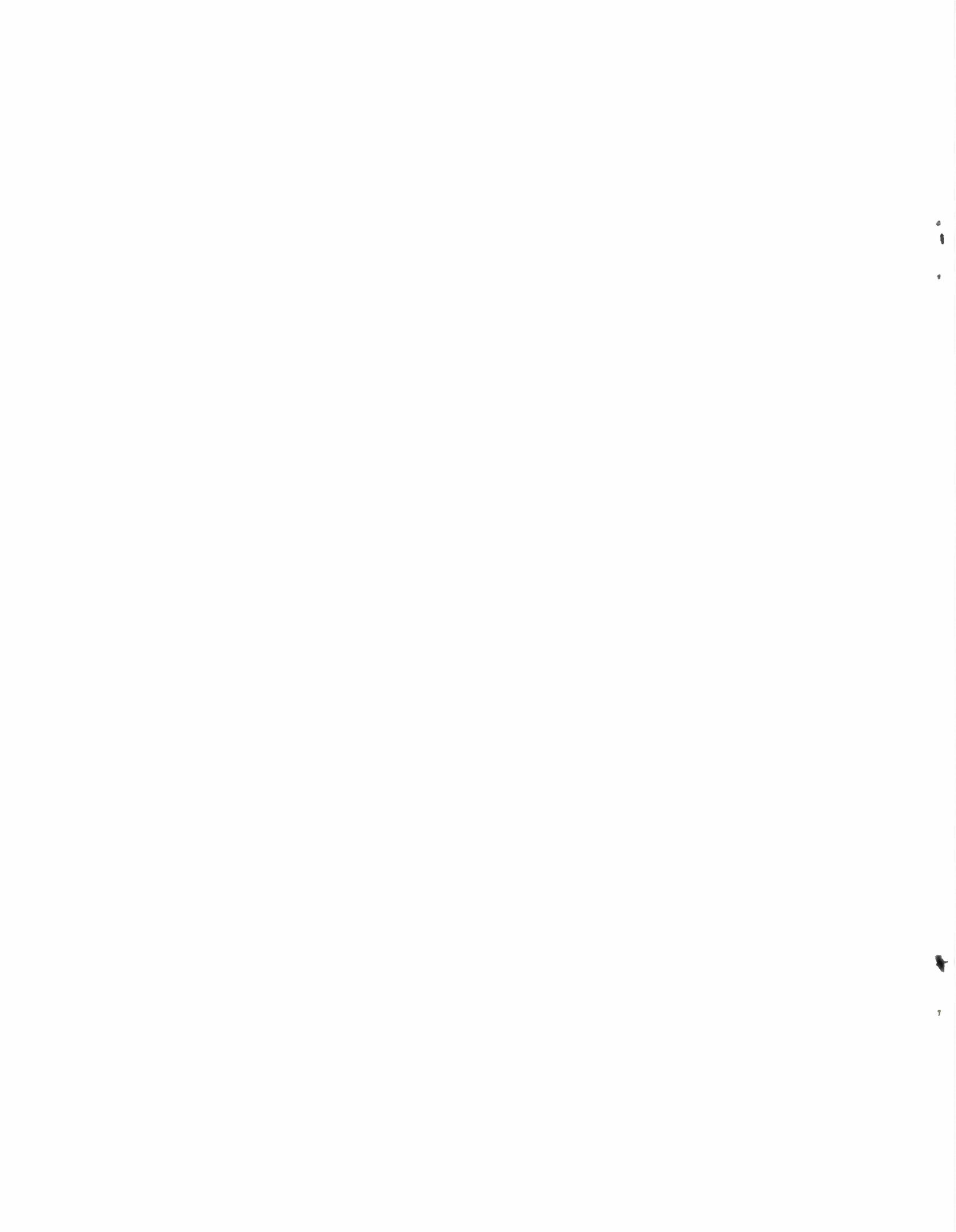
**Student's Guide  
for Computer-Aided  
Troubleshooting**

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# **DC Electronics**

## **Computer-Aided Troubleshooting**



# Table of Contents

<b>Introduction</b> .....	<b>1</b>
<b>What You Need to Know</b> .....	<b>2</b>
How to Use this Manual .....	2
What You Get .....	3
What You Must Have .....	3
<b>Installing the Program</b> .....	<b>4</b>
Installing on a Network .....	6
Installing with SHARE.EXE .....	6
Removing the Program .....	6
<b>Operating the Program</b> .....	<b>7</b>
Mouse and Keyboard .....	7
Scroll Bar .....	7
Buttons .....	9
<b>Using the Program</b> .....	<b>10</b>
Student Workdisks .....	10
Starting the Program .....	10
Running the Program .....	11
Menus and Screens .....	13
Using the Tools .....	18
Leaving the Program .....	22
<b>Evaluating Yourself</b> .....	<b>23</b>
Using the Tb Files .....	23
Factors to Consider .....	24
Additional Ways to Use the Program .....	27
<b>The Problems</b> .....	<b>28</b>
Objectives of the Program .....	28
Series Resistors .....	29
Series/Parallel Resistors .....	29
Resistor Bridge .....	30
R/C Combination .....	30
<b>Answer Sheet</b> .....	<b>31</b>

## **Acknowledgments**

We wish to express our thanks to the staff of **Heathkit Educational Systems**. Their contribution to this team effort, in providing our students with quality educational materials, has been significant.

---

# Introduction

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Welcome to Computer-Aided Troubleshooting (CAT) from NRI Schools. NRI's DC Electronics Computer-Aided Troubleshooting Package is an interactive software program. With this troubleshooting software, you, the student, actually interact with "life-like" equipment malfunctions. Full-color animations bring a sense of realism to problem-solving interactions. You are placed in a challenging electronics troubleshooting environment where you are not restricted simply to reading from a textbook. The program draws you into actual troubleshooting situations where you participate in complete safety and privacy. It provides you with both rewarding responses and constructive reinforcement. It is beneficial in that it provides an alternate, game-like method of teaching electronic troubleshooting.

The program offers you the opportunity to learn troubleshooting through fast-paced, hands-on simulations in a totally nonthreatening environment. By performing these experiments on the computer, you experience the real and practical side of electronics first-hand without worry of damaging equipment or yourself.

# What You Need to Know

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## How to Use this Manual

This Student's Guide contains the documentation for the NRI DC Electronics Computer-Aided Troubleshooting program. This manual is written for the electronics student and the licensed site installer. It is assumed that the student or the installer has some limited computer knowledge of hardware and software, MS-DOS in particular.

This manual is divided into sections. The first, which you are reading, introduces the program and the manual itself. It contains a list of what is included in this product and the system requirements needed to successfully run the program.

The next three sections cover installing, operating, and using the program. Here, you'll find a simple installation procedure. It covers how to use the mouse, keyboard, and other features. These sections also tell you what you'll see in the program: menus, screens, windows, and tools.

The remainder of the manual contains further information and a detailed list of the troubleshooting examples, plus an answer for each problem. Because the answer to each of the troubleshooting problems is included in this manual, it is merely regarded as an adjunct, not as an examination, within your course. Thus, it will serve to enhance your troubleshooting knowledge and abilities.

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## What You Get

The NRI DC Electronics Computer-Aided Troubleshooting (CAT) program consists of:

- one or more 3.5" program disks
- one Student's Guide

## What You Must Have

In order to run the CAT Program, the computer must be equipped with this hardware:

- 8088, 80286, 80386, 80486 or better processor (PC compatible)
- 640 KB or more of RAM
- Hard disk drive with 2 MB or more of free disk space
- EGA or VGA color monitor and driver
- One or more 3.5" floppy drives
- Mouse

And this software:

- MS-DOS 3.1 or higher

**NOTE:** Most of the functions of this program can be accomplished using only the keyboard. However, a mouse is required for a few operations and is highly recommended for efficient use of the program.

# Installing the Program

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Through a joint effort by **NRI** and **Heathkit Educational Systems**, this interactive electronic troubleshooting program has been made available. You will note appropriate credits as you start the program each time. If, by chance, some fault occurs in the installation or operation of this software program, please contact NRI to obtain instructions concerning software correction or replacement procedures.

**NOTE:** The following installation instructions assume that the floppy drive designator on your computer is "A:." If your floppy drive is designated with a letter *other* than "A:," substitute that letter in the instructions.

To install the CAT program, do the following:

1. Insert Disk 1 into floppy disk drive A.
2. Type: **A:**  
Then press: **RETURN** (or **ENTER**)  
(This logs you onto drive A.)  
  
Type: **INSTALL**  
Then press: **RETURN** (or **ENTER**)  
This will start the installation program.
3. Before installation actually begins, the program first checks to make sure your computer's operating environment is compatible with the hardware/software requirements necessary to operate the CAT program (see "What You Must Have" for the hardware/software requirements). If your computer's environment is incompatible in any way, the program will **NOT** install. In this case, a simple explanation as to the incompatibility will appear, and you will be returned to the DOS prompt.  
A typical example is when the installation program does not find a hard drive with enough space for the

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A typical example is when the installation program does not find a hard drive with enough space for the program. In this case, you need to free up space on the hard drive before you run the installation program again. If the installation program verifies that your system is compatible, it will continue with the installation.

4. Next, the program will ask you for the hard drive designator where you wish to install the program. The program will list possible choices based on your system. Simply press the letter for the drive where you want the program installed. **Caution:** Do not simply press the **RETURN** (or **ENTER**) key. You must press the letter of the desired drive.

You will then be given the opportunity to modify the installation path, or accept the default path. The default directory is `CAT_DC`. Unless you specify otherwise the program will be installed in this directory. If you prefer that it be installed in another directory, use the backspace key to remove the `CAT_DC` path and enter the new path name.

5. The installation program will begin copying files from Disk 1 onto your hard drive. If there is more than one disk for the installation of the program, the installation process will ask you to insert the next disk after it finishes copying the necessary files from Disk 1. If you insert an incorrect disk, the installation process will notify you of this situation.
6. Continue this process until all disks have been inserted and copied. Some disks contain many files, and may take a few minutes to install onto your hard drive. When all the CAT disks have been installed, the installation program will automatically exit and return to the DOS prompt.

All of the program files will be contained in a subdirectory on your hard drive called "`CAT_DC`", or whatever path you specified during installation. To access that sub-directory, type in `CD\CAT_DC` and press **RETURN** (or **ENTER**). To run the program, refer to the "Operating the Program" section of this manual.

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NRI*

## **Installing on a Network**

The program may be installed on some types of networks. Follow the preceding installation procedure to install the program on the server. Make sure each user is granted read, write, and file access to the directory the program was installed into.

For more information, refer to your network manuals and your distributor.

## **Installing with SHARE.EXE**

SHARE.EXE provides file sharing and locking to the MS-DOS operating system. If it is running on your computer while you are installing NRI Computer-Aided Instruction (CAI) software, it may cause the INSTALL program to not recognize that the correct disk has been inserted in the floppy drive. If you encounter this problem, check your AUTOEXEC.bat file and make sure SHARE is not being loaded. Once the CAI software has been installed, you can re-enable loading of SHARE.EXE if other software requires it to operate properly. The NRI CAI software should have no problem running with or without SHARE loaded. Only during installation might you encounter this problem.

## **Removing the Program**

The CAT program can be removed from the hard drive at any time. Simply delete the "CAT\_DC" subdirectory (or whatever path you specified during installation) and its files from DOS.

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# Operating the Program

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## Mouse and Keyboard

The CAT program can be operated by both a mouse and a keyboard. Both input devices control the position of an arrow cursor (  ) over program selections. While a mouse is not absolutely required to run the program, we strongly recommend using one for the ease it provides in moving through the program. Also, there are a few operations that can be performed only with the mouse. For computers not equipped with a mouse, the arrow keys on the keyboard (← ↑ → ↓) move the arrow cursor. These arrow keys, as well as the rest of the keyboard, can be used in addition to a mouse.

## Scroll Bar

There are times when the text information appearing in a window is much larger than the window itself. In these instances, all of the information can be reviewed by scrolling. This is accomplished with the help of a scroll bar, located at the edge (usually the left side for this program) of the window. See figure 1 on the next page.

The scroll bar consists of an up direction button (located at the very top), a down direction button (located at the very bottom), and a slider button (located along the vertical path between the up and down direction button). The up and down buttons move the view of the text in small increments, while the slider allows for large, rapid movements of the text body. In order to use these buttons, the user must position the cursor over the button using the mouse,

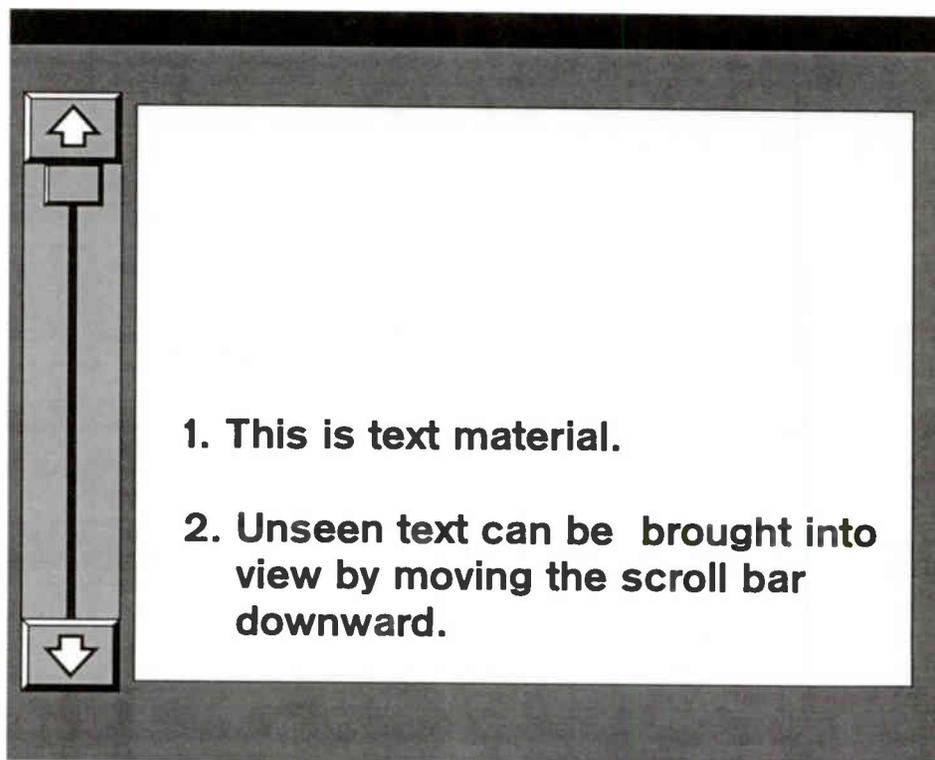


Figure 1. Window with Scroll Bar.

by using the cursor direction keys ( $\leftarrow \uparrow \rightarrow \downarrow$ ), page up (PgUp), and page down (PgDn) keys of the keyboard.

The student has three options for moving text:

1. To scroll text line by line, position the arrow cursor at either the up direction button or the down direction button, and click the mouse button (or press **RETURN**) once. Keeping the mouse button (or **RETURN**) depressed continues the scrolling action.
2. **FOR MOUSE USERS.** Position the arrow cursor directly on the slider button, then press and hold the mouse button. Vertical mouse movement positions the slider button to any desired location on the scroll bar. The text follows the movement of the slider button.
3. **FOR KEYBOARD USERS.** The **PgUp**, and **PgDn** keys may be used. **PgUp** and **PgDn** move the up/down direction button in large steps along the scroll bar.

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## Buttons

A student can also move around in the program by using the mouse to press “buttons” as shown in figure 2 that appear on the screen. Buttons are activated by moving the cursor over the button and either clicking the mouse button or pressing **RETURN**. Using buttons is a procedure that students will pick up very quickly. When a button is selected in a screen, it depresses like a normal switch.

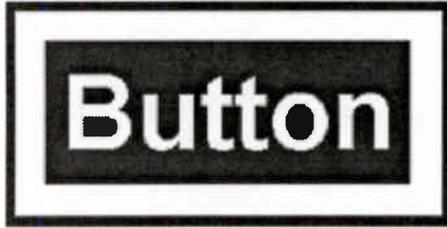


Figure 2. Window Button.

# Using the Program

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## Student Workdisks

To access and operate the installed program, you must provide and use a student workdisk. This disk is your “workbook” for the course. It records every move that you make as you progress through each troubleshooting experience.

Your workdisk must be inserted into a floppy drive to gain access to the program. The first time this is done, the program will ask for your name, and records that information on the disk. The disk then becomes unique for you and the course. Anyone else who tries to access the program must have his or her own workdisk. If a student plans to continue through NRI’s CAT series, another disk will be needed for each course. Any blank, formatted floppy disk may be used as a workdisk.

It is important that you take good care of your workdisks, as the information on each disk is unique. Damaging or losing a disk will result in lost data.

## Starting the Program

To start the DC Troubleshooting program:

- Type: **CD\CAT\_DC** (or path specified in installation)
- Then press: **RETURN** (or **ENTER**)

This logs you into the program subdirectory.

- Type: **DC EXPLORE**
- Then press: **RETURN** (or **ENTER**)

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**NOTE:** This program is incompatible with some disk caching utility software. If you are having problems starting or running the program, make sure you are not running a utility such as *smartdrv.sys*. Also, because the program is graphics intensive, it requires about 500K bytes of free memory. You can free up memory by removing TSR programs such as screen savers, network drivers, etc.

## Running the Program

### Opening Screens

The program begins with an introductory graphics screen followed by an acknowledgment screen that includes copyright information. These two screen displays continue to alternate until the student clicks a mouse button or presses the **RETURN** key on the keyboard.

### Check/Verify Workdisk

Following the opening graphics screen, the program will verify the presence of a student workdisk. The program must see a good workdisk before it will move on. The following outline details the procedure for verifying workdisks.

- I. **Insert Workdisk.** You will first see a window telling you to insert a workdisk (even if you have one already inserted). There are two buttons to choose from at this point.
  1. **Continue.** Press this button if you have a workdisk inserted in one floppy drive for your system. This will move you to "Verify Workdisk," which is item II in this outline.
  2. **Exit to DOS.** If you select this button, another window will appear asking to verify your exit. At this point, you have two choices:
    - a. **Resume the Program.** If you select this, the program will move back to "Insert Workdisk," which is item I above.
    - b. **Confirm Exit to DOS.** If you select this, the program will initiate an exit procedure, which includes creating and using a password. The "Leaving the Program" portion of the User's Guide explains this part of the program.

**II. Verify Workdisk.** The program will search the floppy drives installed on your system for a proper Student Workdisk. If you have two floppy drives, the program will search the "A" drive first. If it does not find a Workdisk in the "A" drive it will then search the "B" drive. There are three possible results during this operation:

1. **New Correct Workdisk Present.** If the program finds a good workdisk which has never been used before, the program will prompt the student to enter the first name, then the last name. Simply type in each name, and press **RETURN**. After the last name has been entered, that workdisk will be configured to work for that name, and for this course only. The program will then move to "Help Request," which is Item III in this outline.
2. **Used Correct Workdisk Present.** If the program finds a good workdisk which has been used before, the program will immediately move to "Help Request," which is Item III in this outline.
3. **Incorrect Workdisk or No Workdisk Present.** If the program fails to find a proper workdisk, a "Disk Read Error" message will appear on the screen. You have two choices at this point:
  - a. **Exit to DOS.** You may select this option to return to a DOS prompt via the password screen as explained later in "Leaving the Program."
  - b. **Continue.** If you select this option, you will return to "Insert Workdisk," which is Item I in this outline.

**III. Help Request.** Once a proper workdisk has been installed and verified by the program, a window will appear offering the chance to review the information in the "Help" portion of the program prior to beginning. This option is offered regardless of whether the student has previously used the program or not. There are two options at this point:

1. **Access Help Window.** By pressing this button, you enter the "Help" portion of the program. See the "Help Window" portion of this User's Guide for more information on the "Help" section.
2. **Begin the Program.** By pressing this button you move to the Main Option Menu of the program, which is the first menu.

## Menus And Screens

This troubleshooting program uses a series of menus that allows the student to move around smoothly and efficiently. Figure 3 shows the general path that the student follows through the program. The arrows point to the direction of the path, and the boxes contain other screen options and options for exiting the current screen.

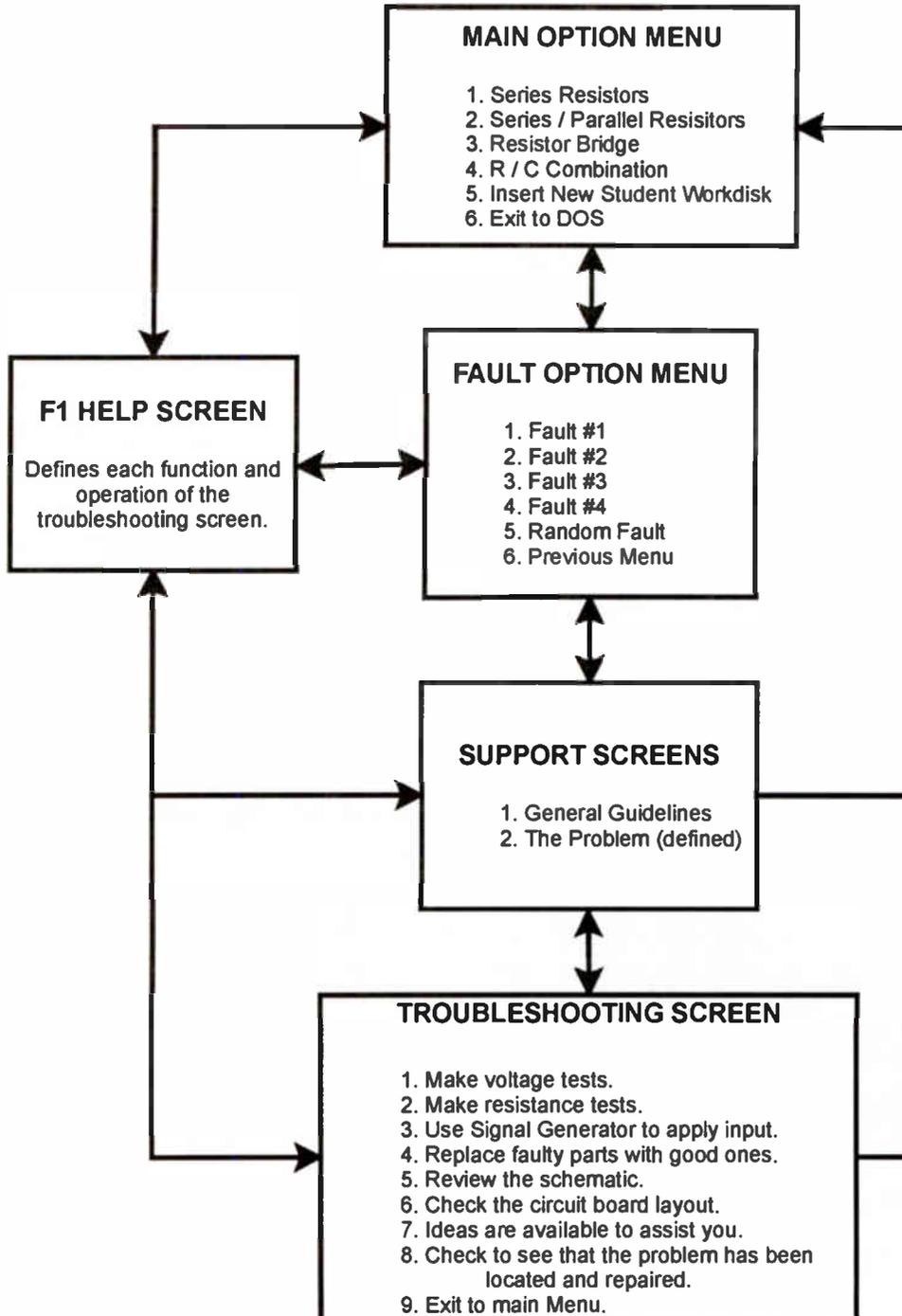


Figure 3. Program Flowchart.

There are five main sections of the program. Each is explained in more detail in the following paragraphs:

- Main Option Menu
- Fault Option Menu
- Support Screens
- Troubleshooting Screen
- Help Screen

## Main Option Menu

The Main Option Menu lists the four basic troubleshooting problems, as shown in figure 4. These are: Series Resistors, Series/Parallel Resistors, Resistor Bridge, and R/C Combination problems. The student selects one of these and proceeds to the Fault Option Menu. The Main Option Menu also offers the opportunity to change to a new student workdisk. This is done when changing students or when the present workdisk is full.

## Fault Option Menu

The student selects one of the faults or returns to the previous menu. The Random Fault is one of the four faults randomly picked by the program, as shown in figure 5.

## Support Screens

These are several screens of text that give general guidelines for troubleshooting DC circuits and describe the problem that the student has selected.

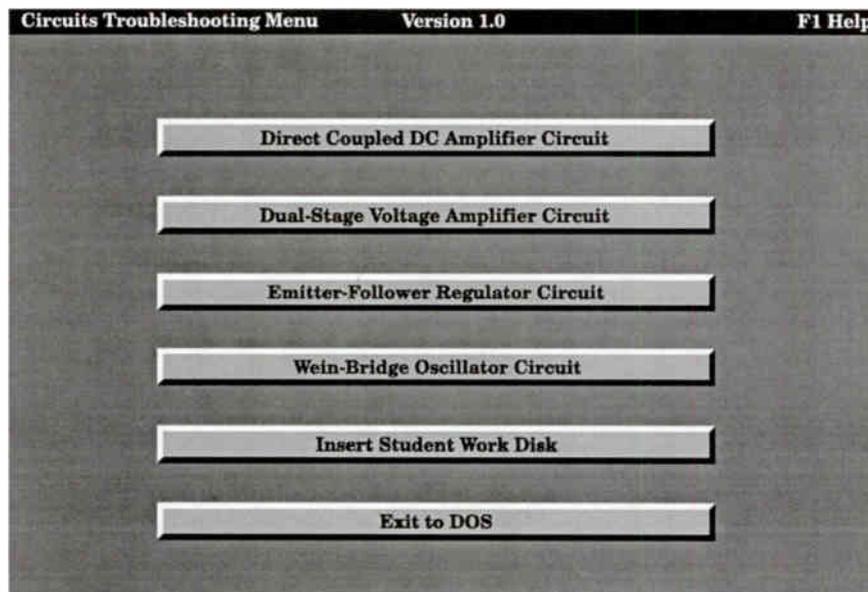


Figure 4. Main Option Menu.

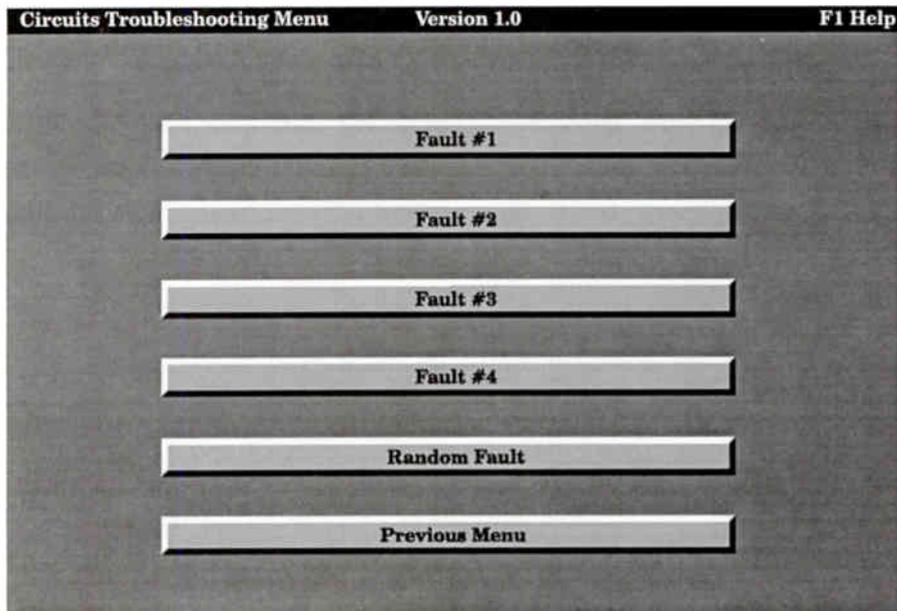


Figure 5. Fault Option Menu.

## General Guidelines

Figure 6 shows the General Guidelines screen. This screen gives the student several important guidelines for troubleshooting DC Circuits. The student can use the scroll bar to move the additional guidelines into view. This screen is displayed at the start of the first problem (Series Resistors) or it can be called up at any time from the Help Screen. The "Exit Guidelines" button takes the student to the next screen.

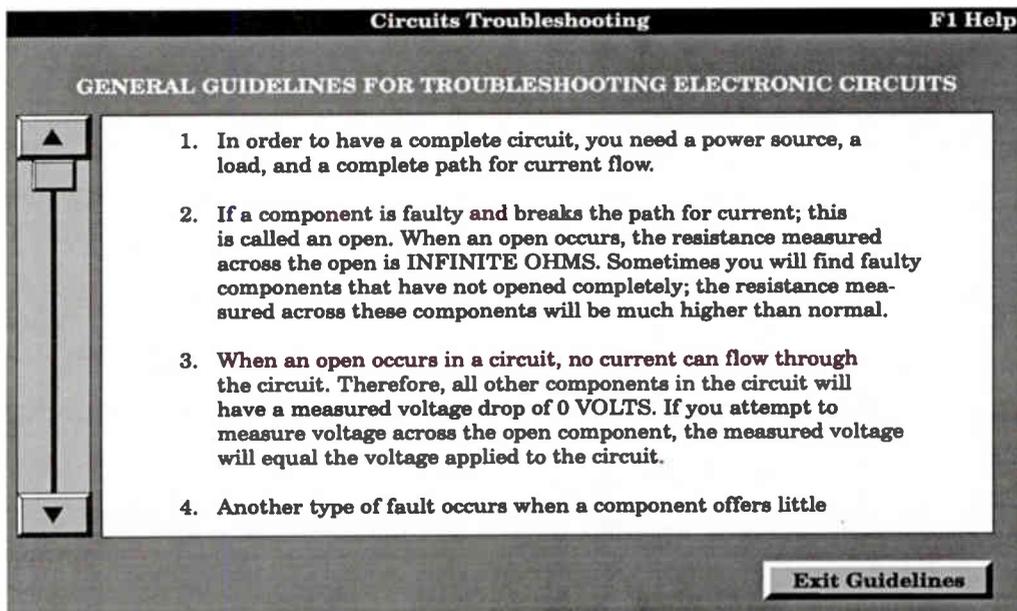


Figure 6. General Guidelines Screen.

## Problem Screen

A typical Problem Screen is shown in figure 7. Problem screens are used to set up the troubleshooting scenario. They place the student in a real life servicing situation. Two or more problem screens explain the problem in enough detail to lead the student into the actual problem.

## Troubleshooting Screen

As shown in figure 8, this screen shows components on a circuit board. Students can turn power on and off to the circuit, make voltage and resistance tests, unsolder components and place them on the workbench, replace bad parts with good ones, look at the schematic or the component view, inquire to get troubleshooting ideas, and finally check to see if they have fixed the problem.

## Help Screen

The Help Screen, figure 9, may be accessed at any time by pressing the F1 key. To operate the Help Screen, just click on a tool or button. A short message indicates exactly what that tool or button does. You can also click on other screen areas such as the push-button switch, circuit board, workbench, meter display and test log. Here again, a message will tell you the purpose or function of the object selected.

When finished, click on the top EXIT button.

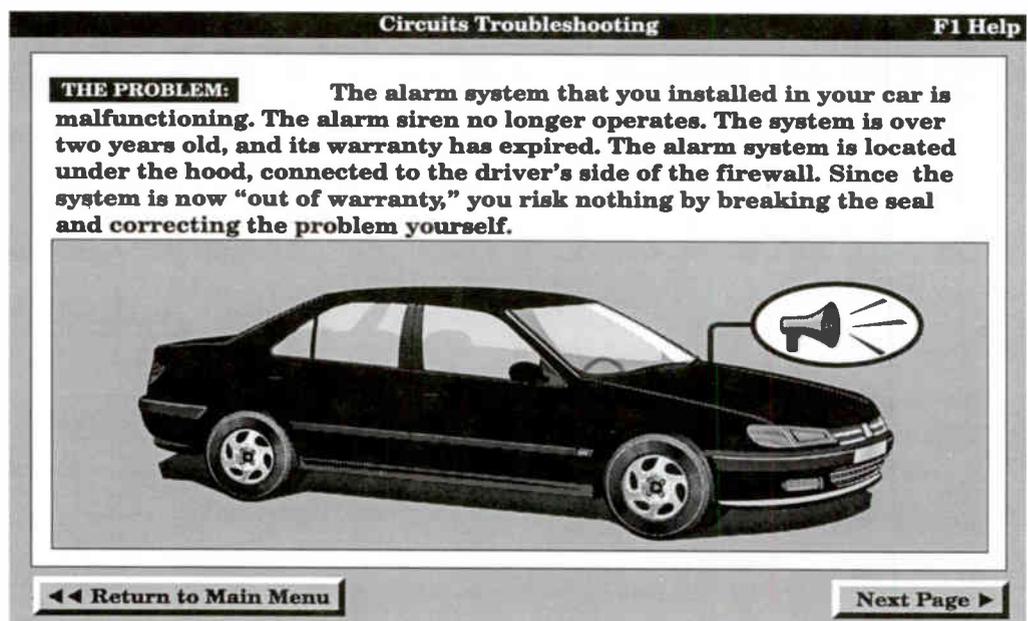


Figure 7. A typical Problem Screen.

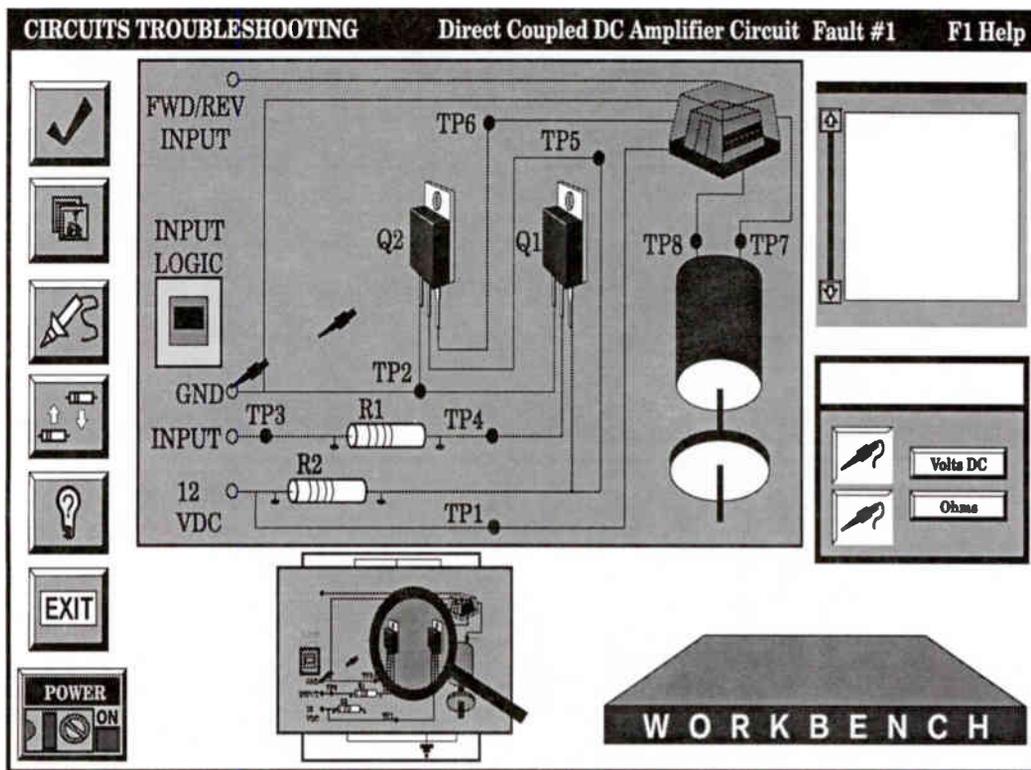


Figure 8. Troubleshooting Screen.

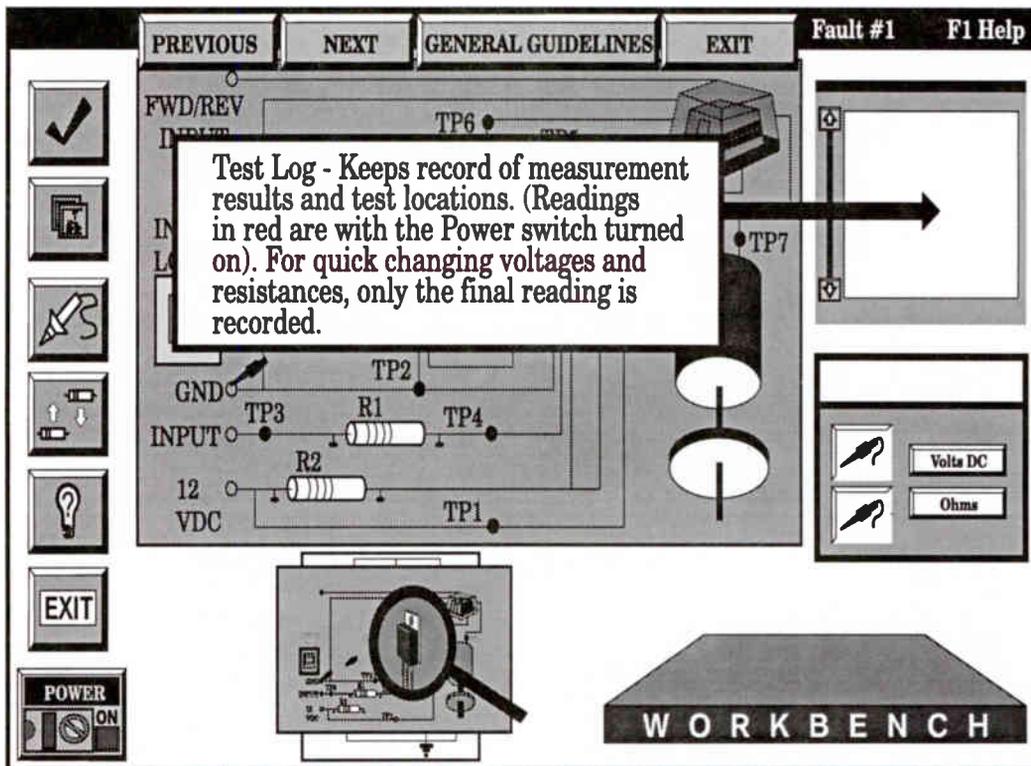
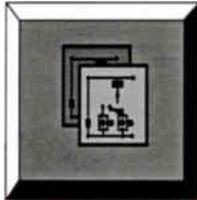


Figure 9. Help Screen.

## Using the Tools

Students will spend most of their time in the Troubleshooting Screen. In this screen, they have access to a number of tools and buttons that allow them to simulate real world troubleshooting. Each of these tools and buttons are explained below.

### Schematic / Component-View Button



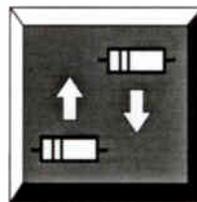
This button allows you to examine either the component view of the circuit or the schematic. You switch from one view to the other by clicking on the button.

### Soldering Iron



The Soldering Iron allows you to remove components from the circuit. It is selected by clicking on the button. When you select this tool, the cursor will be replaced by a small soldering iron icon. Simply click this icon on the component you wish to unsolder. The component will be automatically removed from the circuit and placed on the workbench.

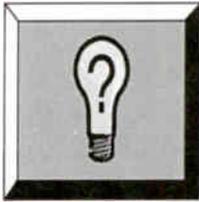
### Swap Component



The Swap Component tool allows you to replace a component with a “known good” component. When you select this tool, the cursor will be replaced by the soldering iron icon. Simply click the icon on the component you wish to replace or the space where a previously removed component belongs. The component will be automatically replaced with a “known good” component of exactly the same type as the one removed.

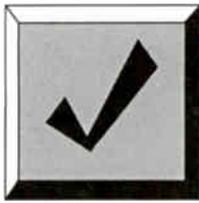
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## Idea or Hint Button



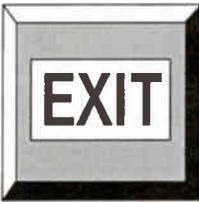
The hint button can give a little nudge if the student gets bogged down. When this button is clicked, a brief message is displayed where the workbench normally appears. The message remains until the mouse is clicked again. For each fault there are three different hints.

## Check Button



This button is used to check the results of the repair. If the repair has been accomplished, a congratulations message will appear. Otherwise a “sorry, please continue” message is given.

## Exit Button



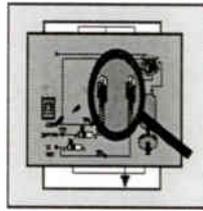
The Exit Button allows you to leave the troubleshooting Screen at any time. It takes you to the Main Options Menu which was discussed earlier.

## Power Button



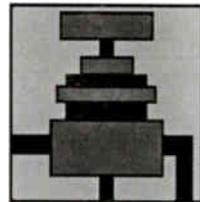
This button controls power to the circuit under test. Click to turn power on. Click again to turn power off. Generally there will be no voltages present in the circuit until power is turned on. Power should be turned on before making voltage measurements. Conversely, power should be turned off before making resistance measurements.

## Board / Schematic Icon



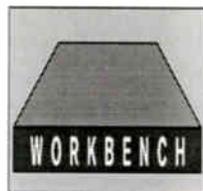
This icon performs the same function as the Schematic/Component-View Button explained above. That is, it allows you to switch back and forth between the schematic diagram and the component view of the circuit under test.

## Switch



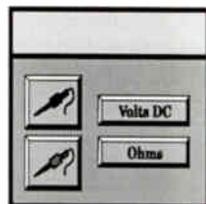
Sometimes a circuit will contain a switch. In this case, the switch may be operated by clicking on its top button. This will open and close the contacts like a real switch. The switch will stay closed for as long as you hold down the mouse button.

## The Workbench



The Workbench area serves two purposes. First, it is the area where components are placed when removed from the circuit with the soldering iron. Resistance and continuity checks can be made on components in this area. Second, it acts as a message display area. Both hint and warning messages appear here.

## The Multimeter



The Multimeter is the primary instrument used to troubleshoot the circuit. This meter is an autoranging digital multimeter capable of measuring DC Volts and Resistance. The appropriate mode is chosen by clicking on the DC Volts or

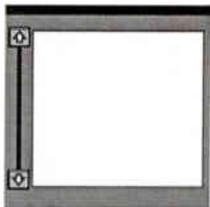
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Ohms Button on the meter. The meter's input impedance is high enough that it will not load the circuit under test. The autoranging feature means that it will automatically choose the right range.

The meter also has an autoblanking feature that blanks out the display until the digital count stops its runup. Therefore, quick changes in voltage or resistance may be missed. As with many digital meters, infinite ohms are indicated by a single 1 in the far left display.

To use the test leads, first click on the test lead button. Then click on the component lead and the test lead will connect itself there. To reposition the lead, click on the test lead and then on the new destination.

### The Recording Log



The Recording log provides a record of all the measurements made. It automatically scrolls up as new measurements are added. By using the scroll arrows, measurements that have scrolled out of sight can be brought back into view. Voltage readings are red when power is on and black when power is off. Once again, for fast changing conditions, only the final reading is recorded. The log will record up to 200 readings in a single "fault." After 200, any new reading will replace the last one.

## Leaving the Program

The program periodically “updates” your student work-disk. Normally, you should leave the program by using the **Exit Button**. When this is not done there is a good chance that the summary of actions may not be recorded on your student disk.

If you select the **Exit to DOS** button at the bottom of any screen, and do not have the proper password, you will be audibly and visually alerted. The **Exit to DOS** button returns the user to the DOS prompt only when the correct password is given.

The password you establish may be changed at any time to avoid compromise or to reestablish a secure system. To establish a new password, you will need to type **NEW** (at the password-to-DOS screen) and the screen prompts.

If power is lost, due to power failure or inadvertently turning the computer off while still in the troubleshooting program, the last **Fault** will not be updated onto the work-disk. The proper shut down procedure is to first use the **Exit to DOS** button, then enter the proper password, return to DOS, and then remove power.

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# Evaluating Yourself

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One of the prime advantages of using the CAT program is its ability to help you evaluate your performance. For the first time, you have a practical, private, and systematic way of judging your own troubleshooting techniques and procedures. It is as if you have an assistant to stand behind you and, with a stop watch and memo pad, unerringly time and record every step you take.

## Using the Tb Files

Your performance while using the CAT program is recorded on your workdisk as a Tb file. The identification of these files are easily recognized as the first two letters of such a file will be Tb. These files are created when you begin a troubleshooting scenario of the CAT program. Each and every sequential step performed during the scenario is recorded with a time marker noted to the left of the performed step. The contents of these files can be reviewed using a generic text file editor or word processing application program.

After completing your troubleshooting assignment(s), you can review the Tb files for your actions during the scenarios. Keep in mind that the Tb files are named sequentially (i.e. Tba, Tbb, Tbc, Tbd, etc.). If you happen to troubleshoot the first fault more than once, the Tb files will record one file per attempt. You will not be able to determine which scenario you completed by viewing the file names alone.

Once a file is open you may see information similar to that shown in the figure on the following page. This file contains a wealth of information including:

1. The Problem name and Fault number.
2. A statement of what the fault was. For example: The problem was: Resistor R1 is open.
3. Date and time that the problem was started.
4. A simple circuit representation to refresh your memory (if needed) of the schematic diagram.
5. Under the heading "Recordings," the step by step procedure that you performed. The number of steps may be lengthy and require you to move to the next page to see all of the recorded actions taken.
6. Each step indicates the time the step occurred in minutes and seconds.
7. Each step indicates the procedure performed and its outcome.

## Factors to Consider

As you progress through the CAT program, every step of your performance is captured on the student workdisk. By carefully analyzing the "trail" that you have followed, you can accurately evaluate your performance through the various troubleshooting scenarios.

However, troubleshooting is as much an art as it is a science. Keep in mind that it is your technique you will be judging as well as the final result. Because of troubleshooting's very nature, evaluating one's performance is somewhat subjective. No two technicians will approach troubleshooting in exactly the same way. And while there are general guidelines, it is difficult to list specific rules that are right for every situation. Indeed, troubleshooting philosophy varies widely from one company to the next, and you will even find diverse views among experienced technicians. Consequently, as a student, you will have to make many judgment calls as to how you carry out the troubleshooting assignment. Even so, the following guidelines will be of some use to you in evaluating your performance.

Direct-Coupled DC Amplifier\$1\$Solved

CIRCUITS TROUBLESHOOTING

Direct-Coupled DC Amplifier

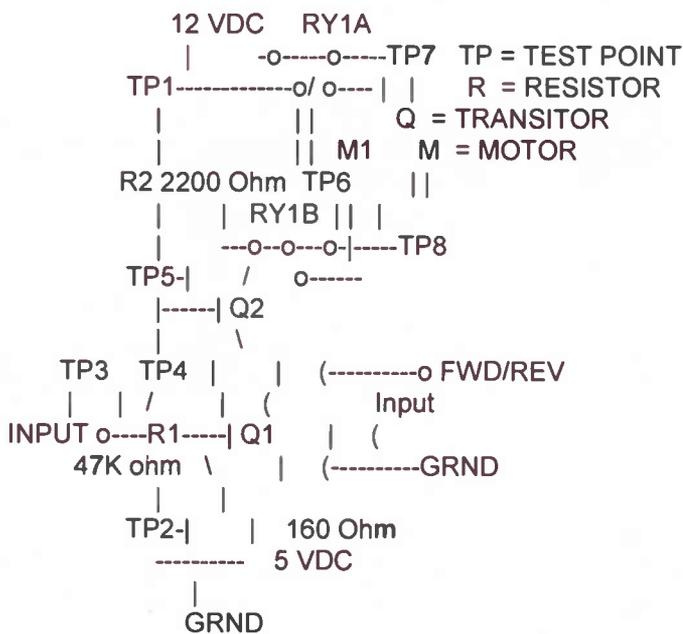
Fault # 1

The problem was : Resistor 2 is OPEN

DATE: Thursday, 11 /23/1996

TIME: 10:22:08

Circuit Setup:



Recordings:

- | 0:08| The technician took a reading on TP1,TP5 -- Infinite ohms
- | 0:12| Technician replaced RESISTOR 2 with a new one
- | 0:15| The technician checked the result and got a right answer

There are several factors you should consider in evaluating your performance. These include:

1. *Did you find the fault and fix it?*

This is the most fundamental question to ask. After all, this was the assignment. Failing repeatedly in this task indicates that you do not fully understand the assignment, or how the program works, or you may have serious deficiencies in your knowledge of the subject. Even so, this is not an unusual situation the first or second time that you are exposed to the program. Usually it indicates that you are not yet comfortable with the program. Examining one's actions as recorded on the workdisk should go a long way toward pointing out your weak areas.

2. *Did you approach the problem in a logical way?*

This is perhaps the single hardest question to answer. Normally, you will be expected to make voltage or resistance measurements prior to replacing a component. Did you do this in a systematic way, making all voltage measurements before moving on to resistance measurements or vice versa? Did you make enough measurements and the right types of measurements to uniquely identify the fault? Did you make far more measurements than were necessary?

3. *Did you use the equipment properly?*

Did you attempt to measure voltage with the power off? A minor infraction. Or did you attempt to measure resistance with the power on? A more serious offense.

4. *Did you follow good safety practices?*

Did you attempt to remove a component with the power applied?

5. *How many components did you replace before fixing the problem?*

Ideally you should replace only the malfunctioning component. Wholesale replacement of parts will eventually result in a "fix" but is not considered good practice.

6. *How long did it take you?*

By reading the Tb file(s) on the student workdisk, you can determine the exact amount of time spent on each step of the troubleshooting scenario as well as the overall problem. You may want to take this into consideration. Time can play a crucial factor in troubleshooting when customers and their money is involved.

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As the student, it is your responsibility to decide how much weight will be placed on each of the above factors and any other factors you may consider important. Also, you may want to change the weight of some factors as you progress. For example, forgetting to shut off the power before working on the circuit might be attributable to unfamiliarity with the program the first time it happens. But, it might be judged more severely on subsequent occurrences.

## **Additional Ways to Use the Program**

Once you become proficient at finding and repairing the faults using your own individually developed techniques, some additional variety can be introduced by setting up special scenarios which will cause you to rethink their techniques. For example, you may want to run through the program under one of the following scenarios:

1. Find and fix the fault as quickly as possible. There are situations in which time to repair is the most important factor. A failure of a key piece of equipment on an assembly line comes to mind. Every second that the line is down costs the company money. When time is the overriding concern, the troubleshooting technique may be radically different.
2. Find and fix the fault with minimum soldering. Soldering is an intrusive procedure. Anytime you remove or replace a component by soldering you risk damage to adjacent components, the circuit board, or the component being removed. This is especially true with today's micro-miniaturized electronics devices and multilayer circuit boards.
3. Find and fix the fault making measurements only with the voltmeter. Limiting the use of test equipment to the voltmeter will cause you to use Ohm's Law and other theoretical concepts. So while this may not be a legitimate technique, it makes an interesting learning experience.

# The Problems

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The Problems and Faults were chosen to give the student a cross section of troubleshooting experience. The early scenarios are designed to ease the student into troubleshooting while the later ones provide a more thought provoking challenge. There are no trick problems although in the last two problems component values and the characteristic of the meter are selected to prompt discussion. All malfunctions are either open or shorted components. There is only one malfunction per fault.

## Objectives of the Program

Upon completion of this exercise you will be able to:

1. Use a schematic diagram and a component view of a circuit, match each component and test point on the schematic with its counterpart on the circuit board.
2. Demonstrate that widely separated points on a circuit board may be “electrically” identical.
3. Demonstrate the proper use of a voltmeter and ohmmeter.
4. Use a series circuit with an open component, find and replace the faulty part.
5. Use a series circuit with a shorted component, find and replace the faulty part.
6. Use a series-parallel circuit with an open component, find and replace the faulty part.
7. Use a series-parallel circuit with a shorted component, find and replace the faulty part.
8. Use a bridge circuit with an open component, find and replace the faulty part.

- 
9. Use a bridge circuit with a shorted component, find and replace the faulty part.
  10. Demonstrate the proper method of testing a switch with an ohmmeter.
  11. Demonstrate the proper method of testing a capacitor with an ohmmeter.
  12. Demonstrate that the resistance value measured across a component connected in a circuit may be vastly different from the value measured across the same component removed from the circuit.
  13. Demonstrate that power should be removed from the circuit before any repair is attempted.
  14. Demonstrate that power should be removed from the circuit before using the Ohmmeter.
  15. Demonstrate that because of component and meter tolerances, resistance and voltage measurements are not always exactly what the student expects.
  16. Demonstrate the value of being able to estimate what voltage or resistance reading to expect.
  17. Demonstrate the unique abnormalities caused in various types of circuits by opens and shorts.

## **Series Resistors**

This first problem is designed to get the student comfortable with using the CAT program. The resistance readings match the color codes exactly and the voltages are about what you would expect from Ohm's Law. The resistance values make it easy for the student to estimate what the voltages should be. The faults introduce a variety of shorts and opens, with symptoms that are easy to spot.

## **Series/Parallel Resistors**

In this problem, the student begins to experience tolerances but still not enough to confuse the outcome. The resistance readings begin to diverge slightly from the "ideal." Here again, resistor and voltage values are such that estimations are fairly easy. The four faults that are introduced will give the student an excellent grasp of the unique characteristics of shorts and opens in the series/parallel combination.

## **Resistor Bridge**

In this problem, the concept of “tolerances” is driven home. Some of the resistance readings are deliberately chosen to cause the student to think about component and meter tolerances. By the time you complete all four faults, you should begin to realize that the readings obtained in the real world may vary from the ideal values predicted by theory alone.

## **R/C Combination**

In this final problem, three additional types of components are introduced: the capacitor, the switch, and the lamp. Also the added feature of being able to open and close the switch, both in and out of the circuit, adds variety, realism, and interest for the student. Here again, component values and the characteristics of the meter are chosen to make the student think. In particular, the value of the capacitor is small enough so that its charge and discharge are hidden by the initial blanking of the meter. Also, when power is removed, the capacitor quickly discharges back through the power supply load resistance (not shown).

# Answer Sheet

<b>DC Electronics Troubleshooting</b>		
<i>Series Resistors</i>		
Fault #1	Control Panel Lights	R1 open
Fault #2	Control Panel Lights	R3 shorted
Fault #3	Control Panel Lights	R3 open
Fault #4	Control Panel Lights	R2 shorted
<i>Series/Parallel Resistors</i>		
Fault #1	Snowmobile	R2 open
Fault #2	Snowmobile	R3 open
Fault #3	Snowmobile	R1 shorted
Fault #4	Snowmobile	R1 open
<i>Resistor Bridge</i>		
Fault #1	Bridge Circuit	R2 open
Fault #2	Bridge Circuit	R4 open
Fault #3	Bridge Circuit	R3 shorted
Fault #4	Bridge Circuit	R1 shorted
<i>R/C Combination</i>		
Fault #1	Test Equipment	R1 open
Fault #2	Test Equipment	L1 open
Fault #3	Test Equipment	C1 shorted
Fault #4	Test Equipment	C1 open

# NOTES

*Please use this page to record any notes  
you may want to review during your studies.*

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Lockport, New York





# **Working with Windows 98 7322**



**Study Guide to  
Accompany  
Windows 98  
Made Easy**

*NRI Schools*

*A Division of The McGraw-Hill Companies*

*Washington, DC 20008*





# **Working with Windows 98**

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# Table of Contents

<b>Module Overview</b> . . . . .	<b>1</b>
<b>Assignment 1: Internet Explorer and the Active Desktop</b> . . . . .	<b>4</b>
Introduction . . . . .	4
Objectives . . . . .	5
Reading Assignment . . . . .	5
Self-Test Questions . . . . .	5
Examination . . . . .	6
<b>Answers to Assignment 1 Self-Test Questions</b> . . . . .	<b>7</b>
<b>Assignment 2: Email, Newsgroups, and Web Pages</b> . . . . .	<b>10</b>
Introduction . . . . .	10
Objectives . . . . .	11
Reading Assignment . . . . .	11
Self-Test Questions . . . . .	11
Examination . . . . .	12
<b>Answers to Assignment 2 Self-Test Questions</b> . . . . .	<b>13</b>
<b>Assignment 3: Web Servers, NetMeeting, and Mobile/Remote Computing</b> . . . . .	<b>15</b>
Introduction . . . . .	15
Objectives . . . . .	16
Reading Assignment . . . . .	16
Self-Test Questions . . . . .	16
Examination . . . . .	17
<b>Answers to Assignment 3 Self-Test Questions</b> . . . . .	<b>18</b>
<b>Assignment 4: Configuration and Management of Windows 98.</b> . . . . .	<b>20</b>
Introduction . . . . .	20
Objectives . . . . .	21
Reading Assignment . . . . .	21
Self-Test Questions . . . . .	21
Examination . . . . .	22
<b>Answers to Assignment 4 Self-Test Questions</b> . . . . .	<b>23</b>
<b>Assignment 5: Working with Windows 98</b> . . . . .	<b>26</b>



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# Module Overview

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Welcome to the second part of your Windows 98 learning experience! In this module, you'll go beyond the basics and learn about Web browsing and communication, as well as Windows 98 configuration and management. Your training consists of a textbook, *Windows 98 Made Easy: The Basics and Beyond*, in conjunction with this study guide, *Working with Windows 98*. We'll cover Chapters 12–22 of your textbook in this module.

This study guide is your key to navigate your way throughout this course. It consists of objectives, reading assignments, self-test questions, and instructions for a graded examination at the end of the first four assignments. Be sure to read the introduction and objectives presented in the study guide before you read the material in the textbook. We strongly suggest that you carefully follow each assignment as it's presented in this study guide. Each assignment provides basic information that you'll use as "stepping stones" to understand later concepts.

Don't forget that you must take an examination after each of the first four assignments. You'll find instructions in each assignment for taking these exams. Before taking an examination, however, please review that assignment's Self-Test Questions. Although the questions don't cover all of the examination material, they do cover many of the assignment's objectives. Working through the Self-Test Questions will help you better understand the reading. Remember, you should feel comfortable with the assignment objectives and textbook reading before taking an assignment examination.

There are five assignments in this module. Let's take a look at them:

### ***Assignment 1: Internet Explorer and the Active Desktop***

This assignment covers Chapters 12–13 in your textbook. Here, you learn the ins and outs of surfing the Internet using Internet Explorer, Microsoft's Web browser that's included with Windows 98. You learn how to search for information on the Web and manage the information that you view in Internet Explorer. Of special interest is a section on blocking unwanted Internet sites from your computer. You also learn all about the Active Desktop, subscriptions, and Web channels. These are all new communications capabilities with Windows 98, and we're certain that you'll be amazed and impressed as you learn about these features.

### ***Assignment 2: Email, Newsgroups, and Web Pages***

This assignment covers Chapters 14–16 in your textbook. You'll take a look at using Windows 98's email package, Outlook Express, to communicate with other users. Newsgroups and discussion groups are also covered. Finally, you'll learn some basics of FrontPage Express, a software program that comes with Windows 98 and lets you create pages to place on the Internet.

### ***Assignment 3: Web Servers, NetMeeting, and Mobile/Remote Computing***

This assignment covers Chapters 17–19 in your textbook. Here, you delve into some advanced features of Windows 98 — Personal Web Server, NetMeeting, and mobile and remote computing. Personal Web Server is a desktop Web Server that lets you actually publish Web pages on an intranet or the Internet. NetMeeting is a software program that lets you communicate with others over computer networks. With NetMeeting, you can set up videoconferences and share applications and information online. Finally, you'll take a look at how Windows 98 can help you hit the road and still remain connected to your home or office computer and networks.

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### ***Assignment 4: Configuration and Management of Windows 98***

This assignment covers Chapters 20–22 in your textbook. Here, you examine the necessary steps for installing devices — such as printers, modems, or multimedia equipment — on your computer. You also learn about the Windows 98 tools and utilities — such as Disk Cleanup, ScanDisk, and Disk Defragmenter — that maintain your system. This is a very important section because you learn how to back up files and prevent loss of information. And finally, you check out some tips for optimizing your system's performance and for troubleshooting.

### ***Assignment 5: Working with Windows 98***

This assignment is a hands-on practical project that you must turn in to your instructor for grading. Be sure to follow the directions carefully for completing the project and sending it in for grading.

# Assignment 1: Internet Explorer and the Active Desktop

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## Introduction

Welcome to the Information Superhighway! No matter if you're an experienced "Net Surfer" or if you've never been on the Internet before, this assignment shows you how Microsoft has made the Internet easy to access and manage with its Internet Explorer. If you're a newcomer to the Internet, we recommend reading Appendix B in the back of your textbook to get a better idea of what the Internet is all about. Here, you'll get an introduction to the Internet and how you can access it. While you may not have Internet access at this time, this section still provides you with the necessary information and know-how for getting connected and maneuvering your way around the 'Net.

When using the Internet, it's important to keep in mind that in terms of what's out there, "anything goes." That is, there are no rules or regulations, no standards, no quality-control mechanisms, and no monitoring. What you basically need to know is that just because you find something on the Internet, it might not necessarily be correct information. You see, *anybody* — and that means you, too! — can publish a Web page on the Internet. As a matter of fact, you will learn how to create and publish a Web page in this course! What this comes down to is that if you wanted, you could publish a "History of America" Web page that says, for example, "Christopher Columbus discovered America in 1776 and named it America because that was his mother's maiden name." No one would stop

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you from making this very incorrect information available to everyone in the world with an Internet connection. So, just a word of warning: As you explore the Internet, it's okay to have fun and even get a little carried away with all the information available at your fingertips, but please take care to note where your information is coming from.

## Objectives

*After completing this assignment, you should be able to:*

- Browse the Internet using Internet Explorer.
- Use an Internet search engine.
- Mark your favorite Web sites.
- Use the Internet Explorer's multimedia, security, and add-in features.
- Understand how Webcasting, subscriptions, channels, and WebTV work.
- Manage the Active Desktop.

## Reading Assignment

Read and study Chapters 12 and 13 in your textbook. When you've finished the reading, return here and answer the Self-Test Questions for this reading assignment.

## Self-Test Questions

*Please check your answers on page 7.*

- 1 Name four ways to launch the Internet Explorer.
- 2 Explain how Windows 98 provides integrated access to both local files and the Internet.
- 3 What is the Links toolbar?
- 4 How can you make sure that the Web page you're viewing is the most up-to-date version?
- 5 What does the History list keep track of?
- 6 What is one problem with the RSACi rating system?
- 7 What kind of information would you put on the Active Desktop?

- 8 What is the difference between channel-defined sites and non-channel defined sites in Windows 98?
- 9 True or false. It's possible to subscribe to a site but just have Internet Explorer tell you (via email or via the Favorites menu) that the site has been updated.
- 10 How is it possible to browse the Web without being connected online? What do you think is an advantage and a disadvantage to this method?

### Examination

The examination for Assignment 1 is packed separately in this module. Once you've completed the work for this assignment, locate *Examination 7323* and complete it according to the instructions provided with it.

Be sure to phone or send in your answers for grading as soon as you complete the exam and check your answers. This should help prevent any unnecessary shipping delays in your study materials.

Once you've completed the examination and sent in your answers for grading, you can go on to the next assignment. You don't need to wait for the graded response to this examination.

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# Answers to Assignment 1

## Self-Test Questions

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- 1 Four ways to launch the Internet Explorer are:
  - Click on the Internet Explorer icon on the Desktop, Taskbar, or Quick Launch toolbar.
  - Open any folder window and type a Web address in the Address field.
  - Click on the Start menu and choose Find | On the Internet.
  - Click on the Start menu, select Favorites, and choose a Web page that you want to open.
- 2 Windows 98 provides integrated access to both local files and the Internet. For example, if you open My Computer and Drive C, you can browse the directories located there for information. When you type an Internet address in the Address window, you'll be taken directly to the Internet. When you click on the Back button, you'll be taken right back to your local file system. This is integrated access.
- 3 The Links toolbar is a toolbar that contains links to some Web sites, such as Microsoft's Best of the Web, Welcome to My Yahoo!, Channel Guide, and Internet Start. You can delete any links that you don't want on the Links toolbar, as well as add new ones that you want to access easily.
- 4 You can make sure that the Web page you're viewing is the most up-to-date version by clicking on the Refresh button, located on the toolbar. When you click this button, Internet Explorer reloads the page for you, ensuring that you've got the latest "edition."

- 5 The History list keeps track of all the places that you've visited on the Web. It organizes your "trips" every day, providing you with daily, weekly, and monthly lists of addresses you've visited on the Web. You can adjust the History list's settings for the number of days that addresses are maintained in the list. For example, as a default, the list keeps addresses that you've visited within the past twenty days. However, you can change the default to two days (if you have limited hard disk space, for example) or even as much as 999 days.
- 6 One problem with the RSACi rating system is that not all Web sites use it. Therefore, by default, Internet Explorer blocks any sites that don't use this rating system. Because of this, children may be blocked from suitable sites that don't happen to use the RSACi rating system. An alternative is to permit Internet Explorer to show sites without ratings, but this defeats the purpose of preventing children from gaining access to sites that may not be suitable.
- 7 The Active Desktop is the place to run active Web content. Some examples of information that you could put on the Active Desktop are news from Web sites such as CNN or MSNBC. You could also put information such as stock quotes, weather reports, and sports scores. Basically, you can put any programs that were created with ActiveX and Java.
- 8 Channel-defined sites are Web sites that support Windows 98 channel technology. Channel-defined sites have a CDF file (channel definition file) that Internet Explorer reads to find out what information at the site has been recently updated. This process is a quick one because Internet Explorer doesn't have to read through all the pages (called *crawling*) to find out what information has been updated, which is what it has to do on non-channel defined sites.
- 9 True. It's possible to subscribe to a site but just have Internet Explorer tell you (via email or via the Favorites menu) that the site has been updated. To do this, go to the Internet site that you want to subscribe to. Choose the Add to Favorites on the Favorites menu and choose the option "Yes, but only tell me when this page is updated." You may want to select this option if you want to download the new information at your own convenience and not at a predetermined time.

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10 You can browse the Web without being connected online if you take advantage of Windows 98's offline browsing feature. Basically, this feature lets you download the contents of a Web site at night or when you're not using your computer. Then, when you go to view the information, you access the site as if you were online. An advantage of this method is that you save time by downloading content when you're not at your computer. This way, you don't have to wait for it to load. A disadvantage is that the information you're viewing offline isn't the most up-to-date information, which is a main feature of the Internet. While this wouldn't be a big deal if you were looking up, for example, the role of the United States in World War II, it might matter a great deal if you were trying to catch up on the day's current events. As a comparison, it would be like reading yesterday's newspaper tomorrow.

# Assignment 2: Email, Newsgroups, and Web Pages

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## Introduction

“Just email it to me” is an attitude that’s sweeping the world. While we used to have to wait several days for a letter to arrive via the Postal Service, with a click of the mouse we can send and retrieve information within seconds over email (short for “electronic mail”). Email is an amazing technological advancement which may soon rival the telephone for ease of use and popularity. However, many people still aren’t comfortable with the email process — whether it’s writing a basic message, sending an attachment, retrieving mail, or filing messages. This assignment will show you the basics and beyond of email messages.

You’ll also learn about newsgroups in this assignment. We think that you’re going to really enjoy this section! Newsgroups are public discussion groups via email about pretty much anything. You can join a newsgroup that discusses *Seinfeld*, the Gulf War, Shintoism, or even child care, just to name a few topics. Be forewarned, however: Newsgroups can be very addictive! Before you know it, you can easily spend three or four hours reading and replying to messages. This is natural in the beginning, as you’re learning and discovering the power of communication in newsgroups. But be careful: Remember that life does go on outside of the newsgroups! (We’re telling you this information from personal experience!) Try not to spend too much time wrapped up in a newsgroup.

Finally, this assignment will show you how to publish Web pages with FrontPage Express. Take a minute to think about what this means: You will be able to put something of yours on the Internet for the whole world to see! Maybe you’ve always wanted to write a book but

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never had the chance to get it published. Well, if you want, you can put your book online for anyone to read. This assignment won't show you how to write your book, but it will show you how to use FrontPage Express, which is included with Windows 98. FrontPage Express is basically a Web page-layout program. It uses HTML (hypertext markup language) — a language used to place information on Web pages.

## Objectives

*After completing this assignment, you should be able to:*

- Format, send, and receive email messages with attachments using Outlook Express.
- Access Web pages with Outlook Express.
- Organize your email in folders and make your email messages secure.
- Access, subscribe to, participate in, and respond to newsgroups using Outlook Express.
- Manage newsgroup messages and change newsgroup properties.
- Understand the Web publishing process.
- Use FrontPage Express to publish and edit your Web pages.

## Reading Assignment

Read and study Chapters 14–16 in your textbook. When you've finished the reading, return here and answer the Self-Test Questions for this reading assignment.

## Self-Test Questions

*Please check your answers on page 13.*

- 1 Where are newly received messages located in Outlook Express?
- 2 If you receive a message that has a paperclip icon next to it, what does it mean?
- 3 What does the Reply to All feature do?

- 4 Explain how you can format Outlook Express email messages in HTML, and why you might want to do this.
- 5 How can you create a signature in Outlook Express?
- 6 How would you go about getting a digital ID?
- 7 Why is it important to follow a newsgroup's etiquette conventions?
- 8 How can you ask Outlook Express to not show newsgroup messages that contain the words "sell" or "sale," for example?
- 9 Explain what FrontPage Express is and what you'd use it for.
- 10 How do you create a hyperlink in FrontPage Express?

### Examination

The examination for Assignment 2 is packed separately in this module. Once you've completed the work for this assignment, locate *Examination 7324* and complete it according to the instructions provided with it.

Be sure to phone or send in your answers for grading as soon as you complete the exam and check your answers. This should help prevent any unnecessary shipping delays in your study materials.

Once you've completed the examination and sent in your answers for grading, you can go on to the next assignment. You don't need to wait for the graded response to this examination.

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# Answers to Assignment 2

## Self-Test Questions

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- 1 Newly received messages in Outlook Express are located in the **Inbox**. However, keep in mind that you'll only receive new messages if you're connected to the appropriate mail server.
- 2 If you receive a message that has a paperclip icon next to it, it means that the email message contains an attachment. An attachment is a file that was delivered along with the email message.
- 3 When you select the **Reply to All** feature when responding to an email message, you're replying to every single person who received that email message, not just the email message's author. For example, let's say that you, Sarah Smith, and Jake Smith received an email message from John Smith. If you select **Reply to All**, you're replying to Sarah, Jake, and John. However, if you only want to reply to John, you'd want to select the **Reply to Author** button.
- 4 You can create email messages with **HTML** content in Outlook Express by choosing **Options** on the **Tools** menu, clicking the **Send** tab, and then enabling the **HTML** in the **Mail sending format** and **News sending format** fields. You might want to do this so that readers of your messages can view the formatting in your messages.
- 5 You can create a signature in Outlook Express via the **Stationery** dialog box. Click on the **Signature** button to open the **Signature** dialog box. You can create the text of your signature here, or you can designate a signature file. This dialog box is also the place to create a business card, which is an attachment that contains personal information about you.

- 6 To get a digital ID, open the Tools menu and select Options. Next, select the Security tab. You can click on the More Information button to learn more about digital IDs. Or, you can select the Get Digital ID button and it will connect you to Microsoft's digital information site.
- 7 It's important to follow a newsgroup's etiquette conventions because if you don't, you're likely to get flamed. That is, newsgroup users will send you lots of mean email messages and tell you about the mistakes you've made in using the newsgroup.
- 8 You can ask Outlook Express to not show newsgroup messages that contain the words "sell" or "sale" by using the Newsgroup Filters feature, located in the Tools menu in Outlook Express. Click on the Add button to make a new filter.
- 9 FrontPage Express is a program for creating Web pages. It basically looks and works like a word-processing or page-layout program. With FrontPage, you can format pages to post them on the Internet. FrontPage Express formats your pages in HTML code, but you don't even need to know this programming language to use FrontPage Express. It works just like a page-layout program! For example, if you want to bold a section of text, you simply highlight the text and press the Bold button on the Format toolbar — It's that easy. FrontPage Express even contains a New Page Wizard that walks you through the process of creating a typical home page. FrontPage Express also makes it easy to create hyperlinks to other pages or Web sites.
- 10 To create a hyperlink in FrontPage Express, type some text and highlight the part that you want to be the hyperlink. Next, select Hyperlink from the Insert menu. You can select where you want your hyperlink to go: On an existing open page, a page on the World Wide Web, or a new page that you haven't yet created. Next, choose the type of link that you want to create. (See Table 16-1 in your textbook for a description of the various links that are available.) Now you can type in the link's address in the URL field and then click OK.

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# Assignment 3: Web Servers, NetMeeting, and Mobile/Remote Computing

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## Introduction

This assignment will show you the real power of Windows 98 with its Personal Web Server (PWS), NetMeeting, and remote computing options. While these may not be programs that you'll use every day, they are features that can make your life much easier!

PWS is a software program, included with Windows 98, that basically puts Web pages out on the Internet for you. Your textbook calls PWS a "desktop Web server," which is an accurate description. With PWS, you can publish Web pages for the entire Internet community to see. The difference between FrontPage Express and PWS is that FrontPage Express helps you create and format your Web pages, while PWS acts as a server that serves up the pages for the Internet. If you're interested in creating and publishing Web pages, you'll want to study the PWS section in your textbook in detail.

NetMeeting is also included with Windows 98. It's a software program that lets you communicate with people over computer networks. With NetMeeting, one of the neat things that you can do is set up a videoconference. Keep in mind that to take advantage of the videoconferencing capabilities, you'll need a camera. Before you rush out and buy one, you should decide if you'll even need to use the videoconference feature. It is a nice program if you have a need for it. You might want to look beyond its obvious business advantages and see how you might use it in your personal life. Do you have family members living all over the country or even the world? NetMeeting could be a great communication tool for keeping in touch with

them. This assignment provides you with the ins and outs of using NetMeeting.

Finally, you discover the power of remote computing. This is a wonderful feature for people who are on the go but who need access to an office or home computer network. Just think: Wouldn't it be great if you could access the office computer from your laptop when you're actually three states away from the office? It can be done with Windows 98's remote computing.

### Objectives

*After completing this assignment, you should be able to:*

- Create and publish a Web page.
- Make non-HTML documents available on your Web site.
- Create a guest book and collect information from visitors.
- Use NetMeeting to communicate with others.
- Understand how NetMeeting can be used to share applications and documents with multiple users.
- Understand the many mobile/remote features of Windows 98.

### Reading Assignment

Read and study Chapters 17–19 in your textbook. When you've finished the reading, return here and answer the Self-Test Questions for this reading assignment.

### Self-Test Questions

*Please check your answers on page 18.*

- 1 Where is PWS located?
- 2 What is a *drop box*?
- 3 If you create a home page with FrontPage Express, where should you save the files?
- 4 What equipment is necessary to make phone calls and to set up videoconferences with NetMeeting?

- 
- 5 How can you transfer files to members of your NetMeeting session?
  - 6 What is NetMeeting's Whiteboard?
  - 7 What is *docking*?
  - 8 What is *deferred printing*?
  - 9 Explain the idea of the Briefcase.
  - 10 What is Windows CE?

## Examination

The examination for Assignment 3 is packed separately in this module. Once you've completed the work for this assignment, locate *Examination 7325* and complete it according to the instructions provided with it.

Be sure to phone or send in your answers for grading as soon as you complete the exam and check your answers. This should help prevent any unnecessary shipping delays in your study materials.

Once you've completed the examination and sent in your answers for grading, you can go on to the next assignment. You don't need to wait for the graded response to this examination.

# Answers to Assignment 3

## Self-Test Questions

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- 1 PWS is included with Windows 98, but it's not included with the normal installation. To use PWS, you must install it from the Windows 98 CD-ROM. Choose Run from the Start menu and type in the following line:  
*d:\add-ons\pws\setup.exe*  
After you've installed PWS, you can access it from the Publish icon on your Desktop.
- 2 A *drop box* is a private mail box where visitors to your Web site can leave messages for you. Visitors just need to click on the "Leave a Private Message" option that's set up on your home page. You can access your private messages through the Personal Web Manager. Click the Web site icon in the left pane and then click the Open Your Drop Box option.
- 3 If you create a home page within FrontPage Express, you should save the files in the wwwroot folder. You should also put any graphic elements or any other of your home page inserts into this folder.
- 4 To make phone calls and set up videoconferences with NetMeeting, you would need a modem, sound card, microphone, and speakers. You should have a Pentium-type computer with at least 32MB of RAM. To video-conference, you'll also need a camera.
- 5 There are two ways to transfer files to members of your NetMeeting session. One way is simply clicking and dragging the file into the NetMeeting window, where it's automatically delivered to members of the session. Or, if you don't have the file that you want to transfer handy, you can use the File Transfer option on the Tools menu.

- 
- 6 NetMeeting's Whiteboard is basically a whiteboard program. You've probably been to meetings where a whiteboard was used; it's basically a white board that's hung on a wall. You can write on the whiteboard with special markers that easily erase with a dry sponge. It's like a grown-up version of a blackboard. NetMeeting has expanded this idea for use over the Internet or an intranet. The program works like the Paint program. You can draw graphics or whatever you want; participants in the session can view your drawings and even add to them or create their own.
  - 7 *Docking* is when you quickly attach or detach your laptop to and from a desktop connection. *Hot-docking* is when you can remove your laptop from a docking port without even having to turn it off. You can reconnect it at another docking station or use it as a stand-alone computer as soon as you detach it from the docking station.
  - 8 Windows 98's deferred printing feature allows you to send print jobs to a printer even when you're away from that printer. Basically, the print jobs are saved to a disk and then when you reconnect to that printer, the print jobs go through.
  - 9 The Briefcase is designed to help you keep track of files when you're working off a desktop computer and a laptop. What you do is this: When you're ready to travel with your laptop, copy the files you'll need from your desktop computer into the Briefcase — just like you'd place files inside an actual briefcase. Then, copy the files from your briefcase onto your laptop. You can edit the files on your laptop, and then copy them back into the briefcase again when you plan to return to your desktop computer. When you copy them from the Briefcase onto your desktop, the Briefcase automatically updates the files that have changed in their original location; you don't have to copy the files to their original location.
  - 10 Windows CE is the travel version of Windows 98. It's an operating system that's used by many handheld PCs (H/PCs) and palm computers. The CE operating system runs versions of the same applications that are on Windows 98: Microsoft Excel, Word, Internet Explorer, and Outlook Express, for example. The system is set up so that you can plug your H/PC into your Windows 98 desktop computer. You can share information back and forth between the two computers.
-

# Assignment 4: Configuration and Management of Windows 98

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## Introduction

This assignment touches on the configuration and management of your Windows 98 system. You will examine how to install and configure any devices (such as a printer, modem, or multimedia equipment) that you may want to add to your system. Don't think that just because you purchased a brand-new computer fully loaded with devices, you won't need to worry about add-ons. With the way technology is expanding these days, you will always need to know how to add and install devices.

You'll find that this assignment is a little technical in nature, due to the many different hardware options and configurations required for installing devices. Don't feel threatened! Just try to get an overall understanding of the configuration-and-management process rather than a micro view of the various steps that you need to do for a specific task. As with any type of skill, it's difficult to understand something until you *have* to do it. By understanding the general way that devices are added on, when it's time for you to install and configure one, you'll know the basics about what to do, and then you can consult a manual or even your textbook for the detailed steps.

This assignment also covers hard drive maintenance and troubleshooting for your Windows 98 system. While these topics may sound like something that you'd rather leave to the "techies," you should really think again! It's a smart idea to be aware of the behind-the-scenes workings and controls of your system, and with Windows 98, it's easy to understand and implement the techniques and options that you'll learn about in this assignment. Take some time to really get to know how you can optimize and

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exercise preventive maintenance on your computer — It's well worth it!

## Objectives

*After completing this assignment, you should be able to:*

- Install and set up devices, such as printers, modems, and multimedia technologies.
- Understand how you can change and configure device settings.
- Use the Windows Maintenance Wizard, Disk Cleanup, ScanDisk, Disk Defragmenter, and DriveSpace to perform system maintenance and enhancement tasks.
- Scan your system for viruses and back up your system and data files.
- Adjust and optimize your system's performance configurations.
- Use Microsoft System Information Utility and System Monitor.

## Reading Assignment

Read and study Chapters 20–22 in your textbook. When you've finished the reading, return here and answer the Self-Test Questions for this reading assignment.

## Self-Test Questions

*Please check your answers on page 23.*

- 1 Where is the main place for installing and configuring new devices for Windows 98?
- 2 If you're viewing your system properties in the Device Manager and see an exclamation point over a listed device, what does this mean?
- 3 When you view the currently installed printers in the Printers folder in the Control Panel, what do the "check," "hand," "disk," and "cable" placed near a printer icon signify?
- 4 Where can you set up and configure a modem?
- 5 What is the Windows Maintenance Wizard?

- 6 Where is the Windows 98 program for scanning for software viruses?
- 7 True or false. You can easily back up your hard drive right to another file or folder on the same hard drive.
- 8 Where do you check your Windows 98 system performance?
- 9 How can you get the latest Windows 98 updates?
- 10 True or false. Windows 98's System Monitor is a tool that directly lets you know when you have a problem with your operating system and computer.

### Examination

The examination for Assignment 4 is packed separately in this module. Once you've completed the work for this assignment, locate *Examination 7326* and complete it according to the instructions provided with it.

Be sure to phone or send in your answers for grading as soon as you complete the exam and check your answers. This should help prevent any unnecessary shipping delays in your study materials.

Once you've completed the examination and sent in your answers for grading, you can go on to the next assignment. You don't need to wait for the graded response to this examination.

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# Answers to Assignment 4

## Self-Test Questions

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- 1 The main place for installing and configuring new devices for Windows 98 is the Control Panel. You can use the Add New Hardware utility to start up a wizard that will help you with the installation and configuration process.
- 2 If you're viewing your system properties in the Device Manager and see an exclamation point over a listed device, it means that there is a problem with that device. You can select the device and click Properties to see information about the device and resolve any problems.
- 3 When you view the currently installed printers in the Printers folder in the Control Panel, the "check" symbol placed near a printer icon means that the printer is the default printer. A "hand" symbol placed near a printer icon means that the printer is available for other network users to access. The "disk" symbol placed near a printer icon means that the printer prints to a file. Finally, the "cable" symbol placed near a printer icon means that the printer is a network printer that's attached to another computer.
- 4 You can set up and configure a modem with the Modems utility in the Control Panel. You can use the Install New Modem Wizard to easily add a modem.

- 5 The Windows Maintenance Wizard is a feature of Windows 98 that schedules disk housekeeping tasks for times when you're not going to be using your computer. It arranges for activities such as the Disk Defragmenter, which rearranges the way that programs are stored on your computer so that the programs will run faster. Another activity that it can schedule is the ScanDisk utility, which scans for and corrects hard drive errors. Disk Cleanup, which removes unnecessary files to free up disk space, is also scheduled by the Windows Maintenance Wizard. Keep in mind that you don't have to wait for the Windows Maintenance Wizard to schedule these tasks for you; you can run any of them at any time you choose.
- 6 Windows 98 doesn't contain a program for scanning for software viruses. The authors of your textbook recommend software programs from Symantec or McAfee.
- 7 False. You don't want to back up your hard drive right to another file or folder on the same hard drive because if you lose your hard drive, your backup files will be lost, too! You want to back your files up to any of the following:
  - A floppy disk
  - A zip-type drive
  - Another hard drive on your system
  - Another computer on your network
  - A tape drive
  - A server on the Internet
- 8 You can check your Windows 98 system performance in the System utility. You can open the System utility either by right-clicking on the My Computer icon or by opening it up in the Control Panel. Once you open the System Properties dialog box, click on the Performance tab. Here, you'll find performance information such as Memory, System Resources, File System, and Virtual Memory.

- 
- 9 You can get the latest Windows 98 updates by going to Microsoft's Web site. All you have to do is select Windows Update on the Start menu. This will take you to the Windows 98 update site. There, you can access the Update Wizard.
- 10 False. Windows 98's System Monitor doesn't directly let you know when you have a problem with your operating system and computer. Instead, you need to run the program over a period of time to see how your system performs.

# Assignment 5: Working with Windows 98

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Congratulations! You've arrived at the last assignment in your Windows 98 course: the hands-on project. This project is packed separately in this module. Locate *Project 7327* and complete it according to the instructions provided with it.

Keep in mind that this project requires you to complete five exercises on your computer and mail us your work for grading. Be sure to set aside enough time to do the project carefully and completely. Don't rush through the work. Have fun with your project, and if you have trouble remembering how to perform a particular task, feel free to consult your textbook for more information.

Good luck, and we wish you success as you work with Windows 98!

# NOTES

*Please use this page to record any notes you may want to review during your studies.*

# NOTES

*Please use this page to record any notes you may want to review during your studies.*



## **PRACTICE WHAT YOU LEARN**

Everyone knows that steady practice is needed to master a sport. But did you ever stop to consider the importance of steady application to a course of study? To be able to use what you know, you have to practice.

As you read through these lessons, make a special note of sections that seem difficult. You must ask yourself if you understand each idea presented. Develop confidence in your knowledge of the basics before you attempt to go on.

It has been said that children must learn to walk before they run. So, too, must students practice what they learn before they can apply their knowledge effectively. Review your lessons at every opportunity. Each section will require a knowledge of what has come before.

How do beginners become experts? By recognizing and mastering each detail of the job set before them.





**Solving Computer Problems**

**6133**

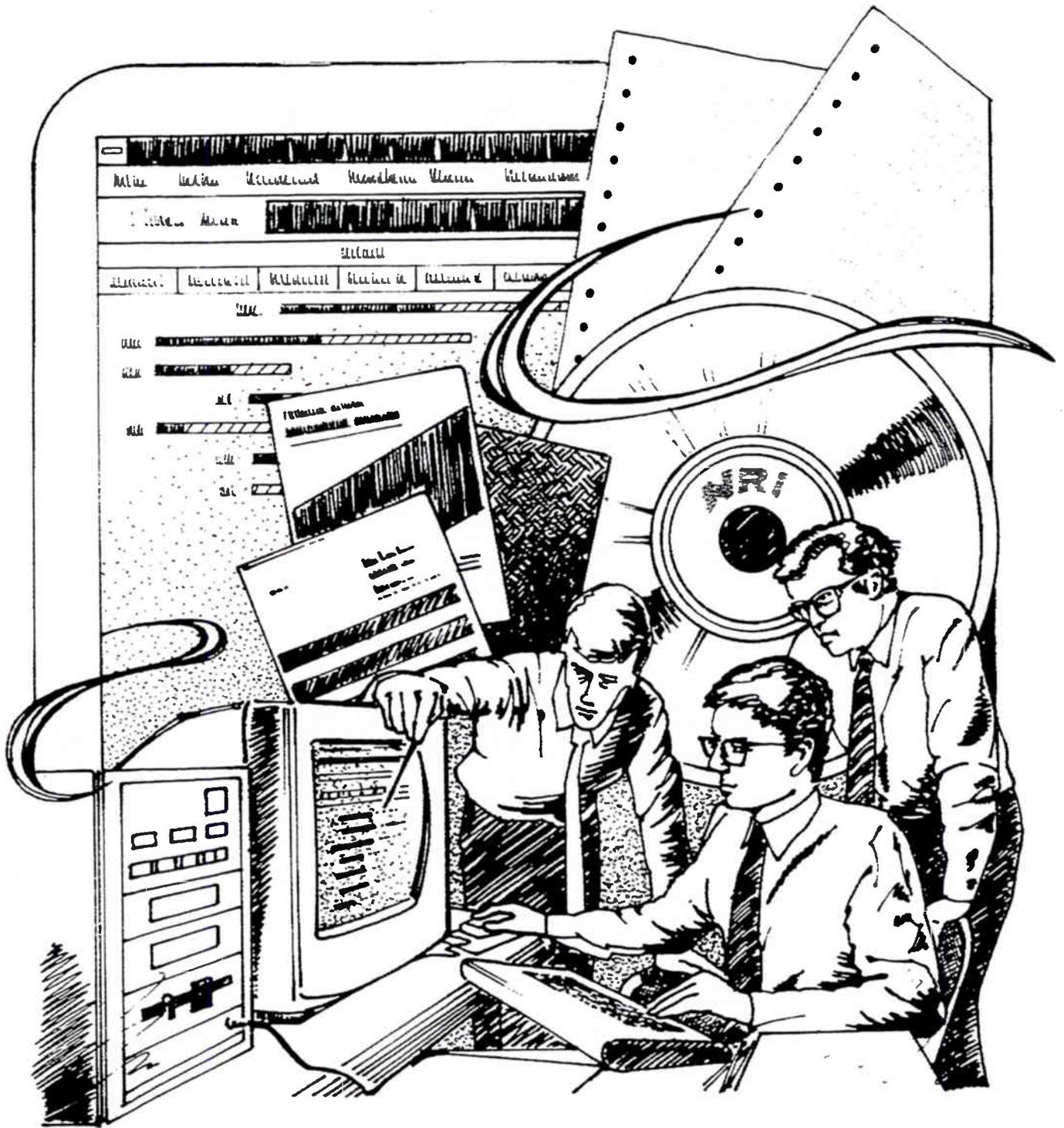
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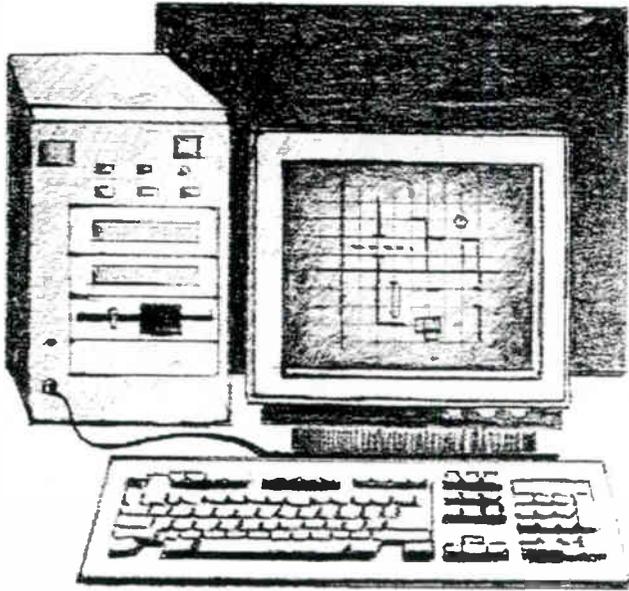


# Solving Computer Problems

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# Table of Contents

<b>Overview</b> . . . . .	<b>1</b>
<b>Computer Troubleshooting</b> . . . . .	<b>2</b>
<b>Using Troubleshooter</b> . . . . .	<b>4</b>
Making a Backup Copy of Troubleshooter . . . . .	<b>4</b>
Setting Up Your Computer . . . . .	<b>5</b>
CD-ROM Testing . . . . .	<b>8</b>
<b>Computer Troubleshooting</b> . . . . .	<b>12</b>
Computer Won't Start . . . . .	<b>12</b>
Computer Will Not Boot . . . . .	<b>13</b>
Computer Runs Slow . . . . .	<b>14</b>
<b>Examination Questions</b> . . . . .	<b>16</b>



## Lesson Objectives

*After you complete this training unit you will be able to:*

- Explain the use of loop-back plugs.
- Describe the testing procedures for CD-ROM drives and sound cards using Troubleshooter.
- Describe the steps of a typical troubleshooting procedure.
- List the values of the voltages provided to the motherboard from the power supply.
- Describe the effects of an IRQ conflict.

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# Overview

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Servicing microcomputers can be a long, tedious process. Often one has no idea where to start when confronted with a completely "dead" machine. In other cases, an intermittent problem that occurs randomly can take a great deal of time and patience to track down. To add to these problems, the physical construction and layout of the various computers available is far from "standard," which means that knowing the layout and construction of one machine will not help when dealing with another machine.

Even with the use of expensive and sophisticated test equipment, it can be quite difficult to pinpoint troubles that develop in computers. Oftentimes, diagnostic software or diagnostic cards are of little use if the computer is not functioning enough to get the diagnostic equipment running on the computer. These situations require a more basic approach to troubleshooting.

If the computer will turn on, and begin to boot, diagnostic software is the best bet to find the problem. The better software packages on the market have their own operating system. By booting from the diagnostic software diskette, problems caused by software and hardware conflicts are eliminated.

Diagnostic software can also be of great value in "burning in" a new computer for delivery to a customer. Diagnostic software can test the RAM and other circuits that are prone to early failure. Running a variety of tests over a 24 to 48-hour period can often identify marginal parts and avoid early failure in the customer's location. Frequently, such software also is used after a computer has been repaired, in order to gain some assurance that additional breakdowns will not occur after the machine is returned to its owner. Diagnostic software is also useful for isolating and identifying problems associated with peripheral devices, such as serial and parallel ports, display adapters, and disk drives, as well as special-purpose devices.

In this training unit, we have supplied you with the *Troubleshooter* diagnostic software package. It has all the features you need to thoroughly analyze and test computers that are at least minimally operational. It is an excellent tool for checking almost every component in a computer. Troubleshooter will prove invaluable to you when you service computers.

# Computer Troubleshooting

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Troubleshooting is a logical step-by-step procedure used by a technician to solve problems. This applies to auto mechanics, air-conditioning technicians, telephone repairmen, or computer technicians. The procedure used by the technician has been developed over time into a system that works best for that technician. To solve computer problems, you'll need to develop your own systematic troubleshooting procedure. In this manual, we'll give you some ideas or steps to follow; however, the procedure you use will evolve as you gain experience solving computer problems.

All troubleshooting procedures have common elements. For example, a generic troubleshooting procedure is shown below. This generic procedure can be adapted to auto repair, air-conditioning service, or computer servicing.

- Talk to the user
- Confirm the problem
- Diagnose the problem
- Repair the problem
- Verify repairs

**Talk to the user:** In order to establish a starting point in your troubleshooting, you will need to talk to the user. Often, the computer technician will receive a service call from an

office manager or other contact person, rather than the actual user. The information provided to you may not be complete. Talking to the actual user will provide you with a starting point for your troubleshooting. For example, suppose that the service call was for a computer that locks up. When you talk to the user, you will find that the actual complaint is that the mouse does not work in DOS application on a Windows 95 machine.

As you can see, the problem varies greatly depending on who's reporting it. Also, the solution has been changed from a hardware repair to simply loading the mouse driver in the AUTOEXEC.BAT file of the computer.

**Confirm the problem:** Any problem reported by a user must be confirmed by the technician. This step may give you some insight to the cause of the problem. Also, you could spend hours trying to fix a problem with the computer only to find out that the actual problem is operator error or caused by something other than the computer.

**Diagnose the problem:** This is where the troubleshooting becomes very personalized and complaint-specific. The steps you take to locate the source of the problem will depend on the type of complaint. Also, the steps you follow may not be the same as those used by

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another technician. For a computer that will not boot, for example, you may start by measuring the power supply output voltage, while another technician may start with the hard drive.

**Repair the problem:** Fixing computer problems can be anything from replacing the power supply, motherboard, or other hardware to installing and/or reconfiguring software.

**Verify repairs:** Once the previous step is complete, you need to make sure that the problem is, in fact, fixed. Sometimes, you'll

find that the initial repair caused another problem, or hid additional problems. Checking the operation of the computer after the repairs is an essential part of the complete troubleshooting procedure.

Now, let's take a look at the use of Troubleshooter. Then, we will discuss some of the most common computer complaints.

## Using Troubleshooter

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ForeFront's Troubleshooter is a self-booting computer diagnostic software package. Since the software is self-booting, it does not rely on the operating system of the computer to boot. This eliminates conflicts from hardware drivers and tests the components directly for true accuracy.

In this training unit, we'll look at some of the features of Troubleshooter. As you will see, the software is easy to use and understand, and comes with an extensive user's manual.

### Making a Backup Copy of Troubleshooter

As this manual is written, the Troubleshooter software is provided in two ways: on a single 5 1/4" 360K diskette and on a single 3 1/2" 720K diskette. These diskettes are not copy protected, so you will need to back up the original for safety and use the backup copy for all your experiments. You also should use the backups for testing unknown computers. That way, even if some flaw should destroy the data on your working diskettes, you can replace them with fresh backups and continue your tests.

Turn on your computer, if it's not already running. Once your computer completely boots, insert the 3 1/2" Troubleshooter diskette in drive A. Double click on the *My Computer* icon. This will display the devices that are available within, or connected to your computer. Single click the left mouse button on the icon for the A: drive.

With the A: drive icon highlighted, single click the right mouse button. From the menu shown in Figure 1, left click *Copy Disk*. The window shown in Figure 2 will be displayed. As you can see, the information in this window

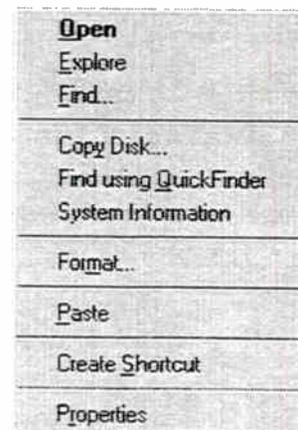
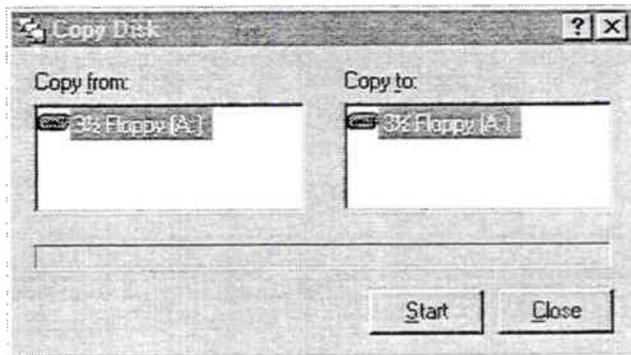


Figure 1. When you right click on the A: drive icon, you will see this menu.



**Figure 2.** The Copy Disk window allows you to select a source drive and a destination drive.

tells you how the copy procedure will be performed. Click **Start**.

The information on the diskette will be read into memory. At some point during the procedure, you will be asked to insert the destination diskette. Remove the Troubleshooter diskette and insert a blank 3 1/2" diskette into your A: drive and click **OK**. This diskette does not need to be formatted; the Copy Disk procedure will format the diskette before any information is written to the disk.

While the diskette is copying, fill out a disk label for your backup copy of the Troubleshooter diskette. When the copying is complete, remove the diskette and affix the label. Place the original diskette in a safe place.

Also, if you have not already done so, now is a good time to register your software. Once the registration is complete, you will have access to technical support from the manufacturer. The software manufacturer will also inform you of any updates to the software package. Generally, software registration places you on the company's mailing list so you'll also receive offers to purchase other products from the manufacturer, often at a discount from the retail price. As you can see, it's a good idea to register any software you purchase.

Once your Troubleshooter software is copied, you are ready to begin troubleshooting computer problems.

## Setting Up Your Computer

Close all Windows 95 applications and shut down your computer in the normal manner. When directed, turn off the power to your computer. Once the computer is off, disconnect any peripheral devices such as the printer, the mouse, and the joystick.

With the Troubleshooter, you received three loop-back plugs. These loop-back plugs are attached to the serial and parallel port of your computer. These plugs provide an input/output path for testing the operation of these ports. In the package, you received a 25-pin male plug which is connected to the parallel port; a 25-pin female plug, which is connected to 25-pin serial connectors (typically used for external modems), and a 9-pin female plug which is connected to 9-pin serial connectors (typically used for the mouse). Remove these plugs from the package and connect them to the correct ports on the back of the computer. **NOTE:** Your computer may not have a 25-pin serial port. Also, many of the computers you'll service in the field will not have all three connectors.

When the loop-back plugs are in place, turn on your computer and insert the Troubleshooter diskette (your backup copy) in the A: drive. (As you probably noticed, Troubleshooter is provided in both 3 1/2" and 5 1/4" formats. This way, you can use the software on computers that have a 5 1/4" floppy as the A: drive.) Once the computer boots, you will be at the **MAIN MENU** of the Troubleshooter software, shown in Figure 3, on the following page.

# SOLVING COMPUTER PROBLEMS

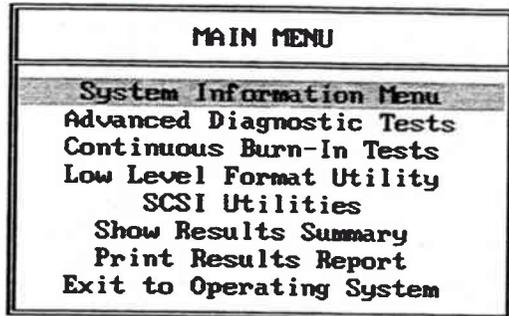


Figure 3. From the Main Menu of Troubleshooter you can get system information, go to the diagnostic menu, or select any of the features of Troubleshooter.

**NOTE:** If the computer you are testing boots to the normal operating system, Windows 95 or MS-DOS, you will need to change the boot sequence of the system bios. Reboot the computer and press the DEL key during the startup sequence. Depending on the brand of bios, the boot sequence is set under the Advanced CMOS Setup option. Set the boot sequence to A:,C:.. After the sequence has been set, save the settings and exit to the operating system. The computer should now boot from the A: drive. If there is no diskette in the A: drive, the computer will look to the C: drive.

As you can see on the bottom of the screen, the up and down arrow keys move the bar through the menu options. The ENTER key selects the highlighted option. With the System Information Menu option highlighted, press ENTER.

The options from the System Information menu will cause the software to examine the computer configuration and produce a report of the results of the examination. This will often give you a starting point for your diagnosis.

With the arrow keys, select the option from the menu and observe the reports displayed on the screen. As you make your selections, you can skip the Device Driver Information

option, since, without MS-DOS being loaded, no drivers are available. We'll show you how to check the driver later. When you have seen the results for all of the options, press ESC until you return to the MAIN MENU.

From the main menu, select *Advanced Diagnostic Tests* and press ENTER. You will receive the menu shown in Figure 4. Some of the options from this menu activate a test directly; others, such as the memory test, bring up another menu where you can select options for the test.

Select all of the options from this menu so that you are familiar with the testing performed. Some of the tests, such as the memory test, will take several minutes to complete. Also, some of the tests, such as the mouse and Multimedia test, will not operate without the drivers loaded. Refer to the Troubleshooter User's Manual before you perform the Non-Destructive Write Test. In some circumstances, this test may result in corruption of data.

During the tests, you may find that some of the tests failed on your computer. For instance, your computer may have failed the Turbo Switch Test under the Input Device Menu, or it may have failed the Handshaking

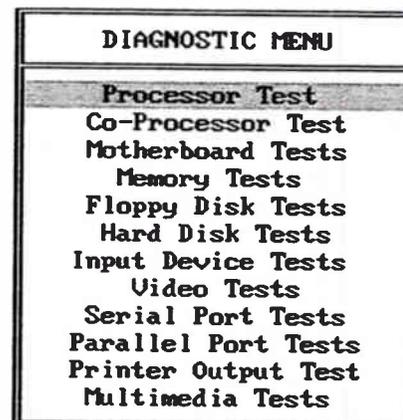


Figure 4. From the Advanced Diagnostic Menu, you can select a type of testing you wish to perform.

Test when testing COM2 under the Serial Port Test Menu. Don't be concerned about the test results at this time. Your computer may not have a turbo switch, or your modem (COM2) may not be connected to the phone line and therefore cannot provide a handshake signal for this test.

When you have tried all of the Advanced Diagnostic Tests, press ESC until you return to the main menu.

Now, move the highlight bar to the Continuous Burn-In Tests option and press ENTER. The Burn-In menu, shown in Figure 5, will be displayed. From this menu, you can select the test that will be performed during burn-in. For the purpose of this experiment, select only the first three tests. When you've selected the tests, press F10 to continue.

The next screen, shown in Figure 6, on the next page, gives you a listing of the tests selected. On this screen, the duration of the burn-in tests are selected. You can select the number of passes (from 1 to 9999) or the length of time (from 00:01 to 99:59) the burn-in tests

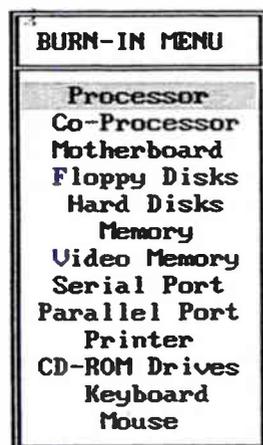


Figure 5. From the Burn-In Menu, you can select the tests you wish to perform during the burn-in process. It is also a good idea to run these tests as part of regular maintenance on the computer.

will run on the computer. However, you cannot enter both the number of passes and the length of time. For this demonstration, enter 5 in the Passes column for each of the tests listed. when you are finished, press F10 to start the burn-in process.

The burn-in process will start with the first test listed and continue through the listed tests in order. When all of the tests are completed, the process will start from the first test again, and continue until all of the tests have run the selected number of passes or for the length of time entered. When the burn-in process is completed, a summary of the results will be displayed on the screen. Look through the summary of the results for your computer, when finished, press ESC until you return to the MAIN MENU.

The Low Level Format Utility is used to correct problems in the sectors of a hard drive. **DO NOT RUN THIS UTILITY NOW.** You should only run the utility when all other tests and repairs to a hard drive have been attempted. This utility will reformat the hard drive. There is no way to recover the data from the drive once it has been low-level formatted.

The remaining options on the MAIN MENU are self-explanatory, or are fully covered in the User's Manual. Select *Exit to Operating System*. Be sure to read through the instructions in the manual, and be sure that you are familiar with all of the testing procedures before you take Troubleshooter to the field.

One of the many advantages of Troubleshooter over other forms of diagnostic software is the fact that it is self-booting and eliminates problems caused by driver conflicts. However, Troubleshooter will also operate under MS-DOS so that you can check the sound card and CD-ROM drives. Just start the computer in the normal fashion. From the Windows 95

# SOLVING COMPUTER PROBLEMS

Troubleshooter Diagnostics Burn-In		
Test Description	Passes	Time HH:MM
> PROCESSOR CO-PROCESSOR MOTHERBOARD	Processor Exercise Math Coprocessor Exercise DMA Controller Tests System Timer Tests Interrupt Test Keyboard Controller Tests PCI Bus Tests CMOS RAM/Clock Tests	10

Press <F10> to Continue with Tests, <F1> for Help

Figure 6. Once the tests have been selected, you'll need to set the number of passes or the length of time each test is run. New computers should have the burn-in tests run for a minimum of 24 hours.

desktop, click START. Click "Shut Down", and select "Restart the computer" in MS-DOS mode. Insert the Troubleshooter diskette in drive A:, type A:TS and press ENTER. Troubleshooter will now be able to test any devices whose drivers are loaded in the AUTOEXEC.BAT file.

**NOTE:** Windows 95 does not automatically load drivers into the AUTOEXEC.BAT file. If you are going to test the mouse, sound card, and CD-ROM drive with Troubleshooter, you will need to add a line to the AUTOEXEC.BAT file so that these drivers are loaded. Refer to the manual that came with the device for the correct procedure to load these drivers.

## CD-ROM Testing

The Troubleshooter software package comes with two CD-ROMs which are used to test

CD-ROM drives. The first is the Troubleshooter CD-ROM Test Disc. This CD is used in conjunction with the Troubleshooter diagnostic software. The other CD is the CD Troubleshooter Pro. This CD works independently of the Troubleshooter software and will operate under the MS-DOS, Windows 3.1, or Windows 95 operating system.

To use the CD-ROM test disc, insert this CD into the CD-ROM drive. From a DOS prompt type "A:TS" and press the ENTER key. From the MAIN MENU, select Advanced Diagnostic Tests. From the DIAGNOSTIC MENU, select Multimedia Tests. Here, you can test the PC speaker, sound card, and CD-ROM drive. These tests will only work provided that the drivers for the CD-ROM and sound card have been loaded.

The CD Troubleshooter Pro operates independently of the Troubleshooter software. The CD Troubleshooter Pro was designed to give

an impression of the speed of CD-ROM drives in a simple way. It also contains advanced diagnostic procedures as well as detailed information about the hardware and software used.

The CD Troubleshooter Pro can run under either Windows (3.1 or 95) or MS-DOS. To run the DOS version, log onto the CD-ROM drive (usually d:), and type CDTS from the D:\CDTS\DOS directory. To run the Windows 95 version of the software, click *Start*. From the *Start* menu, click *Run* and enter "D:\CDTS\WINDOWS\CDTSWIN.EXE" and click *OK*. Both versions have extensive on-line help files to help you use the CD Troubleshooter Pro. For the purpose of this discussion, we will be using the Windows 95 version of the software.

The CD Troubleshooter Pro starts with a typical Windows style interface, as shown in Figure 7. Each item on the taskbar activates a pull-down menu. As we did with the Troubleshooter software, we'll only discuss a few of the most common features of the CD Troubleshooter Pro. You can experiment with the various features of the software, and refer to the on-line help for features not covered here.

**File:** From this menu, you can close the current window, save the contents of a window, set up your printer, print the contents of the current window, and exit CD Troubleshooter. If any of the actions cannot be performed, the menu item will appear gray.

**Benchmark:** Like hard drives, CD-ROM drives are quite different with respect to the amount of time needed to access specific data in the space a compact disc offers. Usually, CD-ROM drives are classified in a similar way as hard drives. The speed for finding data on the disc and the time required to transfer that data to the main memory are measured.

The CD-ROM benchmark of CD Troubleshooter measures the performance of your CD-ROM subsystem and gives you individual results for each parameter as well as an overall performance index called ROMarks. Most manufacturers use different technologies to measure the performance of their CD-ROM drives, and this information is not usually easy to use. One major benefit of CD Troubleshooter is that it provides information that can be compared. To ease this comparison between different drives, in addition to measured results, the program combines the individual

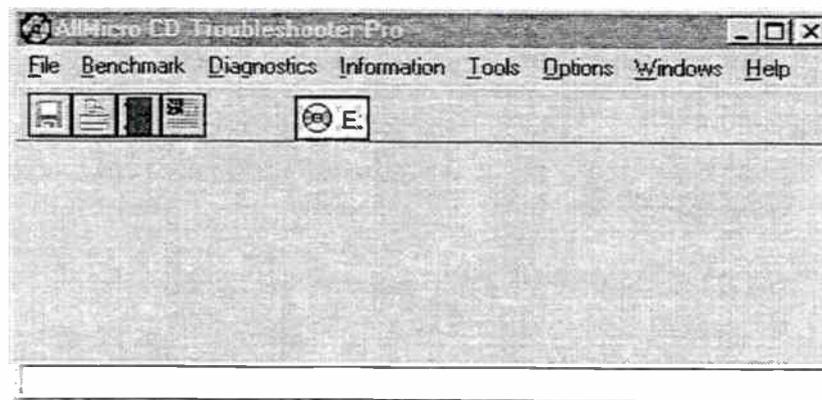


Figure 7. The CD Troubleshooter Pro has its features listed on the taskbar. Each listing on the taskbar activates a pull-down menu.

# SOLVING COMPUTER PROBLEMS

results into a single number which identifies the speed of the drive. CD Troubleshooter is distributed on a special CD called a Reference CD. This CD contains special data used by the program to ensure accurate and reliable performance measurements. Although you could use other CD-ROMs with CD Troubleshooter, the manufacturing process is different and could produce results that are not accurate.

The Benchmark feature of the CD Troubleshooter tests the data transfer rate and data access time of the CD-ROM drive. Troubleshooter then compares the test results against the data on the reference CD. The results of this comparison are then displayed on the screen, as shown in Figure 8. To start the Benchmark feature, click on *Benchmark* and select *CD-ROM Benchmark* from the pull down menu or press F6. This test takes some time to complete, so be patient.

**Diagnostics:** The diagnostic functions of CD Troubleshooter Pro will detect errors in CD-ROM drives and media errors on the CD. The diagnostic functions include:

- **Sequential Read:** The entire CD is read from beginning to end. This is the fastest way to test a CD-ROM for defects.
- **Random Read:** The entire CD is read in small blocks using random positions. Since the drive has to seek blocks at different positions on the disk, the mechanical parts of the drive are being tested. The time required to run this test depends mainly on the average access time of the drive.
- **Reverse Read:** The entire CD is read from end to beginning. Since CD-ROM technology was not designed to work this way, the mechanical parts of the drive are stressed. As with the random read test, the time required to run this test depends mainly on the average access time of the drive.

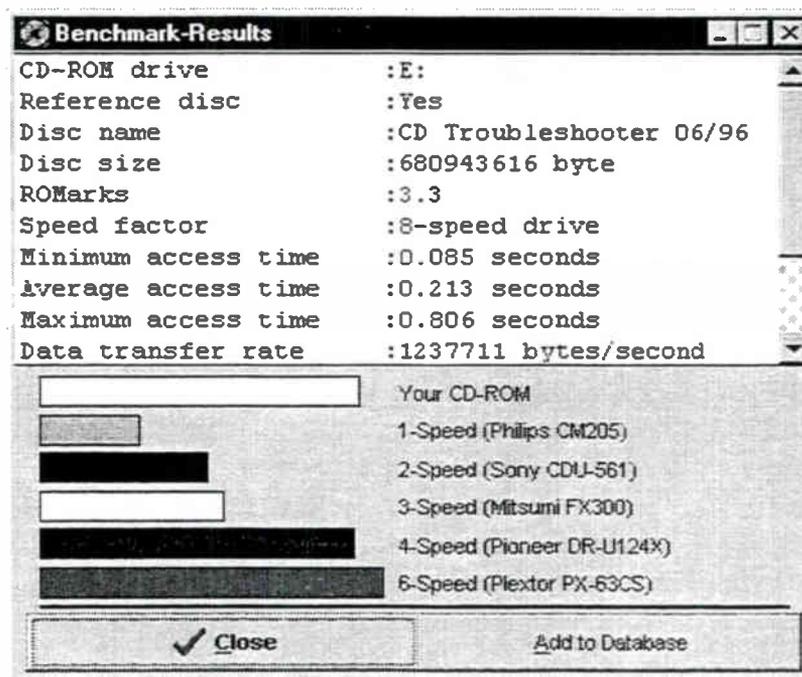


Figure 8. When the Benchmark is complete, you will receive a report on the performance of the CD-ROM drive.

- **Butterfly Read:** The entire disk is read in small blocks alternating from the beginning and from the end. This test may last a long time because the drive is always repositioning itself. The mechanical parts of the drive are thoroughly tested.

Since a typical CD-ROM contains a large amount of data, these tests take a long time to complete. During the tests, you will receive a display, as shown in Figure 9, showing the status of the test.

Each diagnostic function produces a detailed analysis of all data contained on a CD-ROM. Any error reported shows a problem

with either the drive or the CD. Since the tests are designed to read the entire CD, you can repeat the tests with a different CD. If the error does recur with another CD, try cleaning the lens of the drive with a standard CD cleaner. If this does not solve the problem, your CD-ROM drive is probably defective and should be replaced.

The CD-Troubleshooter has many operational options. Read the help files to learn how to customize the operation to fit your needs.

Now, let's move on to solving some of the most common computer problems.

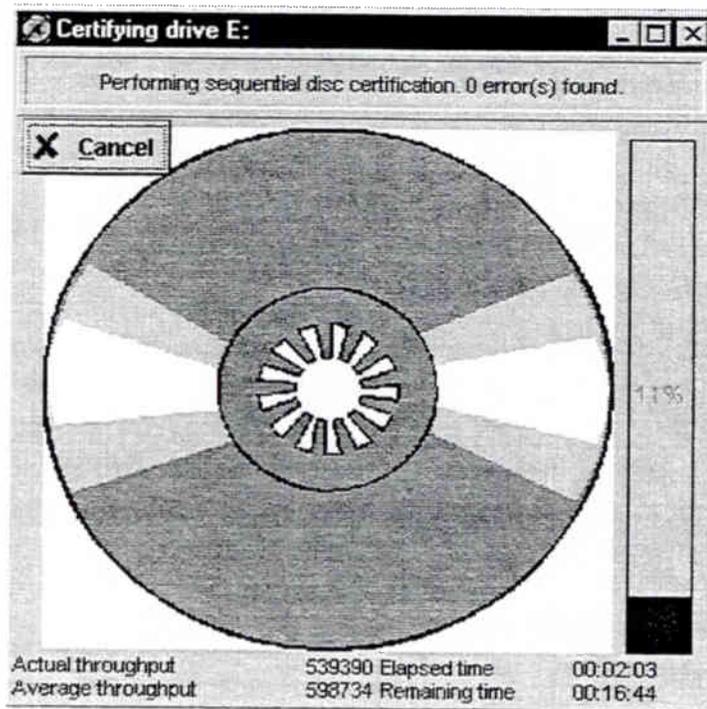


Figure 9. During the diagnostic tests on the CD-ROM drive, you will receive a status screen to show you how much of the test is completed.

# Computer Troubleshooting

---

In this section, we'll discuss some of the most common computer problems. We'll discuss the steps used to find the cause of these problems and the necessary repairs. This section is by no means a complete computer troubleshooting manual, because it does not cover all possible computer problems, or all of the possible causes of any problem — only the most common. As you gain experience in computer repair, you will develop your own troubleshooting procedures that will allow you to solve computer problems efficiently.

One thing to remember: With today's computers, you will not troubleshoot to the component level — you will only troubleshoot to the board level. Once the problem has been isolated to a particular board, that board will be replaced. This also applies to the motherboard, with the exception of the processor and the memory (both system RAM and cache).

## Computer Won't Start

As with any problem, always check the simple solution first. For a computer that won't turn on, always check the power to the computer before you begin troubleshooting the computer. Often, computers are plugged into

power strips which have been known to fail. Check the power strip with a multimeter to be sure that the correct voltage is available at the outlets of the power strip. If the correct voltage is present, check the power cord to the computer. If not, the problem is either the power strip or the AC receptacle that the power strip is plugged into. In either case, this is not a problem for a computer technician.

Once you have determined that power reaches the computer, you are left with three possible faults — power supply, power switch, or motherboard. To locate the problem, you will need to remove the case of the computer. (**Note:** Some newer computers such as the Monorail and the Compaq Presario are not serviceable. They must be returned to the manufacturer for service. Do not attempt to remove the cover from these computers.)

Once the cover has been removed, turn the computer on and observe the operation of the cooling fan on the power supply. Power for this fan is provided from the power supply. If the fan is operational, it indicates that at least part of the power supply is working.

Now, measure the voltage output of the power supply at the motherboard. The power supply connects to the motherboard by way

of two connectors as shown in Figure 10. Measure the voltage at all of the connectors from the power supply and compare your readings with those shown in Figure 10. If the voltages are correct, replace the motherboard. If you have no voltage on any of the wires, replace the power supply. If you measured voltages but the voltages are not correct, turn off the switch and disconnect the two connectors. Turn on the computer and repeat the voltage measurements. Again, if the voltages are correct, replace the motherboard. If the voltages are still not correct, reconnect the power supply to the motherboard. Be sure that the connectors are positioned correctly.

Now, disconnect the power supply connectors to all floppy drives, hard drives, and CD-ROM drives. Repeat the voltage measurements. If the voltages are still not correct, replace the power supply. If the voltages are correct, one of the drives is loading down the power supply. Reconnect the power supply to the drives, one at a time, and repeat the voltage measurement. When you have located the drive that is loading the power supply, replace that drive.

Do not disconnect all of the power supply connectors from the drives and the motherboard. The power supply needs a load connected to the output in order to operate properly. Without this load, either from the drives or the motherboard, your voltage readings will not be correct.

## Computer Will Not Boot

The computer starts, displays the startup sequence on the screen, and then either stops or gives an error message. This problem is typical of a hard drive crash, but could be caused by other problems as well. Before removing the case of the computer, try to isolate the problem first. To do this, reset the computer and insert a bootable diskette (such as your Troubleshooter diskette) into the A: drive. The computer should try to read the A: drive (the light on the drive should turn on). If the computer boots from the A: drive, the problem is in the hard drive. Run Troubleshooter to determine the problem with the hard drive.

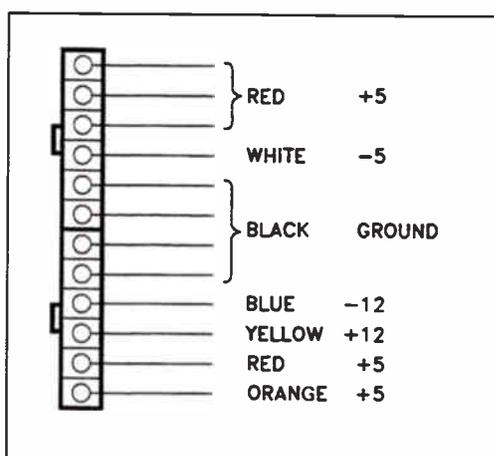


Figure 10. The power supply is connected to the motherboard via two connectors. The orientation of the connectors can be different on different motherboards. However, the black or ground wires from the connectors will always be next to each other.

If the computer still does not boot, and the light on the A: drive does not light, reboot the computer and press the Delete key during the boot process. This will give you access to the BIOS setting of the computer. Select the STANDARD CMOS SETUP from the menu. This will display the types of drives that are set for A, B, and C. Make sure that the A: and B: drives are set correctly and make a note of the parameters that are set for the C: drive. When you are ready, press Esc to return to the main menu.

Next, select BIOS FEATURE SETUP from the main menu. The only item on this screen that you should be concerned with at this time is the BOOT SEQUENCE. Make sure that the boot sequence is set to A:,C:.. Setting the sequence establishes the order that the computer will look for boot information. With the sequence set A,C, the computer will first look at the A: drive. If no system disk is present, the computer then looks at the C: drive. When the boot sequence is set, press Esc to return to the main menu.

From the main menu, select SAVE AND EXIT and answer Yes to any questions displayed. When the computer starts its boot process, insert your Troubleshooter diskette into the A: drive. If the computer boots, run Troubleshooter to determine the problem with your hard drive. If the computer does not boot, remove any diskettes from the drives, and turn off the computer.

With the computer turned off, remove the case and check the connection to the drives. Be sure to check both the data cable and the power connections to the hard and floppy drives. Also, check the connection of the data cables to the controller card. (If you have a Pentium computer, the IDE and floppy controller are

built into the motherboard.) Be sure that the cables are fully seated. If you find any loose connection, try to start up the computer after the connection has been secured. If the computer still does not boot from either drive, you are faced with the prospect of replacing the controller card or motherboard. Since the controller is the easiest to replace, try it first.

If the computer boots from one drive but not from the other, the problem could be caused by the drive or the cable, with the controller card or the motherboard being much less likely since only one drive is affected.

## Computer Runs Slow

This problem is becoming more common with the use of Windows 95 and is often not caused by the computer itself. Windows 95 and applications written specifically for Windows 95 require more system RAM than applications written for Windows 3.1. Although the minimum system requirement of the software is 8 Meg of RAM, the application runs extremely slow with only 8 Meg of RAM. Increasing the system memory to 16 Meg will usually correct the problem.

Another factor in overall computer speed is the hard drive. As hard drives reach their capacity, the access time of the drive slows. The system must search through more information to locate the data requested. Also, the data on a hard drive can become fragmented — this also slows the access time of the drive. The use of disk compression software such as Defrag or Norton's Speedisk will compress the information on the disk and increase the access time.

---

The actual operating speed of the computer can be checked with Troubleshooter, and is displayed in the System Information section of Troubleshooter. If there is any question about the actual operational speed, run the Advanced Diagnostic test on the processor, coprocessor (if applicable), and the motherboard using Troubleshooter. Any problem reported by this test could affect the operational speed of the computer.

In addition to the tests listed above, some of the common complaints from computer users are:

- Can't read disk (floppy, hard, or CD)
- No sound from sound card
- Computer locks up
- Memory errors

All of these problems can be pinpointed using Troubleshooter. This diagnostic software will test the drives and interfaces, sound card and driver, and the memory (both RAM and cache). If the computer locks up, it is usually caused by a conflict between the IRQ or DMA channels of devices such as the sound card and bus mouse. Troubleshooter will also provide information on the IRQ, DMA, and addresses used by various parts of the computer. This information is displayed in both the Interrupt Vector Information and the IRQ Information screens under the System Information menu. Any conflict can be resolved by resetting the device either by software provided with the device, or by jumpers or switches on the device.

# Examination Questions

This is Examination Number 6133.

Make sure you print your name, student number, and examination number in the space provided on the Answer Form. Be sure to fill in the circles beneath your student number and examination number.

**Reminder:** A properly completed Answer Form allows us to evaluate your answer and speed the results and additional study material to you as soon as possible. Do not hold your Answer Forms to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

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1. Why is it desirable to boot the computer being tested from the Troubleshooter diskette?
  - a. Because the computer being tested may not be able to boot.
  - b. To eliminate hardware and software conflicts.
  - c. This is the only way to correctly start Troubleshooter.
  - d. Because Troubleshooter will not operate under an MS-DOS operating system.

2. Why would Troubleshooter be started from an MS-DOS prompt when it uses its own operating system?
  - a. To test the operation of the hard drive.
  - b. To test the operation of the sound card.
  - c. To test the operation of printers.
  - d. You should never start Troubleshooter from MS-DOS.

- 
3. In order to test the operation of the serial port, you must:
    - a. Run Troubleshooter from MS-DOS.
    - b. Run Troubleshooter for the operating system on the diskette.
    - c. Have a printer or mouse connected.
    - d. Connect a loop-back plug to the serial port.
  4. After you have talked to the user, what is the next step in a troubleshooting procedure?
    - a. Diagnose the problem.
    - b. Remove the cover of the computer.
    - c. Verify the problem.
    - d. Run Troubleshooter.
  5. When checking the voltage from the power supply to the motherboard, all of the following voltages should be present except:
    - a. +10 volts.
    - b. +5 volts.
    - c. -12 volts.
    - d. +12 volts.
  6. All of the following could cause slow computer operation except:
    - a. Insufficient RAM.
    - b. IRQ conflicts.
    - c. Fragmented data on the hard drive.
    - d. A full hard drive.
  7. IRQ conflicts will most likely cause:
    - a. The computer to run slowly.
    - b. Lines on the display.
    - c. Printer errors.
    - d. The computer to lock up.
  8. During the burn-in testing, you can set the number of passes for each test anywhere from:
    - a. 1 to 99.
    - b. 1 to 999.
    - c. 1 to 9999.
    - d. 1 to 1000.
  9. If the computer boots from the floppy drive but not from the hard drive, which of the following is the most likely cause?
    - a. The hard drive.
    - b. The motherboard.
    - c. The controller card.
    - d. The power supply.
  10. On a Pentium computer, the IDE and floppy drive controllers are:
    - a. On a separate card attached to the PCI bus.
    - b. On a separate card attached to the local bus.
    - c. Part of the motherboard.
    - d. Part of the drive.
-

# NOTES

*Please use this page to record any notes  
you may want to review during your studies.*

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## **NRI** Graduates Say. . .

"The NRI training I received *greatly* broadened my horizons. My father once showed me a magazine advertisement for your course and I just up and enrolled. Now I see all the good it has done for me!

Thanks to everyone at NRI for your continued support for the 'little guy'."

Vincent R. Salvaterra  
Freelend, Pennsylvania





# Manual for AC Electronics

# 6750



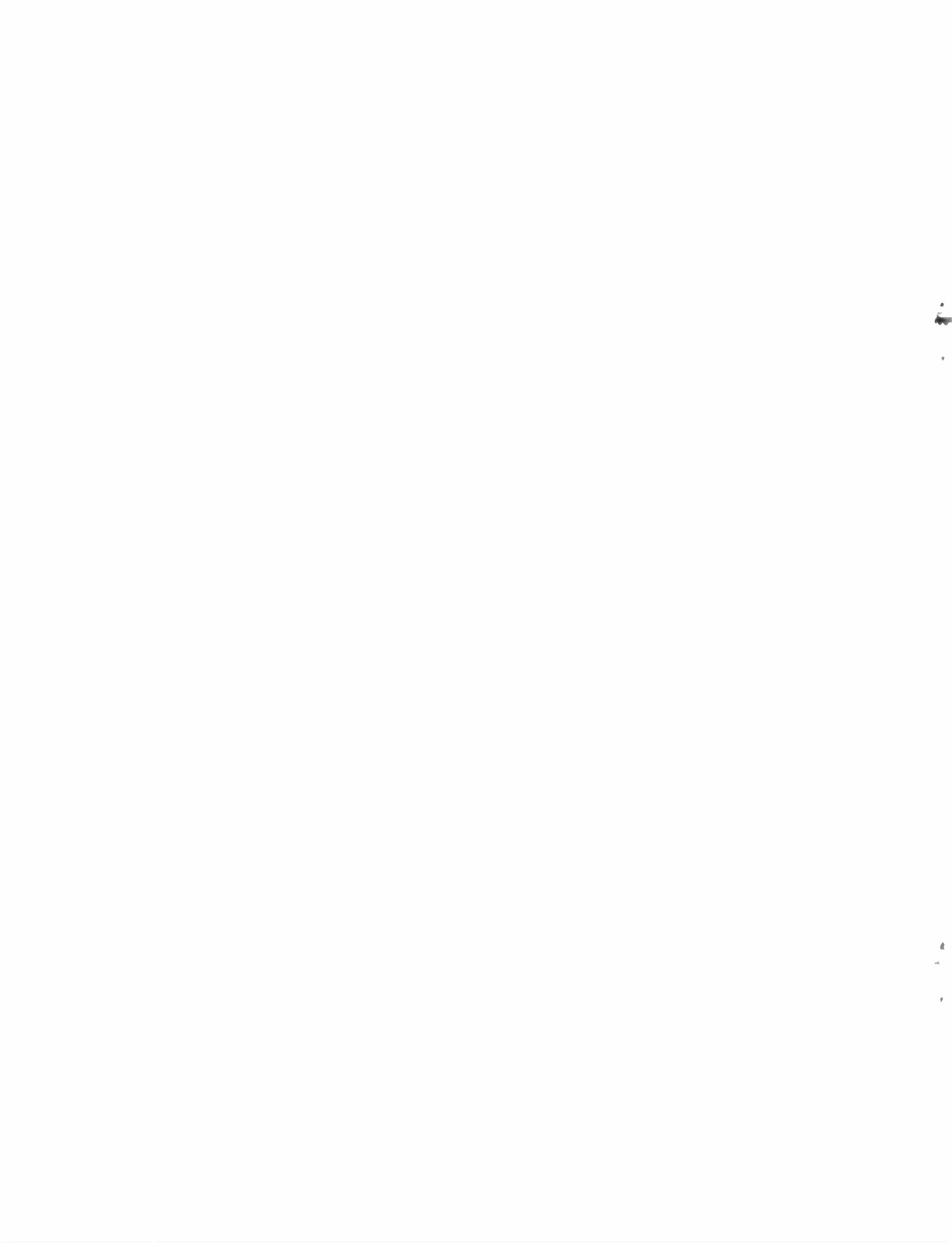
**Student's Guide  
for Computer-Aided  
Troubleshooting**

*NRI Schools*

*A Division of The McGraw-Hill Companies*



*Washington, DC 20008*



# **Manual for AC Electronics**

## **Computer-Aided Troubleshooting**



# Table of Contents

<b>Introduction</b> . . . . .	<b>1</b>
<b>What You Need to Know</b> . . . . .	<b>2</b>
How to Use this Manual . . . . .	2
What You Get . . . . .	3
What You Must Have . . . . .	3
<b>Installing the Program</b> . . . . .	<b>4</b>
Installing on a Network . . . . .	6
Installing with SHARE.EXE . . . . .	6
Removing the Program . . . . .	6
<b>Operating the Program</b> . . . . .	<b>7</b>
Mouse and Keyboard . . . . .	7
Scroll Bar . . . . .	7
Buttons . . . . .	9
<b>Using the Program</b> . . . . .	<b>10</b>
Student Workdisks . . . . .	10
Starting the Program . . . . .	10
Running the Program . . . . .	11
Menus And Screens . . . . .	13
Using the Tools . . . . .	18
Leaving the Program . . . . .	22
<b>Evaluating Yourself</b> . . . . .	<b>23</b>
Using the Tb Files . . . . .	23
Factors to Consider . . . . .	24
Additional Ways to Use the Program . . . . .	27
<b>The Problems</b> . . . . .	<b>28</b>
Objectives of the Program . . . . .	28
RC Circuit . . . . .	29
RL Circuit . . . . .	29
RLC Circuit . . . . .	30
Transformer Circuit . . . . .	30
<b>Answer Sheet</b> . . . . .	<b>31</b>

## **Acknowledgements**

We wish to express our thanks to the staff of **Heathkit Educational Systems**. Their contribution to this team effort, in providing our students with quality educational materials, has been significant.

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# Introduction

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Welcome to Computer-Aided Troubleshooting (CAT) from NRI Schools. NRI's AC Electronics Computer-Aided Troubleshooting Package is an interactive software program. With this troubleshooting software, you, the student, actually interact with "life-like" equipment malfunctions. Full-color animations bring a sense of realism to problem-solving interactions. You are placed in a challenging electronics troubleshooting environment where you are not restricted simply to reading from a textbook. The program draws you into actual troubleshooting situations where you participate in complete safety and privacy. It provides you with both rewarding responses and constructive reinforcement. It is beneficial in that it provides an alternate, game-like method of teaching electronic troubleshooting.

The program offers you the opportunity to learn troubleshooting through fast-paced, hands-on simulations in a totally nonthreatening environment. By performing these experiments on the computer, you experience the real and practical side of electronics first-hand without worry of damaging equipment or yourself.

# What You Need to Know

---

## How to Use this Manual

This Student's Guide contains the documentation for the NRI AC Electronics Computer-Aided Troubleshooting program. This manual is written for the electronics student and the licensed site installer. It is assumed that the student or the installer has some limited computer knowledge of hardware and software, MS-DOS in particular.

This manual is divided into sections. The first, which you are reading, introduces the program and the manual itself. It contains a list of what is included in this product and the system requirements needed to successfully run the program.

The next three sections cover installing, operating, and using the program. Here, you'll find a simple installation procedure. It covers how to use the mouse, keyboard, and other features. These sections also tell you what you'll see in the program: menus, screens, windows, and tools.

The remainder of the manual contains further information and a detailed list of the troubleshooting examples, plus an answer for each problem. Because the answer to each of the troubleshooting problems is included in this manual, it is merely regarded as an adjunct, not as an examination, within your course. Thus, it will serve to enhance your troubleshooting knowledge and abilities.

---

## What You Get

The NRI AC Electronics Computer-Aided Troubleshooting (CAT) program consists of:

- one or more 3.5" program disks
- one Student's Guide

## What You Must Have

In order to run the CAT program, the computer must be equipped with this hardware:

- 8088, 80286, 80386, 80486 or better processor (PC compatible)
- 640 KB or more of RAM
- Hard disk drive with 2 MB or more of free disk space
- EGA or VGA color monitor and driver
- One or more 3.5" floppy drives
- Mouse

And this software:

- MS-DOS 3.1 or higher

**NOTE:** Most of the functions of this program can be accomplished using only the keyboard. However, a mouse is required for a few operations and is highly recommended for efficient use of the program.

# Installing the Program

---

Through a joint effort by **NRI** and **Heathkit Educational Systems**, this interactive electronic troubleshooting program has been made available. You will note appropriate credits as you start the program each time. If, by chance, some fault occurs in the installation or operation of this software program, please contact NRI to obtain instructions concerning software correction or replacement procedures.

**NOTE:** The following installation instructions assume that the floppy drive designator on your computer is "A:." If your floppy drive is designated with a letter other than "A:," substitute that letter in the instructions.

To install the CAT program, do the following:

1. Insert Disk 1 into floppy disk drive A.

2. Type: **A:**

Then press: **RETURN** (or **ENTER**)

(This logs you onto drive A.)

Type: **INSTALL**

Then press: **RETURN** (or **ENTER**)

This will start the installation program.

3. Before installation actually begins, the program first checks to make sure your computer's operating environment is compatible with the hardware/software requirements necessary to operate the CAT program (see "What You Must Have" for the hardware/software requirements). If your computer's environment is incompatible in any way, the program will NOT install. In this case, a simple explanation as to the incompatibility will appear, and you will be returned to the DOS prompt.

---

A typical example is when the installation program does not find a hard drive with enough space for the program. In this case, you need to free up space on the hard drive before you run the installation program again. If the installation program verifies that your system is compatible, it will continue with the installation.

4. Next, the program will ask you for the hard drive designator where you wish to install the program. The program will list possible choices based on your system. Simply press the letter for the drive where you want the program installed. **Caution:** Do not simply press the **RETURN** (or **ENTER**) key. You must press the letter of the desired drive.

You will then be given the opportunity to modify the installation path or accept the default path. The default directory is `CAT_AC`. Unless you specify otherwise the program will be installed in this directory. If you prefer that it be installed in another directory, use the back-space key to remove the `CAT_AC` path and enter the new path name.

5. The installation program will begin copying files from Disk 1 onto your hard drive. If there is more than one disk for the installation of the program, the installation process will ask you to insert the next disk after it finishes copying the necessary files from Disk 1. If you insert an incorrect disk, the installation process will notify you of this situation.
6. Continue this process until all disks have been inserted and copied. Some disks contain many files, and may take a few minutes to install onto your hard drive. When all the CAT disks have been installed, the installation program will automatically exit and return to the DOS prompt.

All of the program files will be contained in a subdirectory on your hard drive called "`CAT_AC`", or whatever path you specified during installation. To access that subdirectory, type in `CD\CAT_AC` and press **RETURN** (or **ENTER**). To run the program, refer to the "Operating the Program" section of this manual.

*Parward  
NR1*

## **Installing on a Network**

The program may be installed on some types of networks. Follow the preceding installation procedure to install the program on the server. Make sure each user is granted read, write, and file access to the directory the program was installed into.

For more information, refer to your network manuals and your distributor.

## **Installing with SHARE.EXE**

SHARE.EXE provides file sharing and locking to the MS-DOS operating system. If it is running on your computer while you are installing NRI Computer-Aided Instruction (CAI) software, it may cause the INSTALL program to not recognize that the correct disk has been inserted in the floppy drive. If you encounter this problem, check your AUTOEXEC.bat file and make sure SHARE is not being loaded. Once the CAI software has been installed, you can re-enable loading of SHARE.EXE if other software requires it to operate properly. The NRI CAI software should have no problem running with or without SHARE loaded. Only during installation might you encounter this problem.

## **Removing the Program**

The CAT program can be removed from the hard drive at any time. Simply delete the "CAT\_AC" subdirectory (or whatever path you specified during installation) and its files from DOS.

---

# Operating the Program

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## Mouse and Keyboard

The CAT program can be operated by both a mouse and a keyboard. Both input devices control the position of an arrow cursor (  ) over program selections. While a mouse is not absolutely required to run the program, we strongly recommend using one for the ease it provides in moving through the program. Also, there are a few operations that can be performed only with the mouse. For computers not equipped with a mouse, the arrow keys on the keyboard (  $\leftarrow$   $\uparrow$   $\rightarrow$   $\downarrow$  ) move the arrow cursor. These arrow keys, as well as the rest of the keyboard, can be used in addition to a mouse.

## Scroll Bar

There are times when the text information appearing in a window is much larger than the window itself. In these instances, all of the information can be reviewed by scrolling. This is accomplished with the help of the scroll bar located at the edge (usually the left side for this program) of the window. See figure 1 on the next page.

The scroll bar consists of an up direction button (located at the very top), a down direction button (located at the very bottom), and a slider button (located along the vertical path between the up and down direction buttons). The up and down direction buttons move the view of the text in small increments, while the slider button allows for large rapid movements of the text body. In order to use these buttons, the user must position the cursor over the button using the mouse or by using the cursor direction

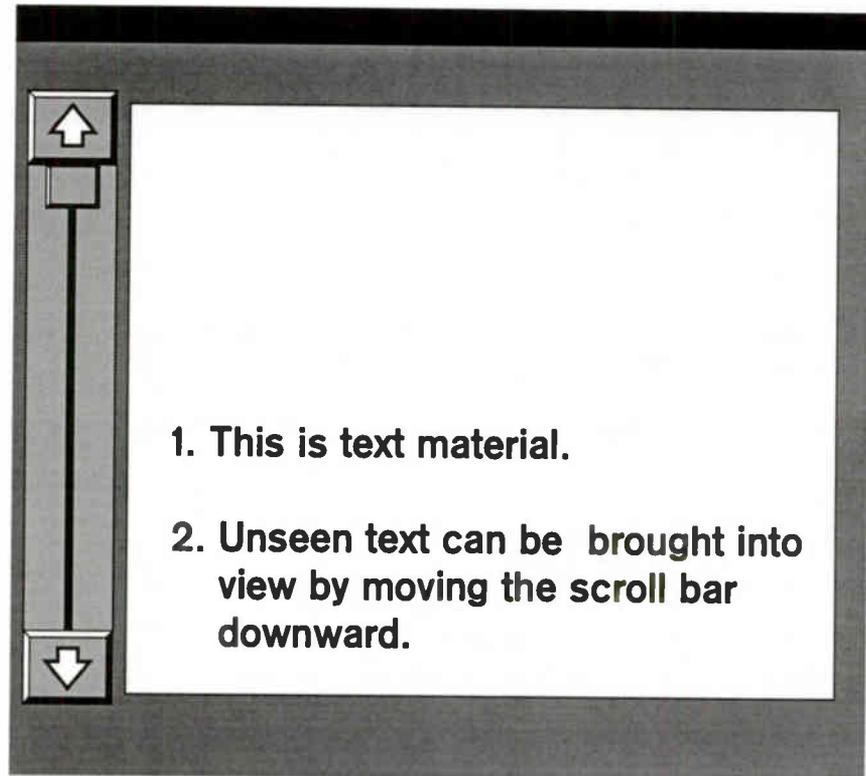


Figure 1. Window with Scroll Bar

keys ( $\uparrow \downarrow$ ), page up (PgUp), and page down (Pgdn) keys of the keyboard.

The student has three options for moving text:

1. To scroll text line by line, position the arrow cursor at either the up direction button or the down direction button, and click the mouse button (or press **RETURN**) once. Keeping the mouse button (or **RETURN**) depressed continues the scrolling action.
2. **FOR MOUSE USERS.** Position the arrow cursor directly on the up/down direction button, then press and hold the mouse button. Vertical mouse movement positions the up/down button to any desired location on the scroll bar. The text follows the movement of the up/down direction button.
3. **FOR KEYBOARD USERS.** The **PgUp**, and **PgDn** keys may be used. **PgUp** and **PgDn** move the up/down direction button in large steps along the scroll bar.

---

## Buttons

A student can also move around in the program by using the mouse to press “buttons” (Figure 2) that appear on the screen. Buttons are activated by moving the cursor over the button and either clicking the mouse button or pressing **RETURN**. Using buttons is a procedure that students will pick up very quickly. When a button is selected in a screen, it depresses like a normal switch.

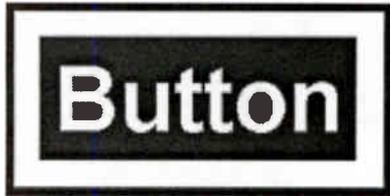


Figure 2. Window Button

# Using the Program

---

## Student Workdisks

To access and operate the installed program, you must provide and use a student workdisk. This disk is your “workbook” for the course. It records every move that you make as you progress through each troubleshooting experience.

Your workdisk must be inserted into a floppy drive to gain access to the program. The first time this is done, the program will ask for your name and record that information on the disk. That disk then becomes unique for you and for that course. Anyone else who tries to access the program must have his or her own workdisk. If a student plans to continue through NRI’s CAT series, another disk will be needed for each course. Any blank, formatted floppy disk may be used as a workdisk.

It is important that you take good care of your workdisks, as the information on each disk is unique. Damaging or losing a disk will result in lost data.

## Starting the Program

To start the AC Troubleshooting program:

- Type: **CD\CAT\_AC** (or path specified in installation)
- Then press: **RETURN** (or **ENTER**)

This logs you into the program subdirectory.

- Type: **AC EXPLORE**
- Then press: **RETURN** (or **ENTER**)

---

**NOTE:** This program is incompatible with some disk caching utility software. If you are having problems starting or running the program, make sure you are not running a utility such as *smartdrv.sys*. Also, because the program is graphics intensive, it requires about 500K bytes of free memory. You can free up memory by removing TSR programs such as screen savers, network drivers, etc.

## Running the Program

### Opening Screens

The program begins with an introductory graphics screen followed by an acknowledgment screen that includes copyright information. These two screen displays continue to alternate until the student clicks a mouse button or presses the **RETURN** key on the keyboard.

### Check/Verify Workdisk

Following the opening graphics screen, the program will verify the presence of a student workdisk. The program must see a good workdisk before it will move on. The following outline details the procedure for verifying workdisks.

- I. **Insert Workdisk.** You will first see a window telling you to insert a workdisk (even if you have one already inserted). There are two buttons to choose from at this point.
  1. **Continue.** Press this button if you have a workdisk inserted in one floppy drive for your system. This will move you to “Verify Workdisk,” which is item II in this outline.
  2. **Exit to DOS.** If you select this button, another window will appear asking to verify your exit. At this point, you have two choices:
    - a. **Resume the Program.** If you select this, the program will move back to “Insert Workdisk,” which is item I above.
    - b. **Confirm Exit to DOS.** If you select this, the program will initiate an exit procedure, which includes creating and using a password. The “Leaving the Program” portion of the User’s Guide explains this part of the program.

- II. Verify Workdisk.** The program will search the floppy drives installed on your system for a proper Student Workdisk. If you have two floppy drives, the program will search the “A” drive first. If it does not find a Workdisk in the “A” drive it will then search the “B” drive. There are three possible results during this operation:
1. **New Correct Workdisk Present.** If the program finds a good workdisk which has never been used before, the program will prompt the student to enter the first name, then the last name. Simply type in each name, and press **RETURN**. After the last name has been entered, that workdisk will be configured to work for that name, and for this course only. The program will then move to “Help Request,” which is Item III in this outline.
  2. **Used Correct Workdisk Present.** If the program finds a good workdisk which has been used before, the program will immediately move to “Help Request,” which is Item III in this outline.
  3. **Incorrect Workdisk or No Workdisk Present.** If the program fails to find a proper workdisk, a “Disk Read Error” message will appear on the screen. You have two choices at this point:
    - a. **Exit to DOS.** You may select this option to return to a DOS prompt via the password screen as explained later in “Leaving the Program.”
    - b. **Continue.** If you select this option, you will return to “Insert Workdisk,” which is Item I in this outline.
- III. Help Request.** Once a proper workdisk has been installed and verified by the program, a window will appear offering the chance to review the information in the “Help” portion of the program prior to beginning. This option is offered regardless of whether the student has previously used the program or not. There are two options at this point:
1. **Access Help Window.** By pressing this button, you enter the “Help” portion of the program. See the “Help Window” portion of this User’s Guide for more information on the “Help” section.
  2. **Begin the Program.** By pressing this button you move to the Main Option Menu of the program, which is the first menu.

## Menus And Screens

This troubleshooting program uses a series of menus that allows the student to move around smoothly and efficiently. Figure 3 shows the general path that the student follows through the program. The arrows point to the direction of the path, and the boxes contain other screen options and options for exiting the current screen.

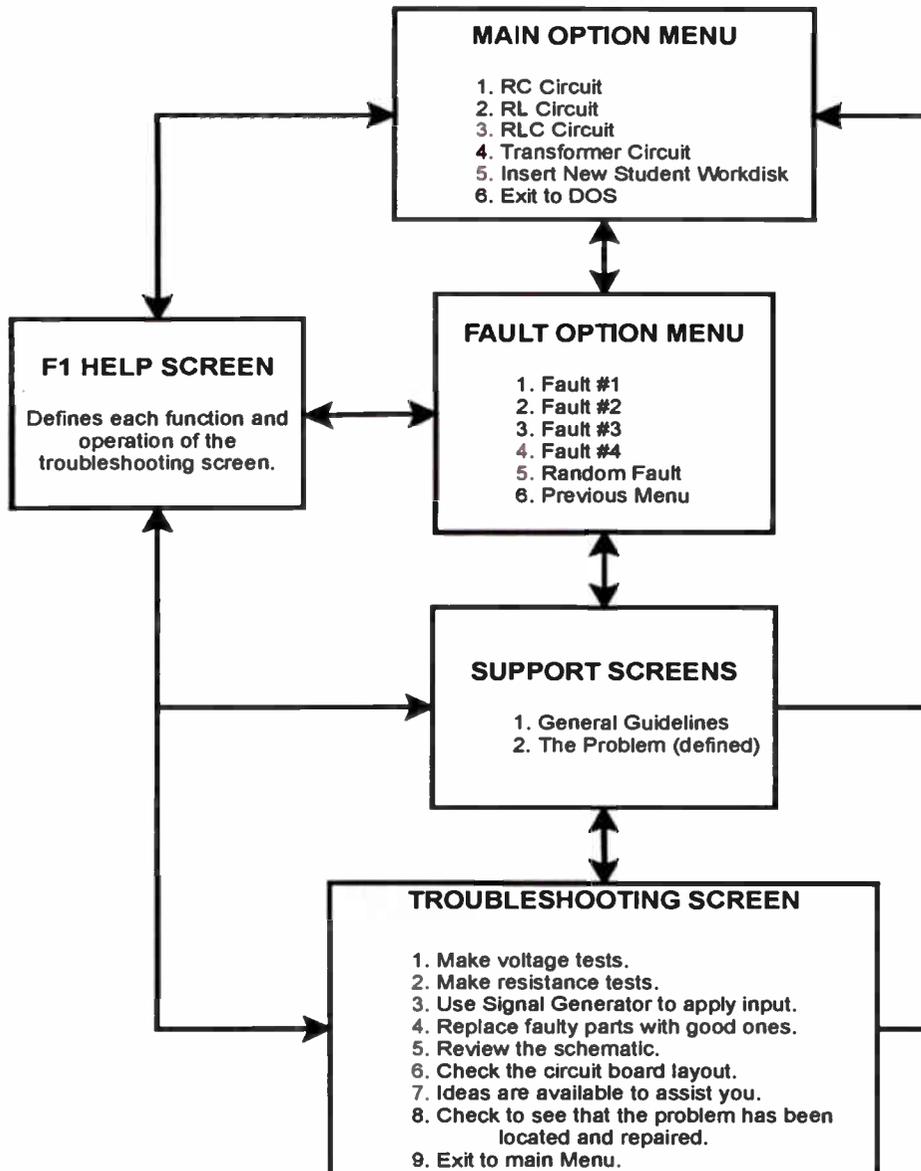


Figure 3. Program Flowchart

There are five main sections of the program. Each is explained in more detail in the following paragraphs:

Main Option Menu

Fault Option Menu

Support Screens

Troubleshooting Screen

Help Screen

## Main Option Menu

The Main Option Menu lists the four basic troubleshooting problems, as shown in figure 4. These are: RC Circuit, RL Circuit, RLC Circuit, and Transformer Circuit problems. The student selects one of these and proceeds to the Fault Option Menu. The Main Option Menu also offers the opportunity to change to a new student workdisk. This is done when changing students or when the present workdisk is full.

## Fault Option Menu

The student selects one of the faults or returns to the previous menu. The Random Fault is one of the four faults randomly picked by the program, as shown in figure 5.

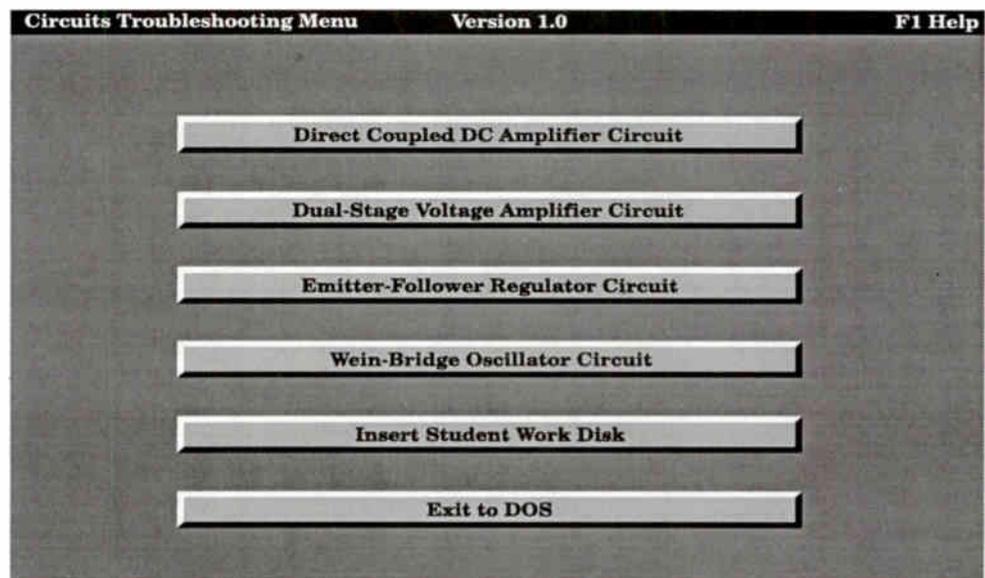


Figure 4. Main Option Menu

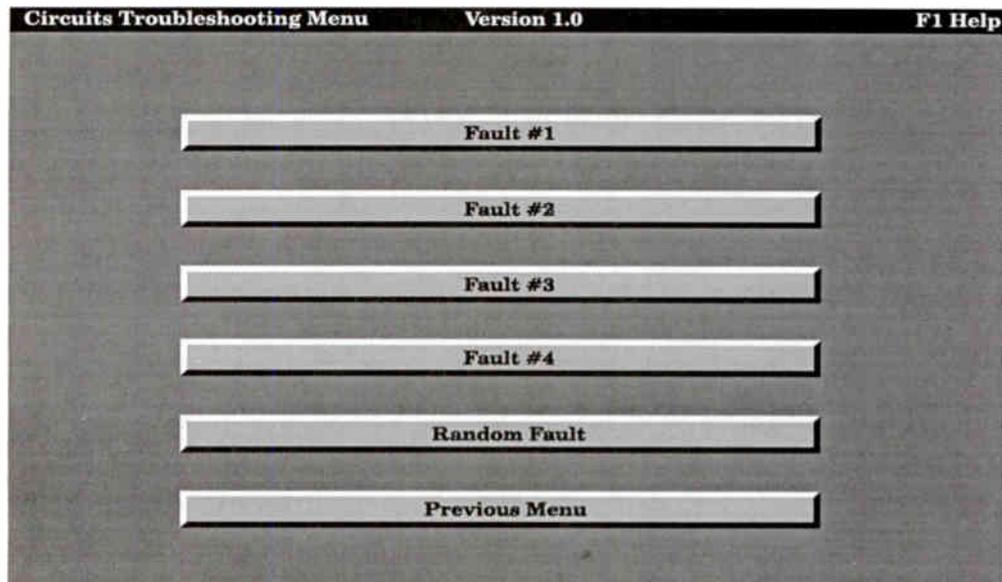


Figure 5. Fault Option Menu.

## Support Screens

These are several screens of text that give general guidelines for troubleshooting AC circuits and describe the problem that the student has selected.

## General Guidelines

Figure 6 shows the General Guidelines screen. This screen gives the student several important guidelines for troubleshooting AC Circuits. The student can use the scroll bar to move the additional guidelines into view. This screen is displayed at the start of the first problem (RC Circuits) or it can be called up at any time from the Help Screen. The "Exit Guidelines" button takes the student to the next screen.

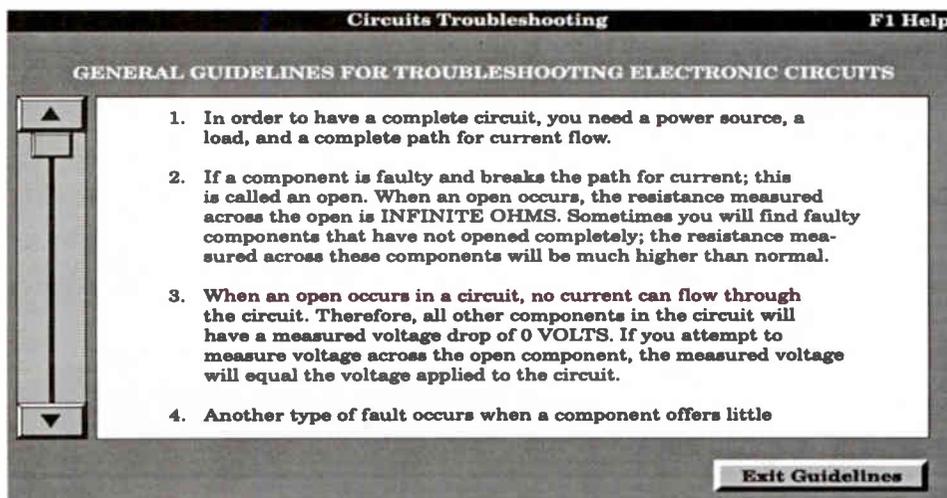


Figure 6. General Guidelines Screen.

## Problem Screen

A typical Problem Screen is shown in figure 7. Problem screens are used to set up the troubleshooting scenario. They place the student in a real life servicing situation. Two or more problem screens explain the problem in enough detail to lead the student into the actual problem.

## Troubleshooting Screen

As shown in figure 8, this screen shows components on a circuit board. Students can turn power on and off to the circuit, make voltage and resistance tests, unsolder components and place them on the workbench, replace bad parts with good ones, look at the schematic or the component view, inquire to get troubleshooting ideas, and finally check to see if they have fixed the problem.

## Help Screen

The Help Screen, figure 9, may be accessed at any time by pressing the F1 key. To operate the Help Screen, just click on a tool or button. A short message indicates exactly what that tool or button does. You can also click on other screen areas such as the push-button switch, circuit board, workbench, meter display and test log. Here again, a message will tell you the purpose or function of the object selected.

When finished, click on the top EXIT button.

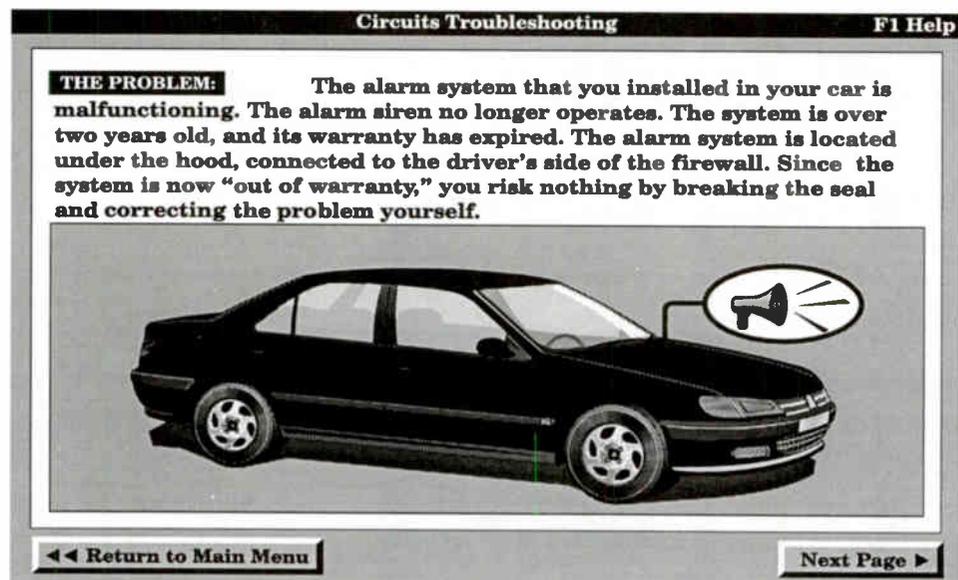


Figure 7. A typical Problem Screen.

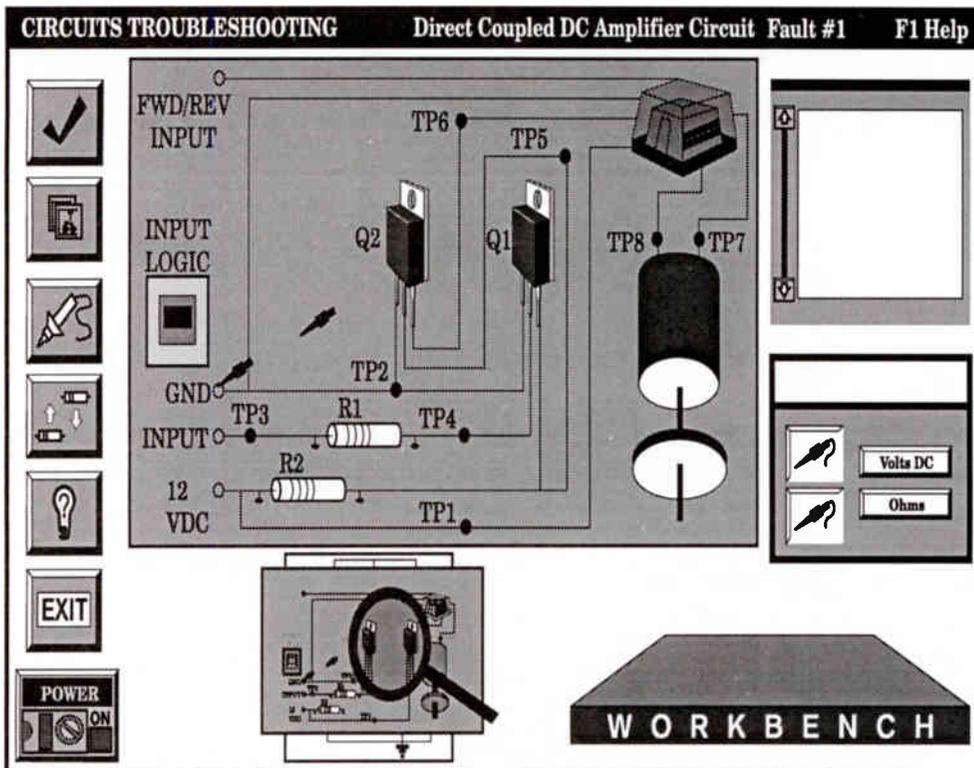


Figure 8. Troubleshooting Screen.

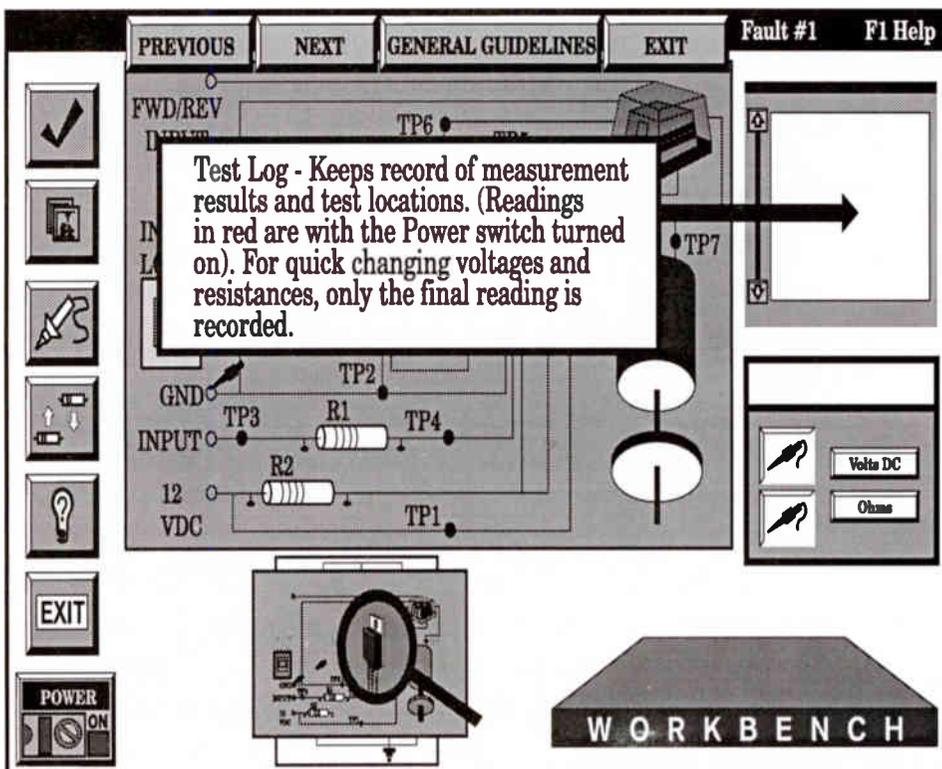
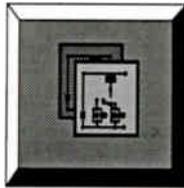


Figure 9. Help Screen.

## Using the Tools

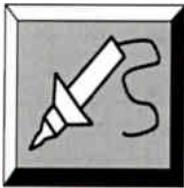
Students will spend most of their time in the Troubleshooting Screen. In this screen, they have access to a number of tools and buttons that allow them to simulate real world troubleshooting. Each of these tools and buttons are explained below.

### Schematic / Component-View Button



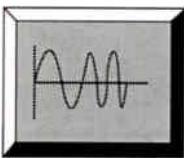
This button allows you to examine either the component view of the circuit or the schematic. You switch from one view to the other by clicking on the button.

### Soldering Iron



The Soldering Iron allows you to remove components from the circuit. It is selected by clicking on the button. When you select this tool, the cursor will be replaced by a small soldering iron icon. Simply click this icon on the component you wish to unsolder. The component will be automatically removed from the circuit and placed on the workbench.

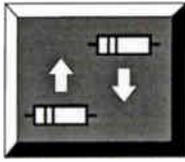
### Signal Generator



The Signal Generator tool allows you to apply a steady or sweeping input signal while monitoring the output with an oscilloscope. Simply click on the Signal Generator button to select either a steady or sweeping input signal. When the button appears showing one cycle of a sine wave, the steady input is selected. When the button appears showing a sine wave increasing in frequency, the sweeping input is selected. Once you have selected the type of input, click on the Power Button to turn the Signal Generator on.

---

## Swap Component



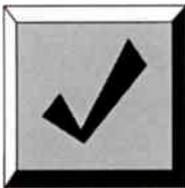
The Swap Component tool allows you to replace a component with a “known good” component. When you select this tool, the cursor will be replaced by the soldering iron icon. Simply click the icon on the component you wish to replace or the space where a previously removed component belongs. The component will be automatically replaced with a “known good” component of exactly the same type as the one removed.

## Idea or Hint Button



The hint button can give a little nudge if the student gets bogged down. When this button is clicked, a brief message is displayed where the workbench normally appears. The message remains until the mouse is clicked again. For each fault there are three different hints.

## Check Button



This button is used to check the results of the repair. If the repair has been accomplished, a congratulations message will appear. Otherwise a “sorry, please continue” message is given.

## Exit Button



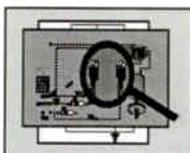
The Exit Button allows you to leave the troubleshooting Screen at any time. It takes you to the Main Options Menu which was discussed earlier.

## Power Button



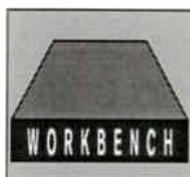
This button controls power to the circuit under test. Click to turn power on. Click again to turn power off. Generally there will be no voltages present in the circuit until power is turned on. Power should be turned on before making voltage measurements. Conversely, power should be turned off before making resistance measurements.

## Board / Schematic Icon



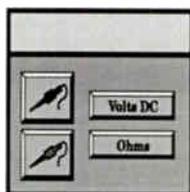
This icon performs the same function as the Schematic/Component-View Button explained above. That is, it allows you to switch back and forth between the schematic diagram and the component view of the circuit under test.

## The Workbench



The Workbench area serves two purposes. First, it is the area where components are placed when removed from the circuit with the soldering iron. Resistance and continuity checks can be made on components in this area. Second, it acts as a message display area. Both hint and warning messages appear here.

## The Multimeter



The Multimeter is the primary instrument used to troubleshoot the circuit. This meter is an autoranging digital multimeter capable of measuring DC Volts and Resistance. The appropriate mode is chosen by clicking on the DC Volts or Ohms Button on the meter. The meter's input impedance is high enough that it will not load the circuit under test. The

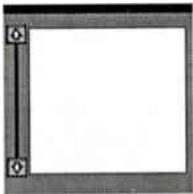
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autoranging feature means that it will automatically choose the right range.

The meter also has an autoblanking feature that blanks out the display until the digital count stops its runup. Therefore, quick changes in voltage or resistance may be missed. As with many digital meters, infinite ohms is indicated by a single 1 in the far left display.

To use the test leads, first click on the test lead button. Then click on the component lead and the test lead will connect itself there. To reposition the lead, click on the test lead and then on the new destination.

### The Recording Log



The Recording log provides a record of all the measurements made. It automatically scrolls up as new measurements are added. By using the scroll arrows, measurements that have scrolled out of sight can be brought back into view. Voltage readings are red when power is on and black when power is off. Once again, for fast changing conditions, only the final reading is recorded. The log will record up to 200 readings in a single "fault." After 200, any new reading will replace the last one.

## Leaving the Program

The program periodically “updates” your student work-disk. Normally, you should leave the program by using the **Exit Button**. When this is not done there is a good chance that the summary of actions may not be recorded on your student disk.

If you select the **Exit to DOS** button at the bottom of any screen, and do not have the proper password, you will be audibly and visually alerted. The **Exit to DOS** button returns the user to the DOS prompt only when the correct password is given.

The password you establish may be changed at any time to avoid compromise or to reestablish a secure system. To establish a new password, you will need to type **NEW** (at the password-to-DOS screen) and follows the screen prompts.

If power is lost, due to power failure or inadvertently turning the computer off while still in the troubleshooting program, the last **Fault** will not be updated onto the work-disk. The proper shut down procedure is to first use the **Exit to DOS** button, then enter the proper password, return to DOS, and then remove power.

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# Evaluating Yourself

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One of the prime advantages of using the CAT program is its ability to help you evaluate your performance. For the first time, you have a practical, private, and systematic way of judging your own troubleshooting techniques and procedures. It is as if you have an assistant to stand behind you and, with a stop watch and memo pad, unerringly time and record every step the you take.

## Using the Tb Files

Your performance while using the CAT program is recorded on your workdisk as a Tb file. The identification of these files are easily recognized as the first two letters of such a file will be Tb. These files are created when you begin a troubleshooting scenario of the CAT program. Each and every sequential step performed during the scenario is recorded with a time marker noted to the left of the performed step. The contents of these files can be reviewed using a generic text file editor or word processing application program.

After completing your troubleshooting assignment(s), you can review the Tb files to retrieve and review your actions during the scenarios. Keep in mind that the Tb files are named sequentially (ie. Tba, Tbb, Tbc, Tbd, etc.) If you happen to troubleshoot the first fault more than once, the Tb files will record one file per attempt. You will not be able to determine which scenario you completed by viewing the file names alone.

Once a file is open you may see information similar to that shown in figure on the following page. This file contains a wealth of information including:

1. The Problem name and Fault number.
2. A statement of what the fault was. For example:  
The problem was: Resistor R1 is open.
3. Date and time that the problem was started.
4. A simple circuit representation to refresh your memory (if needed) of the schematic diagram.
5. Under the heading "Recordings", the step by step procedure that you performed. The number of steps may be lengthy and require you to move to the next page to see all of the recorded actions taken.
6. Each step indicates the time the step occurred in minutes and seconds.
7. Each step indicates the procedure performed and its outcome.

## Factors to Consider

As you progress through the CAT program, every step of your performance has been recorded on the student workdisk. By carefully analyzing the "trail" that you have followed, you can accurately evaluate your performance.

However, troubleshooting is as much an art as it is a science. Keep in mind that it is your technique you will be judging as well as than the final result. Because of troubleshooting's very nature, evaluating one's performance is somewhat subjective. No two technicians will approach troubleshooting in exactly the same way. And while there are general guidelines, it is difficult to list specific rules that are right for every situation. Indeed, troubleshooting philosophy varies widely from one company to the next, and you will even find diverse views among experienced technicians. Consequently, as a student, you will have to make many judgment calls as to how you carry out the troubleshooting assignment. Even so, the following guidelines will be of some use to you in evaluating your performance.

Direct-Coupled DC Amplifier Solved

CIRCUITS TROUBLESHOOTING

Direct-Coupled DC Amplifier

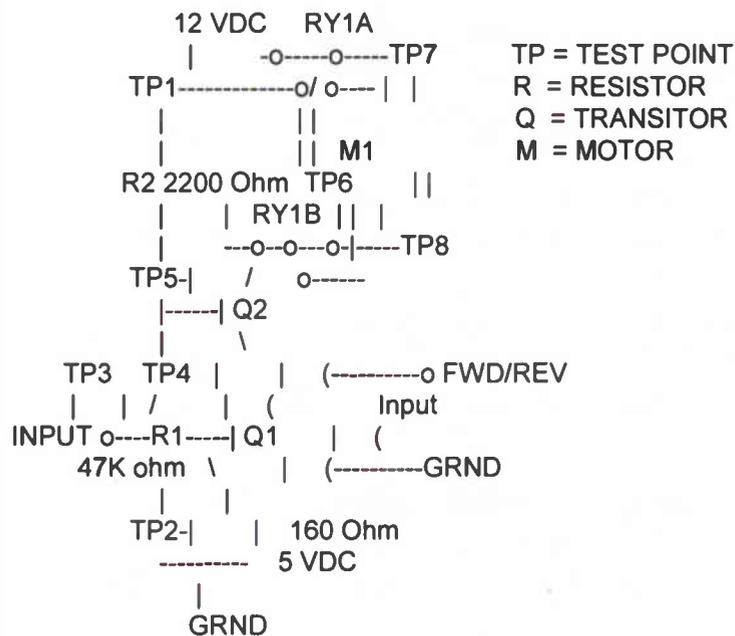
Fault # 1

The problem was : Resistor 2 is OPEN

DATE: Thursday, 11 /23/1996

TIME: 10:22:08

Circuit Setup:



Recordings:

- | 0:08| The technician took a reading on TP1,TP5 -- Infinite ohms
- | 0:12| Technician replaced RESISTOR 2 with a new one
- | 0:15| The technician checked the result and got a right answer

There are several factors you should consider in evaluating your performance. These include:

1. *Did you find the fault and fix it?*

This is the most fundamental question to ask. After all, this was the assignment. Failing repeatedly in this task indicates that you do not fully understand the assignment, or how the program works, or you may have serious deficiencies in your knowledge of the subject. Even so, this is not an unusual situation the first or second time that you are exposed to the program. Usually it indicates that you are not yet comfortable with the program. Examining one's actions as recorded on the workdisk should go a long way toward pointing out your weak areas.

2. *Did you approach the problem in a logical way?*

This is perhaps the single hardest question to answer. Normally, you will be expected to make voltage or resistance measurements prior to replacing a component. Did you do this in a systematic way, making all voltage measurements before moving on to resistance measurements or vice versa? Did you make enough measurements and the right types of measurements to uniquely identify the fault? Did you make far more measurements than were necessary?

3. *Did you use the equipment properly?*

Did you attempt to measure voltage with the power off? A minor infraction. Or did you attempt to measure resistance with the power on? A more serious offense.

4. *Did you follow good safety practices?*

Did you attempt to remove a component with the power applied?

5. *How many components did you replace before fixing the problem?*

Ideally you should replace only the malfunctioning component. Wholesale replacement of parts will eventually result in a "fix" but is not considered good practice.

6. *How long did it take you?*

By reading the Tb files on the student workdisk, you can determine the exact amount of time spent on each-step of the troubleshooting scenario as well as the overall problem. Time can play a crucial factor in troubleshooting when customers and their money are involved.

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As the student, it is your responsibility to decide how much weight will be placed on each of the above factors and any other factors you may consider important. Also, you may want to change the weight of some factors as you progress. For example, forgetting to shut off the power before working on the circuit might be attributable to unfamiliarity with the program the first time it happens. But, it might be judged more severely on subsequent occurrences.

## **Additional Ways to Use the Program**

Once you become proficient at finding and repairing the faults using your own individually developed techniques, some additional variety can be introduced by setting up special scenarios which will cause you to rethink their techniques. For example, you may want to run through the program under one of the following scenarios:

1. Find and fix the fault as quickly as possible. There are situations in which time to repair is the most important factor. A failure of a key piece of equipment on an assembly line comes to mind. Every second that the line is down costs the company money. When time is the overriding concern, the troubleshooting technique may be radically different.
2. Find and fix the fault with minimum soldering. Soldering is an intrusive procedure. Anytime you remove or replace a component by soldering you risk damage to adjacent components, the circuit board, or the component being removed. This is especially true with today's micro-miniaturized electronics devices and multilayer circuit boards.
3. Find and fix the fault making measurements only with the voltmeter. Limiting the use of test equipment to the voltmeter will cause you to use Ohm's Law and other theoretical concepts. So while this may not be a legitimate technique, it makes an interesting learning experience.

# The Problems

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The Problems and Faults were chosen to give the student a cross section of troubleshooting experience. The early scenarios are designed to ease the student into troubleshooting while the later ones provide a more thought provoking challenge. There are no trick problems although in the last two problems component values and the characteristic of the meter are selected to prompt discussion. All malfunctions are either open or shorted components. There is only one malfunction per fault.

## Objectives of the Program

Upon completion of this lesson you will be able to:

1. Use a schematic diagram and a component view of a circuit, match each component and test point on the schematic with its counterpart on the circuit board.
2. Demonstrate that widely separated points on a circuit board may be “electrically” identical.
3. Demonstrate the proper use of a signal generator, voltmeter, and ohmmeter.
4. Use a RC circuit with an open component, find and replace the faulty part.
5. Use a RC circuit with a shorted component, find and replace the faulty part.
6. Use a RL circuit with an open component, find and replace the faulty part.
7. Use a RL circuit with a shorted component, find and replace the faulty part.
8. Use a RLC circuit with an open component, find and replace the faulty part.

- 
9. Use a RLC circuit with a shorted component, find and replace the faulty part.
  10. Use a Transformer circuit with an open component, find and replace the faulty part.
  11. Use a Transformer circuit with a shorted component, find and replace the faulty part.
  12. Demonstrate the proper method of testing a capacitor.
  13. Demonstrate the proper method of testing an inductor.
  14. Demonstrate the proper method of testing a speaker.
  15. Demonstrate the proper method of testing a transformer.
  16. Demonstrate that an input signal should be removed from the circuit before any repair is attempted.
  17. Demonstrate that an input signal should be removed from the circuit before using the Ohmmeter.
  18. Demonstrate that because of component and meter tolerances, resistance and voltage measurements are not always exactly what the student expects.
  19. Demonstrate the value of being able to estimate what voltage or resistance reading to expect.
  20. Demonstrate the unique abnormalities caused in various types of circuits by opens and shorts.

## **RC Circuit**

This circuit is an RC Low-Pass Filter circuit with a cut-off frequency of 8 kHz. This problem introduces the Signal Generator as a useful piece of troubleshooting test equipment. The Signal Generator is used to show the circuit's response to inserting the cut-off frequency or a sweeping frequency.

## **RL Circuit**

This circuit is an RL Low-Pass Filter circuit with a cut-off frequency of 10.6 kHz. The Signal Generator is used again in this problem to show the circuit's response to inserting the cut-off frequency or a sweeping frequency.

## **RLC Circuit**

This circuit is an RLC Band-Pass Filter with a resonant frequency of 50 kHz. It demonstrates that when a component shorts, the circuit configuration and its characteristics change. In this circuit, when C1 is shorted the circuit turns into an RL Low-Pass filter configuration with a cut-off frequency of 15 kHz. When L1 is shorted, the circuit turns into an RC High-Pass filter configuration with a cut-off frequency of 159 kHz. Obviously, this will greatly affect all voltage test results.

## **Transformer Circuit**

This circuit is the audio output circuit of an antique, tube type radio. The transformer is a 5:1 step-down coupling transformer that matches the high impedance of the last tube amplifier stage to the low impedance of the speaker.

# Answer Sheet

<b>AC Electronics Troubleshooting</b>		
<i>RC Circuit</i>		
Fault #1	PA System	R1 open
Fault #2	PA System	C1 shorted
Fault #3	PA System	C1 open
Fault #4	PA System	R1 shorted
<i>RL Circuit</i>		
Fault #1	PA System	L1 shorted
Fault #2	PA System	R1 shorted
Fault #3	PA System	L1 open
Fault #4	PA System	R1 open
<i>RLC Circuit</i>		
Fault #1	Garage Door Opener	L1 open
Fault #2	Garage Door Opener	C1 shorted
Fault #3	Garage Door Opener	L1 shorted
Fault #4	Garage Door Opener	C1 open
<i>Transformer Circuit</i>		
Fault #1	Antique Radio	T1 primary open
Fault #2	Antique Radio	T1 secondary open
Fault #3	Antique Radio	T1 primary shorted
Fault #4	Antique Radio	Speaker open

# NOTES

*Please use this page to record any notes you may want to review during your studies.*

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*Please use this page to record any notes you may want to review during your studies.*

# NOTES

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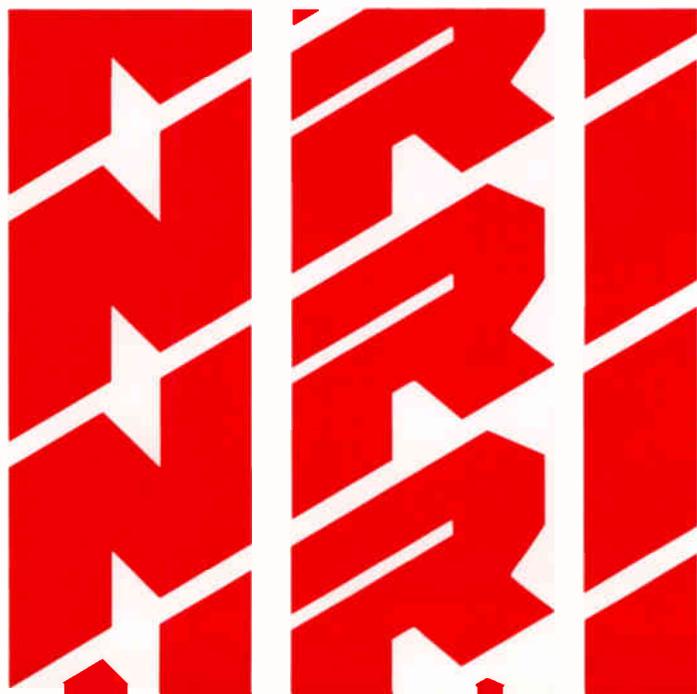
Richard H. Hanchey  
Lumberton, North Carolina





# Introduction to Electronics

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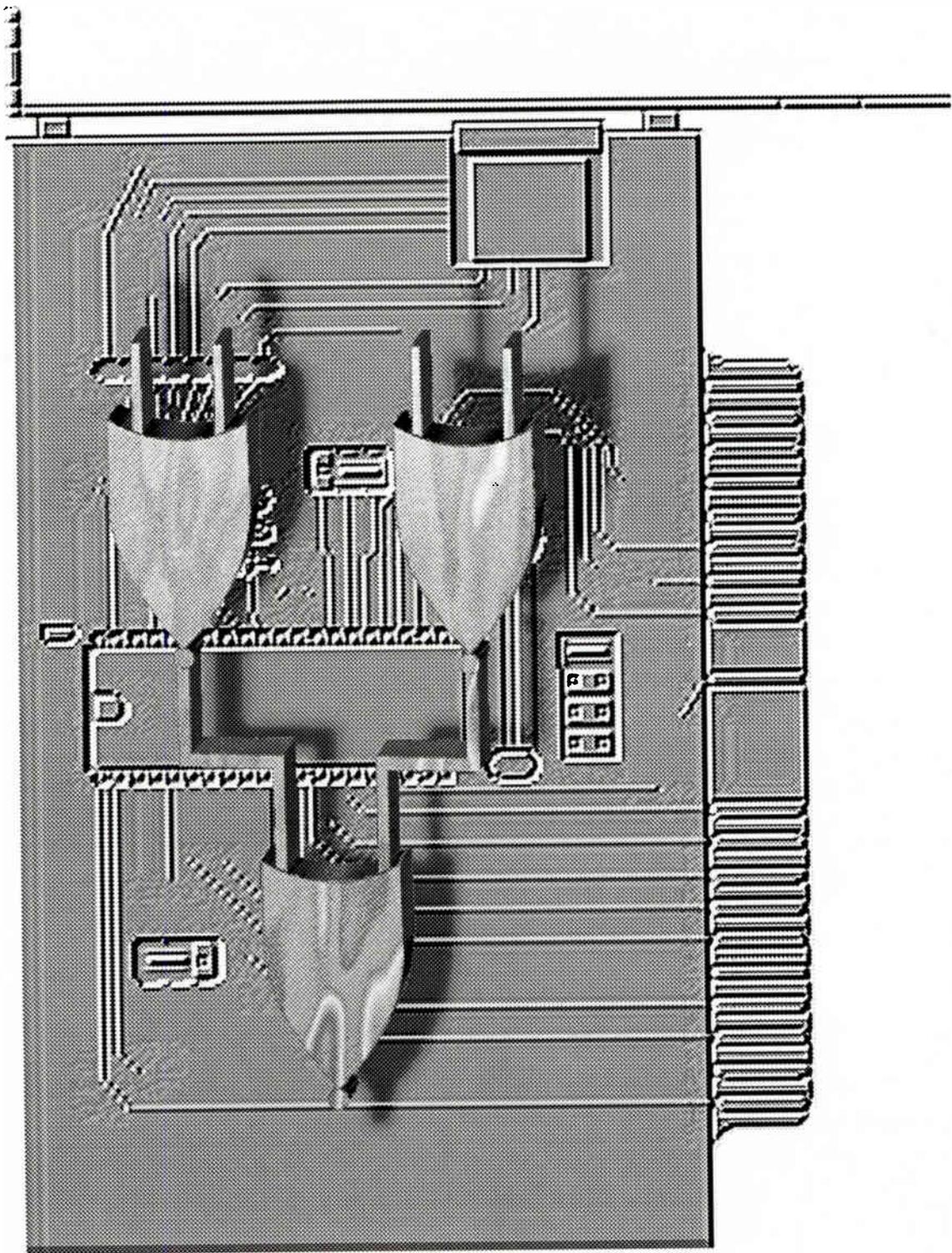
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# Introduction to Electronics

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**INTRODUCTION TO ELECTRONICS (First Edition)**

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# Table of Contents

<b>Introduction</b> . . . . .	<b>1</b>
What Is Electronics? . . . . .	2
<b>Overview of the Electronics Industry</b> . . . . .	<b>3</b>
Communications . . . . .	3
Computers . . . . .	4
Control . . . . .	4
Test and Measurement . . . . .	4
Other Uses of Electronic Equipment . . . . .	5
Self-Test Questions . . . . .	5
<b>Who Uses Electronic Equipment?</b> . . . . .	<b>6</b>
Consumer Electronics . . . . .	6
Business . . . . .	6
Industry . . . . .	6
Government and Military . . . . .	7
Electrical vs. Electronics Industries . . . . .	8
Self-Test Questions . . . . .	9
<b>The Physics of Electronics</b> . . . . .	<b>10</b>
Origin of the Term Electronics . . . . .	10
Basic Electronic Applications . . . . .	11
The Atomic Structure of Matter . . . . .	12
The Law of Charges . . . . .	15
Conductors and Insulators . . . . .	16
Self-Test Questions . . . . .	16
<b>Answers to Self-Test Questions</b> . . . . .	<b>17</b>
<b>Lesson Questions</b> . . . . .	<b>18</b>



## Lesson Objectives

*In this lesson, you will...*

- Become familiar with the general areas of electronics.
- Learn about the atomic structure of matter.
- Discover how atomic particles are involved with electronics.

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# Introduction

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Welcome to the exciting world of electronics. The NRI Electronics lessons are designed to help you learn more about this dynamic field. They will give you a firm understanding of electronic components, circuits, equipment, and systems. As a result, you will better understand and appreciate how this technology has changed and enhanced our

lives. Knowing electronics in depth will give you a greater awareness of what it can do for you and others, and will help you to apply it to your personal life and career. Further, because it is an exciting and rapidly changing field, there is always something new to learn. You will find electronics to be a great hobby or career.

# INTRODUCTION TO ELECTRONICS

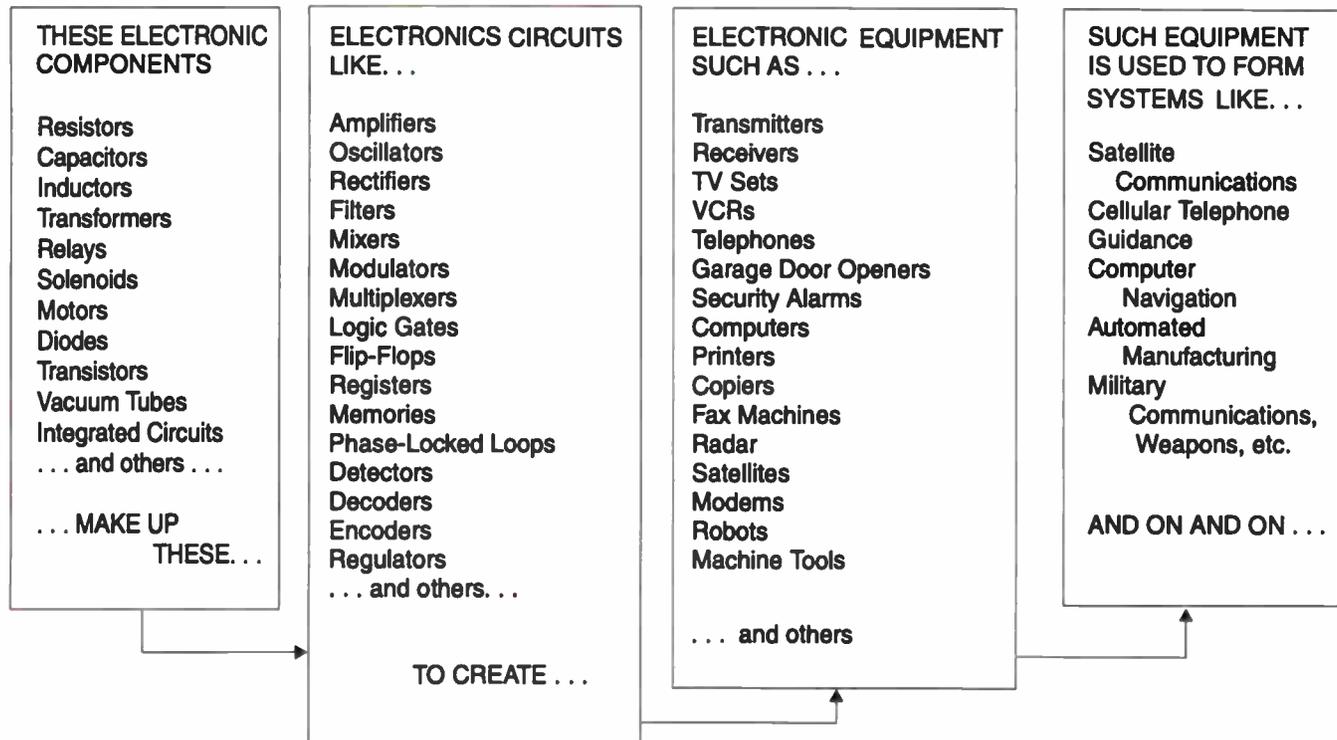


Figure 1. The hierarchy of electronics: Components make up circuits, which make up equipment used to make systems.

## What Is Electronics?

Electronics is the study of the behavior of subatomic particles called *electrons*, and the development and application of circuits and devices that manipulate electronic currents to perform a variety of useful tasks. The general principles of electricity and electronics are derived from physics and are widely known and understood. Electronics, however, is

everchanging, due to the creation of new and better components and circuits which form the electronic instruments and systems with which you are probably familiar. The block diagram in Figure 1 lists some common electronic components and circuits and the types of electronic equipment and systems that are made from them.

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# Overview of the Electronics Industry

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The electronics industry can be roughly divided into four major areas: communications, computers, control, and test and measurement. Almost every type of electronic equipment made, regardless of the application, falls into one of these four major areas. Let's take a look at each in more detail.

## Communications

Communications is the largest field of electronics, as well as the oldest. It includes all of the equipment and technologies people and machines use for communicating with one another. The earliest electronic communications system was the telegraph, followed a generation later by the telephone. Today, the telephone system is by far the largest communications network in the world. Communications also includes all radio and television broadcasting. This is a huge industry with thousands of AM and FM radio and TV stations.

Also included in this category is two-way radio communications. There are so many applications for two-way radio that it is almost impossible to list them all. You are probably familiar with many of them and may even use one of these services yourself. They include aircraft, marine, military, police, fire, taxi, government service, and even personal two-way radios, such as Citizens' Band (CB) and amateur (ham) radio. Cellular telephones also fall into this group.

A special area of communications is data communications, which is essentially the transmission and reception of digital data between computers. Information is transmitted from one computer to another through the telephone system and often by microwave relay or satellite links. Even personal computers communicate through their local area networks (LANs) and modems attached to remote information sources, such as bulletin board systems (BBS) and commercial on-line services (CompuServe, Prodigy, GENIE, and

America Online). There also are many other special types of communications systems and equipment. These include fiber optics, satellites, cable and interactive TV, radar, navigation systems, and facsimile (fax) machines.

Communications is an enormous field that has an impact on all of us every day. You no doubt use many communications devices every day, particularly the telephone, radio, and television.

## Computers

The computer industry is a close second in size to the communications industry. Computers and related devices are almost as widely used as communications equipment. Large mainframe computers have been around since the late 1940s and early 1950s, and, since that time, have greatly evolved in power and capability over the years. There are also the large, fast supercomputers used in scientific research and engineering applications. Smaller, powerful minicomputer systems provide nearly the same computing capacity as the larger mainframes, but at a lower price. Then there are the hundreds of millions of personal computers that are used in offices and homes around the world. Other faster and more powerful desktop computers, basically souped-up personal computers, are engineering and graphics workstations.

Then there are the billions of microcomputers that are built into other pieces of equipment. While most of these are not programmable general-purpose computers, they are computers in the classic sense of the word. However, they are built into or *embedded* in other devices, and are therefore dedicated to a single

function. Some examples are the microprocessors inside TV sets, automobiles, appliances, and factory machine tools.

The computer field also encompasses peripheral devices. These include color and monochrome video monitors, disk drives, printers, mice, and any other device used for computer input or output operations.

## Control

Electronic control equipment is used to automatically manipulate or operate equipment or machinery. One example of control equipment is a device which varies the speed of a motor. Another example is the programmable logic controller (PLC), which is a special type of computer used in industrial applications. PLCs are used to control all kinds of factory machine tools and other equipment. There are also control circuits for dimming lights, switching solenoids and relays, operating valves, and sequencing the cycles in dish and clothes washing machines. Control equipment also includes systems used in automated manufacturing plants, such as computer-controlled machine tools, lathes, mills, conveyers, and other robotic devices.

## Test and Measurement

The test and measurement segment of the electronics industry is devoted to making precise and accurate measurements of physical and electrical phenomena. The design, development, repair, and maintenance of electronic equipment requires instruments that can accurately measure voltage, current, resistance,

---

frequency, etc. A large part of this field is devoted to general-purpose testers, such as multimeters, oscilloscopes, signal generators, and frequency counters.

Of course, test and measurement capabilities are required in many areas. In manufacturing and process control, instruments are needed to make accurate measurements of physical characteristics, such as temperature, liquid level, fluid flow rate, pressure, humidity, and vibration.

Medical electronics is a significant specialized area of the test and measurement field. It's critical that precise measurements of physiological properties be made so that physicians can make accurate diagnoses.

## Other Uses of Electronic Equipment

While most electronic equipment falls into one of the four areas discussed, there are many special areas of electronics that are not so easily classified. Electronic security systems for homes and cars are good examples. There also is the electronic music industry, which encompasses synthesizers, stereo receivers, compact disc (CD) players, digital audio tape (DAT) recorders, and signal conditioning equipment.

As you may have realized, most electronic applications are a mixture of equipment and techniques from two or more of the major areas. For example, an electronic control's output usually is dependent on some input signal from a test or measurement device. Also, many personal computers use communications techniques in the form of LANs or modems connected to remote data sources.

Another example is factory control applications. Most of these include a master control computer that operates other equipment that performs the specific control task. These are often also networked, thus adding the communications function. Such mixtures of the various fields are said to be *interdisciplinary*.

## Self-Test Questions

*Please check your answers on page 17.*

- 1 From what field of study do the principles of electronics come? *Physics*
- 2 Communications between computers is known as *Data* or *or*
- 3 In the field of electronics, what is meant by *interdisciplinary*?

# Who Uses Electronic Equipment?

---

Another way to categorize electronic equipment and systems is by the type of end user. That is, who is the customer for the equipment, and where is it used? The four major customer categories are consumer, business, industrial, and government/military.

## Consumer Electronics

Consumer electronics includes everything that individuals use for personal entertainment or convenience. The telephone is one example. Your CD player and stereo system, TV set, and electronic keyboard also fall into this category, as do home computers, security alarms, garage door openers, and many others. Notice that these consumer electronic products can be sorted by the different categories of communications, computing, and control.

## Business

By business, we mean nonprofit as well as profit-making corporations. One example is large insurance companies with massive mainframe computers and hundreds of networked personal computers. Another example

is hospitals, which use administrative computers and related items and medical electronic equipment, such as patient monitoring devices and magnetic resonance imaging (MRI) machines. Almost all businesses use telephones, fax machines, photocopiers, personal computers (and other computers), intercoms, dictating machines, security systems, building environment controls, fire alarms, etc.

## Industry

Because business and industry seem similar, industrial uses could logically be lumped under the category of business. But industrial applications are considered separately because of the different types of equipment used. For example, industries use manufacturing equipment, such as robots, computer-controlled lathes and mills, conveyer belts, and other types of manufacturing machines. Industrial applications also include computers, control equipment, and test and measurement equipment.

Industries use test and measurement equipment in manufacturing and process control applications to produce chemicals, pharmaceuticals, fertilizer, and other kinds of bulk

THE ELECTRONICS INDUSTRY — A PROFILE				
	COMMUNICATIONS	COMPUTERS	CONTROL	TEST & MEASUREMENT
CONSUMER	TVs Telephones Radios CD Players	Home Computers Calculators	Security Alarms Blenders Washer/Dryers Auto Ignition & Fuel	Thermometers Sphygmomanometer (Blood Pressure Device)
BUSINESS	Telephones Fax Machines Satellite Teleconferencing	Mainframes Minicomputers Personal Computers (PCs)	Copiers Building Security HVAC	Surveying Construction
INDUSTRY	Local Area Networks (LANs)  Telemetry	Programmable Logic Controllers (PLC) Engineering Workstations	Embedded Micros Machine Tools Robots	Manufacturing Process Control Quality Assurance
GOV'T & MILITARY	Satellites — Comm. — Navigation Navigation Systems Global Two-Way	Administrative Database Planning Simulation	Weapons — Missiles — Tanks — Artillery	Weather Environment Protection

Figure 2. Electronics Industry Profile.

materials. And let's not overlook utilities, such as the telephone companies, electric power companies, and gas and water companies, all of which make extensive use of electronic equipment. These only scratch the surface of industrial applications of electronic equipment.

## Government and Military

Since government, including the military, is now the largest employer in our nation and takes in more money than all of the top businesses and industries in the country, it is by far the biggest user of electronics. All government

and military offices use telephones, computers, fax machines, copiers, and other types of standard business equipment.

Also, consider operations like NASA, the FAA, the FBI, the CIA, and the military. The military, in particular, has many special electronic weapons and systems for communications, command, and control. Computing is used extensively, as are satellites and many weapon-related special control and communications systems. Radar and navigation equipment are also in wide use.

Figure 2 shows examples of how the various electronic applications are used in the different

# INTRODUCTION TO ELECTRONICS

marketplaces. This table puts into perspective the variety of applications and markets, which tend to mesh and overlap.

## Electrical vs. Electronics Industries

Electronics is the use of electronic components, circuits, and equipment to perform useful functions, such as computing, communications, and control. Related to and associated with electronics is the electrical industry. This vital industry is primarily concerned with the generation and distribution of electrical

power. This includes the electrical generating plants of utilities and their distribution systems and wiring of electricity to our homes, offices, factories, schools, and hospitals.

Figure 3 is a simplified diagram of the generation and distribution of electricity. Energy is produced by burning coal or oil or through nuclear fission. The energy, in turn, produces heat, steam, and pressure, which are used to drive turbines. A turbine converts heat energy into mechanical energy, which is used to drive a generator that produces electrical energy. The generators produce alternating current. The alternating current is stepped up to a

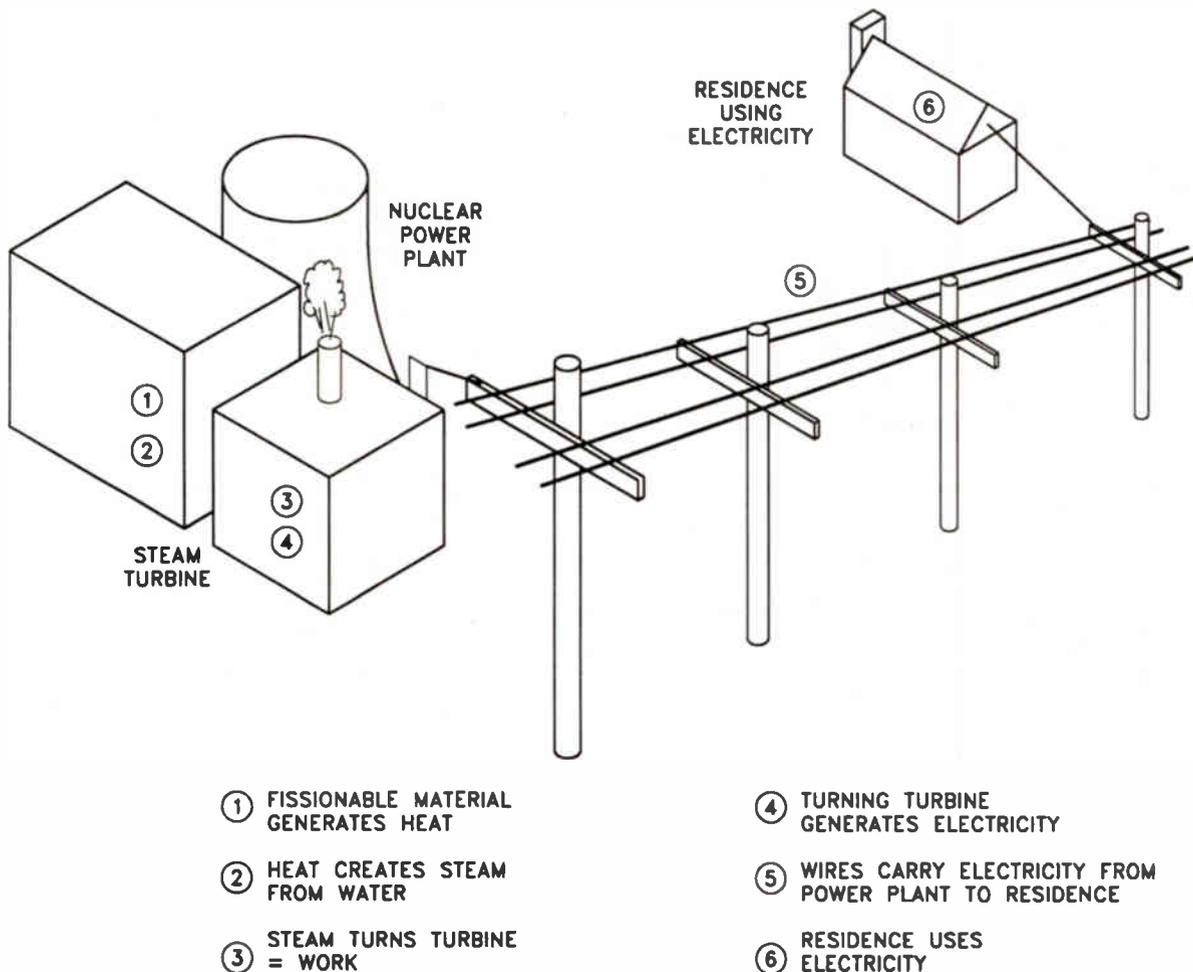


Figure 3. Generating electricity by nuclear fission.

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higher voltage level by transformers and then distributed by power lines. Transformers, in usage areas, step the voltage down before it is wired to homes, offices, and other facilities.

In addition to the generation and distribution of electrical power, the electrical industry also encompasses the distribution and the wiring in homes and buildings; this includes wire, outlets, lighting, switches, circuit breakers, and other equipment found in homes and businesses throughout the country.

## Self-Test Questions

- 4 What is the largest single user of electronic systems? *Communications*
- 5 What is the main difference between the electrical and electronic industries?
- 6 What are the three forms of energy produced when electricity is generated in a nuclear, coal, or oil power plant? *Heat*
- 7 What form of energy does a generator generate? *electrical energy*
- 8 How are transformers used in the electrical industry? *To step up Alternating current to a higher voltage level*
- 9 Where does the energy that operates most electronic equipment originate? *power plant*

## The Physics of Electronics

---

### Origin of the Term “Electronics”

The word electronics is derived from the word *electron*. An electron is a *subatomic particle*. All *matter* (things that we can feel, see, hear, smell, and otherwise sense) is made up of tiny particles called *atoms*. These are combined in an infinite number of ways to produce all physical things.

Atoms are made up of other tiny components: *protons*, *neutrons*, and *electrons*. You will learn more about these *subatomic particles* in the next topic. For now, just remember that electrons can be freed from atoms.

With an external force or pressure, electrons can be pulled away from the atoms and caused to move. If this external force is great enough, it can cause a large number of electrons to move or, as we say, to *flow*. This collective movement of electrons in one direction through some material, such as a wire or a component (like a transistor), is known as *current flow*. When electrons can be made to flow in a concise way, the results can be very useful.

When electron flow is used primarily as an energy or power source, we normally call it *electricity*. Electricity or electrical power is produced

by small batteries or by big generators at your electrical power utility. These power sources cause current to flow, which produces light and heat and which powers all other electrical and electronic equipment in homes and offices.

Electronics is different from electricity in that we precisely control the electron flow to produce a variety of useful effects. For example, varying the amount of electrons moving in a lamp filament allows us to control the lamp brightness, as with a light dimmer. The key to understanding electronics is to realize the many thousands of ways that electron flow can be controlled. You are about to learn how electronic components and circuits are used to control current flow.

Figure 4 is a sketch of a generic electronic application. There is a source of electrical energy, such as a battery or power from a utility company. Its output is called voltage, which is the name of the force that causes the electrons to flow. The electrons make up the current, which flows through a *load*. A load is a device, such as a light bulb, motor, or antenna, that produces the useful or desired end effect. Note that the electrons must also flow through a control element. It is this control element that produces the desired effect in the load. It

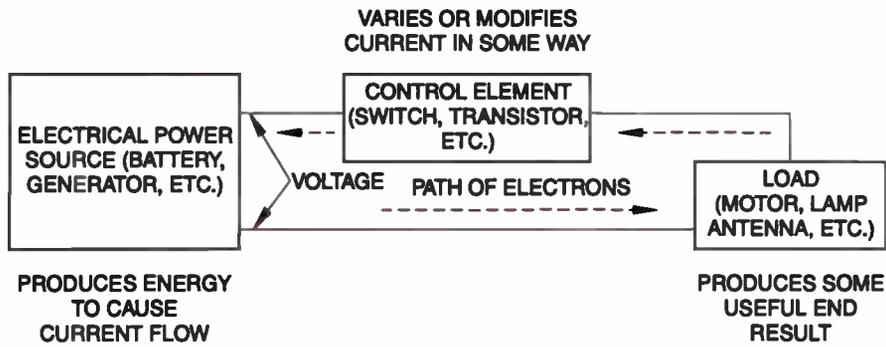


Figure 4. General model or concept for all electronic circuits and equipment.

may be a simple resistor, a transistor, a switch, or some complex collection of parts that form a circuit to produce the desired result.

## Basic Electronic Applications

A flashlight is an example of a basic electronic application. (See Figure 5.) Two flashlight cells are connected to form a battery supply voltage. This causes electrons to flow

through the light bulb (the load). The control element is the OFF/ON switch. If the switch is open, or acting as an insulator, no current can flow because we have broken the path the electrons would have followed. If the switch is closed, or acting as a conductor, it completes the circuit and allows electrons to flow and the lamp to light.

Another example, a variable speed electric motor, is shown in Figure 6, on the next page. The electrical power comes from a wall outlet

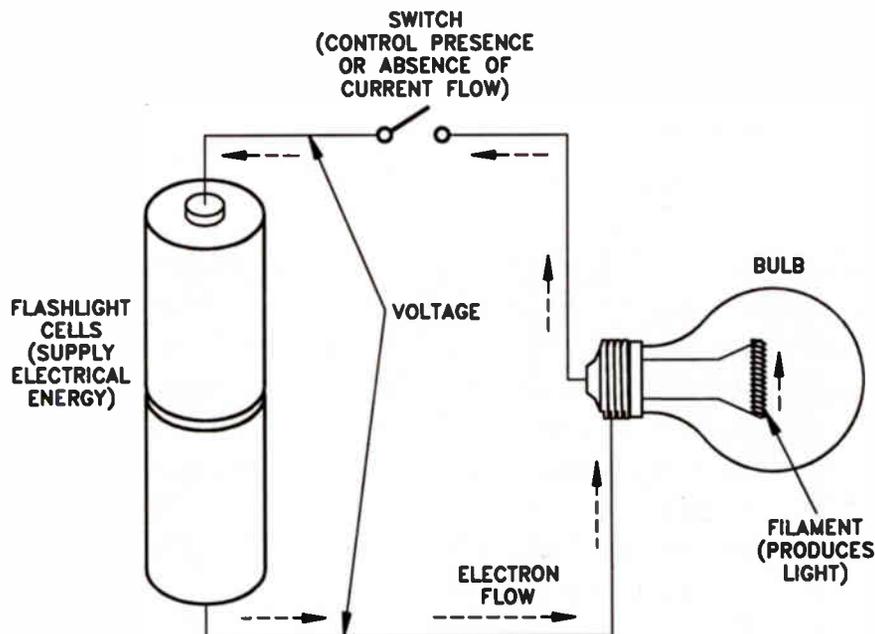


Figure 5. How a basic flashlight operates electronically.

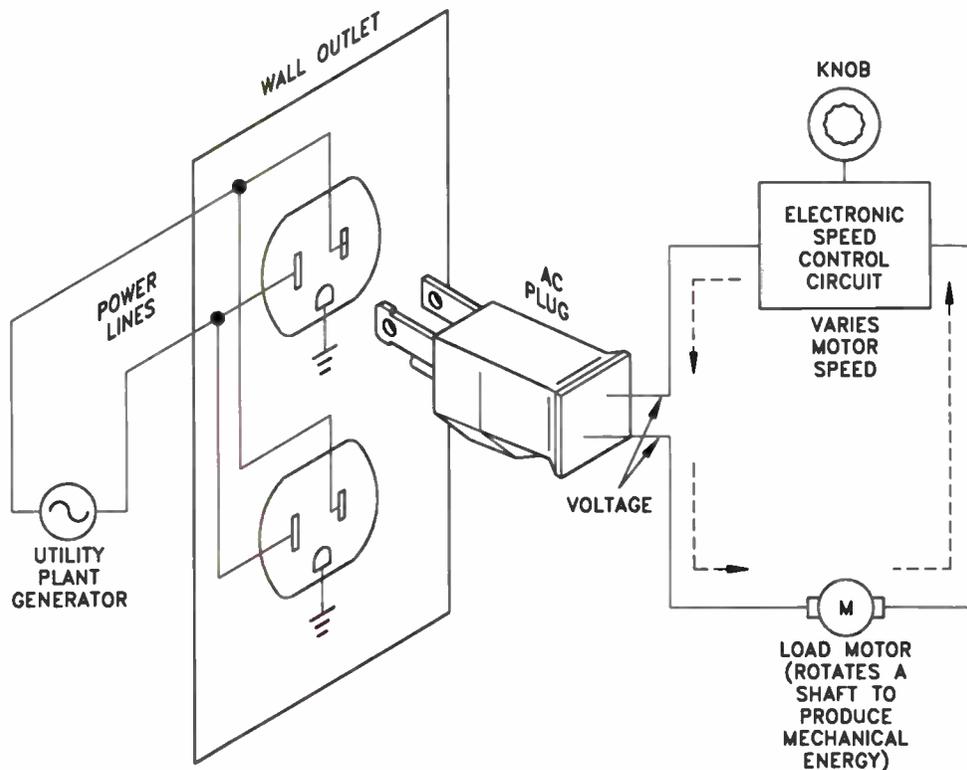


Figure 6. Basic operation of a variable speed electric motor.

and causes electrons to flow in the load, in this case, a motor. The electron flow produces a magnetic field which, in turn, causes the motor to rotate. The control element is a special electronic circuit that controls motor speed.

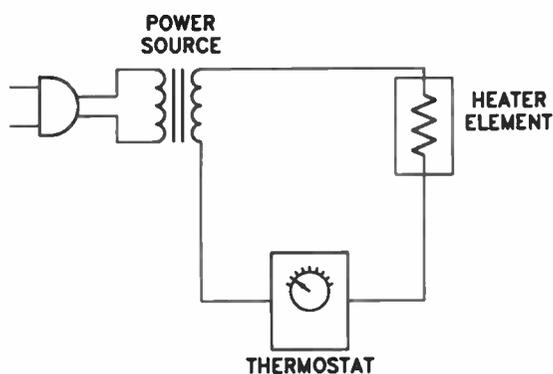
Another example, shown in Figure 7, illustrates automatic temperature control. A special heat-sensitive switch, called a *thermostat*, is connected as the control element between the electrical power outlet and the load — a heating element. Normally, the thermostat is closed, which allows current to flow to activate the heater. As warmer air from the heater reaches the thermostat, the increase in temperature is sensed and will eventually cause the thermostat to open. This will, in turn, cause the heater to turn off, which allows the air around it to cool. When the air gets cool

enough, the thermostat will again close, turn on the heater, and restart the cycle of control operation.

## The Atomic Structure of Matter

You don't have to be a physicist or a rocket scientist to know, understand, and enjoy electronics, but it helps if you know a little about the nature of electricity, which forms the basis of electronics. Let's explore some basic principles of atomic structure and current flow to start you on your way.

There are two basic types of electricity, *static* and *dynamic*. Both involve charges. A *charge* is an invisible electrical force somewhat like a magnetic field. Charges are created by



**Figure 7. Diagram of a thermostat-controlled heating system.**

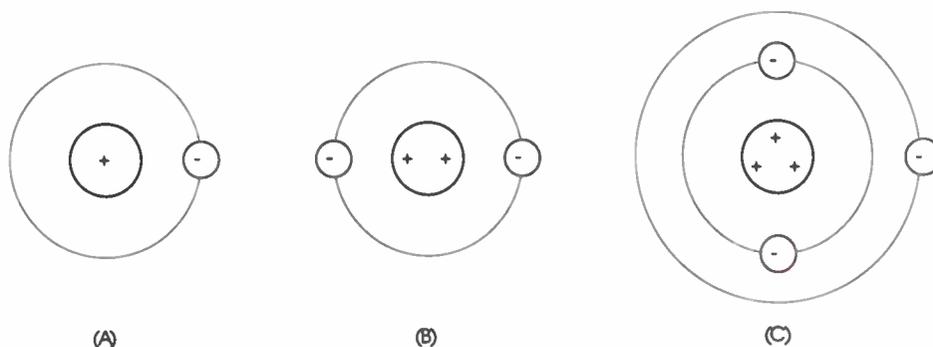
the basic atomic structure of materials. So, to begin our discussion of electricity and electronics, let's start with atoms.

As stated earlier, all substances are made up of tiny particles called atoms. Atoms are so small that a piece of copper the size of a grain of sand contains billions of copper atoms. All of these copper atoms take the same form, and each copper atom can be regarded as an actual piece of copper. There is no smaller unit of copper than one copper atom; this principle is true for all other elements, as well.

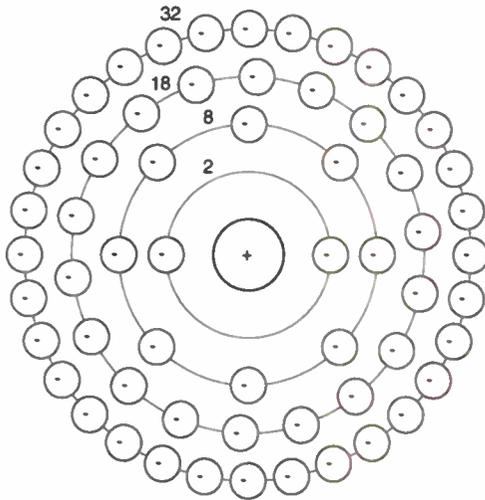
An atom is not solid. At its center is a *nucleus*, which has a positive electrical charge. Traveling around the nucleus in elliptical paths, or *rings*, are small particles called *electrons*, which have a negative charge. Every electron has the same mass and the same negative charge. Most atoms have enough electrons in the rings to balance the positive charge of the nucleus.

The lightest element, hydrogen, has the simplest atomic structure. It has one positive charge in the nucleus and one electron in orbit around the nucleus, as shown in Figure 8(A). Helium, the second element, has two positive charges in the nucleus and two electrons in orbit, as shown in Figure 8(B). Next is a light metal, lithium, with three positive charges in the nucleus and three electrons in orbit, as shown in Figure 8(C).

Notice in Figure 8(C) that lithium's third electron travels in a second ring. The first electron ring of an atom can hold two electrons; once the ring is filled, additional electrons must orbit in other rings. The maximum number of electrons in each of the first four rings of any atom is shown on the next page in Figure 9. In general, to find out the maximum



**Figure 8. (A) The Hydrogen atom. (B) The Helium atom. (C) The Lithium atom.**



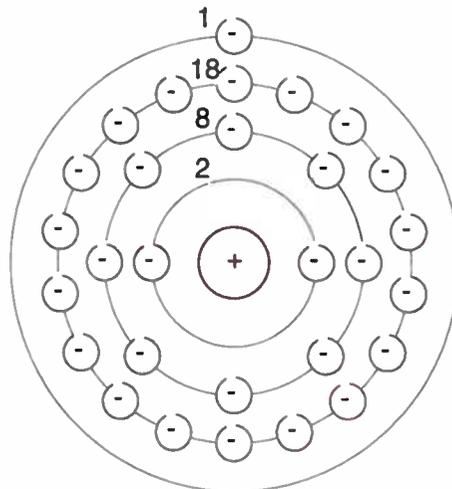
**Figure 9.** The maximum number of electrons possible in each of the first four rings of any atom.

number of electrons that each ring can contain, you simply use the  $2n^2$  law, where "n" is the ring number. For example, for the third ring, the maximum number is  $2(3)^2$ , or 18.

When the sum of the negative charges on the orbiting electrons exactly balances the positive charge of the nucleus, the atom has no overall electrical charge. When the outermost electron ring contains the maximum number of electrons it can hold, the atom is very stable electrically and chemically. It is very difficult to get an electron to move out of a stable atom or to force another electron into it. On the other hand, if the outer ring lacks one or two electrons, it is very easy to force electrons into position to fill the ring. If an extra electron is forced into an atom, whether the outermost ring is filled or not, the atom will have one more electron than it needs to neutralize the charge of the nucleus. The atom itself will then acquire a negative charge. In a comparable fashion, if the outer ring has only one electron in it, that electron

is not held closely to the atom and can be moved easily out of the ring (into space, or to another atom). This leaves the atom short one electron, and the positive charge of the nucleus is not neutralized. The atom, then, will be positively charged.

The copper atom is an excellent example of an atom with one electron in its outer ring. The positive charge of the nucleus of the copper atom is 29. There are 29 electrons in orbit around the nucleus, as shown in Figure 10. The first three rings of the atom are filled; they have all the electrons they can hold. However, the twenty-ninth electron required to neutralize the charge of the nucleus is in a fourth ring by itself. This electron is loosely bound to the nucleus. Under the right conditions, it can move easily from one atom to another. This configuration allows electricity to move easily along a copper wire, and is one reason why copper conductors are widely used in electronic equipment and electrical power distribution.



**Figure 10.** The nucleus of a copper atom has a positive charge of 29. There are normally 29 electrons around the nucleus.

## The Law of Charges

One characteristic of electrical charges is that *like charges repel, and unlike charges attract*. This is known as the *Law of Charges*. Since like charges repel, the electrons in an atom all tend to repel one another, and, at the same time, are attracted by the positive charge of the nucleus. A piece of copper contains billions of atoms. Each atom has a nucleus consisting of 29 positive charges, surrounded by 29 negatively charged electrons, which neutralize this positive charge. The electrons are held by the positive charge on the nucleus which attracts them. At the same time, these electrons repel other electrons in the atom and in nearby atoms. There is a dynamic balance established between the attraction of the nucleus and the circling electrons as they repel other electrons.

If we connect a copper wire to something that pulls electrons from one end and pushes electrons into the other end, an instantaneous chain reaction occurs along the wire. The instant an electron moves out of the fourth ring of one copper atom, its negative charge pushes an electron out of the fourth ring of a nearby atom. This, in turn, pushes an electron out of the fourth ring of another atom. This happens along the entire length of wire; at the instant an electron moves at one end of the wire, an electron moves at the other end.

You can get a better idea of what's happening if you imagine a hollow tube filled with ping-pong balls, as shown in Figure 11(A). Each ping-pong ball is in contact with the next. When you force an additional ball into one end, as shown in Figure 11(B), all the balls in the tube move, and a ball falls out the other end. The movement is nearly instantaneous throughout the length of the tube.

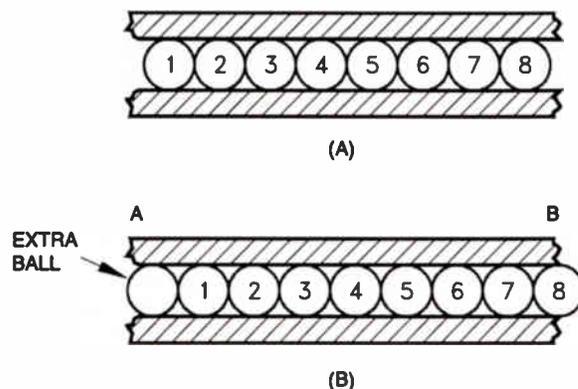


Figure 11. An example with ping-pong balls showing how instantaneous chain reactions can occur in wires. (A) The ping-pong balls remain stationary when no force is applied. (B) When an additional ball is added, the original group of balls shifts to the side, forcing one out of the tube.

Except for the fact that electrons can move much faster than ping-pong balls, the same thing happens when you apply an *electromotive force (EMF)*, or *voltage*, to move an electron at one end (point A) of a wire, as shown in Figure 12. Although the electrons do not touch each other, the force of repulsion between them causes electrons all along the wire to move. If you apply a force great enough to move two electrons, as shown on the next page in Figure 13(A), two electrons would move all along the wire. Similarly, if you increase the force again, three electrons moving at end A, as shown in Figure 13(B), cause a chain reaction of three electrons moving throughout the length of the wire.

The movement of electrons along the wire is called *current flow*. An *electric current* is the movement of electrons that have been forced out of atoms.

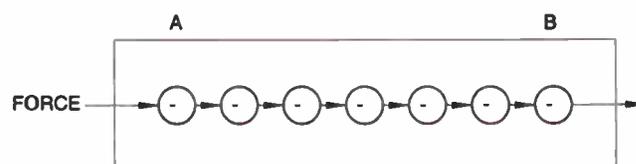
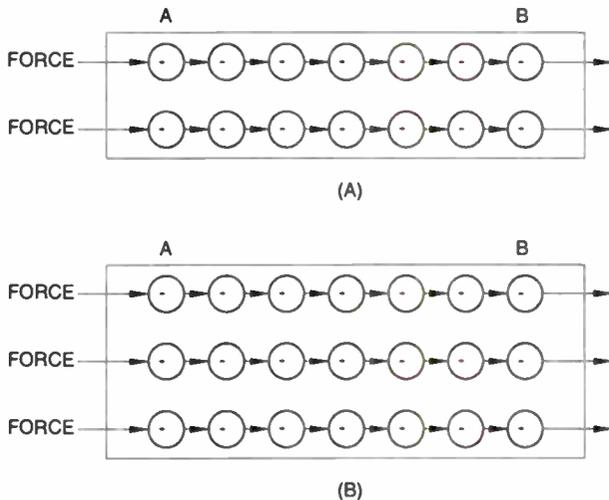


Figure 12. Instantaneous reaction of electrons in a wire.



**Figure 13.** The number of electrons set in motion along a wire depends on the force applied. (A) Two electrons move along the wire when force is applied. (B) Increased force causes three electrons to move along

## Conductors and Insulators

When parts are assembled into an electronic circuit, there are paths along which the designer wants current to flow, and paths along which no current should flow. *Conductors* are used to provide the path for current flow, and *insulators* are used to block current where it is necessary to prevent current from flowing.

Conductors are materials with one or two electrons that can be easily removed from the outer ring. There is no such thing as a perfect conductor, because all conductors offer some resistance or opposition to electric current.

Materials that do not readily give up electrons are used as insulators. Although there is no perfect insulator, materials used as insulators have such a high resistance, and pass so little current, that we can say that these are *nonconducting materials*. The weak current that is passed through insulating material is called *leakage current*, and is so low

that it is usually considered insignificant. Silver is the best known conductor, but it is used only in special applications because of its high cost. Copper is the next best, and because it is relatively inexpensive, it is used in most electrical wiring.

Most copper wire used in electronic equipment is covered with a plastic coating. This cover is an insulator, which is used to prevent a *short circuit*. If we did not use an insulator over the wire, and two wires accidentally came into contact, a short circuit would occur. The current would simply flow out one wire and back through the other and perform no useful function.

## Self-Test Questions

- 10 State the Law of Charges. *Like charges repel, unlike charges attract*
- 11 What things are made up of atoms? *All things*
- 12 From which of the three subatomic particles does the word "electronics" come from? *Electron*
- 13 Which part of an atom has a positive charge? *Nucleus*
- 14 Which part of an atom has a negative charge? *Electron*
- 15 If a copper atom, which normally has 29 electrons and 29 protons, loses one of its electrons, which kind of charge does the atom have? *+*
- 16 What is the definition of current flow? *collection movement of electrons in one direction*
- 17 What is the maximum number of electrons that can fit into the fifth shell of any atom? *50*
- 18 Will two protons attract or repel each other? *Repel*
- 19 Are materials with three or four electrons in the outer ring good conductors? *no*

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# Answers to Self-Test Questions

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- 1 The principles of electronics come from physics.
- 2 Communications between computers is known as data communications.
- 3 *Interdisciplinary* refers to a combination of electronic specialties used in a single application.
- 4 The government is the largest single user of electronic systems.
- 5 The function of the electrical industry is to generate and distribute electrical power; whereas the function of the electronic industry is the production of electronic components, circuits, and equipment to perform useful functions, such as computing, communications, and control.
- 6 Heat energy, mechanical energy, and electrical energy are the three forms of energy produced when electricity is generated in a nuclear, coal, or oil power plant.
- 7 A generator generates electrical energy.
- 8 Transformers are used to step up the voltage before transmission and to step down the voltage after transmission.
- 9 The energy that operates most electronic equipment originates at an electrical utility or a power plant.
- 10 The Law of Charges states that unlike charges attract; like charges repel.
- 11 All things are made up of atoms.
- 12 The word "electronics" comes from the word electron.
- 13 The proton has a positive charge.
- 14 The electron has a negative charge.
- 15 The atom has 29 protons and 28 electrons, which yields a net positive charge.
- 16 Current flow is the movement of electrons along a conductor.
- 17  $2(5)^2$ , or 50 electrons, is the maximum number of electrons that can fit into the fifth shell of any atom.
- 18 Two protons will repel each other.
- 19 No, materials with three or four electrons in the outer ring are not good conductors.



- 
3. Which of the following is a computer peripheral?
- a. Printer.
  - b. Transistor.
  - c. Relay.
  - d. Transformer.
4. Which of the following would most likely be considered an electronic control device?
- a. Lathe.
  - b. Thermostat.
  - c. Capacitor.
  - d. Resistor.
5. Which type particle is not part of an atom?
- a. Proton.
  - b. Photon.
  - c. Electron.
  - d. Neutron.
6. What is the name of the force which causes electrons to flow?
- a. Current.
  - b. Resistance.
  - c. Voltage.
  - d. Inductance.
7. Gold has the simplest atomic structure.
- a. True.
  - b. False.
8. If an atom is neutral and it has two electrons in the first ring and seven electrons in the second, how many protons are in the nucleus?
- a. Nine.
  - b. Two.
  - c. Seven.
  - d. Eleven.
9. The Law of Charges states:
- a. Like charges attract.
  - b. Dislike charges repel.
  - c. Positive charges attract negative charges.
  - d. Negative charges never attract positive charges.
10. Materials that do not readily give up electrons are used as:
- a. Inductors.
  - b. Insulators.
  - c. Transmission cable.
  - d. Conductors.

# NOTES

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*Please use this page to record any notes  
you may want to review during your studies.*



## HOW TO BUILD CONFIDENCE

Self-confidence — an active faith in your power to accomplish whatever you try to do — is a personal asset that can do big things for you.

Nothing builds confidence like success. Each lesson you successfully complete builds your confidence. The more you accomplish, the more confident you become, and the more you are able to achieve.

Success is habit-forming. Once you get started, you'll find yourself doing something successful every day. Before you know it, your little successes will have built up to that big success you've dreamed of. Get into the success habit as fast as you can, by resolving to study every day, even if only for a few minutes.

Another confidence builder is a deep, firm faith in yourself — in your ability to get ahead. If you believe in yourself and are willing to back up this faith with hard work, you can safely let the rest take care of itself. With self-confidence grounded in hard work, you can look forward to success in any field you choose.

Act as if you cannot possibly fail, and you will surely succeed.



# Series Circuits

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Washington, DC 20008



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# Series Circuits



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# Table of Contents

<b>Introduction</b> .....	1
<b>Resistance in Series Circuits</b> .....	2
Review .....	5
Self-Test Questions .....	5
<b>Current in Series Circuits</b> .....	6
A Simple Series Circuit .....	6
Multiple Resistor Circuits .....	7
Review .....	8
Self-Test Questions .....	8
<b>Voltages in Series Circuits</b> .....	9
Voltage Drop .....	9
Kirchhoff's Law .....	10
Review .....	11
Self-Test Questions .....	11
<b>Power in Electrical Circuits</b> .....	12
The Watt .....	12
The Kilowatt Hour .....	13
Review .....	14
Self-Test Questions .....	14
<b>Answers to Self-Test Questions</b> .....	15
<b>Lesson Questions</b> .....	18

# SERIES CIRCUITS

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## Lesson Objectives

In this lesson you will . . .

- Use Ohm's law to find current and voltage in series circuits.
- Apply Ohm's law in different forms to determine the relationship between current, voltage, and resistance in a series circuit.
- Learn how Kirchhoff's law establishes the voltage drops in a series circuit.
- Learn the basic units of electrical power and how electrical power relates to current, voltage, and resistance.

## INTRODUCTION

You have studied voltage, current, resistance, and the units of measure for each. You know that current is measured in amperes, milliamperes, and microamperes. You have also learned that volts, millivolts, microvolts, and kilovolts are units of voltage. In addition, you should remember that resistance is measured in ohms, kilohms, and megohms. These should all be familiar terms. You should know what they mean, and know how to make a conversion from one unit to another.

So far, we have shown you simple series circuits. In a series circuit, there is only one path for current to travel. If a resistor is connected between the negative and positive terminals of a battery, electrons must leave the negative terminal of the battery, flow through the resistance to the positive terminal of the battery, and back

through the battery to the negative terminal. There is only one path for current flow.

A series circuit may contain many resistances. The resistors are connected end-to-end so that electrons flow through each resistor moving from one to the next.

A parallel circuit has multiple paths for current flow. Each resistance may connect directly to the voltage source, or several resistances may branch from a junction. We say that the entire resistive load is "across" the battery in parallel, and there may be many parallel paths for current flow. Electrons leaving the negative terminal of the power source will flow through several different paths to get to the positive terminal.

You will study series circuits in this lesson, and parallel circuits in the next. All circuits found in electronic equipment are either series circuits, parallel circuits, or combinations of both.

# SERIES CIRCUITS

## RESISTANCE IN SERIES CIRCUITS

A series circuit has only one current path, as shown in Fig.1. The current is the same in all parts in the circuit. The current flowing through R1 is the same as the current flowing through R2 and R3. We will use examples of circuits made up of resistors. A series circuit may use many different types of electronic components, however. For example, you could have a series circuit containing several resistors, a transistor, and a coil.

Battery voltage and resistor values for the circuit shown in Fig.1 are provided in Fig.2. In this series circuit, each resistor opposes the flow of current. The total opposition to current flow is equal to the sum of the resistances of the individual resistors. We can express this mathematically as:

$$R_T = R_1 + R_2 + R_3$$

Therefore, in Fig.2, the total resistance is:

$$R_T = 3 + 7 + 5 = 15 \text{ ohms}$$

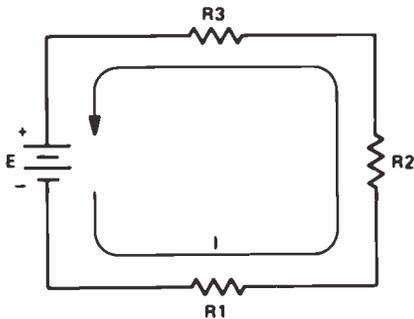


Figure 1. A series circuit.

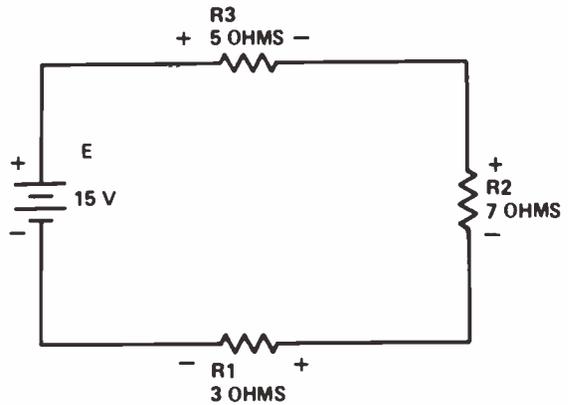


Figure 2. A series circuit.

The three resistors together have a total resistance of 15 ohms. That is, in this series circuit, the same current would flow if the three resistors were replaced with one 15-ohm resistor.

**Polarity.** In Fig.2, electrical current leaves the negative terminal of the battery and flows through R1, R2, and R3. The flow of current through each resistor creates a voltage polarity across it. The polarity of voltage across R1, for example, makes the end connected to the battery more negative than the end connected to R2. The same applies to the junction of R2 and R1; it is more negative than the junction of R2 and R3.

The concept of polarity applies to any component through which current flows. If you were measuring the voltage at different points in the circuit, your knowledge of polarity would enable you to properly connect a meter to the circuit, with the positive meter lead connected to a point more positive than the connection of the negative lead. Polarity is frequently marked on diagrams with small + and - signs. We will discuss this in greater detail later.

# RESISTANCE IN SERIES CIRCUITS

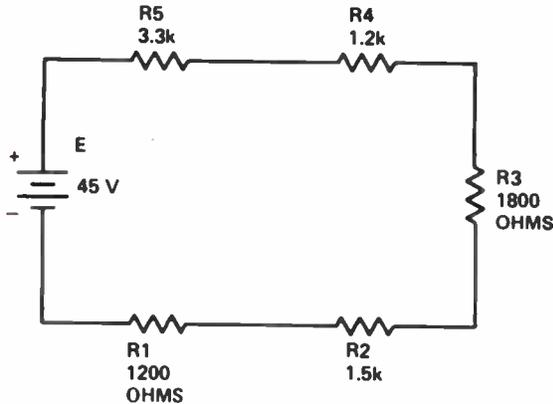


Figure 3. A series circuit with five resistors.

**Calculating Series Resistance.** A more complex series circuit is, which has five resistors instead of three, shown in Fig.3. Some resistance values in the circuit are provided in ohms, others in kilohms (k). To find the total resistance in the circuit, we must convert all resistor values to the same unit.

Let's convert the values to ohms. R1 is already given in ohms — as 1200 ohms. R2 is 1.5 kilohms. To convert this to ohms, simply multiply by 1000, moving the decimal points three places to the right, so that 1.5k equals 1500 ohms. R3 is given in ohms, as 1800 ohms. R4 is 1.2k, which equals 1200 ohms. Similarly, R5 is 3.3k, which is equal to 3300 ohms. As shown in Fig.4, the total resis-

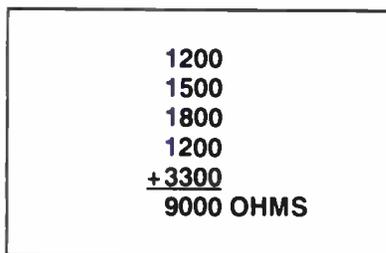


Figure 4. Total value of the resistors in Fig.3.

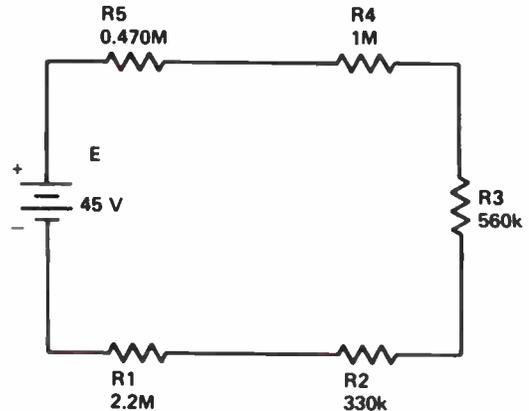


Figure 5. A series circuit with five resistors.

tance is the sum of all five resistance values, or 9000 ohms.

Another circuit containing five resistors is shown in Fig.5. Some of the resistor values are given in megohms (M), others in kilohms. Before you can add the values together to get the total resistance, you must convert all the resistances to the same unit. You can convert all the values to ohms, kilohms, or megohms. It doesn't matter which unit you convert to, as long as they are all the same.

To convert megohms to kilohms, move the decimal point three places to the right. To convert megohms to ohms, move the decimal point six places to the right. To convert kilohms to ohms, move the decimal point three places to the right. To convert kilohms to megohms, move the decimal point three places to the left.

The five resistors we have examined are shown converted to the same unit in Fig.6, on the next page. In the first column, all resistance values have been converted to ohms. In the second column, all have been converted to kilohms, and in the third column, all have been converted to megohms.

# SERIES CIRCUITS

OHMS	KILOHMS	MEGOHMS
2,200,000	2200	2.200
330,000	330	.330
560,000	560	.560
1,000,000	1000	1.000
<u>+470,000</u>	<u>+470</u>	<u>+.470</u>
4,560,000	4560	4.560

Figure 6. The resistances in Fig.5 converted to the same units.

You can see from Fig.6 that we get the correct answer in each case. You can see that 4,560,000 ohms is equal to 4560k, and to 4.560 megohms.

For practical purposes of calculation, you can ignore low-value resistors in a series circuit if one or more resistors has a much higher value than the others. In this case, the low resistances will not appreciably change the total circuit resistance.

In Fig.7, for example, resistors R1, R2, R4, and R5 have very small resistances compared to R3. With only R3 in the circuit, its 4.7M produces a current of 9.57 microamperes. If we add the other resistor values, the total becomes 4,704,700 ohms. Using that value as the total resistance, the current is 9.56 microamperes. The difference is 0.01  $\mu\text{A}$ , which is insignificant. Thus, for practical purposes, we could say that the circuit resistance is effectively 4.7 megohms.

Does this mean that we can ignore the presence of the other components? No. We point this out because it is important to remember that current flow in a series circuit with one or more high-value resistors and one or more low-resistance resistors is determined primarily by the high-value resistors. However, the low-value resistances probably have very specific purposes. Because of their small values, the low-value resistors could be shorted out of the circuit, and not significantly affect the total current. But the loss of their special function in the circuit might drastically affect its overall performance.

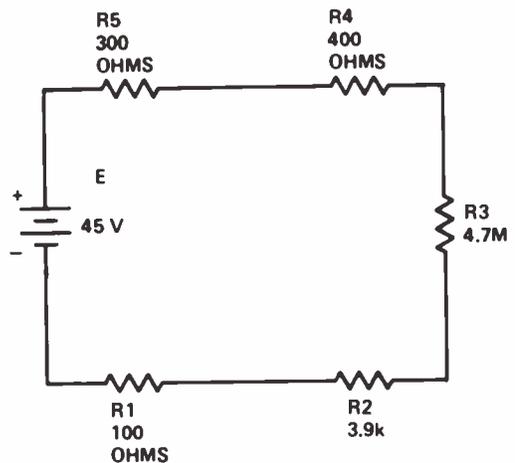


Figure 7. A series circuit where R1, R2, R4, and R5 can be ignored when determining the total resistance.

# RESISTANCE IN SERIES CIRCUITS

## Review

A series circuit is a circuit in which there is only one path through which the electrons can flow. The electrons leave the negative terminal of the voltage source and flow through one part after the other, and back to the positive terminal. The current is the same in all parts of a series circuit. The direction of current flow establishes a voltage polarity across each component.

## Self-Test Questions

Please check your answers on page 15.

- 1 What is a series circuit?
- 2 If R1 equals 3 ohms, R2 equals 4 ohms, and R3 equals 5 ohms, what is the total resistance of the three resistors in series? *12 ohms*
- 3 If these five resistors are connected in series: R1 equals 1500 ohms, R2 equals 2.2k, R3 equals 2700 ohms, R4 equals 4.7k, and R5 equals 1000 ohms, what is the total resistance? *12,100 ohms*
- 4 If these five resistors are connected in series: R1 equals 3.3M, R2 equals 680k, R3 equals 560k, R4 equals 2.2M, and R5 equals 470,000 ohms, what is the total resistance? *7210k*

$$\begin{array}{r} 1500 \\ 2200 \\ 2700 \\ 4700 \\ 1000 \\ \hline 12100 \end{array}$$

$$\begin{array}{r} 680k \\ 470k \\ 2560k \\ 2200k \\ 3300k \\ \hline 7210k \end{array}$$

$$\begin{array}{r} 1000 \\ 33 \\ \hline 3000 \\ 3000 \\ \hline 3000.0 \end{array}$$

# SERIES CIRCUITS

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## CURRENT IN SERIES CIRCUITS

As a technician maintaining electronic equipment, you will seldom have to calculate the current flow in the circuit. However, occasionally you will want to know what the current should be. Calculating the current flow in a circuit is very simple — you use Ohm's law in the form:

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

where  $I$  = current,  $E$  = voltage, and  $R$  = resistance.

### A Simple Series Circuit

Figure 8 is a schematic of the simplest series circuit you will encounter. It is made up of a 12 V voltage source and a single resistor. Suppose  $R_1$  has a resistance of 6 ohms, and we want to find the current flow in the circuit. To do this, we substitute 12 for  $E$  and 6 for  $R$  in the Ohm's law formula and we have:

$$I = \frac{12}{6} = 2 \text{ A}$$

You will seldom find resistances as low as 6 ohms in electronic equipment. Most often the resistance will be in kilohms or megohms. You use the same form of Ohm's law to find the current flow, but you must first convert the resistance to ohms.

As an example, suppose  $R_1$  in Fig.8 has a resistance of 1.2 kilohms. To find the current flow, we first convert 1.2k to 1200 ohms. Then we substitute for  $E$  and  $R$  in the formula, and we have:

$$I = \frac{12}{1200}$$

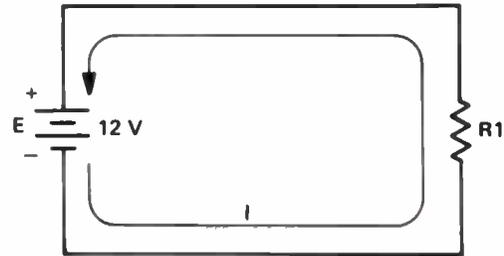


Figure 8. A simple series circuit.

If you have a pocket calculator, you can enter the numbers and perform the division. Your answer will be 0.01 ampere. Rather than work with a decimal number, we simply move the decimal point three places to the right and say that the current is 10 milliamperes (mA).

If you don't have a pocket calculator, and don't like working with decimals, you can multiply by 1000 and you'll get the current in milliamperes. For example:

$$I = \frac{12}{1200} \times \frac{1000}{1}$$

Next, simply cancel out two of the 0s above the division line and the two 0s below the division line:

$$I = \frac{12}{12} \times \frac{10}{1}$$

Finally, divide 12 into 12 and multiply by 10:

$$I = \frac{12}{12} \times 10 = 1 \times 10 = 10 \text{ mA}$$

Now let's suppose the resistance of  $R_1$  in Fig.8 is 600 kilohms. First, you convert this to 600,000 ohms. If you have a calculator, you can enter the

## CURRENT IN SERIES CIRCUITS

values for E and R. Your answer will be either 0.00002 or  $2 \times 10^{-5}$ , depending on the type of calculator you have. This is the current in amperes. You can move the decimal point six places to the right to convert 0.00002 A to 20 microamperes ( $\mu\text{A}$ ).

If you do not have a calculator, you can still find the current. Simply enter the values for E and R in the formula and you have:

$$I = \frac{12}{600,000}$$

If you multiply by 1000 to get the answer in milliamperes, you will still have the problem of dividing 600 into 12. You can get around this by multiplying by 1,000,000. Your answer will be in microamperes:

$$I = \frac{12 \times 1,000,000}{600,000}$$

This looks complex, but allows you to simply cancel five 0s above and below the division line:

$$I = \frac{12 \times 1,000,000}{600,000}$$

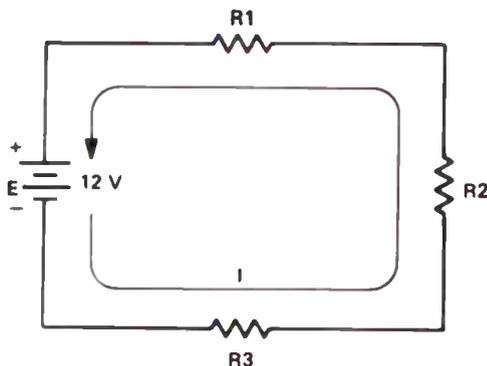


Figure 9. A series circuit with three resistors.

Cancelling the five 0s leaves you with:

$$I = \frac{12 \times 10}{6}$$

Finally, you divide 6 into 12 to get 2, then multiply by 10, or you can multiply 12 by 10 to get 120, and divide by 6 to get the current, 20 microamperes.

### Multiple Resistor Circuits

The same form of Ohm's law can determine the current flow in a series circuit containing two or more resistors. However, you must first add up the total resistance in the circuit. For example, if in Fig.9, R1 equals 1.2k, R2 equals 1.8k, and R3 equals 1000 ohms, you first convert the values of R1 and R2 to ohms, and then add the three resistance values. The total resistance in the circuit is 4000 ohms. This value fits into the formula:

$$I = \frac{12}{4000}$$

To get milliamps:

$$I = \frac{12 \times 1000}{4000}$$

Cancel 0s above and below the line:

$$= \frac{12,000}{4000}$$

$$= \frac{12}{4}$$

$$= 3 \text{ mA}$$

The total current flow in the circuit is 3 milliamperes. The battery supplies 3 mA; the current through R3 is 3 mA; the current through R2 is

# SERIES CIRCUITS

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3 mA; and the current through R1 is 3 milliamperes. It is a series circuit, and the current in all parts of the circuit is the same.

You use the same procedure for a series circuit, regardless of the number of resistors in the circuit. First, you find the total resistance in the circuit by converting all resistances to ohms and adding them. Use the total resistance in the circuit, along with the source voltage, to calculate the current flow in the circuit.

## Review

In this section we have demonstrated how to find the current in a series circuit. In each case, we use Ohm's law in the form:

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

To find the current flow in a series circuit, first find the total resistance in the circuit. The voltage must be expressed in volts and the resistance in ohms. To avoid a decimal division, you can multiply by 1000 to get the current in milliamperes. If necessary, you can multiply by 1,000,000 to get the current in microamperes.

## Self-Test Questions

- 5 What is the current in a series circuit made up of three 4-ohm resistors if the applied voltage is 24 volts?
- 6 A 3k, a 1000-ohm, and a 2k resistor are connected in series across a 12 V battery. What is the current?
- 7 Four resistors are connected in series across a 120 V battery. If R1 equals 2.2M, R2 equals 600k, R3 equals 1.2M, and R4 equals 2,000,000 ohms, what is the circuit current?

Handwritten calculations for the self-test questions:

- For question 5:  $24 \text{ V} / 12 \text{ ohms} = 2 \text{ A}$
- For question 6:  $12 \text{ V} / 5000 \text{ ohms} = 2.4 \text{ mA}$
- For question 7:  $120 \text{ V} / 6000000 \text{ ohms} = 20 \text{ microamps}$

Additional handwritten notes include:  $1.2 \text{ M} = 1200000$ ,  $2.2 \text{ M} = 2200000$ ,  $600 \text{ k} = 600000$ ,  $2000000$ ,  $1.2 \text{ M} = 1200000$ ,  $2000000$ ,  $20 \text{ microamps}$ ,  $2 \text{ A}$ ,  $2 \text{ mA}$ ,  $2000000$ ,  $20 \text{ microamps}$ ,  $1.2$ ,  $2.0$ ,  $2.2$ ,  $.6$ ,  $6.0$ ,  $6000$ ,  $120000$ ,  $120000$ ,  $6$ ,  $120$ ,  $6000000$ .

## VOLTAGES IN SERIES CIRCUITS

In a series circuit having several resistances, if you know the current flow and the resistance values in the circuit, you can find the voltage across each resistor by using Ohm's law in the form:

$$E = I \times R$$

We shorten this formula by leaving out the multiplication sign and writing it as:

$$E = IR$$

### Voltage Drop

Voltage creates, or forces, the flow of electric current through resistances in a series circuit. Each resistance uses up some of the total voltage in the process. The voltage across the resistance, or across any load, is the amount necessary to force current through it. The voltage across a part in a circuit is called the "voltage drop." The direction of current flow establishes the polarity of the voltage drop.

Look at Fig.10, which shows three resistors connected in series. As illustrated, a voltmeter can be connected across each resistor to measure the voltage, according to the polarity of the voltage that appears across the resistor. Reversing the connections to the voltmeter will result in a reading of negative voltage on the meter.

In the circuit shown, electrons leave the negative terminal of the 24 V battery and flow through R3 in the direction indicated by the arrow. The current flow through R3 produces a voltage across the resistor. The end that the electrons enter is negative, and the end from which they leave is

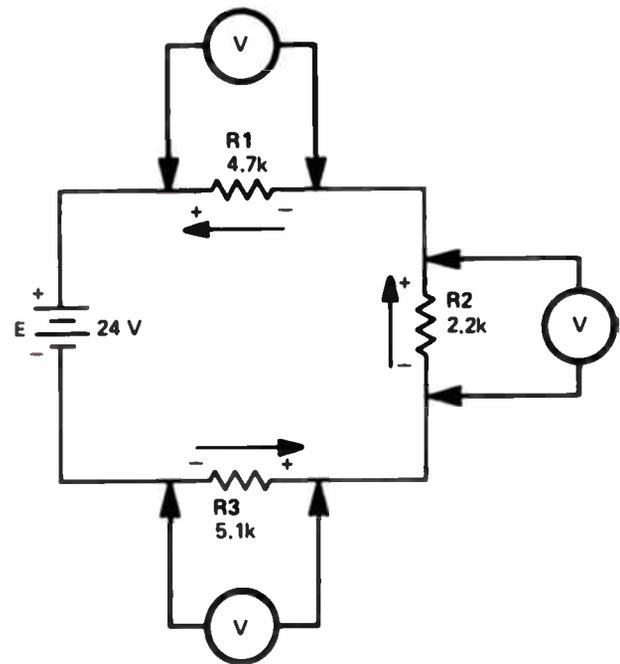


Figure 10. A series circuit showing the polarity of the voltage drop across each component.

positive. The portion of the 24 V used up across the resistor is the voltage drop.

To determine the voltage drop across R3, we must first determine the circuit current. Adding the resistance of the three resistors to get 12,000 ohms, we divide 24 V by 12,000, and calculate a current of 0.002 ampere. Now, using the resistance in ohms and the current in amperes, we can determine the voltage E3 across R3. We substitute 0.002 for I, and 5100 for R to get:

$$E_3 = 0.002 \times 5100 = 10.2 \text{ V}$$

We can go ahead and calculate the voltage across R2 and the voltage across R1 in the same way. We will find that the voltage across R2 is 4.4 V and the voltage across R1 is 9.4 volts.

## SERIES CIRCUITS

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Now, add the three voltage drops together and we have:

$$E = 9.4 + 4.4 + 10.2 = 24$$

Notice that the sum of the voltage drops is equal to the applied voltage. This is always true in any series circuit. In any closed series circuit, the sum of the voltage drops will be equal to the source voltage.

### Kirchhoff's Law

Kirchhoff's law is an important rule in electronics. It states that in any closed series circuit, the sum of the voltage drops will be equal to zero. Let's look again at Fig.10 and see exactly what this means.

If you follow the circuit, beginning from the negative terminal of the battery, you first arrive at R3. The voltage polarity across R3 is such that you move from negative to positive as you go through R3. Again, at R2 you move from negative to positive following the current path, and once again from negative to positive through R1.

When you reach the battery, however, you encounter the positive terminal. If you continue moving in the direction of current flow, you travel from positive to negative, not negative to positive as you did with the resistors in the external circuit. The source voltage polarity is opposite from the polarity of the voltage drops in the load resistances.

Reflecting back to Kirchhoff's law, we are looking for the sum of the voltage drops in the circuit. If we consider the voltage drops across the resistors as being positive voltage values, then the battery must be regarded as a negative voltage drop because it is of opposite polarity. Don't forget that the battery is just as much a part of the circuit as the resistors, since the same cur-

rent must flow through the battery as flows through the rest of the complete series circuit.

Therefore, to add the voltage drops around the circuit, you have to assign a negative value to the voltage across the battery, and positive values to the voltages across the resistors. The voltage drops around the circuit are: +10.2 for R3, +4.4 for R2, +9.4 for R1, and therefore -24 for the battery. The algebraic sum of these values is zero, as Kirchhoff's law states. This is true of all electronic circuits. It is also another way of saying that the sum of the voltage drops across the resistances in a series circuit is equal to the source voltage.

Another important thing to notice is that R3 has the highest resistance and the largest voltage drop. R2 has the lowest resistance and the lowest voltage drop across it. In any series circuit, the size of the voltage drop across a resistor depends upon the resistance of the resistor. The higher the resistance, the greater the voltage drop; the lower the resistance, the smaller the voltage drop.

In a circuit like the one shown in Fig.10, if the voltage drop across two of the resistors is known, you can use Kirchhoff's law to find the voltage across the third. For example, suppose the voltage across R1 is 9.4 V and the voltage across R3 is 10.2 volts. What is the voltage drop across R2?

We know that the sum of the three voltages must be equal to 24 volts. Adding together the voltages across R1 and R3, we get 19.6 volts. Since the sum of all three must be 24, we subtract 19.6 from 24, for a difference of 4.4 V, the voltage across R2.

There is another way to use Kirchhoff's law. Suppose you have a 6-ohm and a 9-ohm resistor connected in series, and the voltage drop across the 6-ohm resistor is 12 volts. How can you calculate the battery voltage?

# VOLTAGES IN SERIES CIRCUITS

You know that the sum of the voltage drops is equal to the source voltage. You also know that in a series circuit, the current is the same in all parts of the circuit, so the current through the 9-ohm resistor is the same as the current through the 6-ohm resistor. The current through the 6-ohm resistor is equal to the voltage drop divided by the resistance value. Since 12 divided by 6 is 2, the current in the circuit is 2 amperes. The voltage drop across the 9-ohm resistor is equal to:

$$\begin{aligned} E &= IR \\ E &= 9 \times 2 \\ E &= 18 \text{ V} \end{aligned}$$

Add 18 V and 12 V to find the source voltage — 30 volts.

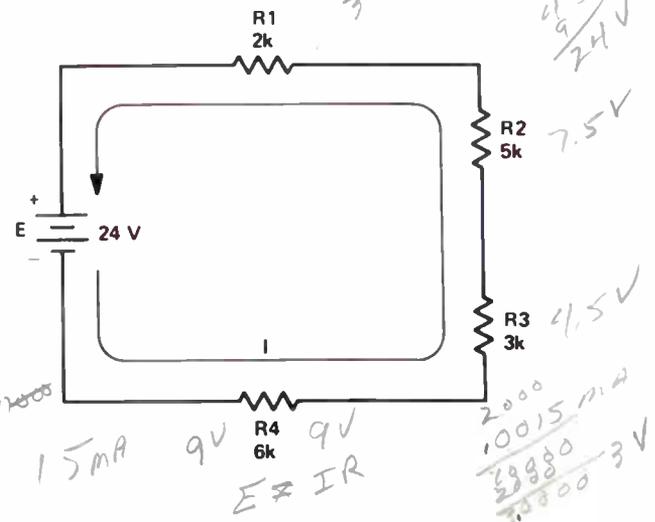
## Review

We have covered some very important points in this section of the lesson; points that you should remember. First, you learned that the voltage across the resistor in a circuit is called a voltage drop. As Fig. 10 shows, of the 24 V applied by the battery, part is being dropped across each resistor. You also learned that in any closed circuit the sum of the voltage drops around the complete circuit must be equal to zero. This is simply another way of saying that the sum of all the voltage drops is equal to the source voltage.

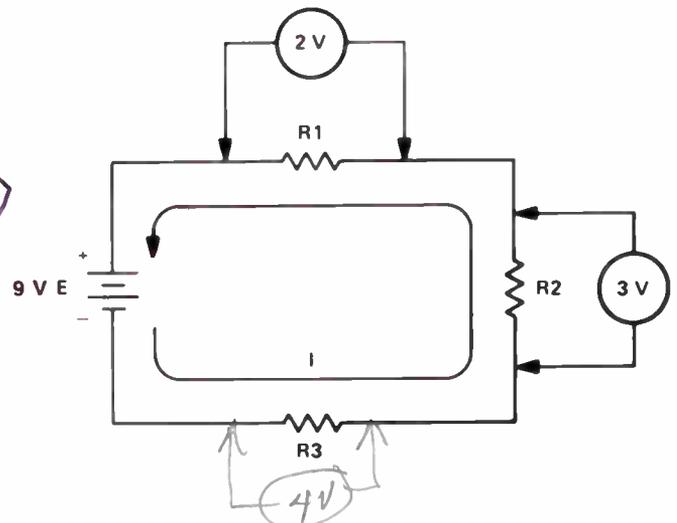
You also learned that the voltage across a resistor in a series circuit has a certain polarity. The end that the electrons enter is negative and the end from which they leave is positive. This will be true of all dc circuits. You also learned that by multiplying the current (in amperes) by the resistance (in ohms), you can find the voltage drop across a resistor.

## Self-Test Questions

- Four 3k resistors are connected in series across a 12 V battery. What is the voltage across each resistor?
- Find the voltage drop across each resistor in the circuit shown below.



- In the circuit below, if the battery voltage is 9 V, the voltage drop across R1 is 2 V, and the voltage drop across R2 is 3 V, what is the voltage drop across R3?



# SERIES CIRCUITS

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## POWER IN ELECTRICAL CIRCUITS

Power in an electrical circuit is the rate at which energy is consumed. The basic unit for electrical power is the watt (W). This is a familiar term — electric light bulbs are rated in watts. A 60 W bulb consumes 60 W of electrical energy per hour. A 100 W electric bulb consumes 100 W — almost twice as much power as a 60 W bulb.

### The Watt

In an electrical circuit, power is equal to the product of the voltage and the current, or:

$$P = E \times I$$

We generally drop the multiplication sign and simplify the formula as:

$$P = EI$$

This formula tells us that if a power source supplies a voltage of 1 V to a circuit, and a current of 1 A flows, the power being supplied is 1 watt. If the power source supplies 10 V and a current of 2 A, the power being supplied is 20 W ( $10 \times 2 = 20$  watts).

You can see that the current used by a 100 W electric bulb operating on a 120 V line is slightly less than 1 ampere. We can find the exact value by rearranging the power formula to:

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

Substituting 100 W for P and 120 V for E we get:

$$I = \frac{100}{120} = 0.83 \text{ A}$$

A 60 W light bulb draws somewhat less current:

$$I = \frac{60}{120} = 0.5 \text{ A}$$

The power in an electrical circuit can also be expressed in terms of current and resistance by combining the power formula with Ohm's law. For example, from Ohm's law we know that:

$$E = I \times R$$

If we substitute  $I \times R$  for E in the power formula we have:

$$\begin{aligned} P &= E \times I \\ &= I \times R \times I = I \times I \times R \end{aligned}$$

If we drop the multiplication sign and write  $I \times I$  as  $I^2$ , we have the formula:

$$P = I^2 R$$

You will see this expression many times in electronics: "P equals I squared R." Later you'll see how useful this form of the power equation is. (The expression  $I^2$  means I times I.)

We can also express the power in an electrical circuit in terms of voltage and resistance. Going back to our original formula:

$$P = E \times I$$

and Ohm's law in the form of:

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

if we substitute  $\frac{E}{R}$  for I we get:

$$P = E \times \frac{E}{R}$$

# POWER IN ELECTRICAL CIRCUITS

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We usually write this as:

$$P = \frac{E^2}{R} \quad 7^a$$

The expression  $E^2$  means E times E. This is read, "P equals E squared over R." This form of the power equation can be used when we know the voltage across the part and the resistance of the part.

Even though you may never have to do any calculating with these three power formulas, you should remember them because they tell you a great deal about what is happening in a circuit. The three formulas are:

$$P = EI$$

$$P = I^2R$$

$$P = \frac{E^2}{R}$$

Some devices use large amounts of power. When the watt is too small a unit of measure, we use the kilowatt. Kilowatt is abbreviated kW. A kilowatt is equal to 1000 watts. 10,000 W equal 10 kilowatts. Some radio broadcast stations operating on the standard AM broadcast band operate with a power of 50 kilowatts. These are the stations that you can hear all over the country after sundown. Local radio stations broadcasting to a metropolitan area usually have a power of about 5 kilowatts. An even larger unit than the kilowatt is the megawatt (MW). The megawatt is equal to 1,000,000 watts.

In the opposite case, sometimes a watt is too large a unit, so power is measured in milliwatts. There are 1000 milliwatts (mW) in a watt; 1 mW is one thousandth of a watt. An even smaller unit is the microwatt ( $\mu$ W), a millionth of a watt. There are 1,000,000  $\mu$ W in a watt.

In electronics you will seldom run into the term megawatt or microwatt. However, you will frequently encounter milliwatt, watt, and kilowatt.

## The Kilowatt Hour

The kilowatt hour, or kWh, is the unit that the power company uses to measure how much electricity you consume. If you use 1 kW of electricity (1000 W) for 1 hour, you have used 1 kilowatt hour.

If you turn on a 100 W bulb it will use 100 W of power. If you turned on 10 of them, you would be using 1 kW of power. If you leave them on for 1 hour, you will have used 1 kilowatt hour. You can also use 1 kWh of electricity by burning one 100 W bulb for 10 hours.

The burner on an electric stove uses about 1500 W of electricity. This is equal to 1.5 kilowatts. So, if you leave it on for 1 hour, you'll use 1.5 kWh of electricity. You would have to burn a 100 W electric light bulb for 15 hours to use the same quantity of electricity.

If you ever want to check your electric bill, all you need to do is multiply the number of kilowatt hours used by the charge per kilowatt hour. For example, if you used 120 kWh in a month, and the power company charges 6¢ per kilowatt hour, your bill for the month would be \$7.20 ( $120 \times 0.06 = 7.20$ ). If you live in an area where most of the electricity is generated by hydroelectric power, the charge for a kilowatt hour will be quite low. On the other hand, if you live in an area where the electricity is generated by burning coal or oil, the rate per kilowatt hour will be much higher.

# SERIES CIRCUITS

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## Review

The unit of electric power is the watt. The power in watts is equal to the product of the voltage multiplied by the current in the circuit. Two other units of power that you will encounter are the kilowatt, which is equal to 1,000 W, and the milliwatt, which is equal to one thousandth of a watt.

The kilowatt hour is the unit by which the power company charges you for the power used. If you use 1000 W of electricity (or 1 kW) for 1 hour, you will have consumed 1 kWh of electricity.

## Self-Test Questions

- 11 How much power is being consumed in a circuit if the voltage is 100 V and the current is 5 amperes? *500w*
- 12 How much power is being consumed in a circuit if the current is 1 A and the resistance is 1000 ohms? *1000w or 1kw*
- 13 How much power is being consumed in the circuit if the voltage is 100 V and the resistance is 1000 ohms? *10w*
- 14 How many kilowatt hours will be consumed in operating a portable oven for 2 hours if the oven is operating on a 120 V power line and draws 5 amperes? *1.2 kw*

$$\begin{array}{r} 120 \\ 5 \\ \hline 600\text{w} \\ \times 2 \\ \hline 1200 \end{array} \qquad 1.2 \text{ kw}$$

# ANSWERS TO SELF-TEST QUESTIONS

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## ANSWERS TO SELF-TEST QUESTIONS

- 1 A series circuit is a circuit in which the voltage source and the parts are connected so there is only one current path. The current leaving the negative terminal of the voltage source flows first through one part and then another to the positive terminal of the voltage source, and through the source back to the negative terminal. There is only one path through which current can flow.

- 2 The total resistance in the circuit will be equal to the resistance of the sum of the resistors.

$$R_T = 3 + 4 + 5 = 12 \text{ ohms}$$

- 3 To find the total resistance, you express all resistances in ohms and add them:

$$\begin{array}{r} 1500 \\ 2200 \\ 2700 \\ 4700 \\ +1000 \\ \hline 12,100 \end{array}$$

The total resistance is 12,100 ohms, or 12.1 kilohms.

- 4 To obtain the total resistance, you must first express the resistance of all resistors in the same unit and then add them. You need to express the resistance in ohms, or kilohms, as shown at the top of the next column.

$$\begin{array}{r} 3,300,000 \\ 680,000 \\ 560,000 \\ 2,200,000 \\ +470,000 \\ \hline 7,210,000 \\ \text{(ohms)} \end{array} \qquad \begin{array}{r} 3300 \\ 680 \\ 560 \\ 2200 \\ +470 \\ \hline 7210 \\ \text{(kilohms)} \end{array}$$

5  $I = \frac{24}{12} = 2 \text{ A}$

- 6 In this example, the total resistance is 6000 ohms. To find the current we use:

$$I = \frac{12}{6000}$$

To get rid of the decimal division, we multiply by 1000, which will give us our answer in milliamperes:

$$I = \frac{12}{6000} \times 1000$$

Now, we cancel three 0s above and below the division line and divide 6 into 12 and get 2 milliamperes.

$$I = \frac{12,000}{6000} = 2 \text{ mA}$$

- 7 The total resistance in the circuit is 6M, or 6,000,000 ohms. Substituting 120 for E and 6,000,000 for R we have:

$$I = \frac{120}{6,000,000}$$

Next, we multiply by 1,000,000 to avoid the decimal division.

$$I = \frac{120}{6,000,000} \times 1,000,000 \mu\text{A}$$

## SERIES CIRCUITS

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Now, we cancel the six 0s above and below the division line, and divide 6 into 120, to give us our answer, 20 microamperes.

$$I = \frac{120,000,000}{6,000,000} = 20 \mu\text{A}$$

- 8 You do not have to find the current to get the answer here. Since all resistors have the same value, 3k, they will have the same voltage across them. So, to find the voltage across each of the four, you simply divide 4 V into 12 V and find that the voltage across each resistor will be 3 volts.
- 9 The first step in this problem is to find the total resistance by adding the resistance of each resistor. The total resistance is 16k, which is equal to 16,000 ohms. Now that we know the resistance, we can find the current in the circuit:

$$I = \frac{24}{16,000} \quad 12$$

Next, we multiply by 1000 to get the current in millamperes, and to avoid the decimal division:

$$I = \frac{24}{16,000} \times 1000$$

Now, cancel the three 0s above and below the division line, and divide 16 into 24 to get the current 1.5 millamperes.

$$I = \frac{24,000}{16,000} = 1.5 \text{ mA}$$

We use the formula  $E = I \times R$  to find the voltage. The current must be in amperes and the resistance in ohms. 1.5 mA is 0.0015 ampere. The resistance of R1 is 2k, so we have

$E = 0.0015 \times 2000 = 3$  volts. Using this same procedure of multiplying the resistance of each resistor by the current of 0.0015, we find the remaining voltages: R2 equals 7.5 V, R3 equals 4.5 V, and R4 equals 9 volts. The four voltages total 24 V, so we know that your answer is correct.

- 10 Here we know that the voltage across R1 is 2 V, the voltage across R2 is 3 V, and the total voltage is 9 volts. To find the voltage across R3, we simply add the voltage across R1 and R2 and get 5 V, and then subtract this from 9 V to get the voltage across R3 — 4 volts.
- 11 To find the power in this case we use the power formula  $P = E \times I$ . Substituting 100 V for E and 5 A for I, we have:

$$P = 100 \times 5 = 500 \text{ W}$$

- 12 In this case, we use the power formula  $P = I^2R$ . We substitute 1 for I and 1000 for R and we have:

$$P = 1 \times 1 \times 1000 \\ = 1000 \text{ W, or } 1 \text{ kW}$$

- 13 In this case, we use the power formula  $P = E^2/R$ . Substituting 100 V for E and 1000 ohms for R, we have:

$$P = \frac{100 \times 100}{1000} = 10 \text{ W}$$

- 14 To find the number of kilowatt hours used, we first find the power being used. We do this by multiplying the voltage by the current to get 600 watts. Next, we multiply by the time, which is 2 hours. Thus we will have 1200 Watt hours, or 1.2 kilowatt hours.

## Lesson Summary

Some of the important facts that you should remember about this lesson are:

- Ohm's law describes the simple relationship between current, voltage, and resistance in electrical circuits.
- Ohm's law takes three basic forms; one determines resistance, one determines current, and one determines voltage in a circuit.
- Kirchhoff's law states that the sum of the voltage drops in a series circuit is equal to the source voltage.
- Current, voltage, and resistance determine the power used in a circuit.

$$P = E^2/R$$

$$2 \sqrt{16}$$

# SERIES CIRCUITS

## LESSON QUESTIONS

This is Lesson Number 2218.

Make sure you print your name, student number, and lesson number in the space provided on the Lesson Answer Form. Be sure to fill in the circles beneath your student number and lesson number.

**Reminder:** A properly completed Lesson Answer Form allows us to evaluate your answers and speed the results and additional study material to you as soon as possible. Do not hold your Lesson Answer Forms to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

Name <u>John Smith</u>	
Print	
Student No.	Lesson No.
XY01237894	2218
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- The total resistance of three 15-ohm resistors connected in series is:
  - 45 ohms.
  - 30 ohms.
  - 15 ohms.
  - 5 ohms.
- A 1000-ohm, a 2200-ohm, and a 4700-ohm resistor are connected in series. Their total resistance will be:
  - 6900 ohms.
  - 7500 ohms.
  - 7900 ohms.
  - 8900 ohms.
- What is the total resistance of a 5.6k, a 2200-ohm, a 4.7k, and a 1000-ohm resistor connected in series?
  - 3303 ohms.
  - 10,000 ohms.
  - 13,500 ohms.
  - 15,000 ohms.

5600  
2200  
4700  
1000  
-----  
13500

- A 3-ohm, 5-ohm, and 4-ohm resistor are connected in series across a battery. The voltage drop across the 3-ohm resistor is 6 volts. The battery voltage is:
  - 6 volts.
  - 8 volts.
  - 10 volts.
  - 24 volts.
- If three resistors are connected in series across a 12 V battery, and the voltage drop across one resistor is 3 V and the voltage drop across the second resistor is 2 V, the voltage drop across the third resistor will be:
  - 2 volts.
  - 3 volts.
  - 7 volts.
  - 12 volts.

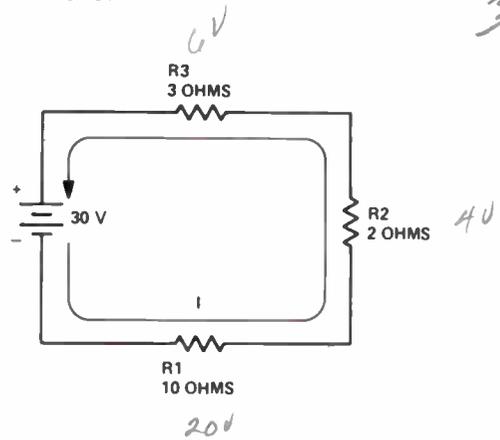
# LESSON QUESTIONS

6. Three 2.2k resistors are connected in series across a 12 V battery. The voltage drop across each resistor will be:
- 2 volts.
  - 4 volts.**
  - 6 volts.
  - 8 volts.

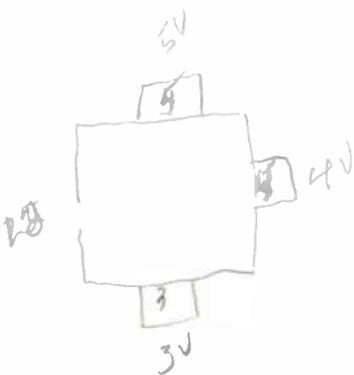
7. A 3-ohm, 4-ohm, and 5-ohm resistor are connected in series across a 12 V battery. The voltage drop across the 3-ohm resistor will be:
- 2 volts.
  - 3 volts.**
  - 4 volts.
  - 5 volts.

8. In the example described above in Question 7, how much power is the battery supplying to the circuit?
- 12 watts.**
  - 24 watts.
  - 48 watts.
  - 96 watts.

9. In the circuit shown below, the power dissipated by R2 is:
- 4 watts.
  - 8 watts.**
  - 12 watts.
  - 16 watts.



10. How much will it cost to operate five 100 W bulbs for 24 hours if electricity costs 6¢ per kilowatt hour?
- 24 cents.
  - 48 cents.
  - 72 cents.**
  - 96 cents.



Handwritten notes for Question 8:

$$P = E \times I$$

$$P = \frac{V}{R} \times I$$

$$12 \times 2 = 24$$

$$\sqrt{144}$$

Handwritten notes for Question 10:

$$12 \times 12 = 144$$

$$\sqrt{144}$$

Handwritten notes for Question 10:

$$2.2 \times 600 \times 12 = 15840$$

$$\frac{15840}{1000} = 15.84 \text{ kWh}$$

$$15.84 \times 6 = 95.04 \text{ cents}$$

## NOTES

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## BELIEVE IN YOURSELF

Here are a number of statements made by famous, successful people on the subject of believing in yourself. I quote several of them just to show you how important self-confidence really is:

“Anything that you have a real desire to do, you have the capacity to do. Believe *that* and act upon your belief. There are no dreams that can't come true.”

“Believe in yourself. Believe in humanity. Believe in the success of your undertakings. Fear nothing and no one. This way, you cannot fail!”

“I CAN IF I THINK I CAN! Write these words in letters an inch high and put them where you can see them every day. Memorize and repeat them — aloud and to yourself — a dozen times a day.”





# Parallel Circuits

2219



*NRI Schools*

*A Division of The McGraw-Hill Companies*

*Washington, DC 20008*





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# Parallel Circuits



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# Table of Contents

<b>Introduction</b> .....	1
<b>Parallel Circuits</b> .....	2
Resistors in Parallel .....	2
Voltage and Current in Parallel Circuits .....	7
Review .....	7
Self-Test Questions .....	7
<b>Series-Parallel Circuits</b> .....	8
Resistance in Series-Parallel Circuits .....	8
Voltage and Current in Series-Parallel Circuits .....	9
Review .....	11
Self-Test Questions .....	11
<b>Answers to Self-Test Questions</b> .....	12
<b>Lesson Questions</b> .....	15

## PARALLEL CIRCUITS

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# Lesson Objectives

In this lesson you will . . .

- Learn how to identify parallel circuits.
- Discover how resistance in parallel behaves differently from resistance in series.
- Learn how to determine voltages and currents in parallel circuits.
- See how combinations of parallel and series circuits work.

### INTRODUCTION

Electronic circuits can be connected in two basic ways: in series and in parallel. Because of their simplicity, we have discussed only series circuits so far. In this lesson we will move forward to parallel circuits. Later you will study circuits in which some parts connect in parallel and other parts connect in series. These combination circuits are called series-parallel circuits. Most pieces of electronic equipment are composed of many combinations of series and parallel circuits.

A 3-bulb floor lamp is a good example of a parallel circuit. Many of these lamps have a 3-position switch. Rotating the switch from the OFF position to the ON position lights one lamp. The next rotation turns on two lamps. The two

lamps are connected in parallel. There is a separate current path through each lamp.

If you rotate the switch once more, all three lamps light. This illustrates the way that current moves in three parallel circuit paths. If one light bulb burns out or is removed, the other two still light. This is because there is an independent path for current flow through each bulb. If the three bulbs were in series, removing one would keep the other two from lighting, because only one current path would exist. If the current path is broken in a series circuit, there is no path for current flow.

Just as there are rules for series circuits, there are also rules for parallel circuits. In this lesson you'll learn what these rules are, and you'll see how they will help you in future lessons and in your career in electronics. Now let's go ahead with the study of parallel circuits.

## PARALLEL CIRCUITS

### PARALLEL CIRCUITS

In a series circuit, the same current flows through all parts of the circuit. A *parallel circuit* may have a number of different branches, each with a different amount of current flow. If two resistances connect in parallel, there are two paths for current; if three resistances are in parallel, there are three paths for current. The current flowing in each path or branch of the circuit can be, and usually is, different. Let's look at some typical parallel circuits.

#### Resistors in Parallel

In Fig.1(A) two 6-ohm resistors are connected in parallel. Figure 1(B) shows how these resistors could be connected across a battery. When electrons from the negative terminal of the battery reach the junction of the two resistors, half of the electrons flow through one resistor, and

half flow through the other resistor. In this case, the electron flow divides exactly in half, since the two resistors are of equal value. In contrast, resistors of different values would cause a proportional difference in current flow through each parallel branch.

The electrons flowing in each resistor join again at the other junction of the two resistors, and flow back to the positive terminal of the battery. Figure 1(C) shows a different way to draw the same circuit, but its difference from the diagram in Fig.1(B) is that it does not indicate a change in the basic operation of the circuit. Electrons flowing from the negative terminal of the battery divide at the junction; half go through one 6-ohm resistor and half through the other. The two currents join at the other junction, and return to the positive terminal of the battery.

Remember that two 6-ohm resistors in series create a total resistance equal to the sum of the two values, or 12 ohms. What about two 6-ohm

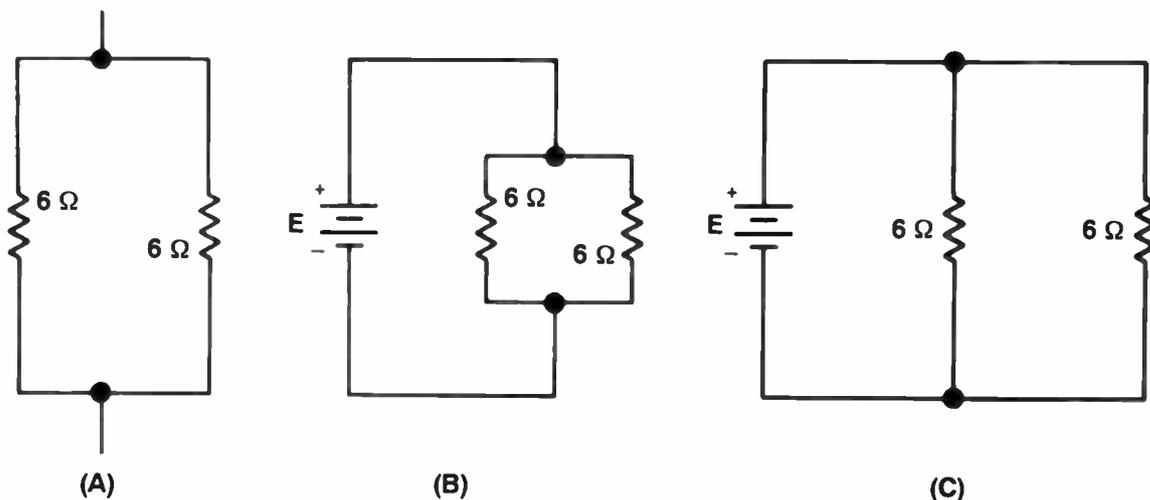


Figure 1. Simple parallel resistor circuits.

## PARALLEL CIRCUITS

resistors connected in parallel? What effect does this have on the total resistance?

To find the total resistance of the two 6-ohm resistors connected in parallel, let's first assume that the battery voltage is 6 volts. As you can see, the battery voltage is directly applied across each resistor, so each resistor has a voltage drop equal to 6 volts. This is unlike the case for voltage drops in a series circuit, where the source voltage is distributed among the resistances in the circuit because only one current path exists. Here, each resistance experiences the full force of applied voltage.

With 6 V applied from the battery, the current flow through each resistor will be:

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

where I is the current in amperes, E is voltage in volts, and R is resistance in ohms.

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

Since 1 A flows through each resistor, the total current flow in the circuit is 2 amperes. This is an important point to remember: parallel circuits draw more current than series circuits containing the same resistance values. In comparison, a series circuit with two 6-ohm resistors has a total current flow of 0.5 A, or 500 milliamperes.

To find the total resistance in a circuit voltage of 6 V and a current of 2 A, use this formula:

$$\begin{aligned} R_T &= \frac{E}{I} \\ &= \frac{6}{2} \\ &= 3 \text{ ohms} \end{aligned}$$

The resistance of two 6-ohm resistors connected in parallel is 3 ohms. Remember to calculate the total circuit current first, then divide that into the applied voltage to get the total circuit resistance. Each resistor is still 6 ohms individually. It is the combination of the two in parallel that makes the difference.

Notice that the total resistance becomes exactly half the value of either resistor. This will always be true; when two resistors of equal value are connected in parallel, the total resistance of the parallel combination is half the value of one of the resistors alone.

By the same token, the combined resistance of three equal resistors in parallel is one-third the resistance of one. A parallel connection of four equal-value resistors has one-fourth the resistance of one resistor alone.

The relationships described above hold true for any value of applied voltage. For example, if the battery voltage is 12 V, the current flow through each resistor is 2 A, for a total current of 4 amperes. The resistance is equal to 12 V divided by 4 A, so once again the resistance is 3 ohms.

**Unequal Resistances in Parallel.** What if the resistors are not equal in value? In Fig.2(A), on the next page, we have a 4-ohm and an 8-ohm resistor connected in parallel. In the circuit shown in Fig.2(B), these two resistors are shown connected to an 8 V battery.

To find the total resistance of the two unequal resistors in parallel, we must again calculate the total current flow. In the branch with the 4-ohm resistance, the current is 2 A, or 8 V divided by 4 ohms. In the other branch the current is 1 A, or 8 V divided by 8 ohms. The total current flow is the sum of the currents in the branches: 2 + 1 = 3 amperes. The total resistance of the two resistors in parallel is equal to 8 V divided by 3 A, or approximately 2.67 ohms.

## PARALLEL CIRCUITS

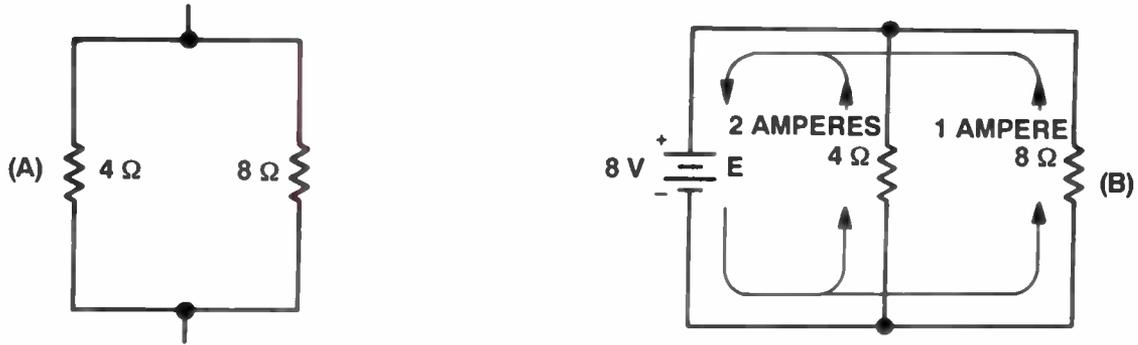


Figure 2. Finding the value of a 4-ohm resistor in parallel with an 8-ohm resistor.

The preceding examples are quite simple because the resistance values are low, and it is easy to divide the voltage by the resistance to get the current. However, this is not always the case. For this reason, there is another method of finding the value of resistors in parallel. We use the formula:

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

What you are doing is multiplying the resistor values, and then dividing the result by the sum of the resistor values. For the case of the equal-value resistors in the section above, this equation becomes:

$$R_T = \frac{6 \times 6}{6 + 6} = \frac{36}{12} = 3 \text{ ohms}$$

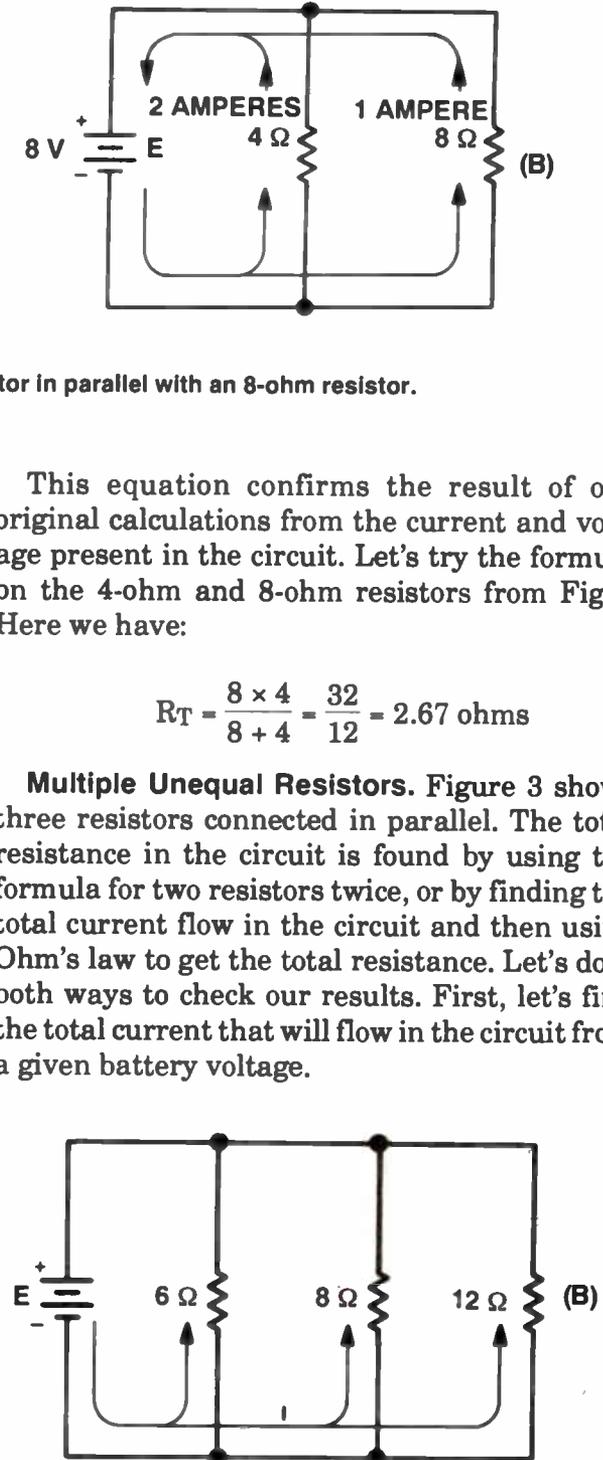
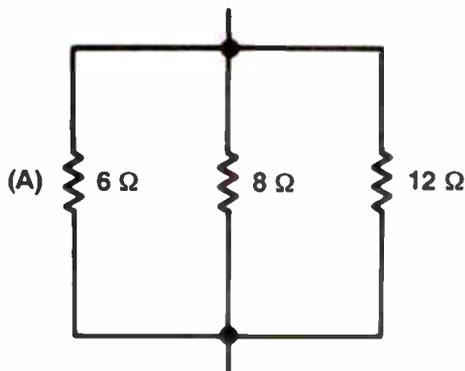


Figure 3. A parallel circuit with three current paths.

## PARALLEL CIRCUITS

Let's use as an example a voltage of 24 V, which is the lowest voltage that all three resistance values will divide into evenly. Since 24 divided by 6 is 4, the current through the 6-ohm branch is 4 amperes. And 24 divided by 8 is 3, so the current through the 8-ohm branch is 3 amperes. Finally, 24 divided by 12 is 2, so the current flow through the 12-ohm branch is 2 amperes. Therefore, the total current flow in the circuit with a voltage of 24 V applied will be 9 A (4 + 3 + 2 = 9). Now, by using Ohm's law and substituting 24 V for the voltage, and 9 A for the current, we get:

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

$$= \frac{24}{9}$$

$$= 2.67 \text{ ohms}$$

Let's solve the same problem using the formula for two resistors in parallel. Group the 6-ohm and the 12-ohm resistors first, and find their parallel resistance. Substituting 6 and 12 in the formula we get:

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

This means that the total resistance of a 6- and a 12-ohm resistor connected in parallel is 4 ohms. We can treat this combination as a single 4-ohm resistor and find its resistance in parallel with an 8-ohm resistor. Using the formula we get:

$$R = \frac{4 \times 8}{4 + 8} = \frac{32}{12} = 2.67 \text{ ohms}$$

Figure 4 shows five resistors in parallel. We can easily find the total resistance of this combination either by assuming a voltage and finding the total current, or by grouping the

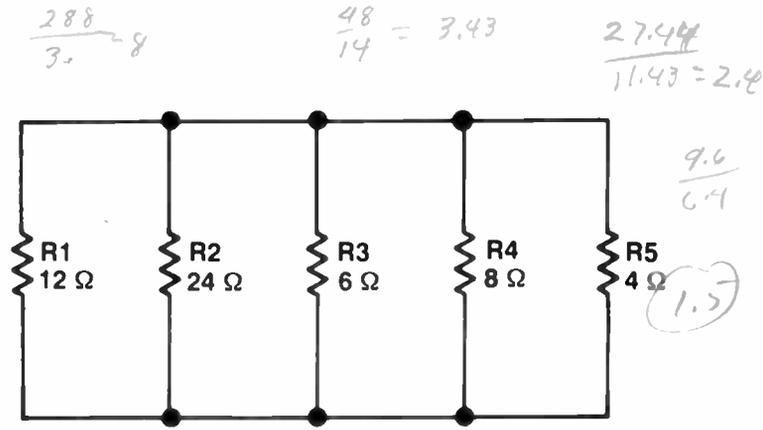


Figure 4. Five resistors in parallel.

resistors in groups of two and working out the problem using the parallel resistance formula. Let's use the latter method first.

Take R1 and R2 and substitute 12 and 24 in the formula. This will give us:

$$R = \frac{12 \times 24}{12 + 24} = \frac{288}{36} = 8 \text{ ohms}$$

The total resistance of R1 and R2 in parallel is 8 ohms. However, R4 is a single 8-ohm resistor, so R1 and R2 in parallel with R4 are the same as two 8-ohm resistors in parallel. Since the resistance of two equal-value resistors in parallel is half the resistance of one, the total combination of R1, R2, and R4 must be 4 ohms.

By fortunate coincidence, R5 has a resistance of 4 ohms. The 4-ohm combination of R1, R2, and R4 is in parallel with R5, so the total parallel resistance of these four resistors must be 2 ohms. All we have to do now is find the equivalence of 2 ohms in parallel with 6 ohms. That will be the total resistance of the entire parallel combination. We use the formula to do this:

$$R_T = \frac{6 \times 2}{6 + 2} = \frac{12}{8} = 1.5 \text{ ohms}$$

Calculating the resistance of many resistors in parallel will not always be as easy as in the

## PARALLEL CIRCUITS

previous example. In general, using pair-grouping and the formula is a simple, reliable method of finding parallel resistance. There are usually only two or three resistors involved, so the system works quite well. However, there is another formula for finding the resistance of any number of resistors in parallel. It is a more complicated process, but you may see it in other books, and you should know what it is. The formula is:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5}}$$

To find the parallel resistance of the five resistors in Fig.4, substitute the value of each resistor in to this formula:

$$R_T = \frac{1}{\frac{21}{12} + \frac{11}{24} + \frac{41}{6} + \frac{31}{8} + \frac{61}{4}} = \frac{16}{24} = \frac{2}{3}$$

You must find a common denominator for the fractions beneath the division line before they can be added together. (Again, the lowest common denominator is the smallest number into which all the values will divide.) In this case it is 24. So, by using 24 as our lowest common denominator, each fraction is converted to an equal number of twenty-fourths, and the numerators are combined over the common denominator.

To convert to a common denominator, divide the numbers into 24 and put the result above the line. For example, 12 into 24 equals 2, or 2/24. Similarly, 6 goes into 24 four times, which equals 4/24. Do the same for all the fractions.

$$R_T = \frac{1}{\frac{2}{24} + \frac{1}{24} + \frac{4}{24} + \frac{3}{24} + \frac{6}{24}}$$

After all the fractions have been converted to their common denominator (24), add the top

numbers together. The resulting fraction will be 16/24. The formula will now be:

$$R_T = \frac{1}{\frac{16}{24}}$$

To perform the final division, simply convert the fraction to 24/16. Then divide 24 by 16 to get 1.5 ohms. This is the answer you got with the other method.

$$R_T = \frac{24}{16} = 1.5 \text{ ohms}$$

Another method is to assume a voltage across the parallel combination, find the total current, and use Ohm's law to get the total parallel resistance. Let's assume a voltage of 24 V, since this is the lowest value you can assume and have each resistance divide into it evenly.

With a voltage of 24 V, the current flow through R1 is 2 amperes. There is 1 A of current through R2, 4 A through R3, 3 A through R4, and 6 A through R5. Thus, the total current flow in the circuit is 16 A (2 + 1 + 4 + 3 + 6 = 16). Now, using Ohm's law, the total resistance turns out to be:

$$R_T = \frac{E}{I} = \frac{24}{16} = 1.5 \text{ ohms}$$

Notice that, in each of the preceding examples, the total resistance of resistors connected in parallel is always less than the resistance of the smallest one. This is true because a resistor connected across a voltage source conducts a certain current; if you add another resistor in parallel, regardless of how large a resistance you add, the total current flow in the circuit increases because you have added a current path. Ohm's law tells you that the resistance is equal to the voltage divided by the current; if the current increases, the effective resistance decreases because the voltage remains the same.

## PARALLEL CIRCUITS

### Voltage and Current in Parallel Circuits

In a series circuit, the current is the same in all parts of the circuit. The voltage drop across a part depends upon the resistance of the part. A parallel circuit behaves in an opposite fashion. Since the parts are all connected in parallel directly across the power source, the voltage drop is the same across all of the parallel parts. You cannot have two parts connected in parallel and have unequal voltages across them.

Current flow through each branch of a parallel circuit depends upon the resistance in the branch. The lower the resistance, the higher the current, the higher the resistance, the smaller the current.

### Review

When two or more resistors are connected in parallel, the total resistance of the parallel combination is less than the resistance of the smallest resistor. When equal-value resistors are connected in parallel, the total resistance is equal to the individual resistor value divided by the number of resistors. When resistors are connected in parallel, each has the same voltage across it. The current that flows through each resistor depends upon its value. The highest current flows through the smallest resistor.

The combined resistance of parallel resistors can be calculated by assuming an applied voltage, and then dividing the value of each resistor into the voltage to find the branch current. The total current divided into the assumed voltage equals the combined parallel resistance. You can also take the resistors two at a time and use the following formula to find the total resistance of the parallel combination:

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

### Self-Test Questions

Please check your answers on page 12.

- 1 What is the total resistance of two 50-ohm resistors connected in parallel? 25
- 2 What is the total resistance of a 24-ohm resistor connected in parallel with a 12-ohm resistor? 8
- 3 If a 3-ohm and a 4-ohm resistor are connected in parallel across a 12 V battery, what will be the total current flow from the battery? What will be the total resistance of the 3-ohm and 4-ohm resistance in parallel? 7.2V  
1.7
- 4 If two 8-ohm resistors are connected in parallel with a 1000-ohm resistor, what will be the approximate resistance of the parallel combination? 3.98
- 5 In a parallel circuit, the voltage across all branches of the parallel circuit will be Same.
- 6 In a parallel circuit, the current that flows through each branch of a parallel circuit will depend upon the resistance of the branch. The largest current will flow through the branch having the lower resistance, and the smallest current will flow through the branch having the higher resistance.

## PARALLEL CIRCUITS

### SERIES-PARALLEL CIRCUITS

Series and parallel circuits can be found in all types of electronic equipment. In addition to these two types of circuits, there are many circuits that are combinations of series and parallel circuits. These circuits are called *series-parallel* circuits.

An example of a series-parallel circuit is shown in Fig.5. In this circuit, R2 and R3 are in parallel. Current flowing in the circuit splits into two smaller currents when it reaches the junction of R2 and R3. The current that flows through each resistor is proportional to the resistance of the branch. If the resistors are equal, half the total current flows through each. On the other hand, if one resistor is much larger than the other, more current flows through the smaller resistor. Also, since the two resistors are in parallel, the same voltage drop is present across each resistor.

The combination of the two parallel resistors R2 and R3 is in series with resistor R1 and the battery. While part of the circuit is a parallel circuit, part of it is a simple series circuit. In the series circuit you have the battery, R1, and the parallel combination of R2 and R3.

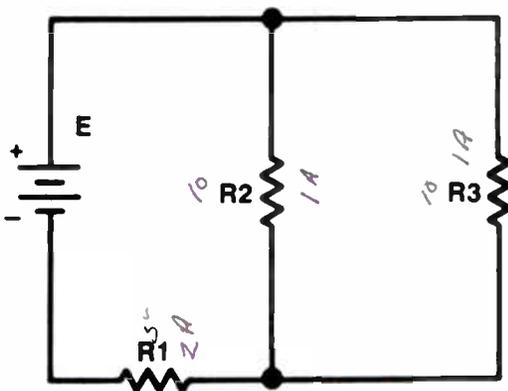


Figure 5. A series-parallel circuit.

In this circuit, electrons leave the negative terminal of the battery and flow through R1. The current divides after leaving R1, and flows through R2 and R3. However, since this parallel combination is in series with R1, the total current flow through R2 and R3 must be equal to the battery current and the current through R1.

#### Resistance in Series-Parallel Circuits

Figure 6 shows a series-parallel circuit similar to the one in Fig.5. In this example, R1 is the series resistor, with a value of 10 ohms. R2 and R3 form the parallel resistor combination. R2 has a resistance of 12 ohms and R3 has a resistance of 24 ohms. What we want to find is the total resistance in the circuit, since it determines the current flow from the battery.

First, find the resistance of R2 and R3 in parallel by using this formula:

$$R_p = \frac{R_2 \times R_3}{R_2 + R_3}$$

Then substitute 12 ohms for R2, and 24 ohms for R3, as shown at the top of the next page.

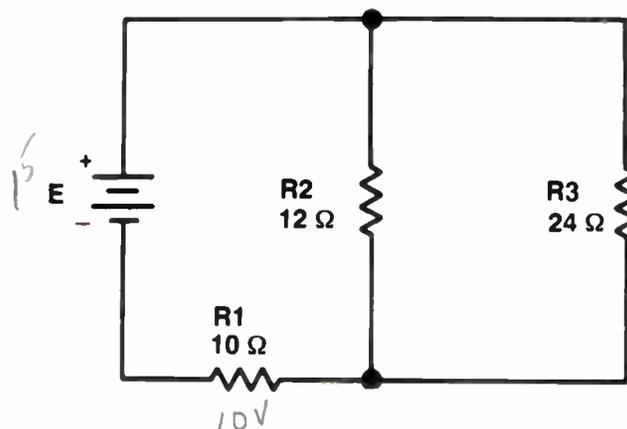


Figure 6. A series-parallel circuit with resistances shown.

## SERIES-PARALLEL CIRCUITS

$$\begin{aligned}
 R_p &= \frac{12 \times 24}{12 + 24} \\
 &= \frac{288}{36} \\
 &= 8 \text{ ohms}
 \end{aligned}$$

Therefore, the combined resistance of R2 in parallel with R3 is 8 ohms. For our purposes, R2 and R3 can be replaced by a single 8-ohm resistor, as shown in Fig.7. Notice the symbol used to indicate that R2 is in parallel with R3. The two parallel lines between R2 and R3 mean "in parallel with." This produces an equivalent simple series circuit with a total resistance of 18 ohms. Let's look at a more complicated circuit. Figure 8, on the next page, shows resistor R1 in series with a parallel combination of R2, R3, and R4. R5 is a second series resistor, followed by another parallel combination of R6 and R7. To find the total resistance in the circuit, we first have to find the equivalent series resistance of the parallel pair R6 and R7, plus the equivalent resistance of the R2, R3, and R4 combination.

First, looking at R2, R3, and R4, notice that each resistor is a 6-ohm resistor. When three equal-value resistors are connected in parallel, the total resistance of the combination is one-third the resistance of any one of the resistors. Therefore, the resistance of this combination is 6 divided by 3, which is 2 ohms. Using the formula to find the total resistance of R6 and R7, we get:

$$\begin{aligned}
 R_T &= \frac{12 \times 6}{12 + 6} \\
 &= \frac{72}{18} \\
 &= 4 \text{ ohms}
 \end{aligned}$$

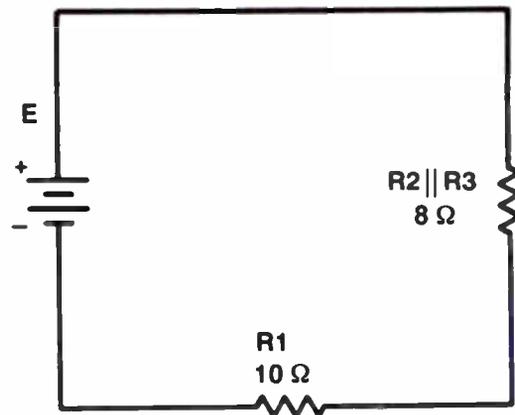


Figure 7. Series equivalent of the circuit in Figure 6.

Now you have a simple series circuit like the one shown in Fig.9, on page 11. To find the total resistance, all you need to do is add the resistance of each resistor:

$$\begin{aligned}
 R_T &= 3 + 2 + 4 + 4 \\
 &= 13 \text{ ohms}
 \end{aligned}$$

### Voltage and Current in Series-Parallel Circuits

Now let's see how the current divides, and what voltage is across each part of the series-parallel circuit shown in Fig.8. Since the total resistance of the circuit is 13 ohms, let's pick an easy battery voltage so our calculations will come out in whole numbers. Let's assume a battery voltage of 39 volts. With a battery voltage of 39 V and a total circuit resistance of 13 ohms, the total current flow for the entire circuit is provided on the next page.

## PARALLEL CIRCUITS

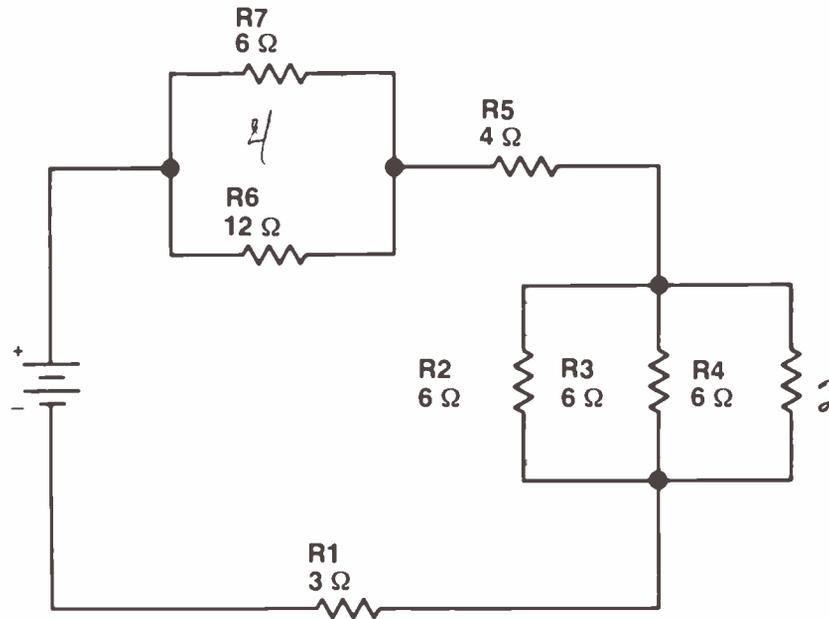


Figure 8. A series-parallel circuit with two series resistors and two parallel branches.

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

$$= \frac{39}{13}$$

$$= 3 \text{ A}$$

This means that the current flow through R1, which is one of the two series resistors, must be 3 amperes. Therefore, the voltage drop across it is:

$$E = IR$$

$$= 3 \times 3$$

$$= 9 \text{ V}$$

Look at R5, the other series resistor. Current flow through R5 is also 3 A, so the voltage drop across it will be 12 V (3 × 4 = 12). What about the parallel combination of R6 and R7? The value of

R6 is 12 ohms, and R7 is 6 ohms. R6 has twice the resistance of R7, so R7 conducts twice as much current. This means that 1 A flows through R6, and 2 A through R7.

The voltage drop can be calculated across R6, across R7, or across the resistance of the parallel combination. The current through R6 is 1 A, so the voltage drop across it is 12 V (1 × 12 = 12). The current flow through R7 is 2 A, so the voltage drop across it is 12 V (2 × 6 = 12). R6 and R7 in parallel have a resistance of 4 ohms. The current flow through the parallel combination is 3 A, so the voltage drop across the parallel combination is 12 V (3 × 4 = 12). Regardless of which way you calculate it, the answer is the same, as it should be for a parallel combination of resistors.

In the case of the parallel combination of R2, R3, and R4, each resistor carries 1 A of current. If you multiply 1 A by 6 ohms you get a voltage drop of 6 volts. Using the other method, the parallel combination has an effective resistance

## SERIES-PARALLEL CIRCUITS

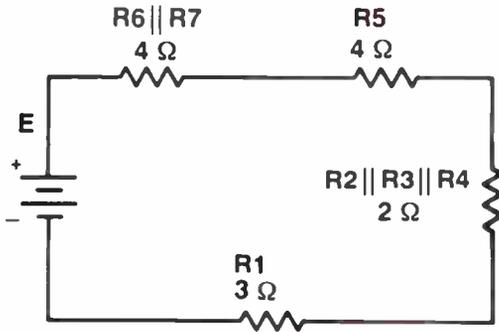


Figure 9. Series equivalent of the circuit in Figure 8.

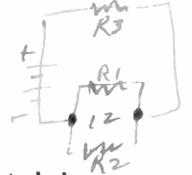
of 2 ohms, and carries a combined current of 3 amperes. Again,  $E = IR = 2 \times 3 = 6$  volts. The voltage drop across the parallel combination works out to be 6 V by any method of computation.

### Review

In a series-parallel circuit, the total current flow is the same in all series branches of the circuit. In the parallel branches, the sum of the currents in the individual branches must be equal to the series current flow. The voltage drop across all components in the parallel branch is the same, and the voltage drop across the series components depends on the resistance of the component and the total current flow in the circuit.

To find the total resistance in a series-parallel circuit, reduce the parallel branch to its equivalent series resistance, and add the series branches to the equivalent resistance of the parallel branches. The total current flow in the circuit can be determined from the source voltage divided by the total resistance of the circuit. The voltage drop across the individual parts in the circuit can be found by Ohm's law.

### Self-Test Questions



- 7 Draw a series-parallel circuit containing a battery and three resistors in which R1 and R2 are in parallel and connected to the negative terminal of the battery, and R3 is a series resistor connected to the positive terminal of the battery.
- 8 If R1 equals 20 ohms, R2 equals 30 ohms, and R3 equals 12 ohms, find the total resistance in the circuit. *24 ohms*
- 9 Using the values of R1, R2, and R3 for the preceding problem, if the battery voltage is 48 V, find the voltage drop across each resistor and the current flow through each resistor in the circuit. *2A*
- 10 If, in a circuit like the one shown on page 8 in Fig.5, R1 equals 5 ohms, R2 equals 10 ohms, and R3 equals 10 ohms, what is the source voltage if the current through R2 is 1 ampere? *24V*

*Handwritten calculations:*

$E = IR$   
 $1 \times 10 = 10V$   
 $2 \times 5 = 10V$   
 $\frac{10}{20} = 0.5A$

$1.775 \times 20 = 35.5$

$\frac{1.775}{23.250} = 0.076$

$\frac{1.775}{15.500} = 0.114$

$\frac{1.775}{48.000} = 0.037$

$\frac{1.775}{23.250} = 0.076$

$\frac{1.775}{48.000} = 0.037$

$\frac{1.775}{23.250} = 0.076$

$\frac{1.775}{48.000} = 0.037$

## PARALLEL CIRCUITS

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### ANSWERS TO SELF-TEST QUESTIONS

- 1 25 ohms. The total resistance of two equal resistors connected in parallel is always one-half the resistance of either resistor.
- 2 8 ohms. You find the resistance of the two resistors in parallel by using the formula:

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

Substituting 24 ohms and 12 ohms for R1 and R2 you get:

$$\begin{aligned} R_T &= \frac{24 \times 12}{24 + 12} \\ &= \frac{288}{36} = 8 \text{ ohms} \end{aligned}$$

- 3 The current flow through each resistor can be found from Ohm's law:

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

The current through the 3-ohm resistor will be:

$$I = \frac{12}{3} = 4 \text{ A}$$

The current through the 4-ohm resistor will be:

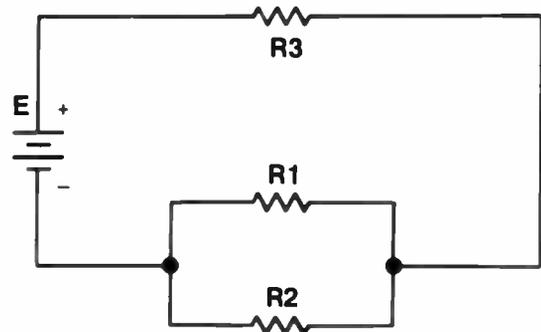
$$I = \frac{12}{4} = 3 \text{ A}$$

The total current flow will be the sum of these two currents: 7 amperes. You can use this value of current and the voltage of 12 V to find the resistance of the two resistors in parallel. (See the formula at the top of the next column.)

$$R = \frac{E}{I} = \frac{12}{7} = 1.7 \text{ ohms}$$

- 4 Slightly less than 4 ohms. The resistance of two 8-ohm resistors in parallel will be 4 ohms — half the resistance of either resistor. The 1000-ohm resistor is so large that we can almost ignore it because it will not appreciably affect the total resistance of this circuit. However, it will reduce it slightly below 4 ohms; the exact value would be about 3.98 ohms. If you said 4 ohms is the correct answer rather than slightly below 4 ohms, you are close enough.
- 5 In a parallel circuit, the voltage across all branches of the parallel circuit will be the same.
- 6 In a parallel circuit, the currents through each branch of the parallel circuit will depend upon the resistance of each branch. The largest current will flow through the branch having the lowest resistance, and the smallest current will flow through the branch having the highest resistance.

7



## ANSWERS TO SELF-TEST QUESTIONS

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- 8 24 ohms. The total resistance of the parallel combination of R1 and R2 can be found from the parallel resistor formula. Substituting these values we get:

$$R_T = \frac{20 \times 30}{20 + 30}$$
$$= \frac{600}{50}$$
$$= 12 \text{ ohms}$$

This resistance is in series with R3, which also has a resistance of 12 ohms, so the total resistance of the circuit is 24 ohms.

- 9 With a voltage of 48 V and a total resistance of 24 ohms, the current flowing in the circuit will be:

$$I = \frac{48}{24} = 2 \text{ A}$$

This means that the voltage drop across R3 will be:

$$E = 2 \times 12 = 24 \text{ V}$$

Therefore, the voltage dropped across the parallel combination of R1 and R2 must also be 24 volts.

The current through R1 must be:

$$I = \frac{24}{20} = 1.2 \text{ A}$$

The current through R2 must be:

$$I = \frac{24}{30} = 0.8 \text{ A}$$

- 10 20 volts. If the current through R2 is 1 A, and the resistance of R2 is 10 ohms, the voltage across R2 must be:

$$E = 1 \times 10 = 10 \text{ V}$$

Since R2 and R3 are in parallel, the same voltage must be across R3, and therefore, the current R3 must also be 1 ampere. This means the total current must be 2 A, so the voltage across R1 must be:

$$E = 2 \times 5 = 10 \text{ V}$$

Therefore, the source voltage must be 20 V (10 + 10 = 20).

# Lesson Summary

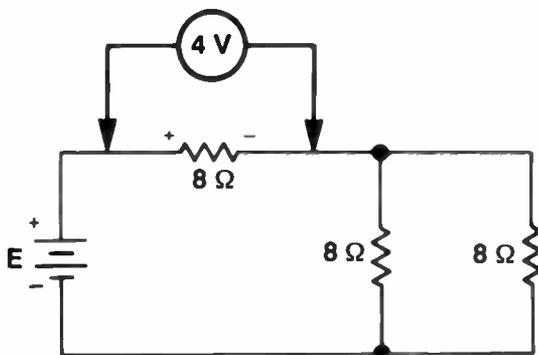
**Some of the important facts that you should remember about this lesson are:**

- Parallel circuits provide multiple paths for current flow.
- Adding resistance in parallel decreases the total resistance of the circuit.
- The same voltage exists across parallel circuit branches, but the current may be different in each branch.
- Parallel circuits can be in series with other parallel networks in the same circuit.

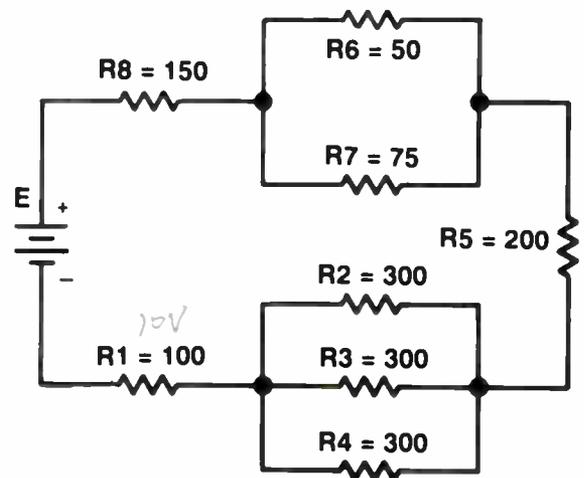


## PARALLEL CIRCUITS

5. Resistors  $R_1$  and  $R_2$  are connected in parallel. The resistance of  $R_1$  is 5 ohms, and the current through it is 2 amperes. The current through  $R_2$  is 0.5 A, and the resistance of  $R_2$  is:
- 5 ohms.
  - 10 ohms.
  - 15 ohms.
  - 20 ohms.
6. Three 6-ohm resistors are connected in parallel. A fourth 6-ohm resistor is connected in series with the parallel combination. The series-parallel network is connected to a battery. If the voltage drop across the series 6-ohm resistor is 6 V, the voltage drop across the parallel-connected 6-ohm resistor combination is:
- 2 volts.
  - 3 volts.
  - 6 volts.
  - 18 volts.
7. In the circuit shown below, the battery voltage is:
- 4 volts.
  - 6 volts.
  - 8 volts.
  - 10 volts.



8. If a 10-ohm, a 100-ohm, a 1000-ohm, and a 10,000-ohm resistor are connected in parallel, the total resistance of the parallel combination will be:
- Greater than 10 ohms.
  - 10 ohms.
  - Less than 10 ohms.
  - Approximately 100 ohms.
9. If a 100-ohm resistor is connected in series with three 100-ohm resistors that are connected in parallel, the total resistance of the series-parallel combination will be:
- Greater than 100 ohms.
  - 100 ohms.
  - Less than 100 ohms
  - 400 ohms.
10. In the circuit shown below, if the voltage across  $R_1$  is 10 V, the voltage across the parallel combination of  $R_2$ ,  $R_3$ , and  $R_4$  will be:
- Greater than 10 volts.
  - 10 volts.
  - Less than 10 volts.
  - 30 volts.



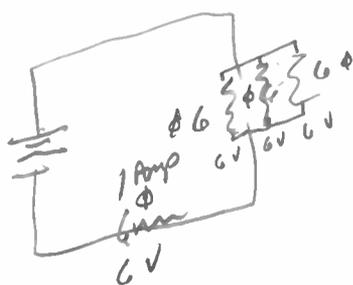
9

33.3 ohms

$$E = I \times R = 10$$

$$\begin{array}{r} 33.3 \\ 3 \overline{) 100} \\ \underline{90} \\ 10 \end{array}$$

$$R = \frac{E}{I} = \frac{10}{.5} =$$



$$E = I \times R$$

$$\frac{10,000}{11}$$

$$\frac{1009}{11} = 9.09$$

$$RT = \frac{1}{\frac{1}{10} + \frac{1}{200} + \frac{1}{1000} + \frac{1}{10000} + 1 + .01 + .001 + .0001} \quad 8 \text{ ohms}$$

$$\frac{1}{.1111}$$

$$\begin{array}{r} 9.09 \\ 909.09 \\ \hline 918.18 \end{array}$$

## NOTES

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**NOTES**

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**NOTES**

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## NOTHING SUCCEEDS LIKE SUCCESS

“How can I be a success?” The simplest answer to this question is “Finish what you start.”

Until you have achieved success, the individual tasks facing you are relatively unimportant in themselves. The important thing is the effect they have on you, what you learn from them, the practice they give you in succeeding at what you do.

It's easy to find reasons for quitting, especially when things get tough, but what do we accomplish if we do things the easy way? What can we possibly learn by quitting? We only learn how to quit — how to fail.

If success in any undertaking depends on effort (and we all know it does) then the more effort we put into an undertaking, the greater our success will be. You may not be able to detect the potential success present in every individual effort, but it is there. You have to keep in mind, as you take each step, that success can't be reached in one leap; it has to be approached strategically, carefully, and one step at a time.

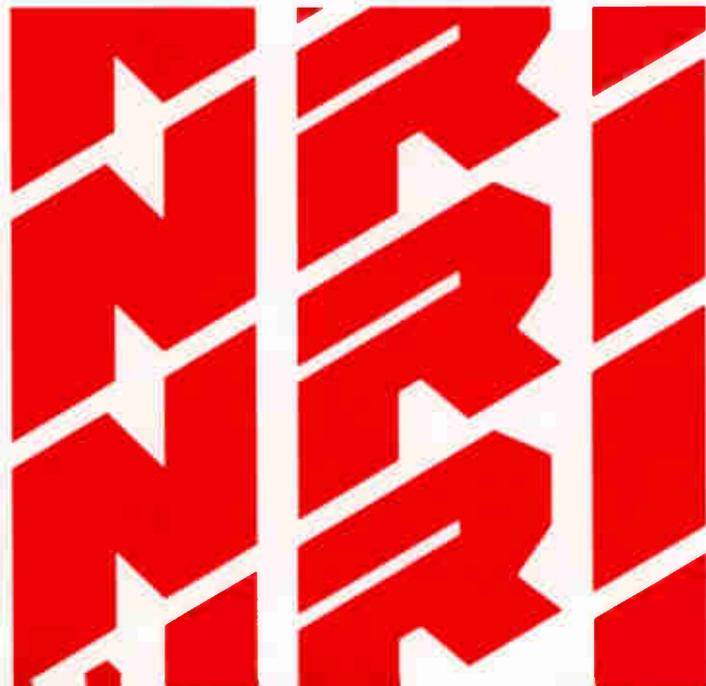
“Nothing succeeds like success.” What does the old saying mean? Simply that each success paves the way for future successes. Failure is merely a failure of *effort* — giving up too easily. You can't really fail unless you quit trying, so stick with each job until you win, and can add it to your list of successes. It's not the *jobs* themselves that make the success: it's what you do with them, what you take from them to the next job.





# Power Sources

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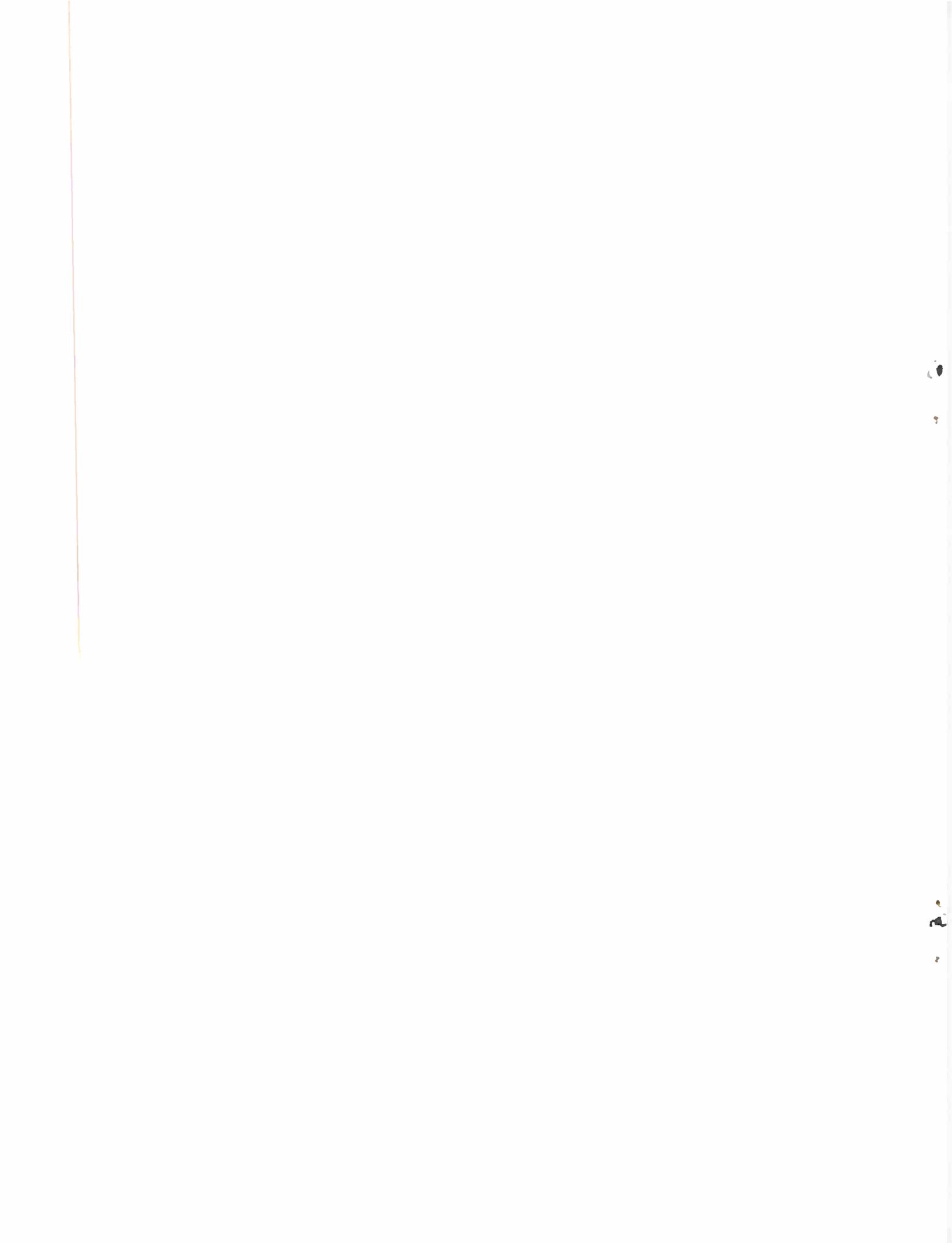


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# Power Sources

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**POWER SOURCES (First Edition)**

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# Table of Contents

<b>Introduction</b> .....	1
<b>Batteries</b> .....	2
Primary Batteries .....	2
Secondary Cells .....	5
Review .....	8
Self-Test Questions .....	8
<b>Magnetism</b> .....	9
Permanent Magnets .....	9
Electromagnets .....	11
Review .....	14
Self-Test Questions .....	14
<b>Generators</b> .....	15
Direct and Alternating Current .....	15
A Simple Generator .....	16
How Voltages Are Pictured .....	17
DC Generators .....	19
AC Values .....	22
Review .....	24
Self-Test Questions .....	24
<b>Answers to Self-Test Questions</b> .....	25
<b>Lesson Questions</b> .....	28

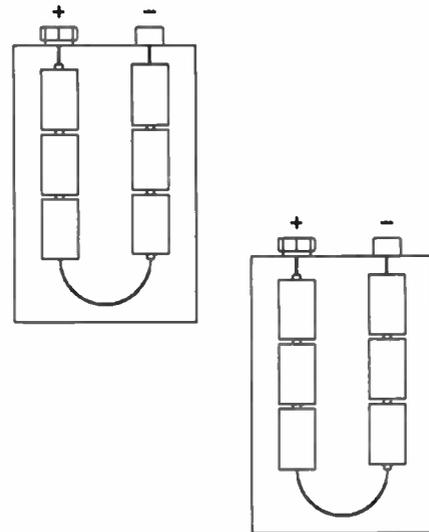
# Lesson Objectives

In this lesson, you will . . .

- Study primary and secondary storage batteries as electrical power sources.
- Review magnetism and electromagnetism.
- Apply electronic principles to magnetic circuits that generate electric current.
- Learn how ac and dc power are generated.
- Learn the waveform characteristics of ac voltage and current.

## INTRODUCTION

There are two common methods of producing electricity. One method is by chemical action, the other uses mechanical action. Both techniques provide a primary source for electrical power. The everyday application of chemical power generation is in the use of batteries of all kinds. In this lesson you will study several types of batteries and explore how they work and how they are best applied. You will then learn how large amounts of electricity are produced by motor-driven generators and other mechanical systems.



## POWER SOURCES

### BATTERIES

Two types of batteries are typically used in electronic applications: primary and secondary. *Primary* batteries are composed of primary cells, which cannot be effectively recharged. An ordinary flashlight battery is an example of a primary battery. A flashlight battery is simply discarded when it wears out. In contrast, a *secondary* battery is made from rechargeable cells, such as the storage batteries used in automobiles and the familiar nicad (nickel-cadmium) batteries used for children's toys and other small electronic products.

A battery produces electricity through a chemical reaction of two different materials; in this reaction, electrons transfer from one to the other. By intercepting the flow of electrons at some point, you can put them to work. The voltage and current produced by the two materials from which the battery is made are determined by the degree of reactivity they have with respect to oxygen, since the chemical action of batteries is what we call an "oxidation" reaction. The greater the reactivity between the two materials, the greater voltage and current potential they have.

#### Primary Batteries

Primary batteries are not rechargeable. The generation of electrical power through transfer of electrons in the battery material eventually uses up the battery. That is, the materials making up the battery stop reacting, and the battery is dead. This may seem to be a major drawback, but primary batteries may be more cost-effective than secondary batteries in certain applications, especially since they boast an extended shelf-life, holding a useful charge for

several years, where rechargeable secondary cells will discharge in a relatively short period of time, with or without a load.

A simple electric cell consists of pieces of two different metals submerged in an acid solution. The voltage produced by the cell depends on the metals used, as has been mentioned. For example, zinc and copper produce a cell voltage of about 1.1 volts. Copper and silver increase the output level to 1.5 volts. In contrast, gold and manganese are quite reactive, and can generate a voltage as high as 3.7 volts. Of course, a battery with this relatively high voltage is not economically practical because of the high costs of gold and manganese.

**Dry Cells.** Dry cells are not really "dry." They are called dry cells because their chemical mixture is in the form of a paste rather than a liquid. The construction of an ordinary carbon and zinc dry cell battery is shown in Fig.1. Carbon-zinc cells are widely used for general-purpose batteries.

Zinc is one of the two reactive metals in the cell. Zinc metal plate formed into a can constitutes the anode. The zinc can also act as the

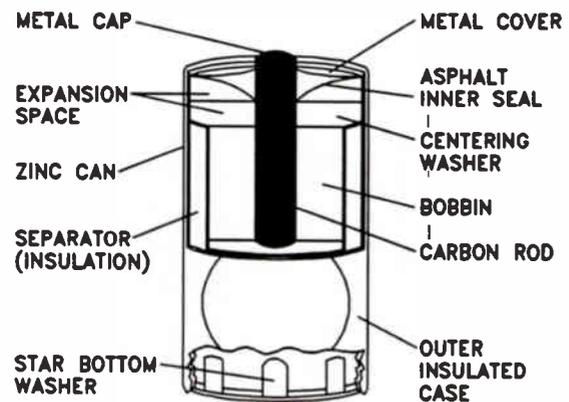


Figure 1. Principal parts of a typical carbon-zinc dry cell.

container for the acid solution and the manganese compound. Zinc cans are usually enclosed in a thin steel jacket to increase durability and reduce the possibility of leakage, since pure zinc is structurally weak.

Inside the can is a separator made of paper or paste. It acts to physically and electrically isolate the positive and negative electrodes, while permitting electrolytic transmission in the acid-electrolyte solution. Paste separators are made of electrolyte plus a gelling agent such as starch or flour. Paper separators provide superior separation and power-to-weight ratio. The paper is coated with a gelling agent and impregnated with electrolyte from the cathode material. Ordinary general-purpose dry cells use an electrolyte made of ammonium chloride, zinc chloride, and water. In heavy-duty cells, the electrolyte has a much higher percentage of zinc chloride.

Most of the material composing the cell is the *cathode mix*. This is the black mix, also known as the "bobbin." It is made of manganese dioxide, carbon black, and electrolyte. The carbon does two things: it holds the electrolyte in a semisolid state, and it increases the electrical conductivity of the mix. Some cells use a very pure form of manganese dioxide, known as EMD (Electrolytic Manganese Dioxide), in the black mix. They are more expensive, but the pure compound makes an extra heavy-duty cell.



Figure 2. A 9 V transistor radio battery.

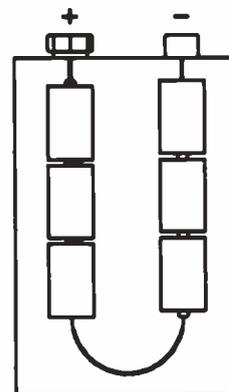


Figure 3. A drawing showing how the six cells are arranged in a 9 V battery.

Although these cells are frequently called *carbon-zinc* batteries, carbon is not a part of the chemical reaction that produces electricity. Carbon is not a metal; the active metals are zinc and manganese. A carbon rod inserted in the center of the black mix helps protect the mix from internally-generated heat, and is used as an electrode attachment point. The porous carbon rod also acts as a vent for hydrogen gas.

The no-load voltage developed by a carbon-zinc cell is nominally 1.5 V, although an unused cell may measure as high as 1.6 volts. Figure 2 is a drawing of a 9 V transistor radio battery. This battery is made up of six 1.5 V cells arranged as shown in Fig.3. The cells are connected in series; each provides a voltage of 1.5 V to give a total voltage of 9 volts.

**Alkaline Cells.** Alkaline cells get their name from the highly caustic base (potassium hydroxide) used in the electrolyte, rather than a slightly acidic one containing a salt such as ammonium- or zinc-chloride. An alkaline cell is similar to a carbon-zinc cell, but has significant differences, as Fig.4 illustrates (on the next page).

## POWER SOURCES

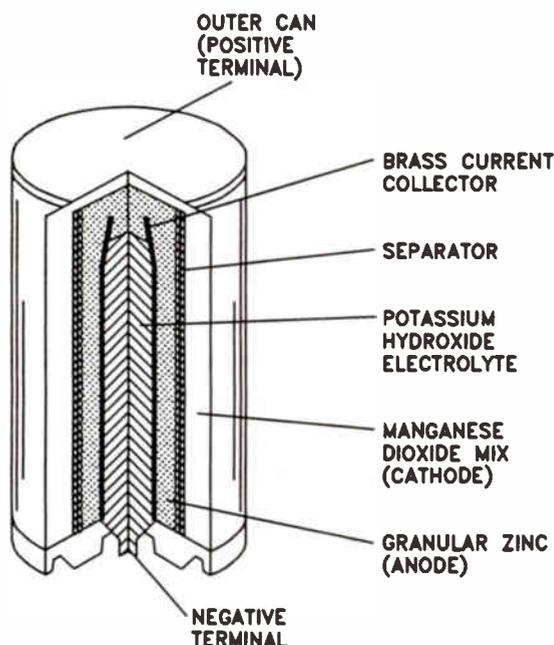


Figure 4. Principal parts of an alkaline cell.

The cathode material of an alkaline cell is EMD, the pure manganese dioxide sometimes used in carbon-zinc cells to improve performance. It is mixed with water, carbon, and some potassium-hydroxide electrolyte. Like a dry cell, the anode is zinc, but the zinc metal is a powder held in a steel jacket. The highly purified zinc powder is mixed with small amounts of mercury, forming an amalgam that greatly reduces hydrogen production in the cell. The separator is made of a porous woven, felted, or bonded material.

Alkaline cells have a no-load voltage of about 1.52 volts. Their performance exceeds that of carbon-zinc types. Alkaline cells have greater temperature tolerance, and their low current-drain performance is better. However, alkalines

are best where moderate to high currents are drawn for an extended time. Carbon-zinc and alkaline cells are both available in a wide range of packages and voltages. Although alkaline cells have (mostly) replaced carbon-zinc types, there are places where carbon-zinc gives better performance for price. Typically, where current drain is low but constant, and operating temperature is not extreme, carbon-zinc cells are more economical. However, they have a relatively short shelf life, so they are best suited to applications where they will be replaced regularly. Alkaline cells can produce higher currents than carbon-zinc cells, and recover more quickly after heavy use. They are ideal for much of today's consumer-electronics equipment: cassette players, portable TVs, and radios. Electronic products can operate for several hours on alkaline cells, but would drain carbon-zinc batteries in 30 minutes.

Alkaline cells have a longer shelf life, and their output voltage decreases more slowly than carbon-zinc cells. You can extend the shelf life of carbon-zinc cells by refrigerating them to slow the chemical reactions that take place even when they are not being used. These reactions are at a much lower level in unused alkaline cells. Even with the benefit of refrigeration, however, carbon-zinc cells still have a much shorter shelf life than alkaline cells.

Low temperatures cause voltage output reductions in all types of batteries. Alkaline cells have a consistent output over a greater temperature range than do carbon-zinc cells. In temperatures below freezing, a carbon-zinc cell is incapable of delivering more than a fraction of its rated current, and is generally considered unusable. Alkaline cells have reduced output at low temperatures, but are still better than the best carbon-zinc cells.

## Secondary Cells

The most desirable quality of secondary cells is their ability to be recharged. Lead-acid secondary cells, frequently called "storage" batteries, are used in automobiles, making them probably the best known example of a secondary cell. There are several other designs for rechargeable batteries. Along with their operating characteristics, we will review the advantages and disadvantages of each.

**Lead-Acid Batteries.** This type of cell has two sets of internal plates. One set of plates is connected, or "bussed," together for the positive terminal; the other set of plates is bussed together and brought out at one point as the negative terminal. The set of positive plates is treated chemically to change it to an oxide of lead, the negative set is pure lead. They fit together as shown in Fig.5.

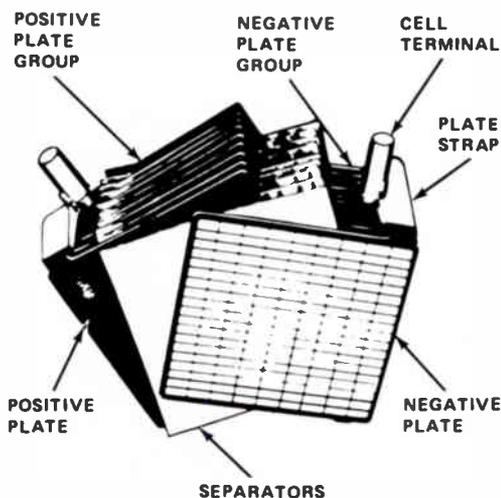


Figure 5. The construction of a storage battery.

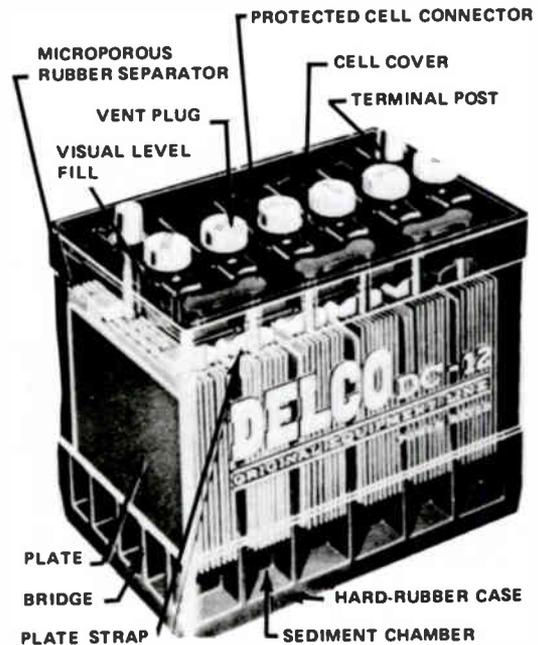


Figure 6. A 6-cell, 12 V battery.

Between the plates are sheets of insulating material called *separators*, made either of porous wood, perforated wood, or fiberglass. The separators keep the plates from touching, which would short-circuit and destroy the cell. Both sets of plates and separators are sealed into a container of sulphuric acid and water. This type of cell produces approximately 2 volts, plus or minus 10% depending upon conditions. Storage batteries used in modern automobiles are made of six cells connected in series so that the battery output voltage is 12 volts. A 6-cell battery is shown in Fig.6.

The lead-acid battery is charged by applying a voltage slightly higher than the battery voltage. The charger forces current through the battery, as shown on the next page in Fig.7. This current causes a chemical change in the battery, which restores the battery to essentially the

## POWER SOURCES

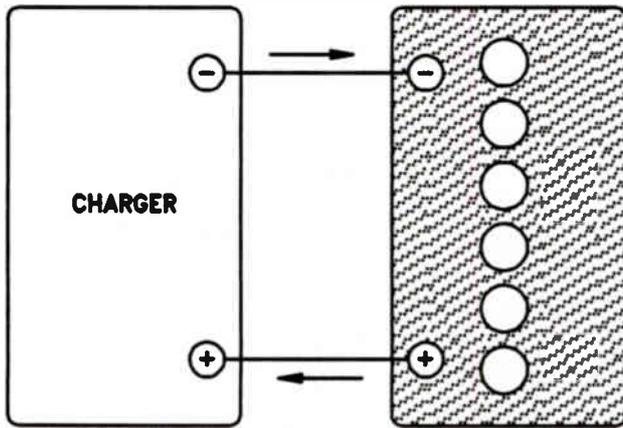


Figure 7. The direction in which current flows when a storage battery is charged.

same reactive chemical state it had before being used as a power source.

Notice the direction of current in Fig.7, as compared to Fig.8. When the battery is being charged, the current is forced through the battery in the opposite direction to which it flows when the battery is supplying current. In an automobile, the battery is connected to an alternator. As long as the car runs at a reasonable speed, the alternator both charges the battery and supplies operating current to the car.

Both small and large lead-acid batteries are available with a gelled electrolyte that allows them to be used in portable equipment without spilling. Lead-acid cells are also available in the form of sealed D-size cells. Lead-acid batteries are capable of sustaining very high rates of discharge. However, like most chemical reactions, the performance of lead-acid cells falls off at cold and very warm temperatures. They must also be kept well charged to achieve good performance over a long lifetime.

**Lithium Cells.** Until recently, lithium cells were not generally regarded as recharge-

able devices. However, rechargeable lithium-manganese oxide cells have made an appearance. They are intended primarily as replacements for nicad cells and large-value capacitors used in keeping memory circuits alive during equipment "off" periods. The internal construction of a flat lithium battery and a cylindrical lithium battery are shown in Fig.9(A) and 9(B), on the next page.

Lithium is an extremely reactive metal, which makes it an excellent component in energy cells. Unfortunately, its high reactivity (it decomposes rapidly in water, for example) makes it difficult to work with. Many of these difficulties have been overcome, however, and lithium-based cells are now found in watches and calculators — wherever a trickle current is needed.

The output of a lithium cell is nominally 3 V; in some applications you can replace two 1.5 V carbon-zinc or alkaline cells with one lithium cell. A lithium battery with a 1.5 V output is also available. Lithium cells have an extremely long shelf life: 5, or even 10, years. Under conditions of low drain, their useful working life may also be five to seven years.

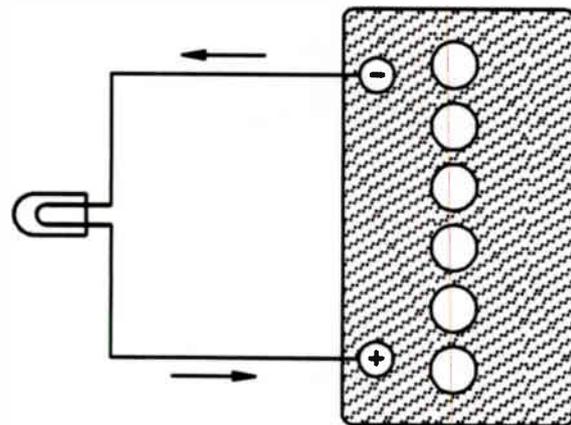
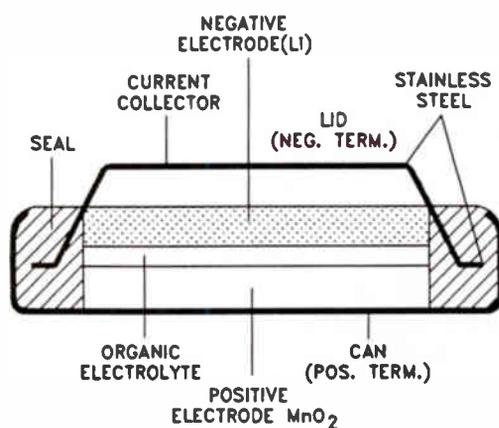
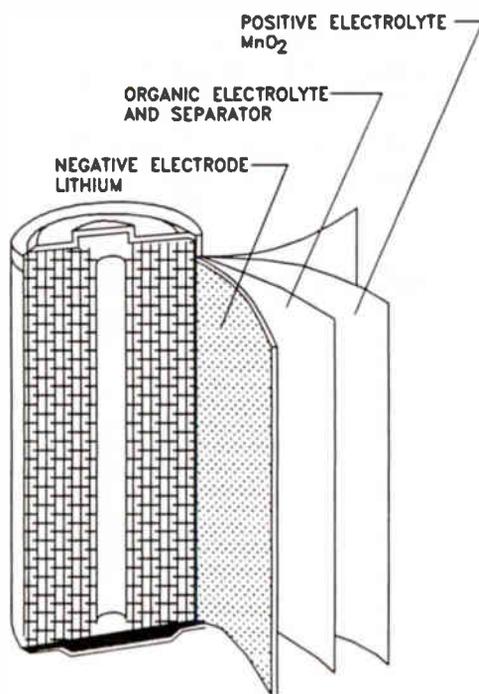


Figure 8. The direction current will flow when the battery is supplying current.



(A)



(B)

Figure 9. Lithium batteries. (A) Construction of an Li/MnO<sub>2</sub> button cell. (B) Construction of an Li/MnO<sub>2</sub> cylindrical cell.

**Nickel-Cadmium Cells.** The internal details of a typical nickel-cadmium cell are similar to those of lithium cells. The active materials are nickel oxide, which forms the cell's positive plate, cadmium for the negative plate, and caustic potassium hydroxide electrolyte. Several manufacturing techniques are used, but typically, the positive and negative electrodes sandwich the separator in the middle. Those three layers are rolled up into a spiral package. The separator may be nylon or polypropylene. A safety vent is provided to help prevent cell rupture from pressure buildup during charging.

The normal rate at which a nicad recharges is at one-tenth the rated output current. For example, 60 mA is the correct charge current for a cell with a rating of 600 mAh (milliampere hours). The charging time should be about 14 to 16 hours. However, this is a nominal rate, and is dependent upon the cell design. Some quick-charge cells can be recharged in four to six hours, and fast-charge devices can be charged at much higher currents in two hours or less. The true limitation on cell charging rate is a function of the temperature increase produced by the charging current, and the possibility of cell rupture or internal plate damage due to internal pressures.

Nickel-cadmium cells do not lose voltage output at the same rate as carbon-zinc and alkaline cells. Fully charged, nicad no-load output voltage is about 1.4 V, which drops almost immediately to 1.25 V, and is then maintained until the charge is nearly exhausted. Nicads can provide very large amounts of current when needed, and perform consistently under conditions of continuous drain. They also have good power output under extremes of temperature.

Nickel-cadmium cells give lasting service when worked hard. In light use, they may develop a "memory" and eventually lose some of their capacity. However, recent developments in

## POWER SOURCES

battery technology have made that much less of a problem. The charge duration of a nickel-cadmium cell on a single charge is only about 70% of that of an equal size alkaline cell.

Nickel-cadmium cells are very convenient to use in a situation where they can be built into a device and the charging current supplied from the outside through a jack. If you use rechargeables to replace throw-away primary cells, it is inconvenient to remove and replace them for charging. Old or worn-out cells in a nickel-cadmium battery pack should be replaced all at once. Mixing old and new can cause the weakest one to reverse polarity and drag down the life and performance of the entire pack.

### Review

In this section of the lesson, we have covered four important primary cells and two important secondary cells. We do not expect you to remember how these cells are made, but you should remember the voltage of each cell and remember their important characteristics.

The most important characteristic of a dry cell is its economy. Its disadvantages are its limited shelf life and its limited current capabilities. The alkaline cell has a much longer shelf life than a dry cell, and a given size alkaline cell is capable of supplying a much higher current than a dry cell. It can also supply the same current as the dry cell for a much longer time. Secondary cells have the advantage that they can be recharged and used again. There are two important types of storage cells: the lead-acid and the nickel-cadmium. The lead-acid cell has a voltage of about 2 V and the nickel-cadmium cell has a voltage of about 1.2 volts. The advantages of the nickel-cadmium cell over the lead-acid cell are that it is lighter, it can be sealed, and it does not require periodic maintenance, as most lead-acid cells do.

### Self-Test Questions

Please check your answers on page 25.

- ✓ 1 Name the two basic types of batteries. *Primary Secondary*
- ✓ 2 What is the principal difference between a primary and a secondary battery? *Secondary can be recharged*
- ✓ 3 The production of electrical power in a battery is by means of a chemical reaction.
- ✓ 4 One advantage of primary cells is their longer shelf life.
- ✓ 5 The chemical reaction in a dry cell takes place between two reactive metals.
- ✓ 6 A fresh carbon-zinc battery has an unloaded output voltage of approximately 1.5V.
- ✓ 7 Why are high-performance dry cells called alkaline batteries? *Higher conductance*
- ✓ 8 When would you choose a carbon-zinc battery over an alkaline battery? *but its voltage is low just enough for that if not in a hurry*
- ✓ 9 What is the no-load output voltage of a lead-acid cell? 2V *10-1920*
- ✓ 10 What is the normal recharge rate for a nickel-cadmium cell? 1/10 rated output current
- ✓ 11 Output voltage from a fully charged nickel-cadmium battery starts out at about 1.4V, and quickly drops to a constant 1.25 volts.
- ✓ 12 Which secondary cell has the longest shelf life? Lithium

## MAGNETISM

Here we are going to briefly study magnetism, because magnetism makes devices like transformers and electric motors possible. Indeed, throughout your entire study of electronics, and your future work in the electronics field, you will find that magnetism plays a key role in many critical electronic functions.

### Permanent Magnets

Some types of iron ore will pick up or attract small pieces of iron or steel. These minerals are natural *magnets*. A piece of iron can be made into a magnet by stroking it several times in one direction with a magnet. Iron or steel converted in this way is said to be "magnetized." Natural magnets are also called *permanent magnets*, because they retain their magnetism almost indefinitely. Modern magnets are made of an alloy called alnico rather than iron. Alnico is a mixture of aluminum, nickel, and cobalt. Alnico magnets are much lighter, stronger, and retain their magnetism better than magnets made of iron or steel.

When a magnetized steel needle is suspended at its balance point by a light thread (as shown in Fig.10), the needle will always line up in a direction corresponding closely to north and south. This phenomenon led to the first practical use of magnets in compasses by early sea voyagers and travelers.

**Poles of the Magnet.** The ends of a permanent magnet are called *poles*. This name was given because, when the magnet is free to pivot on an axis, the ends point toward the poles of the earth. The pole that points toward the North Pole of the

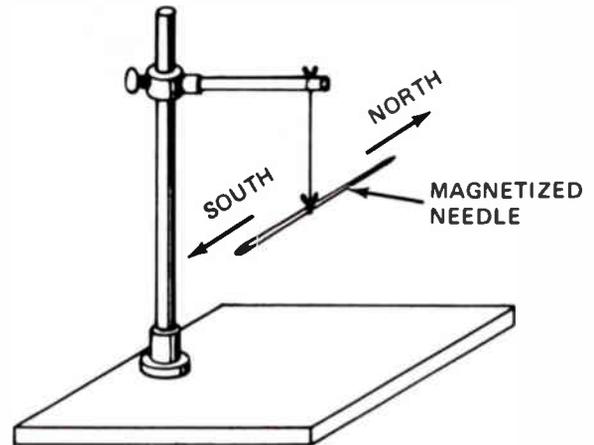


Figure 10. If a magnetized needle is suspended at its balance point, the needle will line up in a north and south direction because it lines up with the earth's magnetic field.

earth is called the *north pole*. The pole that points toward the South Pole of the earth is called the *south pole*.

When two magnets are brought close together, the north poles repel each other, as do the south poles. However, the north pole of each magnet is attracted to the south pole of the other. We describe this phenomenon by saying that like poles repel, and unlike poles attract. This is the basic law of magnetism.

A compass points in a north-south direction because the earth itself is a large magnet. The magnetic poles of the earth affect the magnetic needle of the compass. The South Pole of the earth is actually a magnetic north pole, because it attracts the south pole of the magnetic compass needle. The North Pole of the earth is a magnetic south pole, since it attracts the north pole of the compass.

## POWER SOURCES

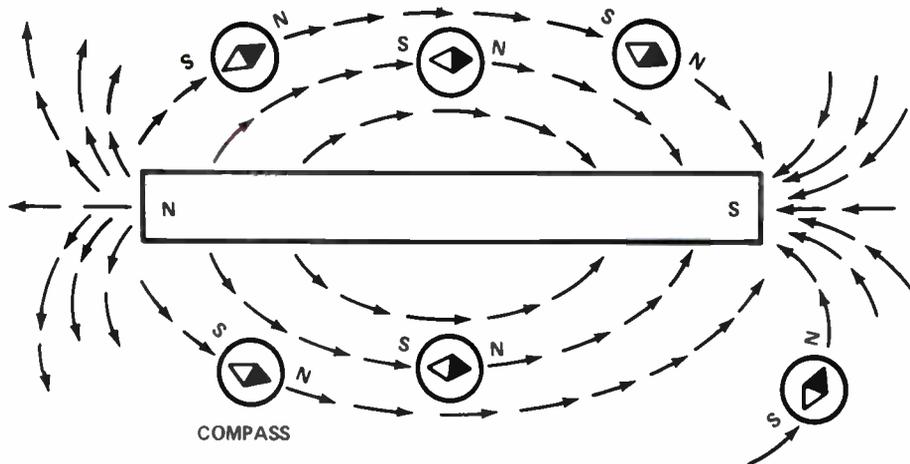


Figure 11. A small compass can be used to trace magnetic lines of force near a permanent magnet.

Notice the similarity between the attraction and repulsion of magnetic poles, and the attraction and repulsion of electric charges. You already know that like charges repel, and unlike charges attract. In magnets, like poles repel, and unlike poles attract. This is a fundamental law of magnetism that you should remember.

**Magnetic Lines of Force.** There are lines of force surrounding a magnet. You can trace the lines of force around a magnet by using a small compass, as shown in Fig. 11. When you move the compass near the north pole of the magnet, the south pole of the compass is attracted to it. The compass needle lines up with the magnetic lines of force. As you move the compass, as shown in Fig. 11, you can trace out the lines of force.

You can also see the lines of force around a magnet by placing a thin sheet of cardboard over the magnet, then sprinkling iron filings evenly over the cardboard. Tap the cardboard gently and the iron filings will arrange themselves in a definite pattern, as shown in Fig. 12(A). As you see, the filings are lined up with the lines of force.

By bringing the north pole of two magnets together and performing the experiment again, you can see the repulsion between the two poles, as Fig. 12(B) shows. Figure 12(C) shows the pattern set up by the attraction between the north pole of one magnet and the south pole of another.

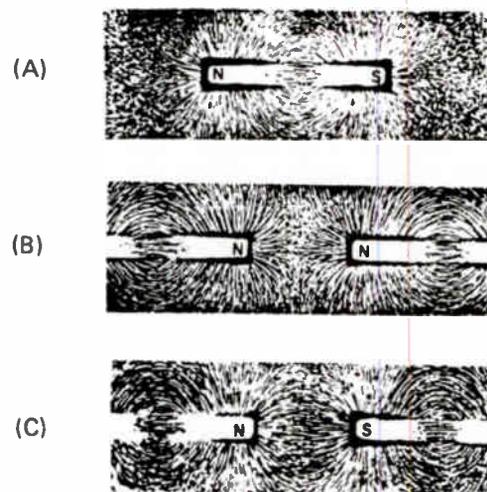


Figure 12. If iron filings are placed on a sheet of cardboard over permanent magnets, they will trace out lines of force.

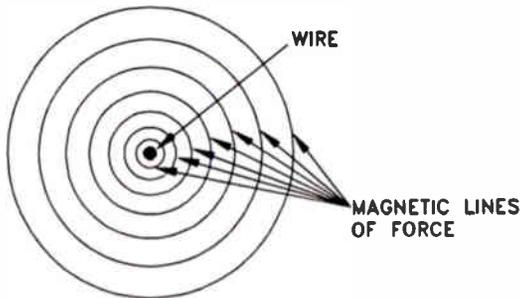


Figure 13. Cross-section of a wire. When electrons flow through a wire, magnetic lines of force surround it.

The lines of force associated with a magnet are called *magnetic lines of force*. Similar lines of force surround electrically charged objects. They are called *electric lines of force*.

## Electromagnets

Electric current flowing in a wire generates a magnetic field in the space around the wire. The production of this type of magnetic field is commonly known as "electromagnetism." The number of lines of force is greater close to the wire, and decreases with distance, as shown in Fig.13.

The relatively weak magnetic field around a single conductor can be made much stronger by winding the wire in the form of a coil, as shown in Fig.14. In a coil, the circular magnetic rings pass through the center of the coil in the same direction and reinforce each other, as shown. This type of magnet is an *electromagnet*. The magnetic effect exists only as long as the current is flowing through the wire.

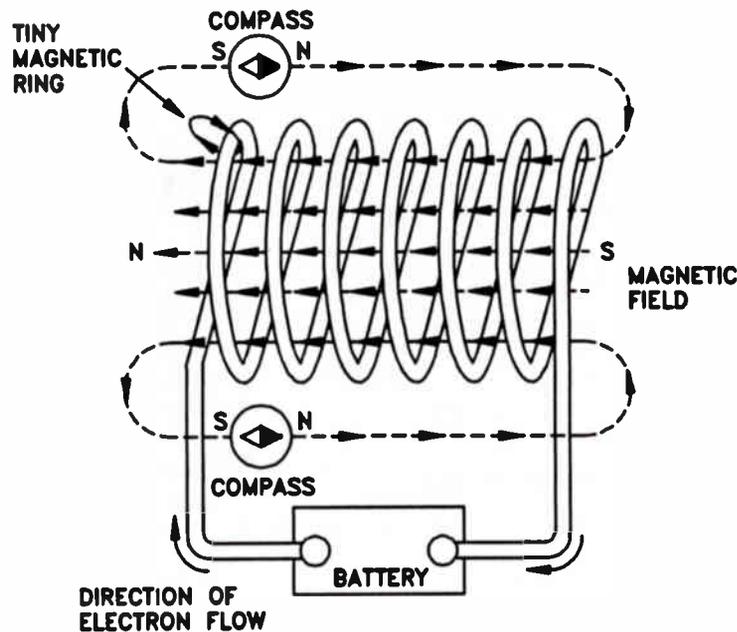


Figure 14. The more turns of a wire in a coil, the stronger the magnetic field becomes when electrons flow through the coil.

## POWER SOURCES

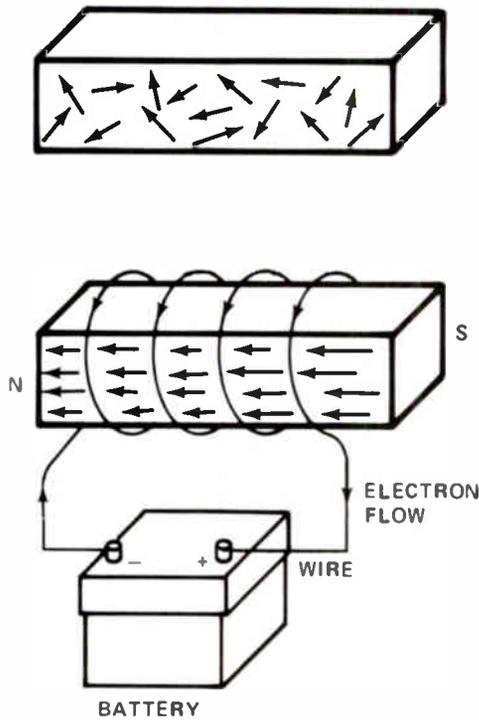


Figure 15. (A) In an unmagnetized bar of iron, the tiny magnets in the iron do not line up. (B) If the iron bar is magnetized, they will line up.

The electromagnet shown in Fig.14 can be made much stronger by inserting an iron bar, or a bar of some magnetic material, inside the coil. The bar is called a *core*. The actual increase in the strength of the magnet will depend upon the type of core material used.

The magnetic core is composed of tiny particles, each one a small magnet with a north and south pole. Under normal conditions, these particles are randomly arranged, as shown in Fig.15(A). In the magnetic field inside the current-carrying coil, the core particles arrange in a single orientation, as shown in Fig.15(B). The entire bar becomes a single strong magnet. When the circuit opens and current flow stops,

the magnetic field collapses. Most of the particles return to a random state, although some residual magnetism remains.

**Induced Currents.** We have seen that current flowing through a coil produces an electromagnet. Is the opposite true? If a magnet is placed inside a coil, will a current flow? A flashlight bulb connected to a coil wound on a hollow form is shown in Fig.16. When the magnet is moved rapidly from outside the coil to inside the center of the coil, the bulb will light while the magnet is moving. When the magnet stops inside the coil, the light goes out. The bulb lights again when the magnet is moved quickly out of the coil. If the magnet is moved rapidly back and forth in the coil, the bulb will light and remain lit as long as the magnet is in motion.

What is happening? Well, the magnetic lines of force that surround the magnet move through the turns of the wire coil. The magnetic lines of force are said to “cut” the turns of the coil as the magnet moves. This action generates, or “induces,” a small voltage in each turn of the coil.

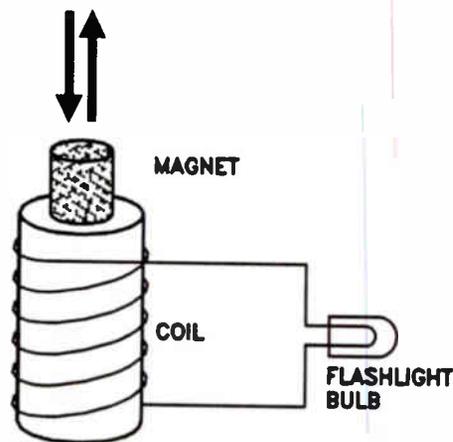


Figure 16. An illustration of how magnetic lines of force induce a voltage.

This effect continues for as long as the number of magnetic lines of force cutting the coil is *changing*. The voltages induced in each turn of wire add together. The total induced voltage produces a current flow through the coil and through the bulb. We call the voltage produced an *induced voltage* and the current an *induced current*, because no physical contact is made, and no chemical action takes place.

Figure 17 shows another way to induce voltage. Two coils are wound on the same form so that they are close together. One coil is labeled L1 and the other L2. Coil L1 is connected to a flashlight battery through a switch labeled SW. Coil L2 is connected to a flashlight bulb. An iron core is inserted through the form on which the coils are wound to increase the strength of the magnetic field.

Closing the switch starts current flowing in L1. The flow of current in L1 induces a voltage in L2, causing the bulb to glow briefly. The glow lasts for only an instant after the switch is closed. Opening the switch interrupts the current flow through L1. Again, the bulb glows for an instant, indicating that opening the switch also caused a voltage to be induced in L2.

The action of the two coils looks much different from the effect obtained with the moving magnet shown in Fig.16. However, the basic principle is much the same. When the switch is closed, current flows in L1, causing a magnetic field to build around it. The magnetic field builds

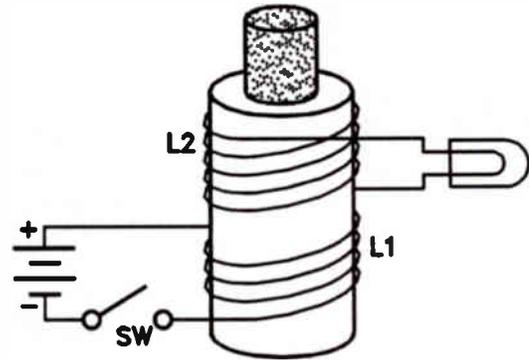


Figure 17. When the circuit to L1 is opened or closed, a voltage will be induced in L2.

quickly, but is not instantaneous. The expansion of the magnetic field around L1 causes magnetic lines of force to cut the turns of L2. This changing, expanding field induces a voltage in L2. Once the field reaches its limit, the number of lines of force cutting L2 is not *changing*. Voltage induction then stops in L2. Opening the switch causes the field around L1 to collapse. Once again, a changing field cuts the turns of L2. As the field collapses, voltage is again induced in L2, and the lamp glows briefly.

It is important to remember that a *change* in a magnetic field around a coil will induce a voltage. It is a changing field that does the job; a constant field does not induce a voltage.

## POWER SOURCES

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### Review

A magnet has a north pole and a south pole. Invisible magnetic lines of force exist in space between the north and south poles of a magnet. Like magnetic poles repel, and unlike magnetic poles attract.

There is a magnetic field around a current-carrying wire. An electromagnet can be made by passing a current through a coil. Inserting an iron core into an electromagnet will result in a stronger magnetic field.

If the number of magnetic lines of force cutting a turn of a coil change, voltage is induced in that turn of the coil. If the magnetic lines of force cutting all the turns of a coil change, there will be a voltage induced in each turn of the coil, and these voltages will add together. If the coil is connected to a complete circuit, current will flow in the circuit.

### Self-Test Questions

- 13 State the basic law of magnetism. *Like repels, opposite attracts*
- 14 If a pole magnet attracts the south pole of a compass, is this a north pole or a south pole? *North pole*
- 15 Are the magnetic lines of force around a current-carrying wire stronger close to the wire, or at a distance?
- 16 What effect will placing an iron core inside an electromagnet have on the strength of the magnetic field? *increase*
- 17 If the ends of a coil are connected to a flashlight bulb and a very strong permanent magnet is placed inside the coil, will the flashlight bulb light? How long will the flashlight bulb remain lit? *Yes while the magnet is moving*

## GENERATORS

Batteries are very useful, but their ability to supply large amounts of power is limited. Even a powerful storage battery cannot supply large amounts of current without soon being exhausted and in need of recharging. Even if storage batteries could supply the large amounts of energy consumed daily by the average large city, we would still need to have some way of recharging the battery. Thus, we would have need for a device other than a battery that is capable of supplying large amounts of electricity.

You have learned that a varying magnetic field cutting through a coil induces a voltage in the coil. If the magnetic field is made to vary constantly, a continuing voltage is induced. The induced voltage can supply current to an external circuit. This is the basic principle of an electric power generator.

Before studying generators, let's learn the differences between direct current and alternating current.

### Direct and Alternating Current

Current supplied by a battery always flows from the negative terminal through the external circuit, and back to the positive terminal. The current always flows in one direction. We call it *direct current*, or *dc current*. The voltage supplied by a battery, or any other voltage source that causes a direct current to flow, is referred to as a *dc voltage*. One terminal on a battery is always the negative terminal and the other terminal is always the positive terminal.

A dc generator is a device that generates direct current. In other words, the current coming from a dc generator always flows in the same direction. This means that the generator terminals always have the same polarity. One terminal is the negative terminal, and the other terminal is the positive terminal. The polarity of a given terminal, negative or positive, does not change.

Devices connected to the generator make up the *load*. The load could be a light bulb, a motor, or a combination of light bulbs and a motor. The dc generator and the load connected to it are called the *dc circuit*. In a dc circuit where the generator voltage is constant and the resistance of the load is constant, the current flowing in the circuit is constant.

*Alternating current*, or *ac current*, is different from direct current. It does not have a constant value or a constant polarity. It changes continuously, according to its characteristic rate (frequency) and voltage potential (amplitude).

Alternating current begins with a zero voltage and polarity. It first flows in one direction, building up to a maximum value, then returns to zero. It then reverses direction and polarity, builds up to a maximum value in the opposite direction, and returns again to zero. This complete process is called a *cycle*.

While there are many devices that operate only on direct current, alternating current has many useful applications. Indeed, our modern industries depend upon large amounts of alternating current being readily available.

Let's proceed and learn more about alternating current and ac voltage, and how a simple generator operates.

## POWER SOURCES

### A Simple Generator

A simple generator of electric current and voltage can be built as shown in Fig.18. This is intended only as an example, and consists of a single turn of wire placed between the poles of a magnet. As the coil rotates, it cuts the magnetic lines of force between the north and south poles of the magnet. This induces a voltage in the coil. The amount of voltage produced depends upon the number of magnetic lines cut by the coil as it rotates, which in turn depends upon the

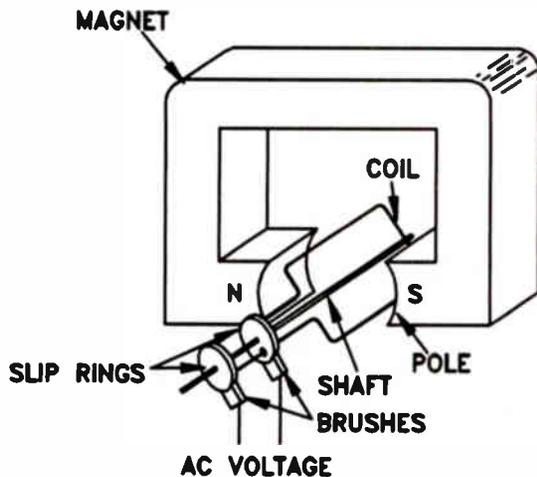


Figure 18. A simple ac generator.

strength of the magnetic field and the speed at which the coil is rotated.

What is the nature of the voltage produced by this generator? When the coil is in the position shown in Fig.19(A), it is *moving* mostly in a direction parallel to the lines of force between the magnetic poles. Therefore, it is not cutting through any lines of force, but only moving parallel to them. Remember, to induce a voltage, the turns of the coil must cut through magnetic lines of force. In Fig.19(A) the coil is not cutting lines of force, so no voltage is induced.

As the coil rotates towards the position shown in Fig.19(B), it begins moving at an angle to the lines of force, and cuts through an increasing number as it moves. Thus, a proportional amount of voltage is induced in the coil. As movement continues toward the position shown in Fig.19(C), more voltage is induced as the coil moves at a sharper angle to the lines of force. Finally, when it reaches the position shown in Fig.19(D), it is moving directly perpendicular to the lines of force, cutting through them at a maximum rate. The voltage induced is at its highest value as the coil moves through the perpendicular point. Continuing to turn, the coil moves through the positions shown in Figures 19(E) and 19(F). It cuts fewer and fewer lines of force until it reaches the position shown in Fig.19(G). Here, the coil is once again moving parallel to the lines of force, so no voltage is being induced.

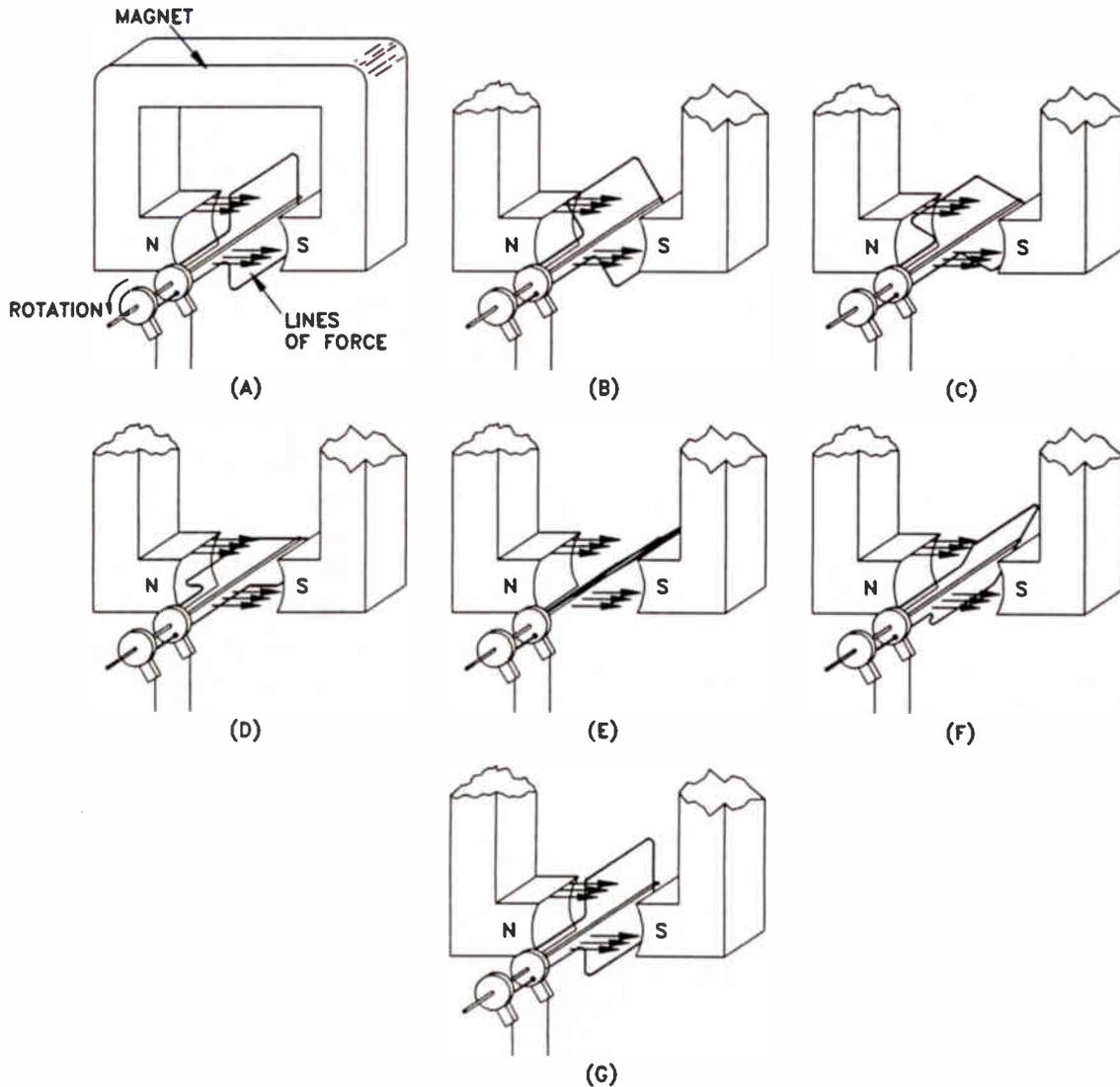


Figure 19. In this illustration, the coil is rotating counterclockwise. The voltage produced by this generator depends upon the movement of the coil in relation to the magnetic lines of force.

## How Voltages Are Pictured

When we discussed series-connected batteries, we said that one terminal of the two batteries could be considered zero, and the voltage at the other terminals marked in reference to this terminal. You can do the same thing with

a generator. You can use one lead as the ground or common lead and measure the voltage at the other lead as either positive or negative with respect to the common lead.

If we assume that one lead is a common or ground lead (or has zero voltage), we can represent the voltage at the other lead as a line on a

## POWER SOURCES

graph. In Fig.20, the horizontal line across the center of the graph is the zero voltage line; it represents the voltage at the ground, or common lead. Each horizontal step above the zero line represents a positive voltage. Lines below the center zero line represent negative voltages. The vertical lines each represent one position of the coil from Fig.19.

To have the convenience of round figures, let's assume the coil generates 100 V at the instant it is in the position shown in Fig.19(D). If the voltage is +100 V with respect to the common terminal, we would place a mark (X) on the graph at the point where the +100 V line crosses the vertical line running through D, as shown in Fig.20(A). Similarly, the voltages induced at the other points would be marked on the graph. This would look like Fig.20(B). We then draw a smooth curve joining all these points, as shown in Fig.20(C). This curve represents the voltage produced by the generator through one-half turn.

As the coil rotates through the remaining half-turn, the voltage polarity reverses. It will be negative with respect to the ground terminal because the coil cuts through the magnetic lines of force from the opposite direction. This produces a curve on the graph like Fig.21(A). Removing the horizontal and vertical reference lines, we can get a better look at the shape of the output voltage, as in Fig.21(B). This is called a *waveform*.

This waveform is how ac voltage supplied by the power company is commonly represented. It is called a *sine* (pronounced sign) wave. The voltage represented by one complete turn of the coil in the magnetic field is a cycle. The power supplied by most power companies in this country is 60-cycle power.

When we say 60 cycle, we mean 60 cycles per second. That is, the voltage goes through 60 cycles, like the one shown in Fig.14, each second. This is called the *frequency* of the ac voltage. To make the two-pole generator like the one in

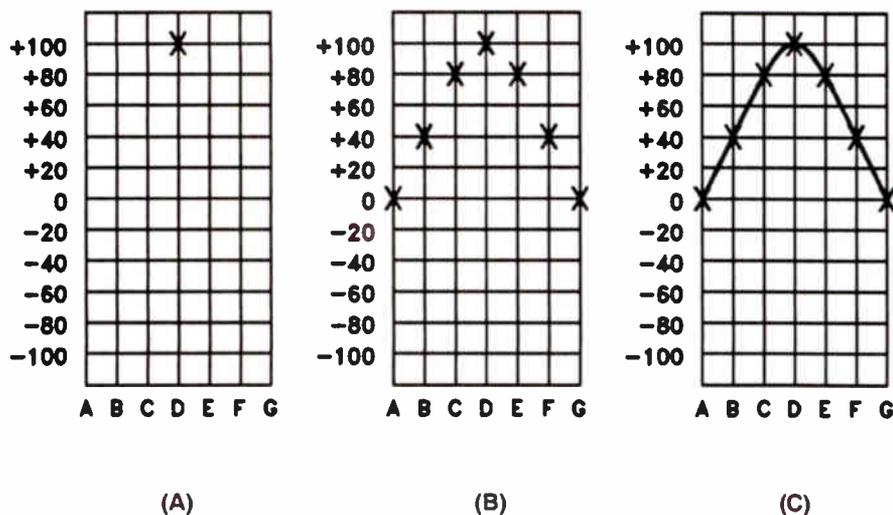


Figure 20. Construction of a graph of the voltage produced by the generator in Figure 11.

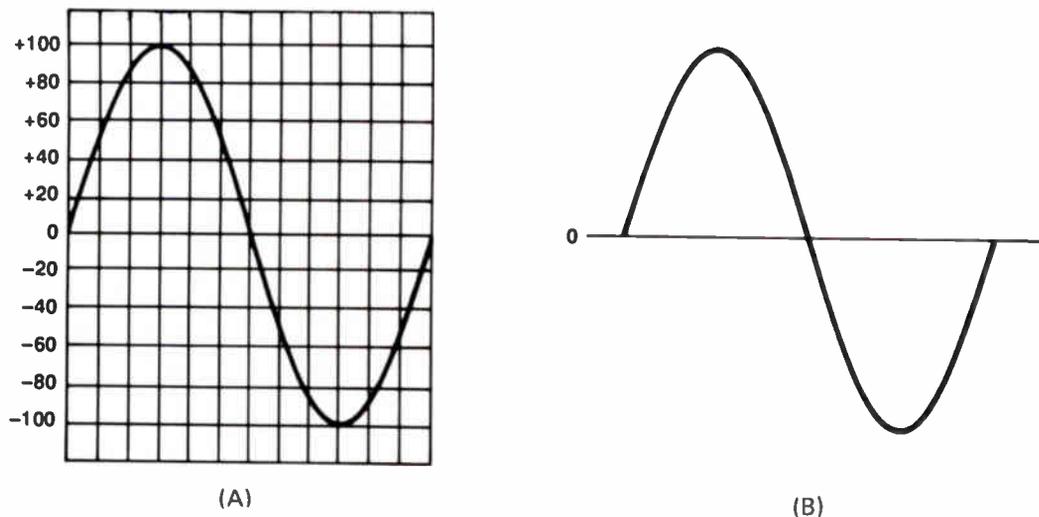


Figure 21. The appearance of the output voltage produced by the generator as it travels through one complete turn.

Fig. 18 produce this type of voltage, it must turn at a speed of 60 revolutions per second, which is 3600 revolutions per minute (rpm). The part of the cycle above the line is called a *positive half-cycle*. The half-cycle below the line is the *negative half-cycle*. The highest voltage reached during the cycle, 100 V in this case, is called the *peak voltage*. There are two peaks: a positive and a negative peak. Each peak is 100 volts. The peak-to-peak voltage, which is the total voltage between the positive peak and the negative peak, is 200 volts. Remember these terms; they will be used frequently in this course.

Another term for frequency of ac voltage is *hertz*, abbreviated Hz. Hertz and cycles-per-second mean exactly the same thing. These expressions are interchangeable, though hertz is the preferred term. When you see the expression 60 Hz, it refers to an alternating voltage, or current, that completes 60 cycles per second.

The voltage generated by this one-turn primitive generator would be extremely low, even with a very strong magnetic field. But higher voltages can be obtained by putting more turns of wire on the coil. In fact, 10 times as much voltage is induced in a 10-turn coil as in a single-turn coil. If one-tenth of a volt is induced in a 1-turn coil, one-tenth of a volt is induced in each turn of a 10-turn coil. These voltages add together to make a total of 1 V available at the output terminals. With 100 turns of wire, we can get 10 V; 1000 turns on the coil would produce 100 volts. Thus, by putting the required number of turns on the coil of a generator, we can generate any desired voltage.

## DC Generators

A practical generator does not use a permanent magnet. Instead, an electromagnet supplies the

## POWER SOURCES

magnetic field. Operating current for the electromagnet can be obtained from the generator itself, from another generator, or even from a battery. However, dc current is required to make an electromagnet. The voltage produced by the generator we discussed is ac. How can we get dc current from an ac generator? A practical ac generator does not use direct physical connections to the wire winding of the coil. The coil rotates at a high speed, which would quickly twist and break off solid connections. So, the ends of the coils connect to slip-rings. Brush contacts ride on the slip-rings, allowing ac voltage to be tapped from a generator. The slip-ring and brush surfaces are precisely-machined parts; the brushes glide over the surface of the slip-rings as the coil rotates, keeping excellent electrical contact with minimum abrasion.

However, we can get dc output if we use two slip-rings and a commutator, as shown in Fig.22. A commutator resembles a slip-ring, but it is split in half and the two halves are insulated from each other. The brushes are placed so that each brush contacts one section of the commutator as the coil makes the first half-revolution, and

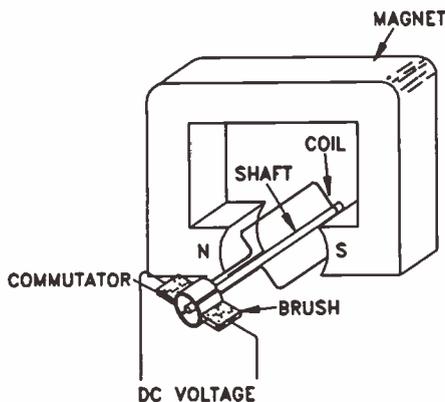


Figure 22. A simple dc generator.

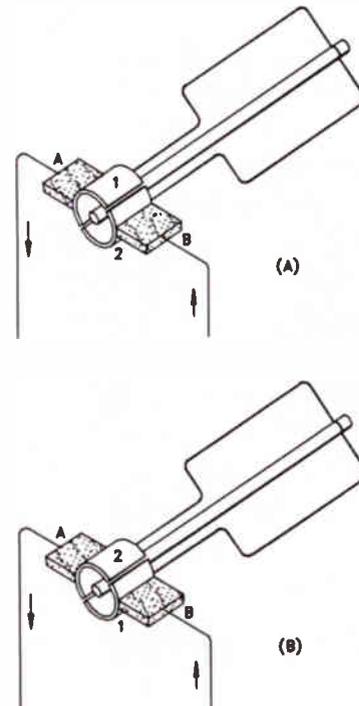


Figure 23. (A) Section 1 of the commutator is negative, and section 2 is positive. (B) Section 1 is positive, and section 2 is negative. Brush A is always connected to the negative section of the commutator, and brush B to the positive section. Current flows in only one direction.

the other section of commutator as the coil makes the second half-revolution. The result is that current in the external circuit always flows in the same direction, as shown in Fig.23. As a result, at the output we have a voltage like that shown in Fig.24.

This is essentially the same wave shape as in Fig.21. The difference is that the negative half-cycle below the line is made positive by the automatic reversing of the connections to the coil achieved by the commutator and brushes.

Voltage like that shown in Fig.24 is called *pulsating dc*. It is defined as a dc voltage because the current flows in one direction. However, since the voltage varies, the amount of current



Figure 24. Output of a simple dc generator.

also varies. The current flows in pulses and actually drops to zero twice during each turn of the coil. Pulsating current can be used in some applications, but it is troublesome because it is not pure dc, like the dc supplied by a battery.

A more efficient generator design is shown in Fig.25. Here there are a number of coils wound on an iron form called an *armature*. The coils are in different positions around the armature. In the position shown, coil A-A' does not cut any lines of force and has no voltage induced in it. Coil B-B' is in a position to cut a few lines of force, and has some voltage induced in it. Coil C-C' is

further into the magnetic field, cutting still more lines of force and generating a proportional amount of voltage. Coil D-D' is cutting directly across the lines of force and the maximum voltage will be induced in it. These coils are connected in series and brought out to the connections on the commutator. Two brushes are used on the commutator. The output voltage from this type of machine will be nearly constant because there will always be one coil in or near each position shown in Fig.25. The voltage produced by the generator will be the voltage of all the coils in series.

While some of the coils are producing very little voltage, the coils near the position D-D' will produce considerable voltage. The commutator used with this type of generator has 12 sections instead of two. There will be some fluctuation in the output voltage, but not nearly as much as in a generator with a single coil.

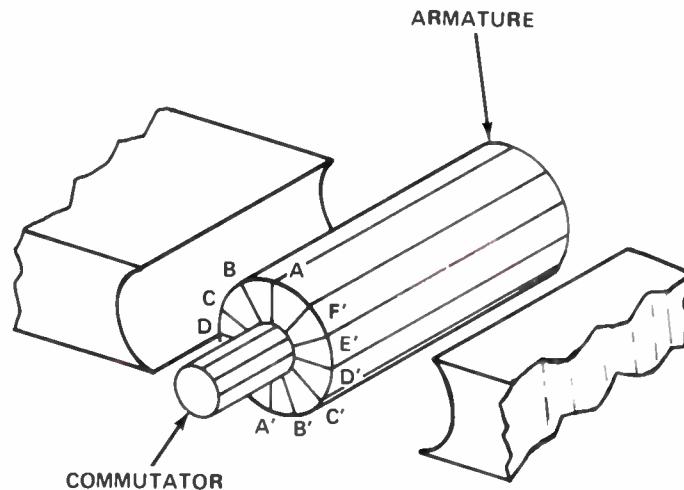


Figure 25. The armature of a dc generator with six series-connected coils.

## POWER SOURCES

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If we designed the 6-coil generator shown in Fig.25 so that its maximum output voltage was 100 V, during the first half-revolution the voltage would rise from 95 V to 100 V, then fall back to 95 V six times. The same thing would happen during the next half-cycle. The advantage is that we can reduce the voltage variation with a 6-coil machine. The single-coil machine, on the other hand, would vary between 0 and 100 V every half-turn. Compare the output from a 100 V single-coil dc generator to the output from a 100 V 6-coil dc generator shown in Fig.26.

### AC Values

Look back at the 1-cycle ac waveform shown in Fig.21. At the start of the cycle, the voltage is zero. After the coil rotates one-quarter of a turn, the voltage reaches its maximum value. At the halfway point, its back to zero again. At three-quarters of a turn, the voltage is at its maximum negative value, and at the end of the cycle the voltage is back to zero. The voltage reaches a maximum value twice in each cycle.

Since ac voltage fluctuates constantly, how do we measure its applied value? When we talk about a dc current, we might say that the current flowing in the circuit is 1 ampere. This means

that a certain number of electrons flow past a given point in the circuit in a period of one second. This same number of electrons continues to flow as long as the current is 1 ampere.

What happens with ac current? With the voltage rising and falling twice each cycle, the current flow has two maximum and two minimum points in each cycle. Therefore, the number of electrons flowing in the circuit is not constant. In fact, it changes continuously as the ac voltage goes through its cycle.

To get around the difficulty caused by its constant variation, we measure ac in terms of equivalent dc. When we say that the ac current flowing in the circuit is 1 A, we mean that the current is the equivalent of 1 A of dc. This equivalence is established on a basis of comparable heat produced. For instance, a dc current of 1 A flowing through a heating element generates a certain measurable amount of heat. When ac current flowing through the same heating element produces the same amount of heat, we define that ac current as 1 ampere.

Basically, the same system is used to measure ac voltage. If a dc voltage of 100 V forces a current of 1 A through a standard resistance, the ac voltage that forces an ac current of 1 A through the same resistance is said to be 100 volts. This is called the *effective*, or *rms voltage*. An ac current that flows as a result of this voltage produces the same heating effect as the equivalent amount of dc current.

From looking at an ac voltage waveform, you can see that the actual voltage is greater than the effective value during part of the cycle, and less than the effective value during the rest. The maximum voltage that the ac reaches during a half-cycle is called the peak voltage, as we mentioned before. The peak voltage is approximately 1.4 times the effective voltage. Since each peak is 1.4 times the effective voltage, the peak-to-peak

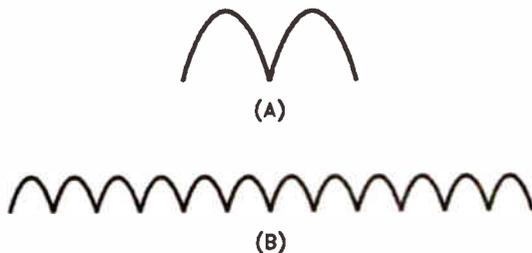


Figure 26. (A) Voltage from a single-turn generator.  
(B) Voltage from a generator with coils like in Figure 25.

voltage is twice that, or 2.8 times the effective voltage. Figure 27 shows an effective ac voltage of 100 volts. The peak value is 140 V, and the peak-to-peak value 280 volts. Study this figure carefully to be sure that you understand it.

It is important to remember that when we are talking about ac voltages, unless we specifically refer to the peak or peak-to-peak voltages, we are talking about effective voltages. Also remember that the peak voltage is 1.4 times — the peak-to-peak voltage is 2.8 times — the effective voltage. Peak voltage, peak-to-peak voltage, and rms voltage are terms you will see many times during your career in electronics. Remember that rms voltage is the same as the effective voltage.

A good example for comparison of voltage measurements is the voltage supplied to most homes in this country. The average power company supplies a voltage of somewhere between 115 and 120 volts, 60 Hz ac, for lighting and general domestic use. This is the effective value of the voltage. Let us assume that the voltage supplied to your home is exactly 120 volts. What is the peak voltage reached during each half-cycle? It will be  $1.4 \times 120$ , which is 168 volts. The peak-to-peak voltage supplied to your home will be 336 V (or  $2.8 \times 120$ ). The net effect of this ac voltage is the same as supplying a dc voltage of 120 V to the electric light.

**The Importance of AC.** You may wonder why we have gone into so much detail in describing alternating current. Alternating current is impor-

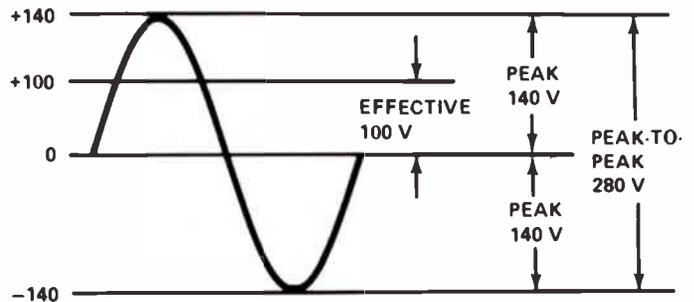


Figure 27. AC waveform showing effective (rms), peak, and peak-to-peak voltages.

tant not only because it is the type of power supplied by the power companies, but also because ac signals are used throughout the entire electronics industry. The sound that comes from the loudspeaker in a radio or telephone receiver, or the sound from your telephone, is produced by ac signals having a frequency not too much higher than the power-line frequency. The radio waves that travel through space to bring you radio and TV programs are actually ac signals of a much higher frequency. AC signals are used in every branch of electronics. In later lessons you will learn how these signals are produced and how they are used. You will also learn that many circuits and components have different behaviors when an ac voltage is applied, as compared to when a dc voltage is applied. You will learn how we take advantage of these differences.

# POWER SOURCES

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## Review

We have covered a great deal of material in the preceding sections. There are several important things that you should remember, including what an ac cycle looks like, and that this ac voltage is called a sine wave.

Remember that when we speak of ac voltage and current, we are speaking of the voltage and current that will produce the same effect as the equivalent values of dc. Remember that the peak value of the ac cycle is 1.4 times the effective value, and the peak-to-peak value is 2.8 times the effective value.

## Self-Test Questions

- 18 What are the two kinds of electrical current produced by power sources? *Ac Dc*
- 19 What kind of voltage produces a current that flows in only one direction? *Dc Direct*
- 20 What do we call voltage that causes current to flow first in one direction, then in the other direction, many times in a second? *Ac Alternating*
- 21 What is the name given to the ac voltage waveform supplied by the power company? *Sine wave*
- 22 What is a cycle? *Zero to 60 to zero etc*
- 23 What do we mean by 60 Hz? *Refers to AC current*
- 24 What device on a dc generator reverses the connections of the coil to produce direct current instead of alternating current? *Commutator*
- 25 What type of current is produced by a simple dc generator? *Pulsating dc*
- 26 What is the difference between 1 A of dc current, and 1 A of ac current? *None*
- 27 If we say the ac voltage is 100 V, are we referring to the effective or the peak value of the ac voltage?
- 28 If the rms voltage is 200 V, what is the peak value of the voltage?

$$\begin{array}{r} 200 \\ \times 1.4 \\ \hline 280 \end{array}$$

## ANSWERS TO SELF-TEST QUESTIONS

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### ANSWERS TO SELF-TEST QUESTIONS

- 1 Primary and secondary are the two basic types of batteries.
- 2 Secondary batteries are rechargeable.
- 3 Electrical power in a battery is the result of chemical reaction.
- 4 Primary batteries have the advantage of a longer shelf life (storage period) without severe loss of charge.
- 5 The chemical reaction in a dry cell is caused by metals such as zinc or lead, and their oxides.
- 6 A fresh carbon-zinc battery has a 1.5 V unloaded output voltage. The typical no-load voltage of a dry cell, or zinc-manganese (carbon-zinc) battery, is 1.5 volts.
- 7 Alkaline batteries get their name from their caustic alkaline base of potassium hydroxide, which is used as part of the electrolyte.
- 8 In conditions of low current drain at a constant warm temperature, carbon-zinc batteries may be more economical than alkaline batteries.
- 9 The no-load voltage of a lead-acid cell is 2 V, plus or minus 10%, depending on conditions.
- 10 The normal recharge rate for a nickel-cadmium cell is approximately 10% of the rated current output.
- 11 A fully-charged nickel-cadmium battery starts at about 1.4 V and quickly drops to a constant 1.25 volts.
- 12 The lithium battery has the longest shelf life.
- 13 The basic law of magnetism states: Like poles repel, and unlike poles attract.
- 14 The basic law of magnetism addresses this statement: If one pole of the magnet attracts the south pole of the compass, the pole must be an unlike pole, and therefore must be a north pole.
- 15 The magnetic lines of force around a current-carrying wire are stronger close to the wire.
- 16 Placing an iron core inside an electromagnet will increase the strength of the field.
- 17 The flashlight bulb will light while the magnet is being placed inside the coil. Once the magnet is inside the coil and no longer moving, the flashlight bulb will no longer light.
- 18 Electrical current power sources produce both direct current and alternating current.
- 19 DC voltage flows in only one direction.
- 20 AC voltage causes current to flow first in one direction, then in the other direction, many times a second.
- 21 The waveform supplied by the power company is called a sine wave.
- 22 The waveform shown in Fig.21(B) represents one cycle. In a cycle of an alternating current, the voltage between the two terminals of the generator starts at zero, then builds up to a maximum value with one polarity, then drops back to zero; it then builds up to a maximum value with the other polarity, and then drops back to zero. During the next cycle it will simply repeat the first cycle.
- 23 The measurement of 60 Hz means 60 cycles per second, which means that there are 60 complete cycles in a second. This means that the voltage starts at zero, builds up to a maximum with one polarity, drops back to zero, builds up to a maximum value at the opposite polarity, and drops back to zero a total of 60 times in a second.

## POWER SOURCES

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- 24 A commutator reverses the connections of the coil to produce dc voltage.
- 25 A simple dc generator, like the one shown in Fig.22, would produce a pulsating dc (shown in the waveform in Fig.24). A pulsating dc of this type is normally not desirable, and the excessive pulsating can be eliminated by means of an armature, such as that shown in Fig.25. The armature holds several coils connected in series to produce a smoother dc output.
- 26 Actually, 1 A of dc current and 1 A of ac current flowing through a heater produces the same amount of heat as a dc current of 1 A flowing through the same heater.
- 27 An ac voltage that is not specified as a peak value is assumed to be the effective or rms value. If we want to provide the peak value, we should specifically state that it is the peak value, or assume the effective (rms) value.
- 28 With a rms voltage of 200 V, the peak value of the voltage is 280 volts. The peak value of an ac voltage is 1.4 times the rms value. Thus, if the rms value is 200 V, the peak value is 280 V (or  $200 \times 1.4$ ).

# Lesson Summary

Some of the important facts you should remember about this lesson are:

- Primary storage batteries are not rechargeable; secondary batteries are.
- The movement of a conductor within a magnetic field generates current and voltage in the conductor.
- The voltage that is produced in a conductor coil, by movement in a magnetic field, is proportional to the strength of the magnetic field and the number of turns in the coil.
- Both ac and dc generators are constructed from multiple sets of magnets and multiple windings of wire.
- AC current is in the form of a sine wave with peak, effective, and peak-to-peak voltage and current characteristics.



## LESSON QUESTIONS

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5. When we say that the effective ac current is 1 A, we mean:
- A constant current of 1 A flows.
  - The peak current is 1 ampere.
  - The current flowing has the effect of 1 A dc.
  - The average current is 1 ampere.
6. If the effective ac voltage produced by a generator is 10 V, the peak voltage is:
- 10 volts.
  - 0 volts.
  - 28 volts.
  - 14 volts.
7. If a two-pole, single-turn ac generator is turning at 1800 rpm, what is the frequency of the ac produced?
- 30 Hz.
  - 60 Hz.
  - 15 Hz.
  - 75 Hz.
8. If you find that when you bring two magnetic poles together they attract each other:
- The two poles must be north poles.
  - The two poles must be south poles.
  - One pole must be a north pole and the other a south pole.
  - Both answers a and b may be correct.
9. The chief advantage of the dry cell over the lead-acid cell is:
- It supplies a higher voltage.
  - It can supply a given current longer.
  - It has a longer shelf life.
  - It is cheaper to manufacture.
10. To induce a voltage in a conductor, what two things are needed?
- Magnetic field and motion.
  - Copper and magnetism.
  - Electrolyte and reactive metal.
  - Current and resistance.

$$\begin{array}{r} 1.4 \\ 10 \\ \hline 14.0 \end{array}$$

## NOTES

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## CASHING IN ON DISCONTENTMENT

Discontentment is a good thing — if it makes you want to do something worthwhile. If you had not been discontented with your current situation, you never would have enrolled in your NRI course.

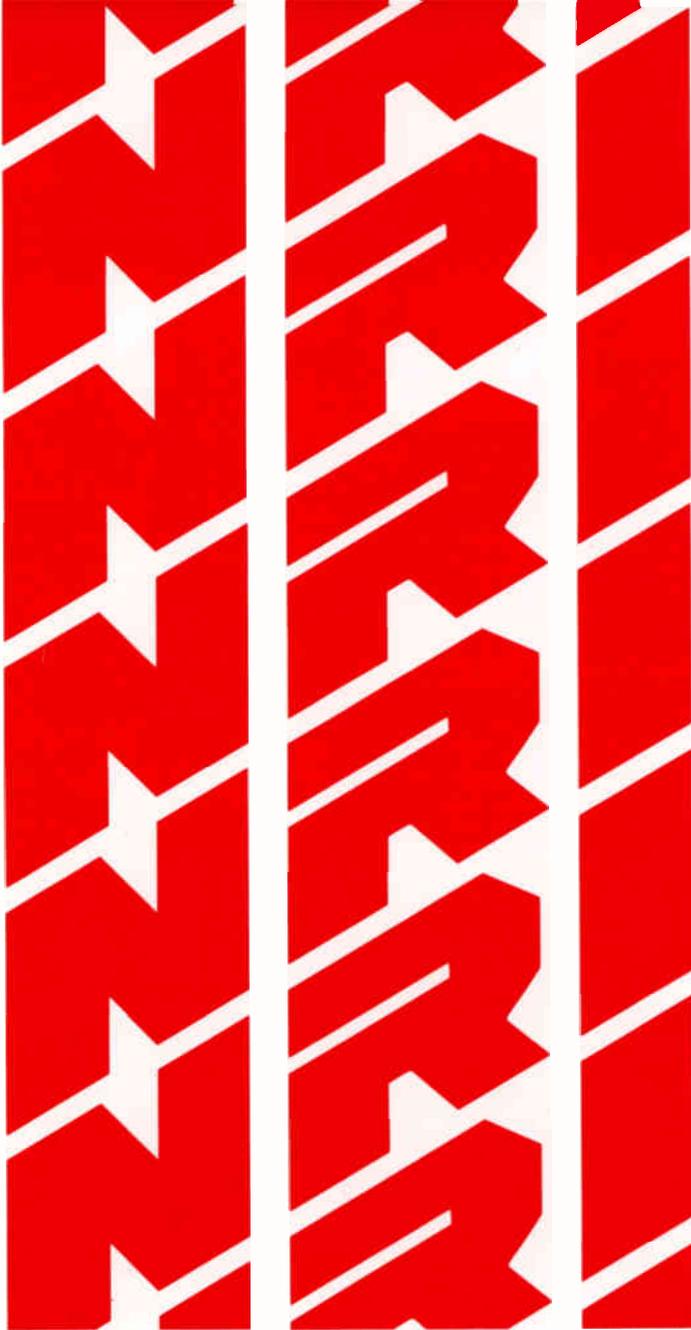
Practically everyone is discontented from time to time. If we allow ourselves to be *floored* by discontentment, we can easily become complainers who find fault with anything and everything and end up bitter and resentful failures.

If we're smart, we learn to use our discontentment to motivate us. We use it to keep us focused on the goals we have set for ourselves. We know that we are creating a better life for ourselves, so sacrifices are worth making. We are happy in our work. We face defeat squarely and come out winners.

At this moment, you may be discontented with many things — your progress in this course, your current earning ability, or your life in general.

Make that discontentment work *for* you. Don't let it get you down. If you do, you may not be able to pick yourself back up again. Keep striving to beat the causes of your discontentment. Remember that it's always darkest before the dawn. And remember, the people who are real successes in life work their hardest when they are face to face with the greatest discouragements and disappointments.





# How Resistors Are Used

2221



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Washington, DC 20008



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# **How Resistors Are Used**

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**HOW RESISTORS ARE USED (First Edition)**

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# Table of Contents

<b>How Resistors Are Used</b> .....	<b>1</b>
<b>Physical Characteristics of Resistors</b> .....	<b>2</b>
Resistor Types .....	2
Resistor Values .....	3
Tolerances .....	3
EIA Values .....	4
Color Code .....	5
Precision Resistors .....	6
Thermistors .....	6
Varistors .....	7
High-Voltage Resistors .....	7
Resistor Wattage Ratings .....	7
Review .....	9
Self-Test Questions .....	9
<b>Using Resistors to Set Circuit Voltages</b> .....	<b>10</b>
Voltage Division .....	10
Series-Dropping Resistors .....	11
Bleeder Resistors .....	13
Review .....	14
Self-Test Questions .....	14
<b>Answers to Self-Test Questions</b> .....	<b>15</b>
<b>Lesson Questions</b> .....	<b>18</b>

## HOW RESISTORS ARE USED

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# Lesson Objectives

In this lesson, you will . . .

- Review resistor types, constructions, and tolerances.
- Learn the resistor color code for identifying resistors.
- Examine how resistors are used to establish circuit voltages.
- Study how resistors can stabilize voltage sources.

## HOW RESISTORS ARE USED

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### HOW RESISTORS ARE USED

This lesson is devoted almost entirely to resistors and their uses. It is important that you learn how they are used so that you can determine if a circuit is working properly. You also need to be able to select a suitable replacement for a resistor when one is needed.

There are many uses for resistors. Different circuits require different operating voltages but, for economy, the required operating voltages must all be obtained from a single power source. Resistors are used to drop the voltage to the correct value. Resistors are also used to isolate parts from each other so that one will not interfere with the operation or action of another.

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## HOW RESISTORS ARE USED

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### PHYSICAL CHARACTERISTICS OF RESISTORS

Resistors come in many shapes and sizes, and with several different design parameters. The design of a resistor depends mostly upon the application for which it is intended. Special variable resistors, called *potentiometers*, are widely used in electronic equipment to control the volume and tone in radio and TV receivers, and to control picture brightness and contrast in TV receivers and video displays. They also control the level of the sound signal in radio transmitters, and the level of both sound and picture signals in TV transmitters. There is no end to the uses of resistors in electronic equipment, so it is important that you understand how they work and are used.

#### Resistor Types

We have already introduced several types of resistors used in electronic equipment, of which the most frequently used is the *carbon resistor*.

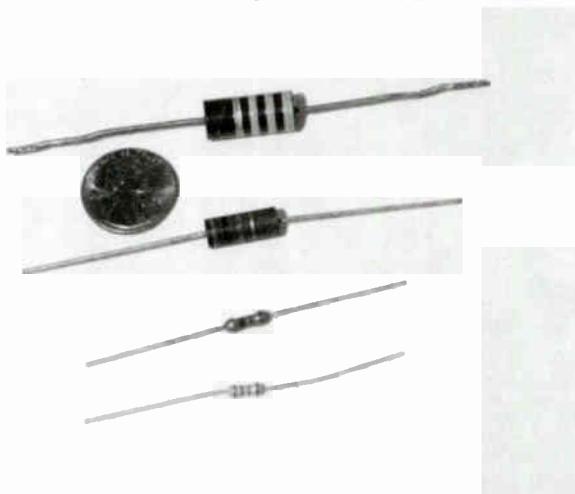


Figure 1. Relative physical size of the four different wattage carbon resistors compared to a penny.

There are two types of carbon resistors; one is made of a carbon compound held together by a cement-type binder, and the other is made by depositing a film of carbon on a thin ceramic rod.

Carbon resistors are manufactured in 1/4 W, 1/2 W, 1 W, and 2 W sizes. Devices such as video cassette recorders and microcomputers contain hundreds of carbon resistors. Most of the carbon resistors in these devices are 1/4 W or 1/2 W resistors. Figure 1 is a photograph showing the relative physical size of the four different wattage carbon resistors as compared to a penny.

There are also wire-wound resistors. A wire-wound resistor is made by winding a resistance wire on a form. Resistance wire is a special type of wire that has a relatively high resistance. Wire-wound resistors have wattage ratings that start at 3 or 4 W, and range upward to very high wattage ratings. Very high wattage rating resistors are large and heavy and are often suspended on mounting brackets, bolted, or riveted to the chassis. Wire-wound resistors cannot be made conveniently in high resistance values. Since they are made by winding wire in a coil on an insulated support, they often take on some of the characteristics of a coil, which may not be desirable.

Metal-oxide resistors are another type. These resistors can be made in higher wattage ratings than carbon resistors, yet still have many of the advantages of carbon resistors. Where larger values of resistance are necessary, metal-oxide resistors must be used instead of wire-wound resistors. The metal-oxide resistor is made by depositing a metal-oxide film on a ceramic or glass tube or rod. The oxide film is in a linear path rather than a winding path, so it does not act like a coil.

The rheostat is one kind of variable resistor. Rheostats may be wire-wound devices, or may be made from a carbon element. A rheostat has a

## PHYSICAL CHARACTERISTICS OF RESISTORS

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sliding contact which rotates to allow selection of the desired resistance. The resistance is determined by the position of the sliding contact with respect to the total resistance available.

The variable resistor shown in Fig.2 is a potentiometer. A potentiometer has three terminals. The resistance between the two outside terminals is constant — equal to the entire resistance of the carbon or wire-wound element inside the control. The center terminal connects to a sliding contact and is adjustable across the resistance element. Like the rheostat, the resistance between the sliding contact and either end of the total resistance is selected by turning the control. Since the total resistance is constant, when the resistance between the slider and one end of the resistance element decreases, the resistance between the slider and the other end increases.

Potentiometers with high resistances are usually carbon controls. Low-resistance potentiometers may either be carbon or wire-wound

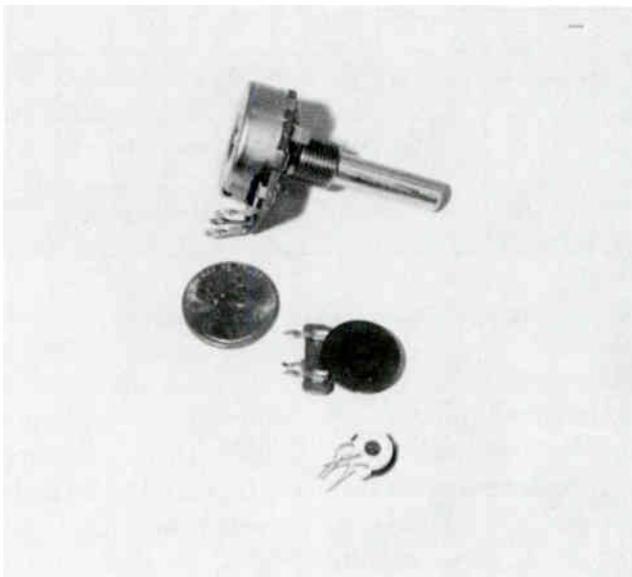


Figure 2. A potentiometer.

controls; most, however, are carbon controls. Carbon controls are preferred over wire-wound controls because they are less likely to develop dirty or burned spots on the resistance element. These spots produce noise as the control is rotated.

### Resistor Values

You should know from your previous lessons that a wide range of resistor values are used in electronic equipment. You should also remember that in abbreviating resistor values the letter k represents a thousand and the letter M represents a million. Thus, a resistor marked 2.2k has a value of 2200 ohms. A resistor marked 2.2 M has a resistance of 2,200,000 ohms. To convert from kilohms to ohms, move the decimal point three places to the right. To convert from ohms to kilohms, move the decimal point three places to the left. To convert from megohms to ohms, move the decimal point six places to the right, and to convert from ohms to megohms, move the decimal point six places to the left.

Sometimes you must convert from megohms to kilohms. For example, a resistor might be marked 0.1 M. To convert this to ohms, move the decimal point six places to the right. Thus, 0.1 M becomes 100,000 ohms. To convert from megohms to kilohms, move the decimal point three places to the right. Therefore, a 0.1 M resistor is the same as a 100k resistor. You will find resistors marked 470k on some diagrams, and 0.47 M on others. Remember that both mean the same thing: the resistance of the resistor is 470,000 ohms.

### Tolerances

The carbon resistor is the most widely used resistor in electronic equipment. These resistors

## HOW RESISTORS ARE USED

are manufactured with a tolerance of either 5 or 10 percent. Occasionally, you will come across a carbon resistor with a tolerance of 20%, but these resistors are infrequently used.

The *tolerance* of a resistor indicates how close its actual resistance is to its rated resistance. Consider a 100-ohm resistor with a 5% tolerance. You will find that 5% of 100 is 5 ohms. If the resistor has a 5% tolerance, its actual resistance is within 5 ohms of 100 ohms. That is, the resistor may have a value anywhere between 95 and 105 ohms. A 10% tolerance in a 100-ohm resistor is 10 ohms. A 10% resistor may have a value anywhere within 10 ohms of 100 ohms, a value between 90 and 110 ohms.

Resistor tolerance is indicated on the body of the resistor with a silver or gold band. A silver band indicates a tolerance of 10% and a gold band a tolerance of 5 percent. A carbon resistor without a silver or gold tolerance band is a 20% resistor.

### EIA Values

The EIA (Electronics Industries Association) has set up standard values for carbon resistors. In designing electronic equipment, you will rarely need a resistor of an exact value. Although, for example, an engineer might calculate that a particular circuit requires a 3721-ohm resistor, that is a nonstandard value. However, 3600 is a standard value, and so is 3900 ohms. Minor changes in the circuit would easily allow one of the standard values to be used.

Standard EIA carbon resistor values are shown in Fig.3. All these values are available in resistors having a 5% tolerance. You can get a carbon resistor having a resistance as low as 0.24 ohm, and as high as 22 megohms. However, 10% resistors are available only in the values that are shaded.

Ohms	Megs	Megs									
0.24	1.1	5.1	24	110	510	2400	11k	51k	240k	1.1	5.1
0.27	1.2	5.6	27	120	560	2700	12k	56k	270k	1.2	5.6
0.30	1.3	6.2	30	130	620	3000	13k	62k	300k	1.3	6.2
0.33	1.5	6.8	33	150	680	3300	15k	68k	330k	1.5	6.8
0.36	1.6	7.5	36	160	750	3600	16k	75k	360k	1.6	7.5
0.39	1.8	8.2	39	180	820	3900	18k	82k	390k	1.8	8.2
0.43	2.0	9.1	43	200	910	4300	20k	91k	430k	2.0	9.1
0.47	2.2	10	47	220	1000	4700	22k	100k	470k	2.2	10
0.51	2.4	11	51	240	1100	5100	24k	110k	510k	2.4	11
0.56	2.7	12	56	270	1200	5600	27k	120k	560k	2.7	12
0.62	3.0	13	62	300	1300	6200	30k	130k	620k	3.0	13
0.68	3.3	15	68	330	1500	6800	33k	150k	680k	3.3	15
0.75	3.6	16	75	360	1600	7500	36k	160k	750k	3.6	16
0.82	3.9	18	82	390	1800	8200	39k	180k	820k	3.9	18
0.91	4.3	20	91	430	2000	9100	43k	200k	910k	4.3	20
1.00	4.7	22	100	470	2200	10k	47k	220k	1 M	4.7	22

Figure 3. Standard EIA resistor values.

Older equipment usually has higher percentages of 10% tolerance resistors. These resistors were less expensive to manufacture, and a 5% resistor was seldom needed. However, new and improved resistor-manufacturing hardware can produce, measure, and sort resistors to the nearest

# PHYSICAL CHARACTERISTICS OF RESISTORS

5% value. Today most resistors are 5%, because they are priced comparably to 10% resistors.

When replacing a 10% resistor you can always substitute a 5% unit. However, this allowance is one-way; you cannot replace a 5% tolerance resistor with a 10% part. It is possible that substituting a 10% resistor for a 5% resistor will alter the performance of the circuit. However, if the industry trend toward 5% tolerance continues, it may soon be impossible to buy a 10% resistor at all.

## Color Code

The resistance value of a carbon resistor is specified by three color bands around the body. To determine the value of a resistor, first find the tolerance band; it will either be silver or gold. Hold the resistor so that the tolerance band is on the right, as shown in Fig.4. The three color bands are to the left of the tolerance band. From left to right, the color of the first band represents the first digit of the resistance value, the second band color indicates the second digit, and the color of the third band (sometimes called the multiplier) indicates the number of zeros to add to the two-digit number formed by the first and second bands.

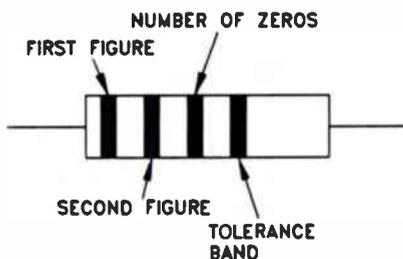


Figure 4. Resistor values and tolerance are identified by color bands as shown.

Color	First Band	Second Band	# of Zeros or Multiplier
Silver	—	—	0.01
Gold	—	—	0.1
Black	0	0	none
Brown	1	1	0
Red	2	2	00
Orange	3	3	000
Yellow	4	4	0000
Green	5	5	00000
Blue	6	6	000000
Purple	7	7	—
Gray	8	8	—
White	9	9	—

Figure 5. Standard resistor color codes.

The standard resistor color codes are shown in the chart in Fig.5. Referring to this chart, suppose the first band is yellow, the second band is purple, and the third band is orange. The yellow band stands for the first digit in the resistance, or 4. The purple band means the second digit is 7, and the orange band adds three 0s after the 7. Therefore, the resistance value is 47,000 ohms, or 47 kilohms.

390000

2600000

460

## HOW RESISTORS ARE USED

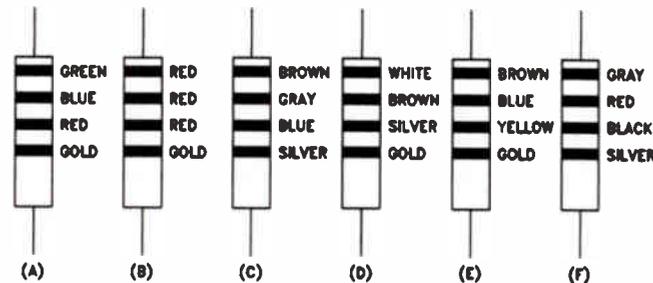


Figure 6. (A) 5600 ohms, 5.6k, 5%; (B) 2200 ohms, 2.2k, 5%; (C) 18,000,000 ohms, 18M, 10%; (D) 0.91 ohms, 5%; (E) 160,000 ohms, 160k, 5%; (F) 82 ohms, 10%.

A resistor coded red, red, brown has a resistance of 220 ohms. A black band in the third position means no 0s are added, so a resistor coded red, red, black has a resistance of 22 ohms. A gold band represents a 0.1 multiplier; therefore, a resistor coded red, red, gold has a resistance of 2.2 ohms, because you move the decimal point one place to the left to indicate multiplication by 0.1. If, in addition to the third gold band, the fourth band (or *tolerance band*) is gold, the resistor value is 2.2 ohms with a 5% tolerance. If the tolerance band is silver, it means that the resistor value is 2.2 ohms with a tolerance of 10%.

A few resistors have a fifth color band after the tolerance band. This is a reliability indicator, and is of little concern to the electronics technician. Resistors rarely fail unless there is an overload failure in the circuit. When the circuit fails, the resistor may burn out regardless of its reliability.

Figure 6 shows several resistors, and the caption gives the value of each of these resistors. Cover the caption and try writing out the resistor values. After you write out all the values, check your answers against the values given in the caption.

### Precision Resistors

In some equipment, usually electronic test equipment, resistors having tolerances of 1% or even 1/2% are used. These resistors are made by a different process than the carbon resistors used in most equipment, and are significantly more expensive than standard resistors.

These 1% and 1/2% resistors are called precision resistors. Their value is usually stamped on the resistor body, along with their tolerance. Although many precision resistors are available "over the counter," some special-application units have to be ordered from the manufacturer or an authorized distributor.

### Thermistors

A thermistor is a special type of resistor. Thermistors are made of a material that decreases in resistance as its temperature increases. We say that a thermistor has a "negative temperature coefficient." This means that as the temperature of the thermistor goes up, its resistance goes down.

## PHYSICAL CHARACTERISTICS OF RESISTORS

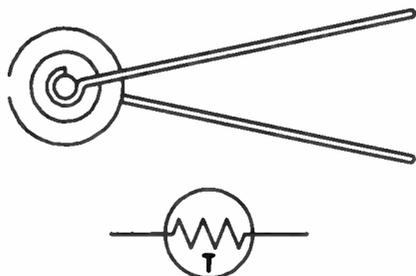


Figure 7. A typical thermistor and its schematic symbol.

A typical thermistor and its schematic symbol are shown in Fig. 7. These devices are frequently used in circuits where there is likely to be a high current surge when the equipment is turned on. When the thermistor is cold it has a high resistance, and most of the applied voltage is dropped across the thermistor. This limits the amount of current that can flow in the circuit. However, as the thermistor warms up, its resistance decreases (sometimes to a very low value) so that normal current can flow in the circuit.

### Varistors

Another special type of resistor is the *varistor*. This type of resistor is also called a *voltage-dependent resistor*, which means that the resistance of the device depends upon the voltage across it. As the voltage across a varistor increases, the resistance of the varistor decreases.

A drawing of a varistor and its schematic symbol are shown in Fig. 8. Varistors are used in circuits where a high voltage might appear suddenly. When this happens, the resistance of the varistor decreases rapidly, drawing off a large current from the voltage source, and preventing damage to other components. Varistors are fre-

quently used in color TV receivers and video displays.

### High-Voltage Resistors

In some applications, resistors are used across circuits where there is a very high voltage. The resistance of the resistor may be so high that the power dissipation is less than 1/2 W, but a 1/2 W carbon resistor is not suitable for high-voltage applications.

A typical high-voltage resistor is shown in Fig. 9, on page 8. It is made by depositing carbon in a spiral groove cut in a ceramic-type body. The resistor is deliberately made several inches long so that there is no possibility of the high voltage arcing across it. Resistors of this type are found in TV receivers, especially color TV receivers.

### Resistor Wattage Ratings

As you know, electrical power is measured in watts. In a previous lesson, you were introduced to three forms of the power equation:

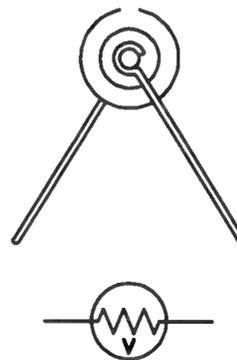


Figure 8. A typical varistor and its schematic symbol.

## HOW RESISTORS ARE USED

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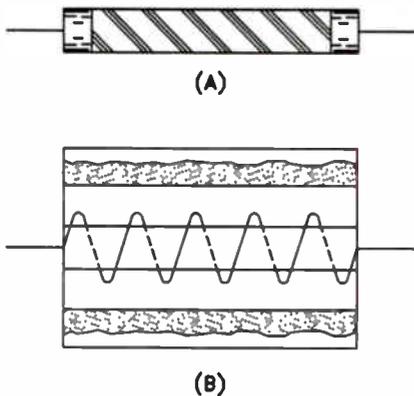


Figure 9. A high-voltage resistor.

$P = EI$ ,  $P = I^2R$ , and  $P = E^2/R$ . In most cases, a resistor in an electrical circuit conducts some amount of current flow. For a  $1/4$  W resistor, the square of the current  $I^2$  times the value of the resistor  $R$  should not exceed  $1/4$  watt. For a  $1/2$  W resistor,  $I^2R$  must not exceed  $1/2$  watt. This is the case for any wattage rating, because exceeding the rating may result in the destruction of the component.

The wattage rating of a resistor is sometimes called its *dissipation rating*. A  $1/2$  W resistor can dissipate  $1/2$  W of power. The resistor consumes

electrical power by dissipating, or radiating, it as heat. In actual practice, if the power in a circuit is  $1/2$  W, we typically use a 1 W resistor, which has twice the dissipation capability necessary. When carbon resistors get hot, they tend to change value. Therefore, it is a good idea to use a larger resistor with a higher power dissipation rating to avoid this problem.

The deposited-film type of resistor is made in ratings of between 2 W and about 10 watts. These resistors are larger than carbon resistors and can handle more power. Unlike carbon resistors, they do not have the tendency to change value when hot, and can be operated closer to their full wattage rating.

Wire-wound resistors can be made with extremely high wattage ratings. You will seldom find wire-wound resistors rated at higher than 10 W in a radio, TV, or microcomputer. However, in radio and TV transmitting equipment, as well as industrial equipment, some wire-wound resistors can dissipate several thousand watts or more. These high-wattage resistors are made from large-diameter resistance wire that can carry a high current. They are wound on big ceramic tubes to provide a large area to dissipate the heat produced by the current flowing through the resistance wire.

# PHYSICAL CHARACTERISTICS OF RESISTORS

## Review

You have reached the point in your course where you should be able to convert ohms to kilohms and to megohms, and then back again without any trouble. This is important because all three units are used by manufacturers on circuit diagrams.

You should memorize the resistor color-code chart. Start by writing it out several times; start with black 0, brown 1, red 2, and so on. It is not very important to remember gold and silver in the third band, because you seldom encounter small-value resistors. However, remember the meanings of the tolerance bands: gold is more valuable than silver and has a value of 5%, and silver has a value of 10 percent. The fifth band is a reliability band. Any time you have to replace a 10% resistor you can use a 5% resistor of the same value.

A thermistor is a resistor which has a resistance that decreases as the resistor warms up. A varistor is a resistor with a resistance which decreases as the voltage across it increases. A high-voltage resistor is a special resistor made several inches long so that the high voltage in the circuit will not jump across it.

## Self-Test Questions

Please check your answers on page 15.

- 1 What is 4.7k equal to in ohms? *47000*
- 2 Express 0.39 M in kilohms and in ohms. *390k 390,000*
- 3 What is 680,000 ohms in kilohms and in megohms? *680k .68m*
- 4 A 2200-ohm, 10% resistor actually has a value of 2000 ohms. Is this resistor within its rated tolerance? *yes*
- 5 A 10,000-ohm resistor has a tolerance of 5 percent. What is the maximum resistance that the resistor might have and still be within tolerance? *9500 to 10500*
- 6 Reading from left to right, the color bands on a resistor are orange, white, yellow, and gold. What is the value and tolerance of the resistor? *3900 39k 5%*
- 7 If a resistor is color-coded brown, black, green, and silver, what is its value and tolerance? *100000 100k 1%*
- 8 If a resistor is color-coded green, blue, orange, and gold, what is its value and tolerance? *5600 56k 5%*
- 9 If a resistor is color-coded red, red, red, and silver, what is its value and tolerance? *220 220 ohms 10%*
- 10 In a piece of electronic test equipment, a 100k, 1% resistor is burned out. You have available a 100k, 1/2% resistor. Can you use this resistor as a replacement? *yes*
- 11 What do we mean when we say that a resistor is dissipating 10 watts? *using 10 watts of power changed to heat*
- 12 If the voltage across a 1000-ohm resistor is 100 V, how much power is the resistor dissipating? *10 watts*
- 13 If the voltage across a 5000-ohm resistor is 50 V, what is the power dissipated by the resistor? *5 WATTS*
- 14 If the current through a resistor is 2 A, and the resistance of the resistor is 25 ohms, what is the power dissipated by the resistor? *100w*

*Handwritten calculations:*

$$1000 \sqrt{10,000} = 10 \text{ watts}$$

$$P = E^2/R$$

$$5000 \sqrt{2500} = 1.5 \text{ Watts}$$

$$P = I^2 R$$

$$\frac{2^2 \times 25}{100}$$

## HOW RESISTORS ARE USED

### USING RESISTORS TO SET CIRCUIT VOLTAGES

We mentioned earlier that in electronic equipment several different operating voltages may be required for different loads. In most cases, these voltages are taken from a single power supply to reduce equipment cost. Resistors are often used to reduce the voltage from the power supply to the required value.

You have seen a number of circuits where one or more resistors connect across a battery to form a series circuit. You also know that the current is the same in all parts of a series circuit, and that each voltage drop is the product of the current multiplied by the resistance. In a single series circuit, a higher resistance has a higher voltage drop across it than a smaller resistance; equal resistances have equal voltage drops.

It is important for you to remember all of this so you will recognize that each voltage drop in a series circuit is proportional to the size of the resistance creating the drop. The greater the resistance, the higher the voltage drop across it.

#### Voltage Division

A string of resistors in series can be regarded as a *voltage divider*. Each resistance produces a voltage drop equal to its proportional part of the applied voltage. Since the current remains the same throughout the circuit, the source voltage divides itself among the resistors in the circuit according to the value of each. (Remember Kirchhoff's law: the sum of the voltage drops in a series circuit is equal to the source voltage.)

For a series loop, there is a direct means of calculating the voltage drop across any par-

ticular resistor, without figuring out the current first. To do this, use the formula:

$$E_R = \frac{R}{R_T} \times E_T$$

$$\frac{10}{30} \times 30$$

Where  $E_R$  is the resistor voltage drop you want to calculate,  $R$  is the value of the resistor,  $R_T$  is the total resistance in the circuit, and  $E_T$  is the source voltage applied to the series circuit.

For example, if three 50-ohm resistors are in series across an applied voltage of 100 V, as shown in Fig. 10, what is the voltage drop across each resistor? Since all of the resistors are equal, each has one-third the total resistance of the circuit, and one-third the total applied voltage, or 33.3 volts.

You can easily verify this relationship by making the complete current and voltage drop calculations. The total resistance in the circuit is 150 ohms, so the series circuit current is 100 V

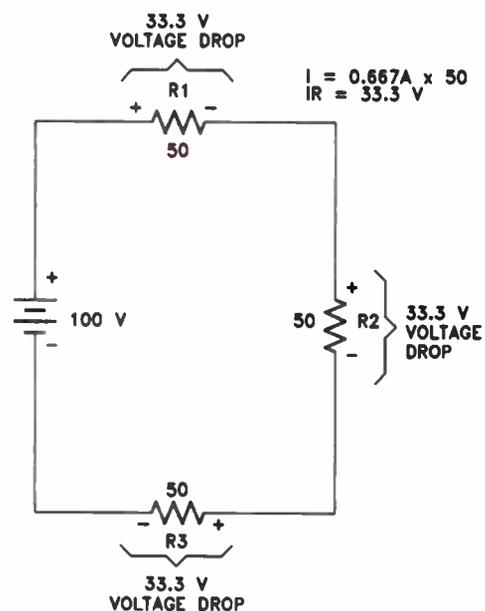


Figure 10. Voltage drops in a series circuit.

## USING RESISTORS TO SET CIRCUIT VOLTAGES

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divided by 150 ohms, or 0.667 amperes. When you multiply the current by the value of resistance to find the voltage drop (using Ohm's law) you find that each resistor has a voltage drop equal to 50 ohms multiplied by 0.667 A, or 33.3 volts.

Unfortunately, circuits will rarely be as simple as those in this example. Suppose the resistors are of unequal value: R1 = 20 ohms, R2 = 30 ohms, and R3 = 50 ohms, like in Fig.11. Add up the total resistance in the circuit (20 + 30 + 50) to get 100 ohms. By itself, R1 is 20/100, or 20% (0.2) of the total resistance. Therefore, the voltage drop across R1 is equal to 20% of the total voltage (0.2 x 100 = 20 volts).

Coincidentally, the numbers come out to round figures in the above example. But, the calculation works for odd numbers as well. Suppose that the resistors in the circuit are more realistic: R1 = 220 ohms, R2 = 470 ohms, and R3 = 1800 ohms. By adding up the total resistance (220 + 470 + 1800), you get 2490 ohms total. Divide R1 (220 ohms) by 2490 to get 8.8 percent. R2 (470

ohms) accounts for 18.9% of the total; the largest resistor, R3 (1800 ohms), accounts for 72.3% of the source voltage.

Given a source voltage of 100 V, the voltages would be 8.8 V across R1, 18.8 V across R2, and 72.3 V across R3. If the source voltage is changed to 150 V, as shown in Fig.12, we can find the voltage drop across each resistor by simply taking its percentage of the source voltage. In this case, that would be 150 x 0.088, or 13.2 V across R1, 150 x 0.188, or 28.2 V across R2, and 150 x 0.723, or 108.4 V across R3.

### Series-Dropping Resistors

In the circuit shown in Fig.13, on page 12, the source voltage is a 100 V battery, and R2 is the load. Let's assume that the load requires an operating voltage of 50 volts. This means that R1, the series-dropping resistor, must reduce the voltage applied to R2 to 50 volts. We know that current flowing through R1 produces a voltage drop across it, so we must select a value for R1 that will drop enough voltage to leave 50 V across

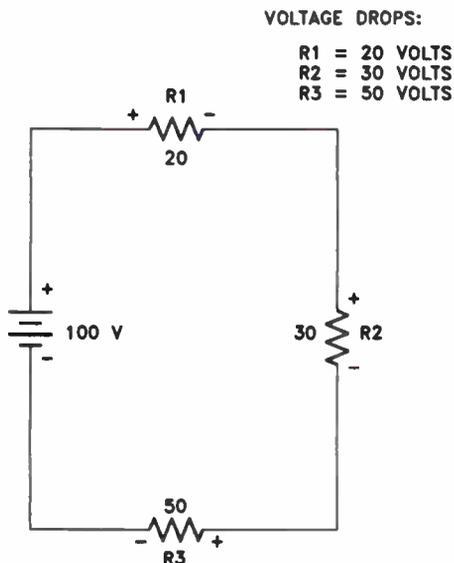


Figure 11. Voltage divider action.

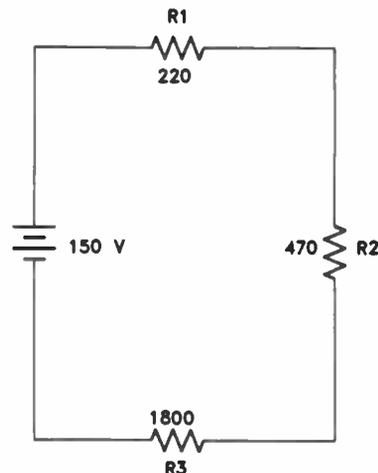


Figure 12. A possible voltage divider arrangement.

*E/R*

*150 / 1800 = .08*  
*150 / 470 = .32*  
*150 / 220 = .69*

## HOW RESISTORS ARE USED

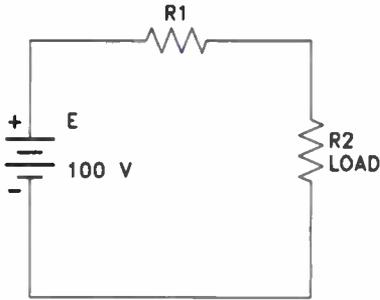


Figure 13. The series-dropping resistor R1 is used to drop the battery voltage to 50 V for the load R2.

R2. With a source voltage of 100 V, this means that R1 must drop 50 volts.

In this case, since each resistance drops 50 V, R1 and R2 will be equal. However, this isn't always the case. When the voltage drops are unequal, you need to know the load resistance and the voltage it requires. You can then use Ohm's law ( $I = E/R$ ) to find the current flow in the circuit. The difference between the source voltage and the voltage required by the load is the voltage that must be dropped by R1. To find the resistance of R1, use Ohm's law in the following form:

$$R_1 = \frac{E}{I}$$

Assume R2 has a resistance of 5000 ohms, with 50 V across it. The current through R2 is:

$$I = \frac{50}{5000} = 0.01 \text{ A}$$

To find the resistance of R1, subtract the 50 V required by R2 from the source voltage of 100 volts. The voltage across R1 must be 50 V:

$$R_1 = \frac{E}{I} = \frac{50}{0.01} = 5000 \text{ ohms}$$

What happens if the resistance of the load (R2) changes? Suppose the resistance of R2 varies by as much as 2500 ohms, as in Fig.14. The resistance of R2 can go as low as 2500 ohms, or as high as 7500 ohms. We show this range of resistances by writing 5000 +/- 2500 and saying "five thousand plus or minus twenty-five hundred."

If the resistance of R2 drops to 2500 ohms, the total resistance in the circuit made up of R1 and R2 is only 7500 ohms. The total current flow increases to:

$$I = \frac{100}{7500} = 0.013 \text{ A}$$

This changes the voltage drop across R1 to:

$$E = 0.013 \times 5000 = 65 \text{ V}$$

Subtracting this from 100 V leaves only 35 V across R2.

If the resistance of R2 increases to 7500 ohms, the total resistance in the circuit is 12,500 ohms. The total current flow in the circuit drops to 0.008 amperes. Now the voltage drop across R1 is:

$$E = 0.008 \times 5000 = 40 \text{ V}$$

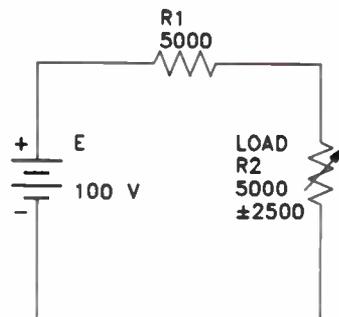


Figure 14. When the values of R2 vary, the voltage across it will vary.

## USING RESISTORS TO SET CIRCUIT VOLTAGES

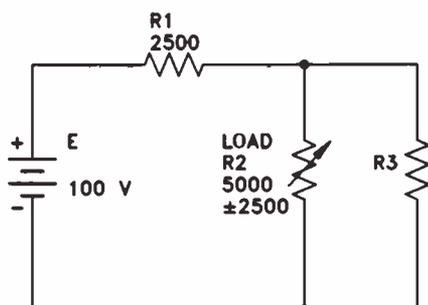


Figure 15. Adding a bleeder resistor, R3, in parallel to R2, will help stabilize the voltage across R2.

All of this means that one series-dropping resistor is not particularly effective as a voltage regulator. Under the conditions given, the voltage applied to the load, R2, can change from 35 V up to 60 V as the resistance of R2 changes.

By adding a third resistor, called a *bleeder resistor*, in parallel with R2, we can take a step closer to stabilizing the voltage across R2.

### Bleeder Resistors

Figure 15 shows the same 100 V source, and R2 as the load with a nominal resistance of 5000 ohms. We've added a third resistor, R3, which also has a value of 5000 ohms. We know that two equal-value resistors connected in parallel have one-half the resistance of one, so the resistance of R2 and R3 in parallel is 2500 ohms. We want a voltage drop of 50 V across the two-resistor network, so we expect the combined current in the parallel pair to be 50 divided by 2500, or 20 milliamps ( $I = E/R$ ). That 20 mA flows through R1 in series, and R1 drops the remaining 50 volts. So, the value of R1 must be 50 V divided by 0.02 A, or 2500 ohms ( $R = E/I$ ).

Let's see what happens when the value of R2 changes. Suppose R2 drops to 2500 ohms. This

causes the combined resistance of R2 and R3 in parallel to drop to 1667 ohms. The total resistance in the circuit (consisting of R1 in series with the parallel combination of R2 and R3) drops to 4167 ohms. Current flow in the circuit increases from 0.02 to 0.024 ampere.

If the current flow through R1 increases from 0.02 A to 0.024 A, its voltage drop increases from 50 to 60 volts. The voltage across the load drops to 40 volts. Remember that in the first example, before R3 was added, the voltage dropped to 35 volts. Here we have a change of 10 V, as opposed to a change of 15 volts.

Suppose R2 increases to 7500 ohms. The parallel resistance of R2 and R3 will be 3000 ohms, and the total resistance in the circuit is 5500 ohms. With a source voltage of 100 V, the current flow in the circuit decreases to 0.018 A, the voltage drop across R1 drops to approximately 45.5 V, and the voltage drop across the load to 54.5 volts. Remember that in the last case, before we added R3, the voltage drop across the load climbed to 60 volts. The addition of the bleeder resistor has stabilized the voltage across the load to a significant degree.

The addition of a bleeder resistor increases the current through R1, allowing the use of a smaller series-dropping resistor. Changes in load current, therefore, have less effect on the voltage drop across the series resistor and the voltage across the load remains more constant. The greater the current through the bleeder resistor (that is, the smaller the resistor), the greater the voltage-stabilizing effect. However, since the current through the bleeder is wasted current, a compromise between voltage stability and power lost in the bleeder is generally reached.

At one time, bleeder resistors were widely used in electronics applications to stabilize the voltage in various circuits. They are still found in electronic equipment, but usually for a different

## HOW RESISTORS ARE USED

---

purpose, as you will learn later. There are better and more economical ways to maintain a constant voltage in modern equipment .

### Review

Resistors can be used to establish fixed voltages in a series circuit. Their values can be calculated easily by following the principle of voltage division, where the voltage drop across each resistor is directly proportional to the relative value of that resistor with respect to the source voltage.

Resistors are often used to drop a voltage from a power source to a lower value needed in a circuit. Bleeder resistors are used across a load through which the current varies to stabilize the voltage across the load. Bleeders were widely used for this purpose, but now there are better devices available and bleeders are used less often.

### Self-Test Questions

- 15 In a series circuit containing 10-, 20-, and 30-ohm resistors, what is the voltage drop across each resistor if the source voltage is 30 volts?
- 16 Determine the voltage drops of the circuit shown in Fig.12 by using Ohm's law to calculate the circuit current first. Do these figures correspond with the percentage values listed in the text above (8.8%, 18.9%, and 72.3%)?
- 17 What is a series-dropping resistor used for?
- 18 What is the purpose of the bleeder?
- 19 Which type of bleeder is more effective, a high-resistance bleeder that draws very little current, or a low-resistance bleeder that draws a substantial current?
- 20 If a load that requires an operating voltage of 60 V is to be operated from a 150 V source, what voltage must the series-dropping resistor drop?
- 21 If, in the preceding example, the resistance of the load is 1200 ohms, what should the resistance of the series-dropping resistor be?

$$I = \frac{E}{R} \quad \frac{60V}{1200\Omega} = .05A$$
$$R = \frac{E}{I} \quad \frac{90V}{.05} = 1800\Omega$$

## ANSWERS TO SELF-TEST QUESTIONS

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### ANSWERS TO SELF-TEST QUESTIONS

- 1 4.7k is equal to 4700 ohms.
- 2 0.39 M equals 390k, and 390,000 ohms.
- 3 680,000 ohms equals 680k, or 0.68 M.
- 4 The resistor is within its rated tolerance. A 2200 resistor with a tolerance of 10% may vary as much as 220 ohms above or below its indicated value. Subtracting 220 from 2200 gives 1980 as the lowest limit of the resistor. Since 2000 ohms is between this lower limit and the indicated value of the resistor, the resistor is within tolerance.
- 5 The resistor may have a resistance of 10,500 ohms. Five percent of 10,000 ohms is 500 ohms. Therefore, the maximum value the resistor can have and still be within tolerance is 10,500 ohms.
- 6 390,000 ohms, or 390k. The tolerance is 5%.
- 7 1,000,000, ohms or 1 M. The tolerance is 10%.
- 8 56,000 ohms, or 56k. The tolerance is 5%.
- 9 2200 ohms, or 2.2k. The tolerance is 10%.
- 10 Yes, the 1/2% resistor has a closer tolerance than the 1% resistor. It is a better resistor. You can always use a better resistor, one with a closer tolerance, as a replacement.
- 11 When we say a resistor is dissipating 10 W, we mean that the resistor is using 10 W of electrical energy. We say it is dissipating the power because it changes the power from electrical energy to heat.
- 12 10 watts. To find the power dissipated by the resistor we use the formula:

$$P = \frac{E^2}{R}$$

Substitute 100 for E and 1000 for R:

$$P = \frac{100 \times 100}{1000}$$

(Canceling three 0s above the line and three 0s below the line gives you  $P = 10$  watts.)

- 13 1/2 watt. To solve the problem use the formula:

$$P = \frac{E^2}{R}$$

Substitute 50 V for E and 5000 ohms for R:

$$P = \frac{50 \times 50}{5000}$$

$$= \frac{2500}{5000}$$

$$= \frac{1}{2} \text{ W}$$

- 14 100 watts. To solve the problem use the formula:

$$P = I^2 R$$

Substitute 2 for I and 25 for R:

$$P = 2 \times 2 \times 25$$

$$= 100 \text{ W}$$

- 15 The total resistance is 10 + 20 + 30, or 60 ohms. For R1, 10 ohms is 10/60, or 1/6, so its voltage drop is 1/6 of the source voltage. One-sixth of 30 is 5 volts. R2 equals 20/60, or 1/3; one-third of 30 equals 10 volts. R3 is one-half the total resistance, and drops one-half the total voltage, or 15 volts.

## HOW RESISTORS ARE USED

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- 16 The total resistance in the circuit is 2490 ohms (220 + 470 + 1800). Current is  $E/R$ , or  $150/2490$ , which equals 0.060 amperes. Multiplying 0.060 by 220, 470, and 1800 produces voltage drop figures of 13.2 V, 28.3 V, and 108.4 V, respectively. This corresponds with the values that can be determined from the percentage that each resistor represents of the total, by multiplying the percentage represented by the resistor and the value of the source voltage.
- 17 A series-dropping resistor drops the available voltage to the value required by the load.
- 18 A bleeder is used to regulate, or to help maintain a constant voltage across the load.
- 19 A low-resistance bleeder that draws a substantial current is more effective than a high-resistance bleeder that draws only a small current.

- 20 90 volts.  
21 1800 ohms.

$$I = \frac{60}{1200}$$
$$= 0.05 \text{ A}$$

The value of the series-dropping resistor can be found using the formula:

$$R = \frac{E}{I}$$
$$= \frac{90}{0.05}$$
$$= 1800 \text{ ohms}$$

## Lesson Summary

**Some of the important facts you should remember about this letter are:**

- Resistors are available in many values, wattage ratings, and designs.
- You can identify the value and tolerance of a resistor by reading the color-coded bands on its body.
- Resistors determine the currents in an electronic circuit, and therefore determine most of the voltage drops.
- A bleeder resistor can help stabilize a source voltage, but uses some circuit current unproductively.



## LESSON QUESTIONS

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7. What are the color-code bands of a 120-ohm, 5% resistor?
- Brown, red, black, and gold.
  - Black, red, black, and silver.
  - Brown, red, brown, and gold.
  - Black, red, brown, and gold.
8. What are the color-code bands of a 47,000-ohm, 10% resistor?
- Yellow, purple, orange, and gold.
  - Yellow, purple, orange, and silver.
  - Yellow, purple, red, and gold.
  - Yellow, purple, yellow, and gold.
9. A 750-ohm load must be operated with a voltage of 75 volts. The available voltage is 125 volts. What value of series-dropping resistor should be used to drop the voltage?
- 250 ohms.
  - 500 ohms.
  - 750 ohms.
  - 1000 ohms.
10. The resistance of a thermistor:
- Increases as the voltage increases.
  - Decreases as the temperature increases.
  - Increases as the temperature increases.
  - Decreases as the voltage decreases.

$$\frac{75}{750} = .1$$
$$\frac{50}{.1} = 500$$

## NOTES

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*Please use this page to record any notes  
you may want to review during your studies.*



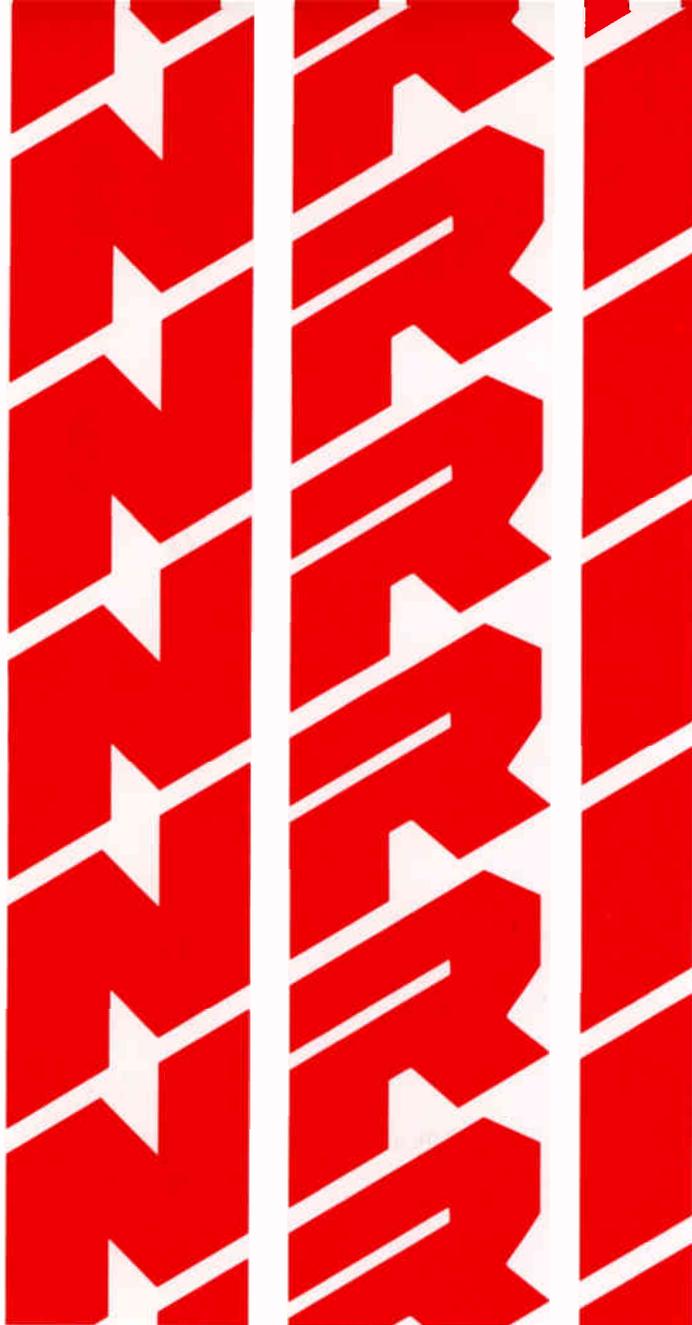
## HELP YOUR MEMORY

Experience is a great teacher, providing you have a *great* memory! Even if you don't have a good memory, there are things that you can do to make the most of the one you have. An unusual design or production problem may take you hours to figure out the first time you encounter it — but the *next time*, you should be able to solve the problem in a flash. Unfortunately, that *next time* may not occur for several months; by then you may have completely forgotten what you did the first time.

You can aid your memory by keeping notes. Every time you encounter a difficult situation, write up a careful and complete description of it and how you corrected the problem.

After collecting this information, you'll never use it if you don't organize it and keep it close to your work area. Use a file system or a notebook to arrange your notes by project name or topic. In time, you will have a valuable storehouse of troubleshooting information — such as only *you* can collect!





## How Coils Are Used

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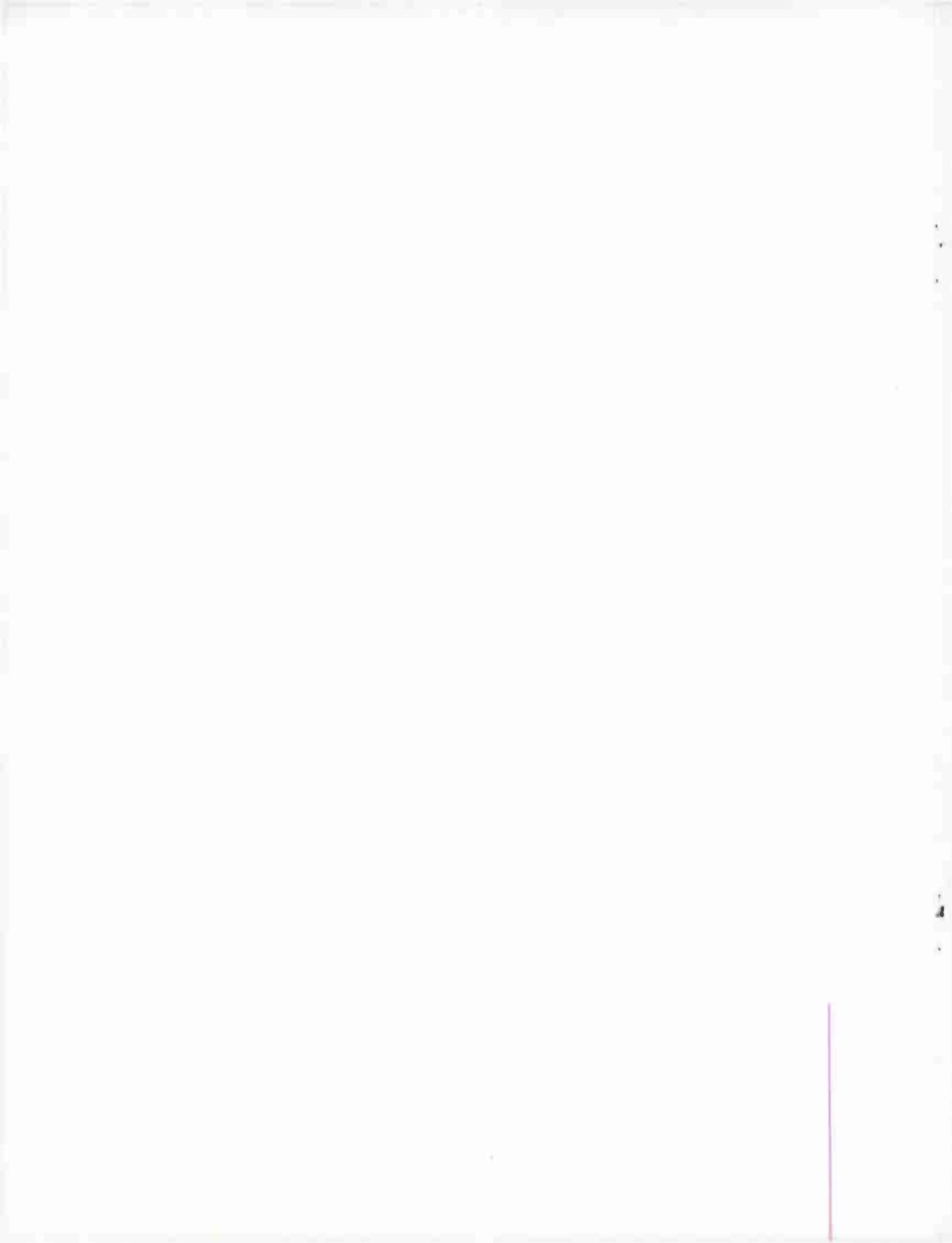


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# **How Coils Are Used**



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# Table of Contents

<b>Introduction</b> .....	1
<b>Characteristics of Coils</b> .....	2
How Coils Produce Voltage .....	5
Lenz's Law for Coils .....	7
Methods of Changing Flux Linkages .....	8
Review .....	10
Self-Test Questions .....	10
<b>Inductance</b> .....	11
Self-Induced Voltages .....	11
Units of Inductance .....	11
Factors Affecting Inductance .....	12
Inductive Reactance .....	12
Mutual Inductance .....	13
Review .....	15
Self-Test Questions .....	15
<b>Applying Ohm's Law to Coils</b> .....	16
Phase .....	16
Impedance .....	19
Finding the Current in an AC Circuit .....	20
The Q of a Coil .....	21
Review .....	22
Self-Test Questions .....	22
<b>Answers to Self-Test Questions</b> .....	23
<b>Lesson Questions</b> .....	26

## HOW COILS ARE USED

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# Lesson Objectives

In this lesson you will . . .

- Discover how coils and magnets can produce voltage and current.
- Learn Lenz's Law for coils.
- Be introduced to the properties of inductance.
- Examine how inductance affects inductive reactance.
- Learn how inductance and resistance combine to form impedance.
- Learn about the effects of inductance on the current and voltage phases in an electronic circuit.

### INTRODUCTION

You will look at inductance in this lesson, and you will discover how it relates to electromotive force. Inductance is an interesting phenomenon which continues to be studied and explored. Each electron in an electric current creates a small magnetic field when it moves. A current, which consists simply of many moving electrons,

creates a larger magnetic field that is the sum of all the fields of the individual moving electrons. The magnetic field and the current are firmly interrelated. If either is changed, the other will also change.

In this lesson you will learn how inductance affects dc circuits and how it opposes current in an ac circuit. You will also learn about the factors that affect inductance and how inductors affect circuit behavior.

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## HOW COILS ARE USED

### CHARACTERISTICS OF COILS

Coils are important components in many electronic circuits. Almost every piece of electronic equipment has one or more coils in it. You will see coils of one or two turns, and even hundreds — or thousands — of turns. Coils that are self-supporting and contain only air and coils wound on a nonmagnetic material (such as cardboard) are called air-core coils. Coils that are wound on a magnetic material (such as iron or steel) are called iron-core coils.

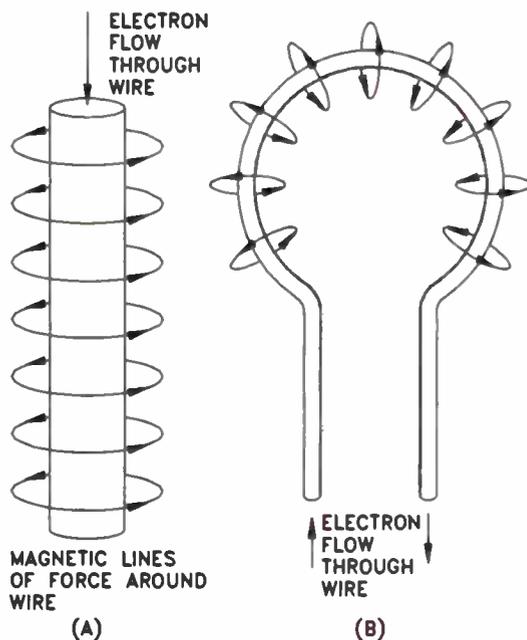


Figure 1. (A) When current flows through a wire, magnetic lines of force are set up around the wire. (B) When the wire is bent into a loop, the lines of force all go through the loop in the same direction.

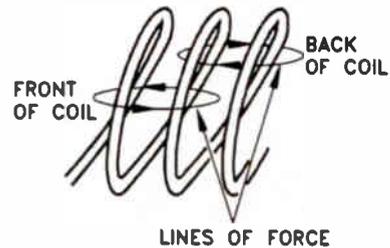


Figure 2. Lines of force loop around both turns of the coil.

You already know that when current flows through a wire there is a magnetic field created around the wire. As Fig.1(A) shows, this field is made up of circular magnetic lines of force (flux) around the wire. The field is much stronger closer to the wire than it is at a distance. When the wire is bent into the form of a loop, as shown in Fig.1(B), all the magnetic lines of force go through the loop in the same direction. This tends to concentrate the magnetic lines of force and produce a much stronger magnetic field.

In the 2-turn coil shown in Fig.2, the magnetic lines of force loop around both turns of the coil. This field can be made stronger by winding even more turns on the coil, as shown in Fig.3. Here you can see that the magnetic lines of force go through the coil and then separate, some flowing around one side of the coil and some flowing around the other side. Notice that the magnetic lines of force are complete loops flowing through the entire center of the coil, around one side, and then back through the center of the coil.

Like the resistance to electric current found in conductors, magnetic lines of force flowing around a coil encounter opposition to the magnetic field. This resistance is called reluctance. We can reduce the reluctance in a magnetic circuit by placing an iron core inside the coil, as shown in Fig.4(A). Iron has much lower reluctance

## CHARACTERISTICS OF COILS

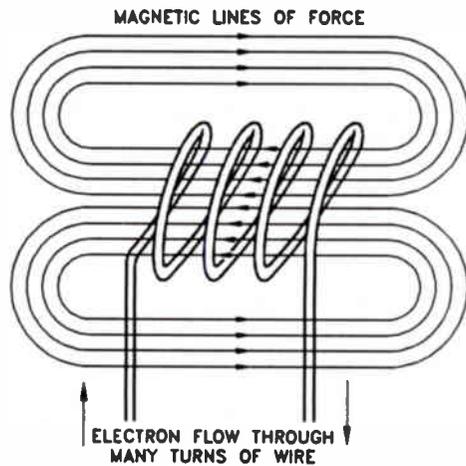


Figure 3. Magnetic lines of force form complete loops, passing through and around the coil.

than air, and tends to concentrate and strengthen the magnetic field. The magnetic lines of force leaving the end of the core still flow through the air.

By using a core such as the one shown in Fig.4(B), this reluctance can be further reduced by providing a complete magnetic path for the lines of force.

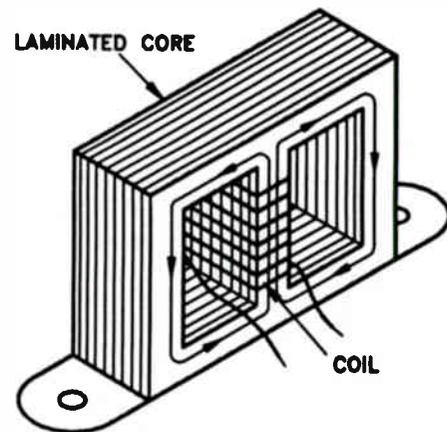
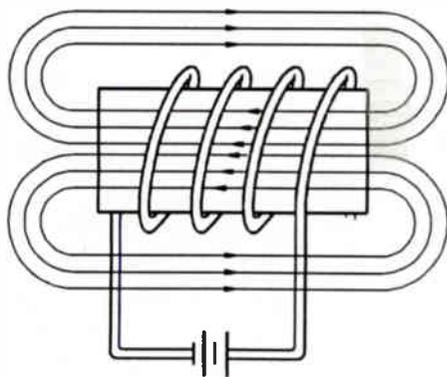
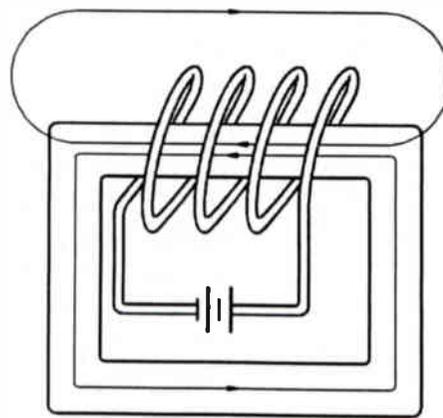


Figure 5. Iron cores have a greater flux than air cores.

However, this is not a complete solution. Because the lines of force flow in loops in both directions, some of the lines of force will continue to flow through the air. By constructing a core as shown in Fig.5, we can establish a complete magnetic path around both sides of the coil, and minimize reluctance.



(A)



(B)

Figure 4. (A) Inserting an iron core in a coil reduces the reluctance and increases the number of magnetic lines of force. (B) A complete iron core reduces the reluctance still further.

## HOW COILS ARE USED

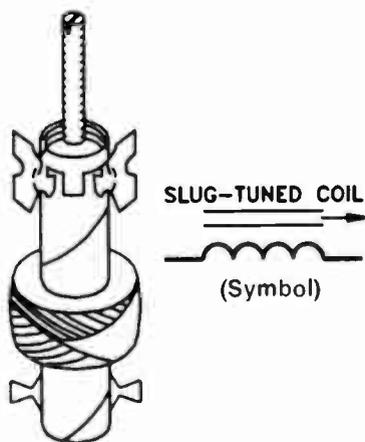


Figure 6. A slug-tuned coil and its schematic symbol.

Iron-core coils work best at low frequencies. Coils used at high frequencies have either an air core or a ferrite core such as the one shown in Fig.6. This coil is wound on a cardboard form with an adjustable ferrite core inside. The core, or “slug,” can move in and out of the coil by means of a screw-type adjustment at the top. The schematic symbol for this type of coil is shown.

Not all coils of this type have screw adjustments. In some, the ferrite slug is threaded and slotted. It can be screwed in or out of the coil with a nonmagnetic alignment tool. This coil uses the same schematic symbol as the screw type.

Slugs are made of different materials, but ferrite is the most common. Ferrite has very high magnetic permeability — the ability to accept magnetization. It is made of powdered iron with other materials such as manganese, cobalt, nickel, or zinc added to give the desired permeability. These materials are mixed together, then fired at a high temperature. When they cool they form a solid slug. The permeability of the material depends upon the materials used.

Electric circuits have an electromotive force or voltage that causes current to flow. An electromagnetic circuit has a magnetomotive force that

produces magnetic flux. This magnetomotive force is measured in ampere-turns. If a coil has 1 turn and the current flowing through it is 1 A, the magnetomotive force is 1 ampere-turn. If the coil has 2 turns and 1 A, it has 2 ampere-turns. If it has 10 turns, it is 10 ampere-turns. If the 10-turn coil has 2 A flowing through it, the magnetomotive force is 20 ampere-turns.

The equivalent of current in magnetic circuits is the magnetic lines of force, or magnetic flux; the more magnetic lines of force there are, the greater the magnetic flux. The number of magnetic lines of force produced depends upon the magnetomotive force. The higher the magnetomotive force, the greater the number of magnetic lines of force, and the greater the flux density. Flux density also depends upon the reluctance or resistance to the magnetic lines of force. The lower the reluctance, the greater the flux.

Again, note the similarity between the magnetic circuit and the electric circuit. The magnetic circuit essentially follows Ohm's law for electric circuits. If you increase the magnetomotive force, which is the equivalent of voltage, you'll increase the magnetic flux, which is the equivalent of current. If you reduce the reluctance, you'll increase the magnetic flux.

Remember that when we discussed the conductivity of materials, we said that copper is a good conductor of electricity, but silver is even better. Copper is a better conductor than aluminum and iron. Because conductivity of materials varies, wires of the same size and length may have a different resistance, depending on the materials from which they are made.

Similarly, magnetic circuits may have a different reluctance depending on the permeability of the materials in the magnetic path. Permeability in magnetic circuits is the equivalent of conductance in an electrical circuit. We base

## CHARACTERISTICS OF COILS

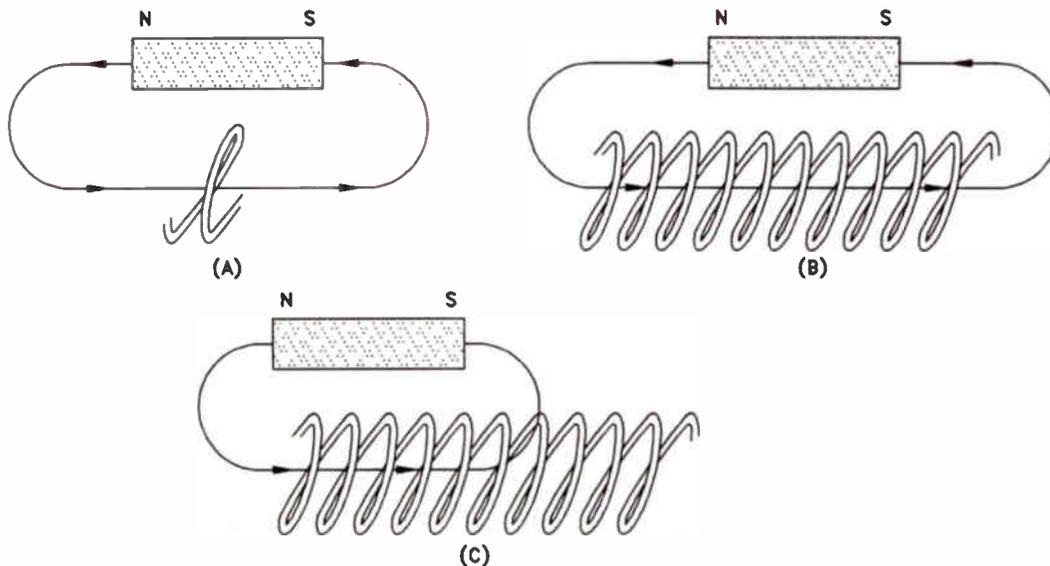


Figure 7. How the number of flux linkages can be changed. (A) There is one flux linkage. (B) There are 10 flux linkages. (C) There are six flux linkages.

the permeability of materials on air — the permeability of air is one. Magnetic materials have a higher permeability than non-magnetic materials. If the permeability of a material is 20, we can expect 20 times the magnetic flux through this material than there would be through air for the same number of ampere-turns.

Magnetic circuits are important because they can help you understand how coils work. You should remember what is meant by magnetomotive force, magnetic flux, reluctance, and permeability.

### How Coils Produce Voltage

It is important that you understand how a voltage can be produced by a coil. To see this, you must first learn something about flux and flux linkages, and then see how changing the flux linkages of a coil will produce a voltage in the coil.

**Flux Linkages.** Suppose you have a magnet that produces a single magnetic line of force. If the magnet is brought near a coil having one turn, such as that shown in Fig.7(A), there will be one magnetic line linking with (or passing through) the one-turn coil, and there will be one flux linkage. If there were 10 turns on the coil and one line of force passed through all 10 turns, then there would be 10 flux linkages, as shown in Fig.7(B).

In turn, if the single magnetic line passed through and linked only 6 turns of the 10-turn coil, as shown in Fig.7(C), there would be only 6 flux linkages. Flux linkage tells us how many magnetic lines of force pass through and “link” the turns of a coil. If we have a magnet that produces 100 magnetic lines, and if the entire 100 lines are linked to a coil having 80 turns, the number of flux linkages is  $80 \times 100$ , or 8000 flux linkages.

## HOW COILS ARE USED

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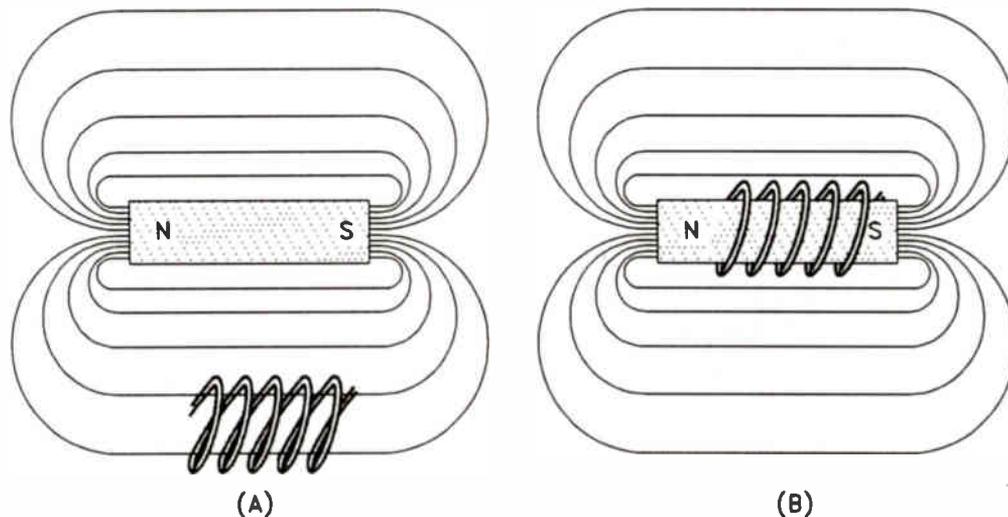


Figure 8. (A) There are 10 flux linkages with the magnet outside of the coil. (B) There are 50 flux linkages when the magnet is moved inside the coil.

Figure 8(A) shows a magnet with 10 magnetic lines of force, but only two of them cut through all 5 turns of the coil. Consequently, there is a total of 10 flux linkages. As you can see, part of the flux is lost, because not all of the lines of force cut through the coil. This is called *flux leakage*.

If we move the magnet to the position shown in Fig.8(B), so that the magnet is placed inside the coil and all 10 lines cut through the 5 turns of the coil, there is a total of 50 flux linkages. When the number of flux linkages increases from 10 to 50, a voltage is produced in the coil as the magnet moves. This voltage, as you know, is called induced voltage. If the magnet is moved away from the coil so that the number of flux linkages decreases, a voltage is again induced in the coil as the magnet moves.

In each of these cases there is a change of 40 flux linkages. If we have a stronger magnet so that the number of lines of force is greater, and

therefore the change in flux linkages is greater, a larger voltage is induced in the coil.

By moving the magnet either toward or away from the coil, there is a voltage induced in the coil that is affected by the speed with which the magnet is moved. If the magnet is moved slowly so that the number of flux linkages changes slowly, the voltage induced in the coil is small. However, if the magnet is moved rapidly so that the change in flux linkage occurs very quickly, the voltage induced is higher. In other words, the voltage induced in the coil depends not only on the *change* in flux linkages, but also upon the *speed* with which the change occurs. Basically, this is another way of stating that the voltage induced depends upon the number of lines of force that “cut” the windings of the coil in a unit of time. The faster the change occurs, the higher the induced voltage.

## CHARACTERISTICS OF COILS

### Lenz's Law for Coils

The polarity of the voltage induced in a coil depends on the direction of the flux and whether the flux linkages are increasing or decreasing. This relationship is known as *Lenz's law*, named after the man who discovered it.

Voltage is induced when the number of flux linkages cutting a coil changes. If the circuit is complete, this induced voltage sends a current through the coil. This current opposes the change in the magnetic flux. If the flux linkages are increasing, the magnetic flux produced by

the current in the coil opposes the increase. If the flux linkages are decreasing, the magnetic flux produced by the current in the coil opposes the decrease.

This is an important concept, and may be better understood by referring to the circuit shown in Fig.9. In Fig.9(A), there is a magnetic circuit with two flux lines cutting through a 4-turn coil, which creates 8 flux linkages. As the magnet is moved away from the coil, reducing the number of flux linkages, shown in Fig.9(B), a voltage is induced in the coil and current flows. The current flowing in the coil creates

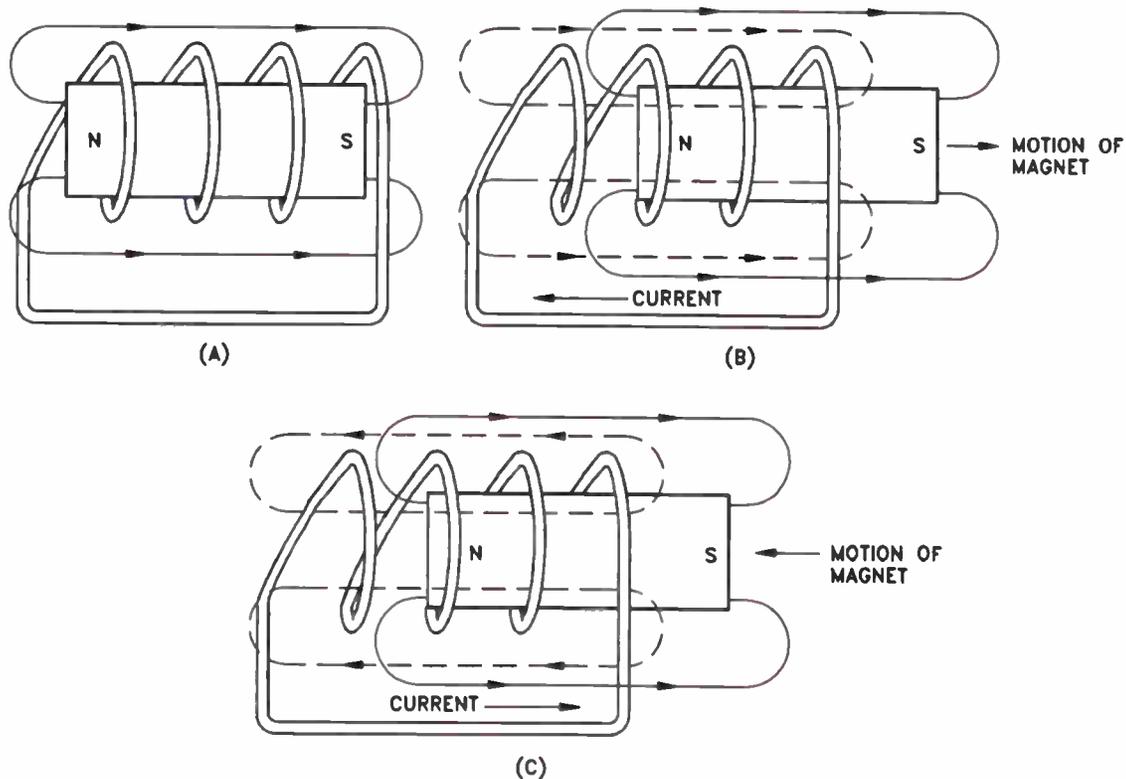


Figure 9. Changing the number of flux linkages induces a voltage in the coil. The polarity of the voltage depends upon whether the number of flux linkages is increasing or decreasing. (A) Eight flux linkages. (B) As the magnet is moved away, the number of flux linkages changes. (C) As the magnet moves back into the coil a voltage is induced.

## HOW COILS ARE USED

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another magnetic field which aids the flux linkages already existing. In other words, it tries to maintain the original eight flux linkages. As long as the number of flux lines are changing, the induced voltage causes an induced current that produces flux lines as shown.

If the magnet is moved back into the coil, as shown in Fig.9(C), the number of flux linkages increases. However, a voltage is induced in the coil that causes a current to flow in the *opposite* direction, and set up its own flux lines of force to oppose the increasing flux lines from the magnet.

If the number of flux linkages is decreasing, the induced voltage has a polarity that causes a current flow to oppose this *decrease* in flux linkages. In turn, if the flux linkages are increasing, the induced voltage will have a polarity that causes the current to flow to oppose this *increase* in flux linkages.

If this sounds to you like the induced current creates a field that fights against the action of the magnetic field that started the whole process, this is essentially what happens. Remember, electrical energy does not spring from nowhere. In this case, the motion of the magnet is a physical energy input which is being converted into electrical energy by the effect of the magnetic field upon the coiled conductor. The currents and the fields act as a load upon the physical movement of the magnet or coil (whichever is being made to move), and that load is expressed as opposing fields.

### Methods of Changing Flux Linkages

There are three methods of producing changes in flux linkages in a coil: moving the coil or the magnet, changing the reluctance, or changing the current flowing in the coil.

**Motion.** You know that when a conductor moves through a magnetic field, it cuts the magnetic lines of force so that a voltage is induced in the conductor. In a generator, for instance, as the coil rotates it moves through and cuts the magnetic lines of force produced by a magnet. The voltage induced creates a current if an external circuit is present. Current flowing in that external circuit creates a field around the coil that opposes the change in the original flux linkages, producing the voltage.

**Changing the Reluctance.** Any change in the reluctance of the material in the magnetic field will change the amount of flux that passes through the coil, thus changing the flux linkages through the coil and inducing a voltage. Remember: a voltage is induced whenever there is a change in flux linkages.

**Changing the Coil Current.** Transformers used on ac power lines are an example of how a changing coil current is used to produce a voltage. You should remember that the voltage on an ac power line is constantly varying from zero up to peak with one polarity, back to zero, to a peak with the opposite polarity, and then back to zero.

As shown in Fig.10(A), a transformer is made by winding two or more coils on a single core. When the first winding of the transformer, the *primary winding*, is plugged into the ac power line, the varying voltage across it will cause a varying current to flow through this winding. The varying current through the primary winding will produce magnetic flux that is constantly changing.

This changing flux induces a voltage in the other winding on the transformer, called the *secondary winding*. The voltage induced in the secondary winding depends upon the ratio of the primary turns to the secondary turns.

## CHARACTERISTICS OF COILS

If both windings have the same number of turns, the voltage induced in the secondary winding is equal to the voltage applied to the primary winding. If the secondary winding has twice as many turns, the voltage induced is twice the voltage applied to the primary winding. This type of transformer is called a *step-up transformer*. If the secondary winding has only half as many turns as the primary winding, the voltage induced in the secondary is equal to half the voltage applied to the primary. This type of transformer is called a *step-down transformer*.

The schematic symbol for a transformer having two windings is shown in Fig.10(B). Figure 10(C) is the schematic symbol of a transformer with two secondary windings. In this case, one winding has more turns than the primary, so it is a step-up secondary winding; the other secondary winding has fewer turns than the primary, so it is a step-down secondary winding. You will learn more about transformers in a later lesson when you study power supplies.

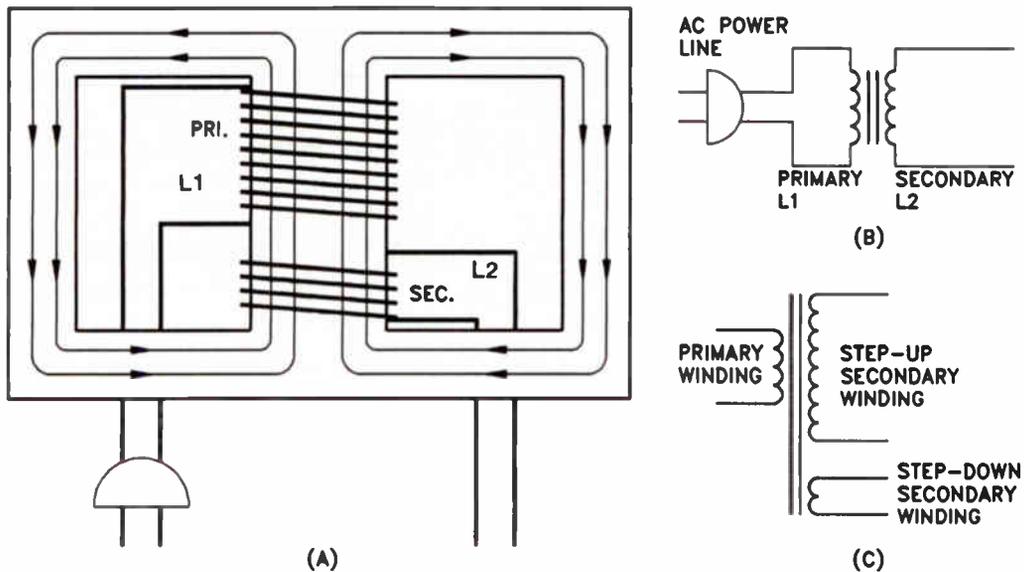


Figure 10. A power transformer. (A) The primary winding is connected directly to the power line. As the current through the primary winding varies, the flux produced by L1 will vary, resulting in a change in flux linkages through the secondary winding, inducing a voltage in the secondary winding L1. (B) The schematic symbol for one primary and one secondary winding. (C) The schematic symbol for one primary and two secondary windings.

## HOW COILS ARE USED

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### Review

There are several important facts that you should remember from this section of the lesson. Remember that a voltage is induced in a coil when the number of flux linkages changes. Either an increase or a decrease in the number of flux linkages will induce a voltage in the coil.

Remember Lenz's law. It states that the induced voltage always acts in such a direction that it tends to oppose the original change in flux linkages.

Changes in flux linkages can be produced by cutting through magnetic lines of force, by changing the reluctance in the magnetic circuit, or by changing the current flowing through the circuit.

### Self-Test Questions

*Please check your answers on page 23.*

- 1 What type of a coil is wound on a cardboard form? *Air-core coils*
- 2 What purpose does an iron core serve in a coil?
- 3 What is magnetomotive force?
- 4 What is the unit used to measure magnetomotive force?
- 5 If the current flow through a 25-turn coil is 2 A, how many ampere-turns are produced?
- 6 What is reluctance?
- 7 Does the magnetic circuit in an air-core coil have a higher reluctance than an iron-core coil?
- 8 What is permeability?
- 9 What is the relationship between flux, magnetomotive force, and reluctance?
- 10 What are flux linkages?
- 11 If three magnetic lines of flux cut through four turns of a coil, how many flux linkages are there?
- 12 If 100 flux linkages cut through a coil, and this number of flux linkages does not change, what will the voltage induced in the coil be?
- 13 According to Lenz's law, if there is a change in the number of flux linkages cutting a coil, induced voltage produces a current. Does the magnetic flux produced by the current aid or oppose the change in flux linkages?
- 14 When the number of flux linkages cutting a coil is reduced, will the field produced by the induced voltage aid or oppose the original lines of force?
- 15 List three methods of changing flux linkages.

## INDUCTANCE

The property of a coil that determines the voltage induced in the coil is called *inductance*. The inductance of a coil depends upon the number of turns of wire on the coil, and upon the permeability of the material. Saying that a coil has inductance is as obvious as saying a resistor has resistance. Inductance is a basic property of coils; it indicates how much voltage is induced in a coil for a given change in flux linkages.

### Self-Induced Voltages

If a voltage is connected to a coil, current will flow through the coil and set up a magnetic field. As Fig.11 illustrates, the magnetic field will produce lines of flux around the coil.

If the current flowing through the coil is suddenly changed, the magnetic field generated by the current also changes. This changes the number of flux linkages produced, and therefore passing through, the turns of the coil. The change in flux linkages within the coil itself (caused by either an increase or decrease in circuit current) induces a voltage in the coil. In accordance with Lenz's law, this voltage opposes the change and causes a current to flow in such a direction as to produce a magnetic field that opposes the change in the magnetic field. The voltage induced in this manner is known as a *self-induced voltage*.

### Units of Inductance

For a given change in flux linkages, the voltage that is induced in a coil depends upon the inductance of the coil. The unit of inductance is the *henry*, abbreviated *H*. It is named after

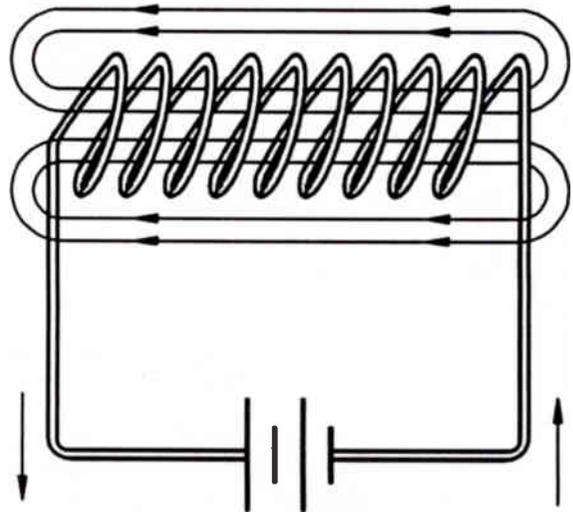


Figure 11. If a voltage source is connected to a coil, current will flow through the coil and a magnetic field will be set up.

Joseph Henry, a scientist who did a great deal of experimentation with coils. A coil will have an inductance of 1 H if a current change of 1 A per second will induce a voltage of 1 V in the coil.

Some iron-core coils used in electronics have an inductance of 10, 20, or perhaps as high as 30 henrys. Most air-core coils, however, have a very small inductance. For convenience, just as the ampere can be broken down into mA and  $\mu\text{A}$ , the henry can be broken down into millihenrys (mH) and microhenrys ( $\mu\text{H}$ ). A millihenry is a thousandth of a henry and a microhenry is a millionth of a henry.

To convert henrys to millihenrys (like converting amperes to milliamperes), just move the decimal point three places to the right. To convert from millihenrys to henrys, move the decimal point three places to the left. To convert henrys to microhenrys, move the decimal point six places to the right, and to convert from microhenrys to henrys, move the decimal point six places to the left. To convert from millihenrys to microhenrys, move the decimal point

## HOW COILS ARE USED

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three places to the right, and to convert from microhenrys to millihenrys, move the decimal point three places to the left.

### Factors Affecting Inductance

The inductance of a coil is affected by the number of turns on the coil. A coil having 200 turns will have a higher inductance than a coil having 100 turns on the same type of core.

Inductance is also affected by the shape and size of the coil. A long coil that has considerable space between the turns will have a lower inductance than a short coil with the same number of turns closer together. The reason for this is that in a coil with more space between turns, many of the lines of flux will escape after cutting through only a few turns of the coil. This results in flux leakage.

The diameter of a coil also affects the inductance in the coil. A coil with a large diameter will have a higher inductance than one with a smaller diameter and the same number of turns.

The inductance of a coil is also affected by the core material. A core material with a high permeability will produce more flux, and therefore more flux linkages. The higher the permeability of the core material, the greater the inductance.

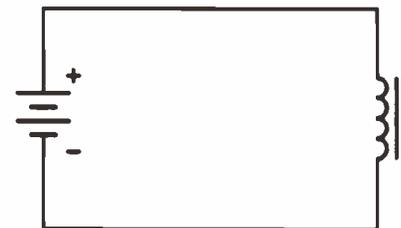
Inductance is not limited to coils alone. Wire-wound resistors have inductance. As a matter of fact, even a straight piece of wire has some inductance, because when a current flows through a wire, a magnetic field is set up around the wire and the wire is cut by magnetic lines. The inductance of a short piece of straight wire is very low (only a fraction of a microhenry), but in some circuits operating at very high frequencies even this small amount may be important.

Because the most important property of a coil is inductance, coils are often called *inductors* or

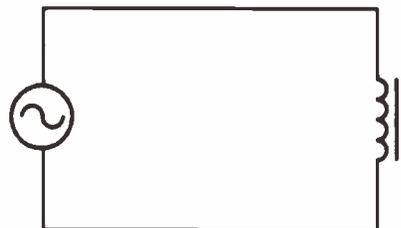
*inductances*. Remember these terms — you will see them often.

### Inductive Reactance

If we connect an iron-core coil across a battery as shown in Fig.12(A), current will flow. When the switch closes, the current that flows produces an increasing magnetic field. That field, in turn, induces a voltage in the coil that opposes the current. However, the induced voltage is not great enough to prevent the current from reaching its maximum value, which is limited only by the dc resistance of the coil wire. When the current reaches its maximum value the magnetic field no longer changes, and subsequently, no more opposing voltage is induced in the coil.



(A)



(B)

Figure 12. (A) A coil connected to a battery, and (B) to an ac generator.

In connecting the same coil across a 60 Hz ac generator, as shown in Fig.12(B), there is an entirely different effect. As the voltage from the generator increases, current increases in the coil. This generates a changing flux which induces a voltage in the coil that opposes the increase in current. When the ac voltage reaches its maximum value and begins to decrease, the current and the magnetic field (and hence the flux) also start to decrease. When this happens, a voltage will be induced in the coil which opposes this change, aiding the existing field.

This induced voltage is called a *counter electromotive force*, which is abbreviated *cemf*. In effect, this cemf subtracts from the applied voltage so that there is considerable opposition to the flow of ac through the coil. This opposition is called *reactance*, and since it is produced by an inductor, it is called *inductive reactance*.

We use the letter L to represent inductance, the letter f to represent frequency, and the letter X to represent reactance. When we want to indicate that the reactance is inductive reactance, we use a subscript L with an uppercase X. The formula for the inductive reactance of a coil is:

$$X_L = 2\pi fL$$

You can see from this formula that inductive reactance varies directly with frequency. If you double the frequency of the ac applied to the coil, the inductive reactance will also double. Similarly, the inductive reactance varies in direct proportion to the inductance of the coil.

You have probably seen the Greek letter  $\pi$  (pronounced pie) before. It is used for finding the area of a circle. The value of  $\pi$  is approximately 3.14, so  $2\pi$  has a value of 6.28. You will often see the formula for inductive reactance written:

$$X_L = 6.28fL$$

(The multiplication signs are frequently omitted for convenience, but the formula actually means  $6.28 \times f \times L$ .)

Now you can get a better idea of how the inductive reactance of a coil limits the current through the coil. A 1 H coil might have a dc resistance of 25–30 ohms. Let's assume it is 30 ohms. If we connect that coil across a 120 V dc power line, a current of 4 A will flow through the coil. However, using the formula for inductive reactance, the same coil, when connected across a 60 Hz power line, will have an inductive reactance of:

$$X_L = 6.28 \times 60 \times 1 = 377 \text{ ohms}$$

If we connect this coil across a 120 V, 60 Hz power line, the inductive reactance alone would limit the current to 0.32 ampere.

### Mutual Inductance

When two coils are placed close together so that the field from one coil cuts the turns on the other, a changing field in the one coil will induce a voltage in the other. We call this *mutual inductance* and it is represented by the letter *M*. Mutual inductance may be either *aiding* or *opposing*, depending upon whether the two fields aid or oppose each other.

If two coils are connected in series, but are far enough apart that their fields do not interact, the total inductance will be equal to the sum of their individual inductances. In other words:

$$L_T = L_1 + L_2$$

If two coils are placed so that their fields interact and they are connected in series, the mutual inductance between the coils enters into the total inductance. If the coils are connected so

## HOW COILS ARE USED

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that their fields aid, the total inductance becomes:

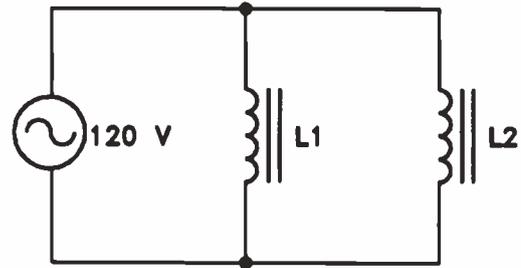
$$L_T = L_1 + L_2 + 2M$$

If they are connected so that their fields oppose, the total inductance becomes:

$$L_T = L_1 + L_2 - 2M$$

When coils are connected in parallel, the effect is similar to resistors connected in parallel. This is easy to see if you look at Fig.13. Coils L1 and L2 are connected in parallel across a 120 V ac generator. If we assume that each coil has an inductive reactance of 120 ohms, there is a current of 1 A flowing through each one, with a total current flow of 2 amperes.

In this example, since the total current is twice what it is through either coil, the combina-



**Figure 13.** Coils connected in parallel act like resistors connected in parallel. The total inductance is less than the inductance of the smallest coil.

tion must have only half the inductive reactance. This means that the total inductance in the circuit must be only half the inductance of either coil. If we connect a third coil in parallel, the total inductance is only one-third the inductance of each individual coil.

### Review

Inductance is the electrical property that describes coils, and the unit of inductance is the henry. When a current flowing through a coil changes, there is a voltage induced in the coil that opposes the change that produces it. This voltage is a self-induced voltage and is called counter electromotive force, abbreviated cemf.

Inductive reactance is the opposition that a coil offers to the flow of ac through it. Inductive reactance is measured in ohms, and is similar to resistance because it opposes the flow of ac through the coil.

When coils are connected in series, the total inductance is the sum of the individual inductances. If they are connected in series and there is mutual coupling between the two, the mutual coupling may either add to the total inductance or subtract from it, depending on whether the fields aid or oppose each other. When coils are connected in parallel, they act like resistors in parallel, so that the total inductance is less than the inductance of the smallest coil.

### Self-Test Questions

- 16 What is the property of a coil that will determine the voltage induced in it?
- 17 If the voltage applied to a coil is suddenly increased, will the self-induced voltage produced in the coil aid or oppose the applied voltage?
- 18 What is the unit used to measure inductance?
- 19 What are three factors that affect the inductance of a coil?
- 20 What is the inductive reactance of a coil?
- 21 What is the unit of measurement for the inductive reactance of a coil?
- 22 What is the inductive reactance of a 10 H coil at a frequency of 60 hertz?
- 23 If two coils, one having an inductance of 6 H and the other having an inductance of 8 H, are placed some distance apart so that there is no mutual inductance between them, what is the total inductance of the two coils if they are connected in series?
- 24 Two coils, one having an inductance of 4 H and the other having an inductance of 3 H, have a mutual inductance of 2 henrys. If the coils are connected in series and are aiding, what will the total inductance be?
- 25 If an 8 H coil and a 7 H coil that have a mutual inductance of 3 H are connected in series in opposition, what will the total inductance of the two coils be?
- 26 Convert 2.2 H to millihenrys.

## HOW COILS ARE USED

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### APPLYING OHM'S LAW TO COILS

Ohm's law tells us that current in a dc circuit depends upon the voltage applied and the resistance in the circuit. This rule applies to ac circuits also, but you must calculate the total opposition to current, which consists of the dc resistance plus any reactance. This composite total opposition to current flow is called *impedance* and is represented by the letter  $Z$ . In this section of the lesson you are going to learn about impedance and about phase — another important aspect of ac circuits.

#### Phase

*Phase* is a common term in the study of electronic circuits. The expressions "in phase," "out of phase," and "phase shift" will become very familiar to you.

In a circuit containing only resistance, if we increase the voltage, the current increases immediately — the increase in current follows the voltage changes instantly. In an ac circuit containing only resistance, as the voltage goes through its cycle, the current varies instantaneously as the voltage varies. We say that the current is in phase with the voltage. This simply means that a change in voltage will produce a similar change in the current flow in the circuit at the same instant.

This is not true of circuits containing coils. Look at the circuit shown in Fig.14. Here we have a resistor and a coil connected in series, and the two are connected across an ac generator. Let's examine the ac current flowing through the circuit to see what happens to the voltage across

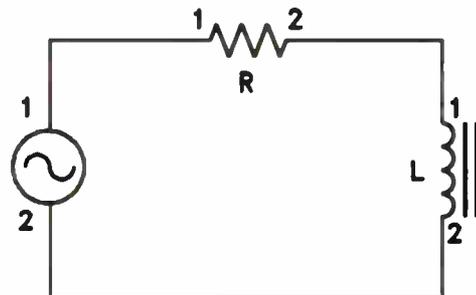


Figure 14. A coil and resistor connected in series across an ac source.

the resistor and the coil as the current goes through its cycle.

Figure 15(A) shows a single current cycle from the ac generator in Fig.14. The start of the sine-wave cycle is marked point A. At the instant the cycle begins at point A, the current is increasing at its maximum rate of change. This occurs at both the upslope and downslope of the ac waveform. The rate of change is greatest during gains or drops in current, and lower (but still changing) around the peaks. At the peaks, the rate of change briefly drops to zero as the direction of current flow reverses.

Consider the voltage across the resistor  $R$ . As the current increases from point A to point C, the voltage drop across the resistor increases at exactly the same rate as the current, generating the waveform shown in Fig.15(B). At point C, as the current reaches its maximum value, so will the voltage. As the current reverses direction and goes through the second half of its cycle, the voltage will follow exactly as shown in the waveform. Notice that at each instant in time throughout the entire cycle, the voltage across the resistor is exactly proportional to the current flowing through it. Here the current and voltage are in phase.

## APPLYING OHM'S LAW TO COILS

The voltage and current across the coil will not be in phase. This is because the voltage across the coil depends upon the rate of flux change. The maximum flux change occurs when the current is changing at its highest rate. Therefore, since the current is changing at a maximum rate at point A in Fig. 15(A), we will have a maximum voltage across the coil. As the current increases from point A to point C, the rate of change decreases until it reaches point C, where it does not change at all, at which point we will see the minimum amount of voltage across the coil.

Remember, this self-induced voltage in the coil opposes the applied voltage from the generator. It is a result of inductive reactance to alternating current in the coil, and is not the same thing as resistive voltage drop. There is a voltage drop across the dc resistance of the coil that may be taken into account if necessary, but for the moment we are measuring the reactively induced voltage.

The voltage across the coil continues to follow the curve shown in Fig. 15(C). The induced voltage decreases until, when the current reaches point C, the voltage has dropped to zero. Now as the current begins to decrease, a voltage is induced in the coil that tries to oppose that change. That is, the voltage builds up from C to a maximum value at E when the current is going through zero and changing at the maximum rate. As the current begins to flow in the opposite direction from E to G, the rate of change once again is decreasing, so the voltage falls from E to G as shown in Fig. 15(C). Finally, as the current falls from G to I, where it once again changes at its maximum rate, the coil voltage builds up from G to I, reaching a maximum value once again.

Compare Fig. 15(A) to Fig. 15(C). In Fig. 15(A), from point A to point I is one cycle. It also represents  $360^\circ$ , or a complete circle extended over time (shown graphically). From A to E is a

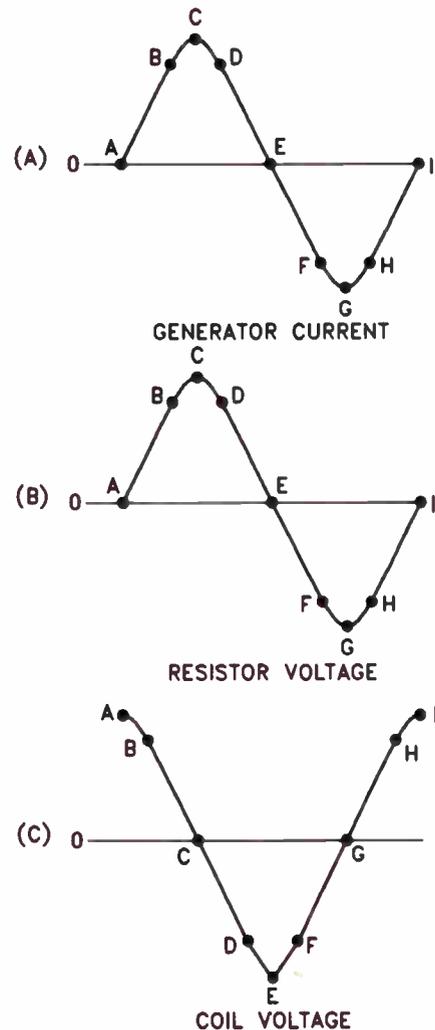


Figure 15. (A) A single current cycle, (B) the resulting voltage drop across the resistor, and (C) the voltage across the coil.

half-cycle ( $180^\circ$ ), and from A to C is a quarter-cycle ( $90^\circ$ ). When the generator current begins its first quarter-cycle increase (from A to C), the induced coil voltage begins to decrease. As generator current peaks, and enters its second quarter-cycle from C to E, once again the coil voltage is a quarter-cycle ahead. This process

## HOW COILS ARE USED

continues indefinitely. We say that the voltage across the coil *leads* the current by 90 degrees.

Conversely, we can say that the current *lags* the voltage by 90°; it means the same thing. In any case, this is an extremely important point for you to remember: in a purely inductive circuit, the current will always lag the voltage by 90 degrees.

None of this changes the fact that current is the same in all parts of a series circuit — that is, the current is the same in the generator, the connecting wires, the resistor, and the coil. The *time lag* (the phase difference) is between current and voltage in the coil.

What about the phase relationship of the circuit current and voltage? Because of the resistive component in the circuit, the voltage phase must

lead the current by some value between 0° and 90°, since the circuit is not purely inductive. Let's assume that the resistance in the circuit of Fig. 14 is equal to the inductive reactance of the coil. The voltage developed across the resistor is equal to  $IR$ , and the voltage developed across the coil is equal to  $IX_L$  (the circuit current times the reactance of the coil). Therefore, the voltage drop across the resistor is equal to the reactive voltage across the coil.

We can use a *vector diagram* (shown below) to determine the phase relationship between the generator voltage and current. This is the relationship in the complete circuit, as "seen by" the generator. We start by drawing the vector  $I$  as shown as Fig. 16(A). The horizontal position of the current vector  $I$  is referred to as zero degrees. Since the voltage across the resistor is in phase

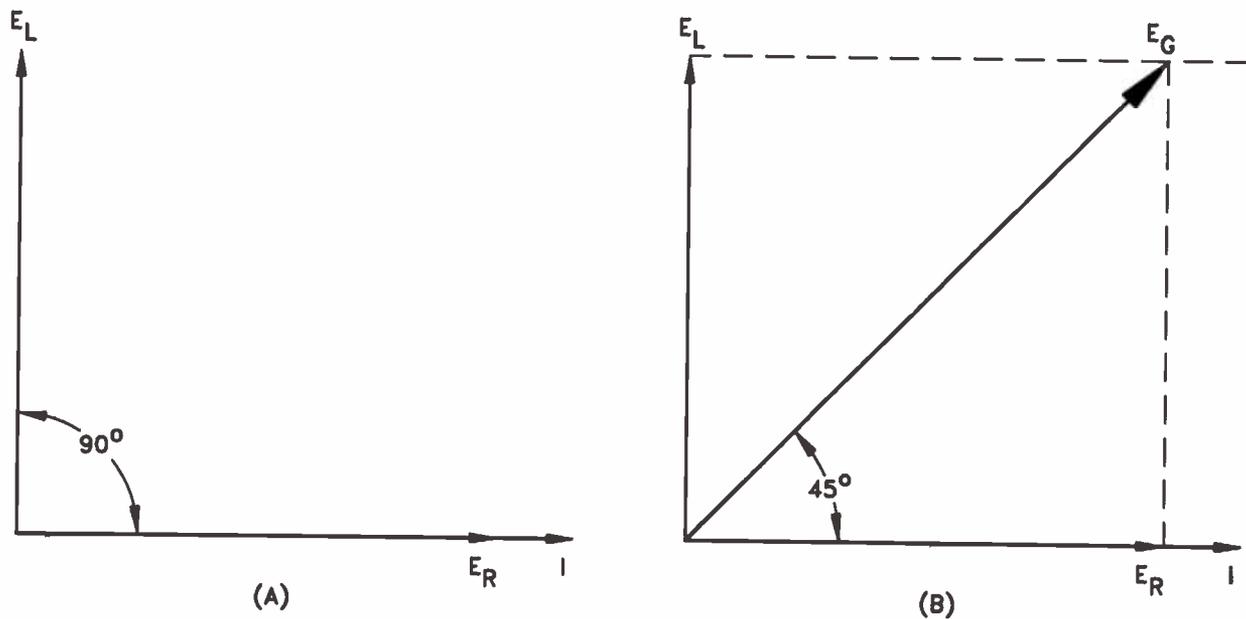


Figure 16. Vector diagrams showing the relationship between circuit current, generator voltage, coil voltage, and resistor voltage of the current shown in Figure 15. (A) The vectors for circuit current ( $E_R$ ) and coil voltage ( $E_L$ ). (B) The generator voltage vector ( $E_G$ ).

## APPLYING OHM'S LAW TO COILS

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with the current through it, we can draw the resistor voltage vector on top of the current vector.

The vector representing the voltage across the coil leads the current by 90 degrees. To diagram this fact, we rotate this vector 90° in a counterclockwise direction. It is the same length as the resistor voltage vector because the two voltages are equal. To find the generator voltage vector, we complete the diagram, as shown in Fig.16(B), by drawing two dotted lines to their junction and completing the generator vector. With the voltage across the coil equal to the voltage across the resistor, the circuit voltage phase will lead the circuit current phase by 45 degrees.

Another important point to notice in our vector diagram is the relative length of the vectors  $E_L$ ,  $E_R$ , and  $E_G$ . The length of the vector  $E_G$  is equal to the generator voltage. Since  $E_L$  and  $E_R$  are equal,  $E_G$  is 1.41 times as long as either vector. At first you might think that this is a contradiction. After all, we said that in a series circuit the sum of the voltage drops is equal to the source voltage.

Let's suppose that the voltage across the resistor is 10 V, and the voltage across the coil is 10 volts. You might think that the voltage across the generator should be 20 volts. However, since the resistor voltage and the coil voltage are not in phase, you cannot add them together using simple arithmetic to get the generator voltage. If we have 10 V across the resistor and 10 V across the coil, the generator voltage is 14.1 volts. If you took an ac voltmeter and measured these voltages and got a reading of 10 V across the resistor and a reading of 10 V across the coil, when you measured the generator voltage you would get a reading of 14.1 volts.

The reason for this out-of-phase condition is that the voltages across the coil and across the resistor do not reach their peak values at the

same time. Remember, the ac voltage is constantly changing. If we measured the circuit voltages at any given instant, using special equipment, we would find the sum of the voltages across the coil and resistor equal to the generator voltage. However, you can find the generator voltage mathematically without using vectors, by using the formula:

$$E_G = \sqrt{E_R^2 + E_L^2}$$

Substituting 10 V for  $E_R$  and 10 V for  $E_L$  we get:

$$E_G = \sqrt{100 + 100} = \sqrt{200} = 14.1 \text{ V}$$

### Impedance

The practical way to study how a coil behaves in an ac circuit is to imagine that the coil is made of a pure inductance with a resistor in series with it. This is essentially the type of circuit used in Fig.14. You should see in the figure that the current in the circuit lags behind the generator voltage. Where the resistance is equal to the inductive reactance, the phase difference is 45 degrees.

In actual practice, the resistance will generally be much smaller than the inductive reactance, so the phase difference will approach 90 degrees.

Consider the case of a 1 H coil having a resistance of 50 ohms at 60 cycles. The inductive reactance of the coil at 60 cycles is 377 ohms. To find the impedance, we use the formula:

$$Z = \sqrt{R^2 + X_L^2}$$

Substituting 377 for  $X_L$  and 50 for the resistance you get:

$$\begin{aligned} Z &= \sqrt{50^2 + 377^2} \\ &= \sqrt{2500 + 142,129} \end{aligned}$$

## HOW COILS ARE USED

$$Z = \sqrt{144,629} = 380 \text{ ohms}$$

Notice that the impedance, or total opposition, is only 380 ohms, even though the inductive reactance of the coil is 377 ohms and the resistance is 50 ohms. In most cases, you will find that the impedance of a coil is only slightly higher than its inductive reactance.

### Finding the Current in an AC Circuit

To find the current in an ac circuit, use Ohm's law in the form:

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

That is, divide the applied voltage by the circuit impedance.

You can find the impedance by formula, or by using vectors. The mathematical method is simpler. Suppose the resistance is 30 ohms and the inductive reactance is 40 ohms, as in Fig.17. We'll assume that the resistance of the coil is so low that we can ignore it, as we do in most practical cases. To find the impedance, use the formula:

$$Z = \sqrt{R^2 + X_L^2}$$

Substituting 30 for R and 40 for  $X_L$  we get:

$$\begin{aligned} Z &= \sqrt{30^2 + 40^2} \\ &= \sqrt{900 + 1600} \\ &= \sqrt{2500} \\ &= 50 \text{ ohms} \end{aligned}$$

The impedance of the circuit is 50 ohms. Since the voltage is 100 V, the current will be as follows:

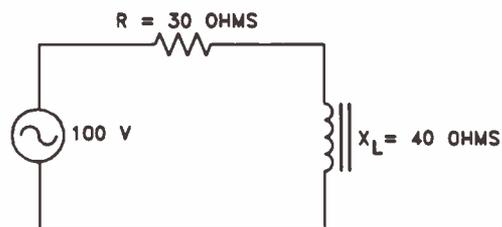


Figure 17. To find the current in this circuit you must first find the impedance.

$$I = \frac{100}{50} = 2 \text{ A}$$

To find the impedance by adding vectors, remember that the voltage across the resistor is in phase with the current.

We therefore draw a current vector with the resistance vector on top of it. If we assume a scale of 10 ohms to an inch, we draw the resistance vector 3" long, as shown in Fig.18. Since the voltage across the coil will lead the current by 90°, we draw the vector representing the inductive reactance 4" long for 40 ohms and rotate it 90° from the resistance vector. To complete the vector diagram, draw a dotted line from the end of the reactance vector parallel to the resistance vector, and another dotted line from the end of the resistance vector parallel to the reactance vector. We could then draw a line from the zero point up to the junction of these two dotted lines, which will give us the impedance vector. If you draw your vector to scale carefully and measure the impedance vector, you will find it is 5" long. Therefore the impedance must be 5 x 10, or 50 ohms.

In the circuit shown in Fig.17, the current flow is 2 A, the voltage across the resistor is 2 x 30, or 60 V, and the voltage across the coil is 2 x 40, or 80 volts. Again, remember that you

## APPLYING OHM'S LAW TO COILS

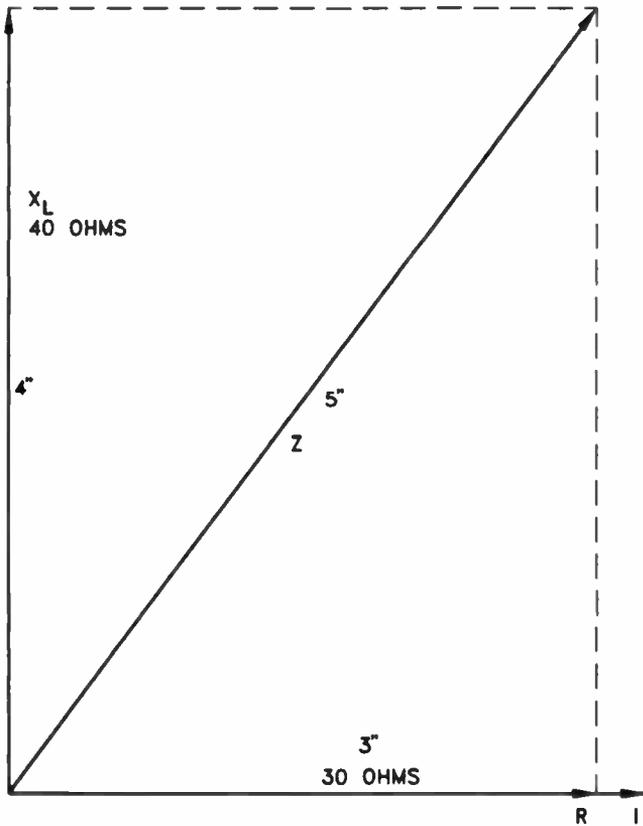


Figure 18. Vector solution for the impedance of the circuit.

can't add these two voltages directly to get the generator voltage since the voltages are not in phase. Using the formula:

$$E_G = \sqrt{E_R^2 + E_L^2}$$

Substituting 60 V for  $E_R$  and 80 V for  $E_L$ , you get:

$$\begin{aligned} E_G &= \sqrt{60^2 + 80^2} \\ &= \sqrt{3600 + 6400} \\ &= \sqrt{10,000} = 100 \text{ V} \end{aligned}$$

At first glance, the voltages across the resistor and inductor in the circuit shown in Fig.17 add up to more than 100 V if you use simple arithmetic. This appears to contradict Kirchhoff's law. However, when you add the voltages vectorially, or by means of the formula we've given, you see that the sum of the two voltages is indeed equal to the source voltage. We can't add them directly using simple arithmetic because they are not in phase.

In the next lesson, when you study capacitors, you will find that a capacitive circuit has essentially the opposite effect of an inductive circuit. In a capacitive circuit the current leads the voltage by 90 degrees.

### The Q of a Coil

Since coils are wound with wire they have resistance as well as inductive reactance. The higher the ratio of inductive reactance to resistance, the better the coil. We call this relationship the  $Q$  of the coil; we will study this in depth in future lessons. It is calculated with the formula:

$$Q = \frac{X_L}{R}$$

## HOW COILS ARE USED

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### Review

You should now understand the term phase and what it means when the current lags the voltage.

You should also understand that impedance is equal to the vector sum of the resistance and reactance. The impedance of a coil will always be greater than the resistance or reactance alone. Sometimes impedance is only slightly higher than the inductive reactance, however.

The voltage across a component in an ac circuit can be found by using Ohm's law. The sum of the individual voltage drops in an ac circuit is equal to the source voltage, provided we add these voltages vectorially. We cannot add them by means of simple arithmetic and expect their sum to be equal to the source voltage.

### Self-Test Questions

- 27 What do we mean when we say that the voltage and current in a circuit are in phase?
- 28 What is the phase relationship between the voltage and current across a resistor?
- 29 What is the phase relationship between the voltage and current across a coil?
- 30 What is meant by impedance?
- 31 A resistor and a coil are connected in series across a generator. If the voltage across the resistor is 12 V and the voltage across the coil is 16 V, what is the generator voltage?

## ANSWERS TO SELF-TEST QUESTIONS

---

### ANSWERS TO SELF-TEST QUESTIONS

- 1 An air-core coil is wound on a cardboard form. The form merely supports the turns of the coil; it has no appreciable effect on the operation of the coil.
- 2 An iron core provides a better path for the magnetic lines of force. We say it has a lower reluctance.
- 3 Magnetomotive force is the force that sends magnetic flux around a magnetic circuit.
- 4 The ampere-turn is used to measure magnetomotive force.
- 5 A 2 A current flow through a 25-turn coil produces 50 ampere-turns.
- 6 Reluctance is the opposition to flux in a magnetic circuit. It is equivalent to resistance in an electrical circuit.
- 7 Yes; the reluctance in the magnetic circuit of an iron-core coil is much lower than the reluctance in the magnetic circuit of an air-core coil.
- 8 The permeability of a material indicates the ability of the material to pass the magnetic lines of force. The higher the permeability of the material, the less reluctance it will offer to magnetic lines of force.
- 9 In a magnetic circuit the flux is equal to the magnetomotive force divided by the reluctance.
- 10 A flux linkage is a magnetic line of flux cutting through a single turn of a coil. If the magnetic line of flux cuts through two turns there will be two flux linkages, and if it cuts through five turns there will be five flux linkages.
- 11 There will be 12 flux linkages. A magnetic line of flux cutting through a single coil produces one flux linkage. Therefore, three lines cutting through four turns produces 12 flux linkages.
- 12 The voltage will be zero. If the number of flux linkages cutting a coil does not change, there is no voltage induced in the coil.
- 13 The induced voltage will produce a current which will, in itself, produce a magnetic field that opposes any change in flux linkages.
- 14 It will aid the original lines of force. If the field is reduced, the induced voltage produced in the coil will cause a current to flow in such a direction that the magnetic field produced will tend to prevent the number of flux linkages from decreasing. In order to do this, it must aid the original field.
- 15 Cutting lines of force, changing the reluctance, and changing the coil current are methods of changing flux linkages.
- 16 Inductance determines the voltage that will be induced in a coil.
- 17 It will oppose the applied voltage. The self-induced voltage will try to keep the current constant so that the flux will remain constant. To do this, it must oppose the applied voltage.
- 18 The henry is the unit of inductance.
- 19 The number of turns on the coil, the diameter of the coil, and the permeability of the core material affect the inductance.
- 20 The inductive reactance of a coil is the opposition the coil offers to the flow of ac current through it.
- 21 The inductive reactance of a coil is measured in ohms.
- 22 3768 ohms. To find the inductive reactance of a coil you use the formula:
$$X_L = 6.28 \times f \times L$$
Substituting 60 for f and 10 for L we have:
$$X_L = 6.28 \times 60 \times 10$$
$$= 3768$$

## HOW COILS ARE USED

---

23 14 henrys. When two coils that are not mutually coupled together are connected in series, the total inductance is simply the sum of the two inductances.

24 11 henrys. To find the total inductance of the two coils, use the formula:

$$L_T = L_1 + L_2 + 2M$$

Substituting 4 H for  $L_1$ , 3 H for  $L_2$ , and 2 H for  $M$  we get:

$$\begin{aligned} L_T &= 4 + 3 + (2 \times 2) \\ &= 11 \text{ H} \end{aligned}$$

25 9 henrys. To find the inductance of the two coils, we use the formula:

$$L_T = L_1 + L_2 - 2M$$

Substituting 8 H for  $L_1$ , 7 H for  $L_2$ , and 3 H for  $M$  we get:

$$\begin{aligned} L_T &= 8 + 7 - (2 \times 3) \\ &= 9 \text{ H} \end{aligned}$$

26 2200 millihenrys. To convert henrys to millihenrys you must multiply by 1000 (which is the same as moving the decimal point three places to the right).

$$2.2 \times 1000 = 2200$$

27 When we say that the voltage and current are in phase, we mean that any change in voltage produces a corresponding change in current. In other words, an increase in voltage causes an instant increase in current, or a decrease in voltage causes an instant decrease in current.

28 The voltage and current across a resistor are in phase.

29 The voltage across a coil will lead the current by 90 degrees. Another way of expressing the same thing is to say that the current lags the voltage by 90 degrees.

30 Impedance is the total opposition to current flow. It is made up of the reactive opposition and the resistive opposition to current flow.

$$\begin{aligned} 31 \quad E_G &= \sqrt{E_R^2 + E_L^2} \\ &= \sqrt{12^2 + 16^2} \\ &= \sqrt{144 + 256} \\ &= \sqrt{400} \\ &= 20 \text{ V} \end{aligned}$$

---

# Lesson Summary

**Some of the important facts you should remember from this lesson are:**

- Voltage and current are induced in a coil and any attached conductors by the relative motion between the coil and the magnet.
- The amount of voltage produced by induction is directly proportional to the number of magnetic lines of force that are cut per unit of time.
- Since inductance acts to oppose a change in the direction of current flow, inductive reactance occurs when alternating current is applied to an inductive circuit.
- Circuit impedance can be calculated by taking the square root of the sum of the squares of the circuit resistance and the inductive reactance.
- Inductive circuits cause a phase shift in circuit voltage, such that voltage phase will lead the current by as much as  $90^\circ$ , depending on how much resistance is also in the circuit.

# HOW COILS ARE USED

## LESSON QUESTIONS

This is Lesson Number 2222.

Make sure you print your name, student number, and lesson number in the space provided on the Lesson Answer Form. Be sure to fill in the circles beneath your student number and lesson number.

**Reminder:** A properly completed Lesson Answer Form allows us to evaluate your answers and speed the results and additional study material to you as soon as possible. Do not hold your Lesson Answer Forms to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

Name John Smith

Print

Student No. XY01237894 Lesson No. 2222

X	Y	0	1	2	3	7	8	9	4	2	2	2	2
●	○	○	○	○	○	○	○	○	○	○	○	○	○
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- If the reluctance of a magnetic circuit is increased, the flux will:
  - Increase.
  - Decrease.
  - Remain the same.
  - Disappear.
- In a magnetic circuit, the equivalent of voltage is:
  - Reluctance.
  - Magnetomotive force.
  - Magnetic flux.
  - Permeability.
- At a frequency of 100 Hz, the inductive reactance of 1 H is:
  - 6.28 ohms.
  - 62.8 ohms.
  - 628 ohms.
  - 6280 ohms.
- Two 15 H coils have a mutual inductance of 5 henrys. What is the total inductance when they are connected in series if the flux of one coil aids the flux of the other?
  - 20 henrys.
  - 30 henrys.
  - 35 henrys.
  - 40 henrys.

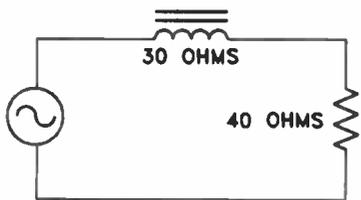
*Handwritten:  $L = L_1 + L_2 + 2M$   
 $15 + 15 + 2 \times 5 = 30 + 10 = 40$*
- If the two coils in the preceding question are connected so that the flux of one opposes the flux of the other, the total inductance is:
  - 20 henrys.
  - 30 henrys.
  - 35 henrys.
  - 40 henrys.

*Handwritten:  $30 - 10 = 20$*

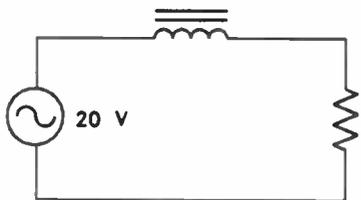
*Handwritten:  $6.28 \times 100 \times 1$   
 $\frac{100}{1.57} = 628.00$*

## LESSON QUESTIONS

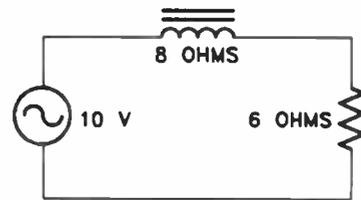
6. The impedance of the circuit shown below is:
- 30 ohms.
  - 40 ohms.
  - 50 ohms.
  - 70 ohms.



7. If the impedance of the circuit shown below is 20 ohms, the current flow is:
- 0.5 ampere.
  - 1 ampere.
  - 2 amperes.
  - 4 amperes.



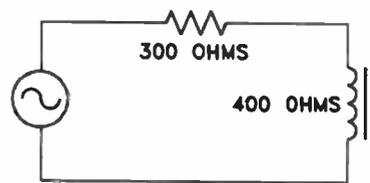
8. In the circuit shown below, the voltage across the coil is:
- 2 volts.
  - 4 volts.
  - 8 volts.
  - 16 volts.



*Handwritten notes:*  
 $1 \times 8 = .8$   
 $\sqrt{\frac{64}{36}} = \sqrt{100} \text{ ohms}$   
 $\frac{10}{10} = 1$

9. If, in the circuit shown above, the frequency of the ac current is doubled, the voltage:
- Across the resistor will increase.
  - Across the coil will remain the same.
  - Across the coil will decrease.
  - Across the coil will increase.

10. If the current flow in the circuit shown below is 1 A, the generator voltage must be:
- 300 volts.
  - 400 volts.
  - 500 volts.
  - 600 volts.



*Handwritten notes:*  
 300  
 400  
 $90,000 + 160,000$   
 $\sqrt{250,000}$

## NOTES

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## LEARNING NEVER ENDS

More and more it becomes evident that learning is a continuous process — that it is impossible to break the habit of studying without slipping backward. Look around you at all the marvelous developments of the last 20 years. You have the advantage of having “grown up” with them, yet there are probably many things you wish you knew more about. Imagine what can happen in the years ahead if you do not keep abreast of the stream of new things that are bound to come.

Your NRI course is preparing you for the problems of today and tomorrow, but you cannot stop here. In 10 years, will you still be up to date? Yes, if you plan your future. Resolve now that you *will* keep up. You have the fundamentals; keep them fresh in your mind by constantly reviewing. Read and study technical literature and textbooks, join in discussion groups and listen to lectures, take advantage of every possible educational opportunity. Then, and only then, can you face the future unafraid, no matter what technical developments the future may hold.





# How Capacitors Are Used

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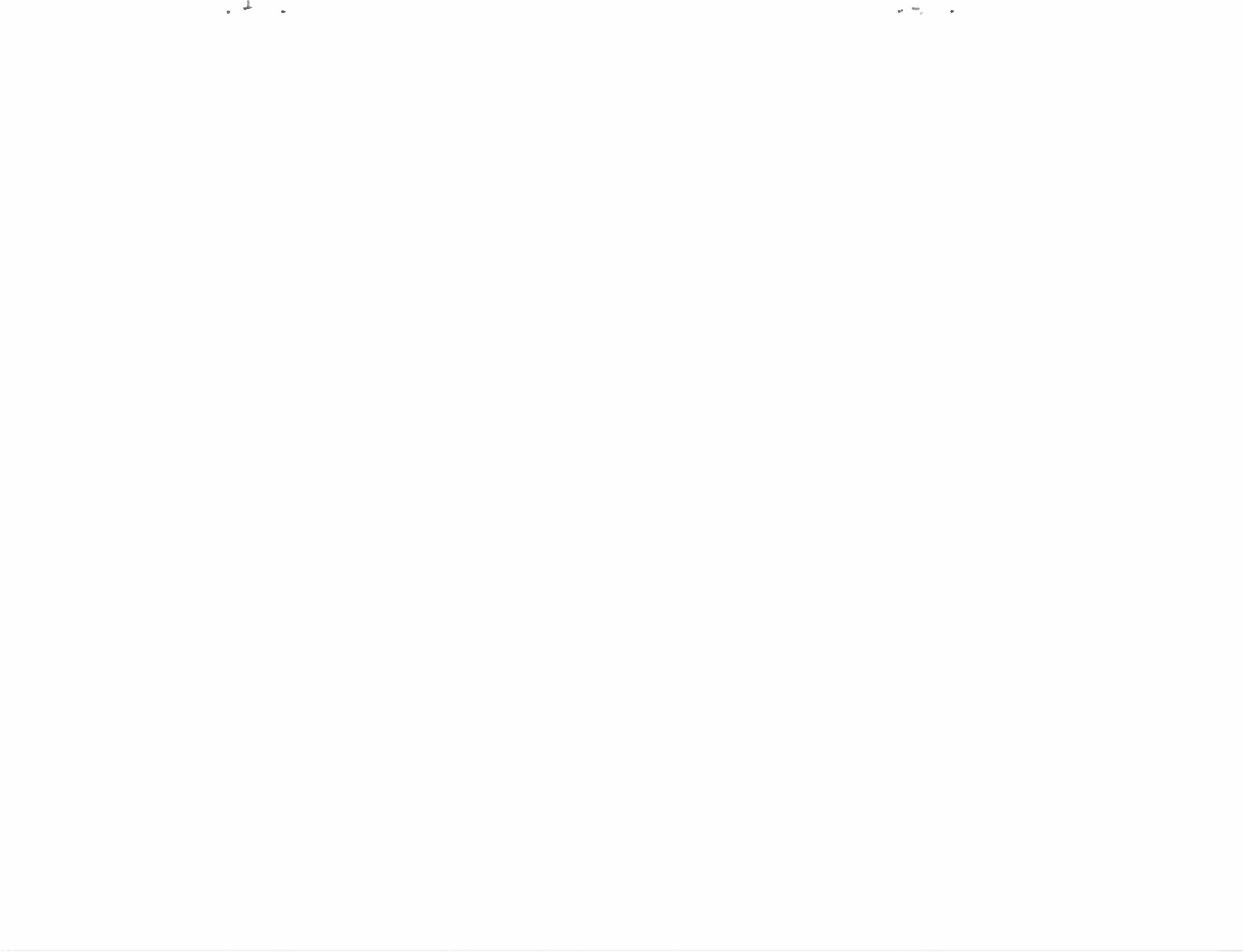


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# **How Capacitors Are Used**



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# Table of Contents

<b>Introduction</b> .....	1
<b>How Capacitors Store Electricity</b> .....	2
Charging a Capacitor .....	3
Capacitance .....	3
Factors Affecting Capacitance .....	4
Review .....	6
Self-Test Questions .....	7
<b>Typical Capacitors</b> .....	8
Variable Capacitors .....	8
Paper Capacitors .....	10
Ceramic Capacitors .....	11
Mica Capacitors .....	12
Electrolytic Capacitors .....	13
Review .....	15
Self-Test Questions .....	15
<b>Capacitors in AC Circuits</b> .....	16
How AC Flows in AC Circuits with Capacitors .....	16
Capacitive Reactance .....	17
Capacitors in Series and Parallel .....	18
Time Constant .....	19
Voltage-Current Phase .....	20
Voltage Distribution .....	20
Impedance .....	21
Review .....	22
Self-Test Questions .....	23
<b>Answers to Self-Test Questions</b> .....	24
<b>Lesson Questions</b> .....	26

## HOW CAPACITORS ARE USED

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# Lesson Objectives

In this lesson you will . . .

- Learn the principles of capacitance.
- Study how capacitors store electricity.
- Learn about the several different types of capacitors.
- See how capacitors affect electrical circuits, and how circuits affect capacitance.
- Study the difference in capacitive effects for alternating and direct current circuits.

### INTRODUCTION

Electrical circuits contain opposing forces. You have studied inductance; now we turn your attention to a circuit element that has effects opposite to those of inductance. This element is capacitance. We can show that inductance and capacitance are opposites by matching each unit of inductance in a circuit with an equivalent unit of capacitance. The result is a circuit in which, at some frequency, the capacitive effect balances the inductive effect, leaving a purely resistive circuit.

Some electronics engineers and manufacturers have devoted a lifetime to the development, improvement, and manufacture of capacitors. Great progress has been made in the quality, efficiency, reliability, and the size reduction of capacitors. Now, with microelectronics, capacitance becomes an integral, invisible part of these microscopically sized circuits.

Capacitance, like inductance, is a part of electronics. The study of capacitance is necessary for successfully solving the circuit problems which we constantly face in electronics.

## HOW CAPACITORS ARE USED

### HOW CAPACITORS STORE ELECTRICITY

A capacitor is nothing more than two pieces of metal separated by a nonconducting material. The material may be air, a gas, a liquid, or a solid. It is called the dielectric, and the metal elements are called plates. If there is nothing between the plates but air, we say the capacitor has an air dielectric.

A simple capacitor made of two metal plates with an air dielectric is shown in Fig. 1. When the plates of the capacitor are connected to a battery, electrons will flow from the negative terminal of the battery into plate A. At the same time, electrons will flow from plate B to the positive terminal of the battery. This is because they are repelled by the surplus of electrons on plate A and attracted by the positive terminal of the battery.

At first, the voltage between the two plates will be zero. A very high current will flow, as shown in Fig. 2, to charge the capacitor. As the capacitor charges, the voltage between the plates builds up, and while the current

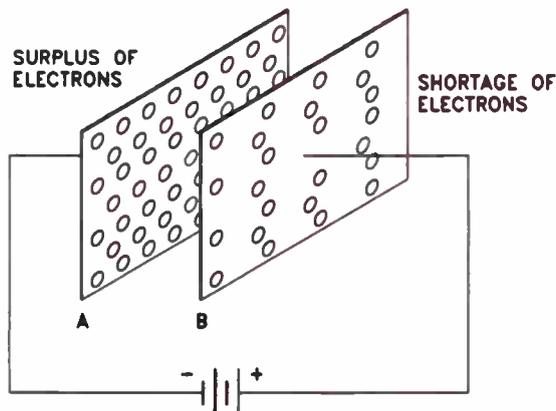


Figure 1. A capacitor is connected to a battery.

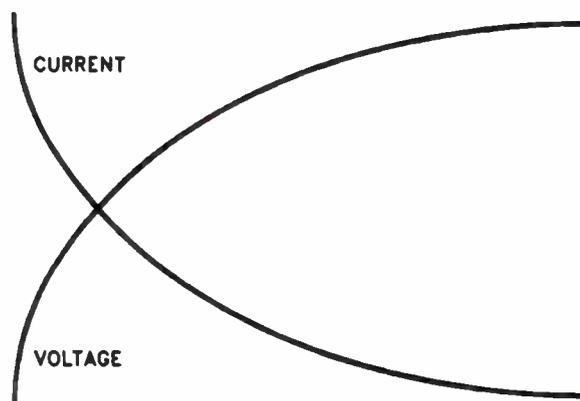


Figure 2. The relationship between the capacitor's voltage and current.

decreases, the capacitor voltage increases. Eventually, the potential between the plates is equal to the battery voltage. At this time, the current is zero, the voltage between the plates is equal to the battery voltage, and we say that the capacitor is charged.

If we disconnect the capacitor from the battery, the condition of imbalance that has been set up on the capacitor plates will remain. We have a surplus of electrons on one plate and a shortage of electrons on the other. Thus, we have electricity stored in the capacitor.

If we connect a wire from one plate of the charged capacitor to the other, electrons will flow from the side having a surplus of electrons over to the side having a shortage of electrons. The flow of electrons will continue until the number of electrons on the two plates is balanced, and there is no longer a charge on them. When the charge has disappeared, we say the capacitor is discharged.

This is a very brief explanation of how a capacitor can store electricity. Large capacitors, particularly those used in high-voltage circuits, can store large amounts of electricity. Before touching the leads of a large capacitor, you

## HOW CAPACITORS STORE ELECTRICITY

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should short the leads together with a screwdriver or similar object to be sure that the capacitor is discharged. If you touch the terminals of a charged capacitor you can receive an unpleasant and possibly dangerous shock.

You might wonder how we can use a capacitor in electronic equipment, because there is no complete path for current to flow through it. Indeed, as shown by the current curve in Fig.2, once the capacitor is charged so that the potential between the two plates is equal to the battery potential, there will be no further current flow. Once a capacitor is charged, it effectively blocks the flow of dc in the circuit.

### Charging a Capacitor

A capacitor does not charge instantly. The length of time it takes to charge a capacitor depends upon two things: the size of the capacitor and the amount of resistance in the circuit.

You might think that there is no resistance in the circuit shown in Fig.1, but this is not true. There is resistance in the leads used to connect the capacitor to the battery; in addition, there is the internal resistance of the battery itself, which is a function of how much current the battery can produce. These two resistances limit the rate at which the capacitor can charge. Because it takes time to charge a capacitor, there is a current flow in the circuit, as shown in Fig.2, when the capacitor is first connected to the battery. This current flows as long as the battery is charging the capacitor. When we disconnect the capacitor from the battery and discharge it, there will be a current flow once again, but this time in the opposite direction. Again, the length of time it takes the capacitor to discharge will depend upon the capacitance of the capacitor and the resistance in the circuit.

The charge on a capacitor depends upon the battery voltage used to charge it. A higher voltage exerts more force on the atoms of the plates and moves more electrons than a lower voltage. There are other things, however, that affect the charge we can store in a capacitor. The electrical size of the capacitor is called the capacitance of the capacitor, and it is just as important as the charging voltage. Let's see what we mean by capacitance.

### Capacitance

The term *capacitance* is used to describe the electrical size of the capacitor in the same way that inductance is used to describe the characteristics of a coil, or the way that resistance is used to indicate the size of a resistor.

The unit of capacitance is the farad (pronounced FAIR-AD). The capacitance of a capacitor is a measure of its ability to store electricity. A capacitor with a high capacitance can store more electrons than a capacitor with a lower capacitance.

A farad actually represents an extremely large capacitance. It is so large that it is never used in electronics. The units used are the microfarad, which is one millionth of a farad, and the picofarad, which is one billionth of a farad. The modern abbreviation for microfarad is  $\mu\text{F}$ , but you will also see mf and mfd used in older texts and diagrams. The abbreviation for picofarad is pF. In older literature, you might run into the term micro-microfarad, abbreviated mmf, which is also a millionth of a microfarad.

Sometimes you will want to change from  $\mu\text{F}$  to pF or from pF to  $\mu\text{F}$ . To change from the larger unit, microfarads, to the smaller unit, picofarads, move the decimal point six places to

## HOW CAPACITORS ARE USED

the right. In other words, a capacitor that has a capacitance of  $0.0005 \mu\text{F}$  has a capacitance of 500 pF. You simply add the zeros to the right of the five and move the decimal point six places to the right.

To convert from picofarads to microfarads, divide by 1,000,000. This is done by moving the decimal six places to the left. A 500 pF capacitor has a capacitance of  $0.0005 \mu\text{F}$ . We simply add zeros to the left of the five and then move the decimal six places to the left.

The words microfarad and capacitor are both rather long, so technicians have shortened them. They generally refer to a  $2 \mu\text{F}$  capacitor as a two-mike cap. A  $0.005 \mu\text{F}$  capacitor is called a double-oh five-mike cap, or a point double-oh five capacitor.

### Factors Affecting Capacitance

The three factors that affect the capacitance of a capacitor are the area of the plates, the spacing between the plates, and the dielectric used between the plates.

In Fig. 3, two capacitors are shown. In Fig. 3(B), the capacitor has larger plates than the one in Fig. 3(A), so we can force more electrons onto plate A and pull more electrons off plate B. Thus the capacitor in Fig. 3(B) has a greater capacitance than the capacitor in Fig. 3(A).

We can also increase the capacitance by adding more plates. In Fig. 4(A), two plates — A1 and A2 — are connected. This effectively increases the plate area and hence the capacitance. Adding additional plates, as shown in Fig. 4(B), increases the capacitance still more.

Reducing the spacing between the plates increases the capacitance. Figure 5(A), on page 6, shows a capacitor charged to the battery potential. If we move the plates closer together, as shown in Fig. 5(B), the electrons on the negative

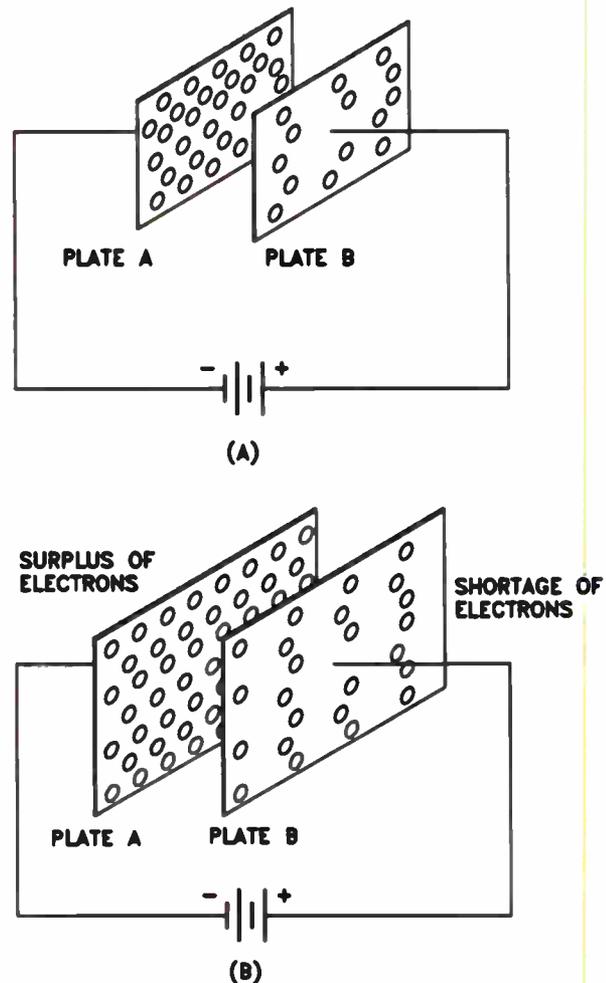


Figure 3. (A) The smaller capacitor. (B) The larger capacitor can store a greater charge.

plate force additional electrons out of the positive plate, thus increasing the positive charge on it. This in turn draws additional electrons into the negative plate, increasing the capacitance of the capacitor.

The third factor that affects the capacitance is the dielectric. The dielectric is the material between the plates of the capacitor. If, instead of air between the plates, we insert a piece of mica, paper, ceramic, or mylar, the capacitance increases, depending upon the dielectric constant of the material.

## HOW CAPACITORS STORE ELECTRICITY

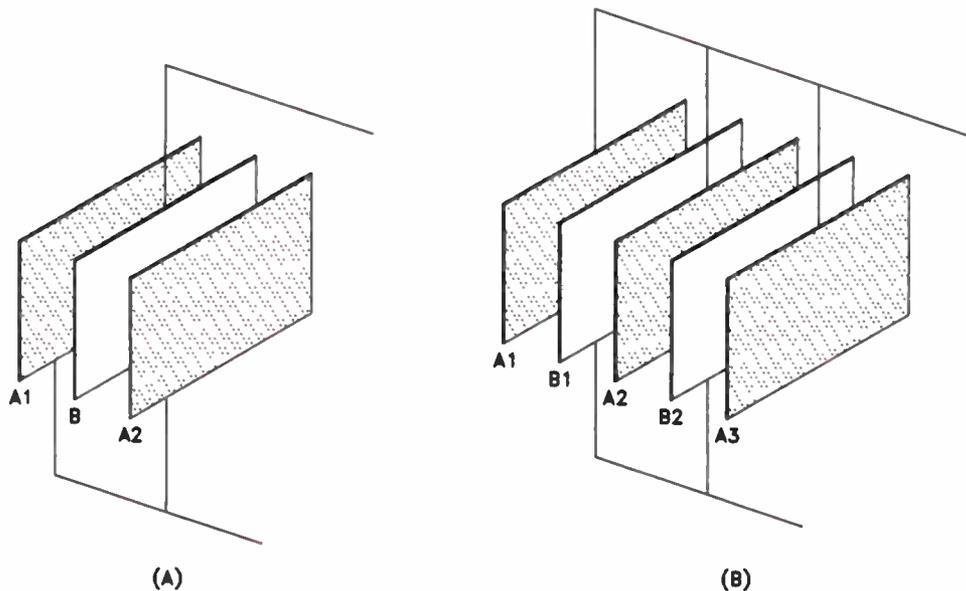


Figure 4. Adding plates to a capacitor increases the capacitance.

**Dielectric Constant.** The degree of effect of the dielectric material on the capacitance compared to the capacitance using air as the dielectric, is called the dielectric constant. The dielectric constant of mica is between six and eight because this is how much it increases the capacitance of a capacitor when inserted between the plates in place of air.

Different materials have different dielectric constants. Paper has about the lowest of any material you find used in capacitors, between 1.5 and 3. Ceramic has one of the highest dielectric constants of any material. The dielectric constant depends on the type of ceramic, but can be as high as 1500. Many ceramic capacitors have a relatively small physical size but a high capacitance.

Figure 6(A), on the next page, shows the plates of a capacitor before they are charged. Between the plates is an atom with electrons going around the nucleus in a circular path. Figure 6(B) shows

the path of the electrons around the nucleus when the capacitor is charged. The electrons are repelled by the negative plate and attracted by the positive plate so that they travel in an oval path. This brings the electrons much closer to the positive plate so that they force additional electrons out of the positive plate. This increased shortage of electrons on the positive plate in turn attracts additional electrons onto the negative plate.

Air is a mixture of gases, and in a gas the atoms are relatively far apart. In solid materials, the atoms are closer together, so inserting a solid material dielectric increases the effect of this distortion. The amount by which the effect is increased depends upon the density of the material and the characteristics of the material itself. The effect is similar to pushing the plates of the capacitor closer together so that they almost touch. This enables us to get a very high capacitance.

## HOW CAPACITORS ARE USED

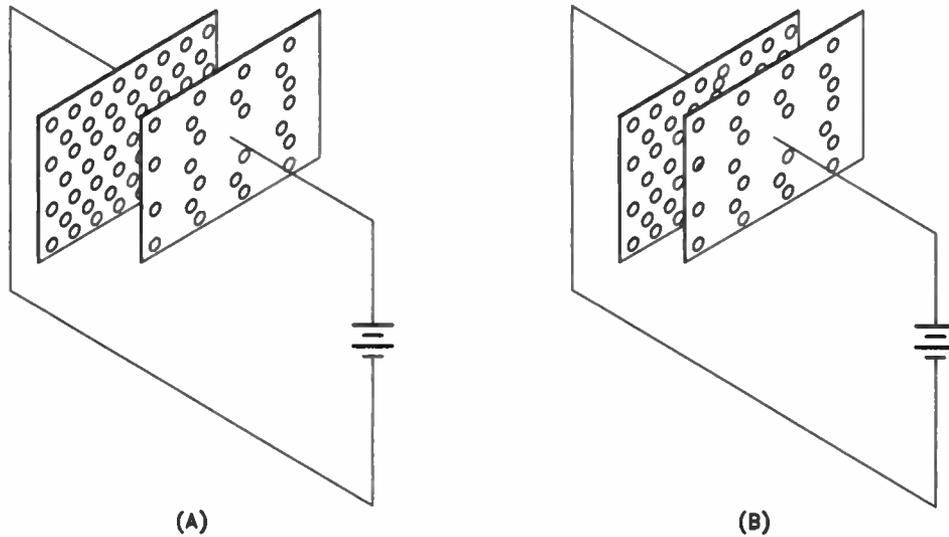


Figure 5. Because the plates are farther apart, the capacitor in (A) has a smaller capacitance than the one shown at (B).

**Voltage Rating.** When manufacturers design a capacitor, they design it for use in a circuit with a certain maximum operating voltage. The voltage is usually marked on the capacitor and is called the working voltage. For example, a capacitor with a working voltage of 12 V is

designed for use in a circuit where the dc operating voltage is 12 V or less.

If you have to replace a defective capacitor, you should use a replacement with a working voltage at least as high as the working voltage of the original. You can use a capacitor with a higher working voltage if there is room. Usually, capacitors that have a higher working voltage are also larger.

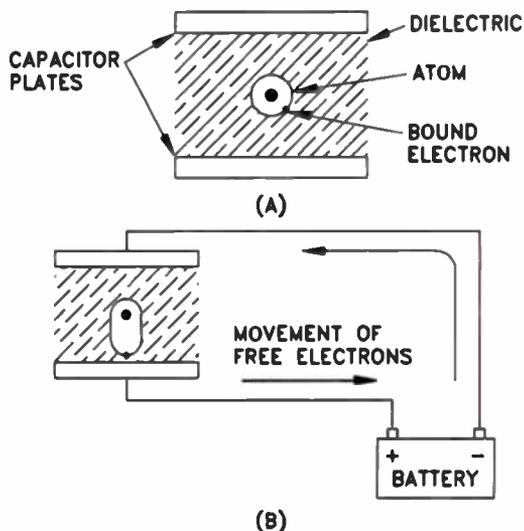


Figure 6. Shifting paths of the electrons in the dielectric.

### Review

The basic action of a capacitor depends upon its ability to store an electric charge. There is no complete circuit through a capacitor, but current flows in a circuit in which the capacitor is connected while the capacitor is being charged and while it is being discharged. A capacitor is not charged instantly; the time it takes to charge a capacitor fully depends on the capacitance and the resistance in the circuit.

The electrical size of a capacitor is measured in farads, but the farad is such a large unit that

# HOW CAPACITORS STORE ELECTRICITY

the practical units are the microfarad (which is a millionth of farad) and the picofarad (which is a millionth of a microfarad).

The capacitance of a capacitor depends upon the area of the plates, the spacing between the plates, and the dielectric between the plates. The dielectric constant of a material is a number that tells you the number of times the capacitance of a capacitor increases when this material is placed between the plates of the capacitor as compared to air.

The voltage rating of the capacitor tells you the maximum safe voltage that you can apply to a capacitor. Capacitors with a higher voltage rating can always be used to replace a defective capacitor in a piece of electronic equipment if there is space.

## Self-Test Questions

Please check your answers on page 24.

- 1 What do we mean when we say that a capacitor is charged? *Charged in terms of the voltage between the plates is equal to the working voltage*
- 2 What two factors affect the length of time it takes to charge a capacitor? *Size of the capacitor & Amount of Resistance in the circuit*
- 3 What factor determines the amount of charge a capacitor can hold for a given amount of voltage? *Capacitance of the capacitor*
- 4 What two practical units are used in electronics to indicate the capacitance of a capacitor? *Microfarad & Picofarad*
- 5 Convert  $0.0033 \mu\text{F}$  to picofarads. *3300 pF*
- 6 Convert  $680 \text{ pF}$  to microfarads. *.00068  $\mu\text{F}$*
- 7 Name the two factors that affect the capacitance of a capacitor. *Area of the plates, the spacing between the plates, & the dielectric used between the plates*
- 8 What is the dielectric constant of a material?
- 9 Why does a material with a dielectric constant greater than air have the effect of increasing the capacitance of a capacitor? *Reduces spacing between plates*
- 10 If a capacitor is marked  $0.02 \mu\text{F}$ , 16 V, what does the marking 16 V mean? *Working voltage that maximum voltage that can be used*

→ The degree of effect of the dielectric material on the capacitor compared to the capacitor using air as a dielectric

## HOW CAPACITORS ARE USED

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### TYPICAL CAPACITORS

Capacitors are also divided into fixed and variable types. A fixed capacitor has a fixed capacitance that cannot be changed, whereas a variable capacitor, as the name implies, is designed so that its capacitance can be varied by some convenient method. Most variable capacitors use an air dielectric, and are called air capacitors. Some variable capacitors have a mica dielectric and are referred to as variable mica capacitors. Most fixed capacitors use some dielectric other than air.

#### Variable Capacitors

Three views of a typical variable capacitor are shown in Fig. 7. The capacitor is made up of two sets of plates as shown in Fig. 7(A). The bottom set of plates is connected to two shafts held in place by two insulators. Connected to these shafts are two terminals for external connections. One shaft and one of the terminals are visible in the photograph.

The bottom plates, called the stator, are stationary. The top plates connect to a rotatable shaft, causing the top set of plates to move in between the stator plates. The plates that can rotate are called the rotor plates or simply the rotor. In Fig. 7(B), the rotor is turned  $90^\circ$  so that the rotor plates are half-meshed with the stator plates. In Fig. 7(C), the rotor has been rotated an additional  $90^\circ$  so that the plates are completely meshed with the stator plates. The schematic symbol is also shown.

Figure 8 shows what happens as we turn the rotor inside the stator. Remember, we said that one factor that affects the capacitance of a capacitor is the area of the plates. In the illustration shown in Fig. 8(A), the area of the rotor that



(A)



(B)



(C)



Figure 7. (A) The capacitor is adjusted for minimum capacitance, (B) half capacitance, and (C) maximum capacitance. The capacitor's schematic symbol is also shown.

is opposite the stator is extremely small. The only area affected is the edges of the two plates. There is a small capacitance between the edge of the stator and the edge of the rotor. As the capacitor turns to the position shown in Fig. 8(B), about one quarter of the rotor plate is opposite the stator plate. The capacitance is much greater than at Fig. 8(A). In Fig. 8(C) about half the rotor is opposite the stator, in Fig. 8(D) about three-fourths, and at Fig. 8(E) the entire rotor is meshed inside the stator so that there is maximum capacitance.

## TYPICAL CAPACITORS

SHADED AREAS INDICATE ACTIVE SURFACES

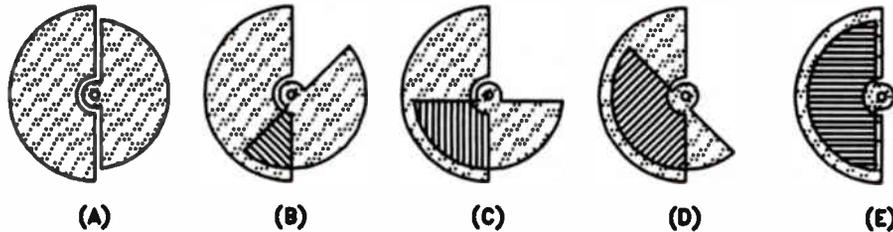


Figure 8. How a variable capacitor with straightline capacitance plates works.

In the capacitor shown in Fig.8, there is just one rotor plate and one stator plate. In the capacitor shown in Fig.7, notice that there are a number of plates on both the rotor and on the stator. By using a number of stator and rotor plates, we can get a much higher capacitance capacitor because the area of the plates is increased.

The capacitance of a variable capacitor also depends on the spacing between the plates. Look at the two capacitors shown in Fig.9. The capacitor in Fig.9(A) is much larger than the one at Fig.9(B), but they have the same maximum capacitance because the spacing between the plates in the capacitor shown in Fig.9(A) is double the spacing between the plates in the capacitor shown at Fig.9(B). The capacitor shown at Fig.9(A) is built for use in circuits in which voltages are higher than those in circuits that use the capacitor shown in Fig.9(B).

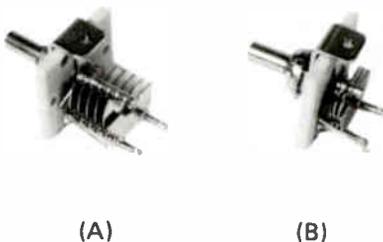


Figure 9. (A) This capacitor has the same maximum capacitance as the one shown at (B).

Another type of variable capacitor is the trimmer capacitor. A typical trimmer capacitor is shown in Fig.10. These capacitors are used to trim, or adjust, the circuit to compensate for variations in other components in the circuit.

A trimmer capacitor is made by securing a fixed plate to an insulated material. On top of the fixed plate is a piece of mica, and the movable plate is secured by a rivet so that it does not touch the fixed plate. The spacing between the plates is changed by tightening or loosening the adjusting screw. If additional capacitance is needed, it can be obtained simply by adding another layer of mica over the adjustable plate and then adding a second fixed plate. Another layer of mica is then added along with a second adjustable plate. Additional layers of plates and mica can be added so that the trimmer may have a number of stationary and adjustable plates.

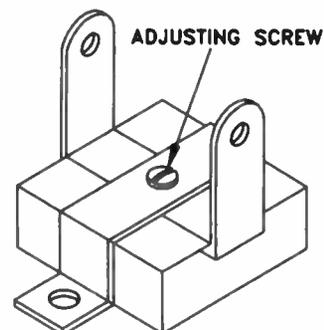


Figure 10. A typical trimmer capacitor.

## HOW CAPACITORS ARE USED

### Paper Capacitors

A paper capacitor is made from two sheets of tinfoil, with a sheet of paper between them, as shown in Fig.11(A). The tinfoil and paper are rolled, as shown in Fig.11(B), until they are shaped like Fig.11(C). Wire leads are then attached to the foil sheets that protrude from each end of the capacitor. After the leads have been attached to the tinfoil, the capacitor is encased in a molded container that keeps out moisture and dirt.

The paper capacitor is so named because a paper dielectric is used between the two plates. Today, however, paper alone is seldom used as the dielectric. Mylar and mylar-coated paper are more widely used. Polyester materials are also used; a capacitor with a polyester dielectric has a very high resistance to humidity. Polystyrene is also used as a dielectric; polystyrene capacitors have a very high insulation resistance.

Two typical capacitors of this type are shown in Fig.12 along with the schematic symbol. The lower capacitor has axial leads, meaning that the leads come out of the ends parallel to the body of the capacitor. The upper capacitor has radial leads that come out of the capacitor at an angle of 90° to the capacitor body.

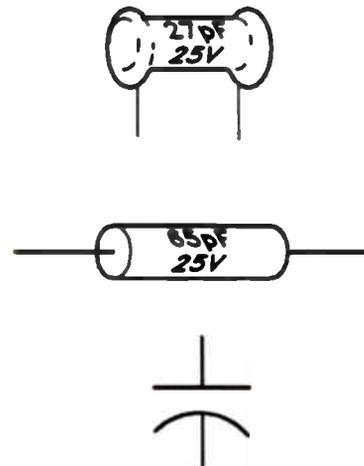


Figure 12. A typical paper capacitor and its schematic symbol.

Years ago, capacitors caused a lot of problems in electronic equipment. However, with today's manufacturing techniques you seldom find a defective capacitor. If anything happens to the case so that it is not a perfect seal, moisture can seep into the capacitor and cause leakage. Sometimes in a radial capacitor, the case is damaged at the end where one of the leads is attached. The connection to the lead may break off, in which case the capacitor is open, or the insulating foil may be damaged, and the capacitor shorted. If you suspect a capacitor is defective, try a new one in the circuit.

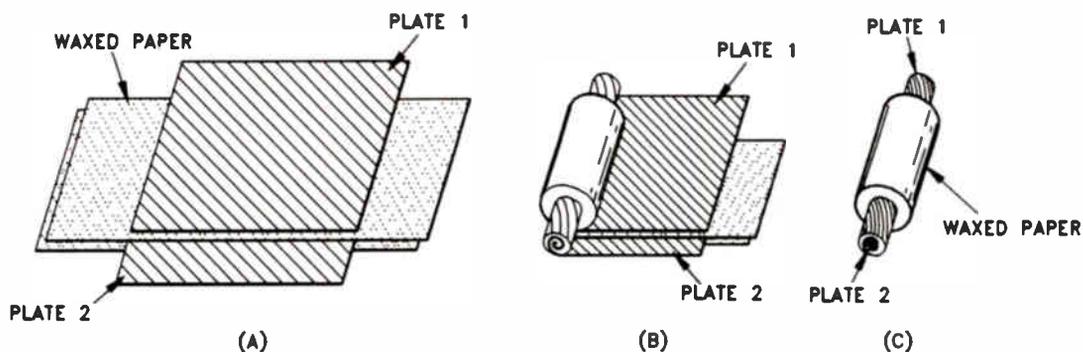


Figure 11. How a paper capacitor is made.

## Ceramic Capacitors

You find more ceramic capacitors in modern electronic equipment than any other type. They are widely used because they are reliable, economical to manufacture, and because they have a relatively large capacitance for their small size.

There are three types of ceramic capacitors: the disc, the tubular, and the feed-through. All three types are shown in Fig. 13 along with the schematic symbol for a feed-through capacitor. The symbol used for tubular and disc ceramics is the same symbol that is used for a paper capacitor.

Of the three types of ceramic capacitors, the disc is by far the most widely used. You seldom see tubular ceramic capacitors because they are much more expensive to manufacture than discs. Feed-through capacitors are used as bypass capacitors in high-frequency circuits.

Disc capacitors are made with capacitances from less than 1 pF up to several  $\mu\text{F}$ . Disc capacitors are like resistors in that they have different tolerances. Common tolerances are 5, 10, or 20 percent. Often the tolerance is indicated on the capacitor by a letter rather than the actual tolerance figure. The letter J is used to represent a 5% tolerance, K a 10% tolerance, and M a 20% tolerance. You'll also find disc capacitors with a tolerance rating of +100% or -0. The letter P is used to represent this tolerance. Another tolerance rating is +80% to -20%, where the letter Z is used to represent this tolerance. Still another tolerance is GMV, or guaranteed minimum value. That is, a capacitor marked 100 pF GMV has a capacitance at least that high. It could have a capacitance of 200 pF or 500 pF, or even higher. The manufacturer has simply guaranteed the minimum capacitance to be at least the value stamped on it.

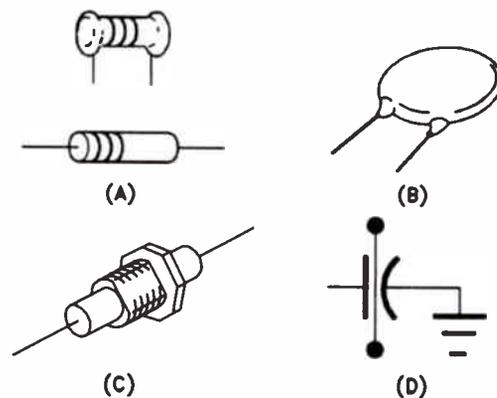


Figure 13. (A) Tubular, (B) disc, and (C) feed-through ceramic capacitors. (D) The schematic symbol for a feed-through capacitor.

Ceramic capacitors also have temperature coefficients. This means that the capacitance may change as the temperature changes. For example, a common type of ceramic capacitor is called a Z5U. This capacitor is designed for operation between 10°C and 85°C. The label Z5 gives you this information. The letter U tells you that the capacitance may change as much as +22% or -56% over that temperature range. However, in many applications, this change in capacitance is not important. The Z5U capacitor is frequently used because it is generally the most inexpensive capacitor available.

Ceramic capacitors are also made with a lower temperature coefficient. For example, a capacitor labeled Z5F has a temperature coefficient of only 7.5 percent. Z5P indicates a temperature change of 10% within the operating range. These capacitors are only used in circuits where a change of capacitance can cause a problem because they are more expensive than the Z5U type.

You will also see ceramic capacitors marked either with the letter N or P followed by a number. The N indicates negative temperature coefficient and P indicates positive temperature coefficient. The capacitance of a capacitor with a

## HOW CAPACITORS ARE USED

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negative temperature coefficient always decreases as the temperature increases. The capacitance of a capacitor with a positive temperature coefficient increases as the temperature increases. The larger the number following the letter N or P, the greater the capacitance change for a given temperature change.

Some ceramic capacitors are marked NPO, which stands for negative, positive, zero. These have neither a negative nor a positive temperature coefficient. Its value does not change as the temperature changes. These capacitors are found only in critical circuits where any change in capacitance would upset the performance of the circuit.

The closer the tolerance of a capacitor and the smaller the temperature coefficient, the more expensive the capacitor is. If you have to replace a defective ceramic capacitor, you can always use one with the same tolerance and the same temperature coefficient as the original. In many cases, you can use a Z5P capacitor to replace a Z5U, or you can use a Z5F capacitor to replace a Z5P capacitor. However, if you have to replace a capacitor with a negative temperature coefficient, one with a positive temperature coefficient, or an NPO capacitor, you should use a replacement with the same temperature coefficient.

Ceramic capacitors are manufactured with many different voltage ratings. Usually, the higher the voltage rating, the larger the physical size of the capacitor. The operating voltage in modern electronic equipment using transistors and integrated circuits is generally quite low, so most ceramic capacitors have a voltage rating as low as 50 volts. When a capacitor of a higher voltage rating is required, the manufacturer specifies a higher voltage rating.

Ceramic capacitors are very reliable, but occasionally a lead wire breaks and a short develops across the capacitor. When this hap-

pens, the shorted capacitor is not hard to find because it has a low resistance reading. Unless there is something connected directly across the capacitor, a low resistance reading indicates that the capacitor is shorted.

### Mica Capacitors

Figure 14 shows the construction of one type of mica capacitor. It is made by placing thin metal foil sheets between thin sheets of mica. The entire unit is sealed in a Bakelite or ceramic container. Mica is brittle and can't be rolled into a round form like paper or mylar, so the shape of a mica capacitor is flat.

Another type of mica is the silver mica capacitor. In this capacitor, thin layers of silver are sprayed onto the mica sheets, as shown in Fig.15. Since the silver layers are very thin, opposite plates of the capacitor can be brought very close together to obtain a relatively high capacitance in a small package.

Although mica capacitors are excellent capacitors, they are no longer frequently used because they are much more expensive than other types.

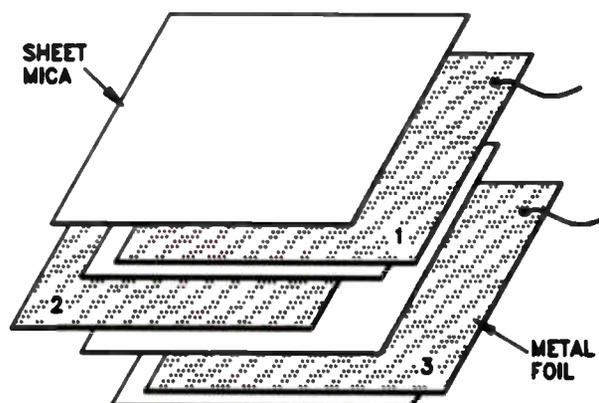


Figure 14. How a mica capacitor is made.

## TYPICAL CAPACITORS

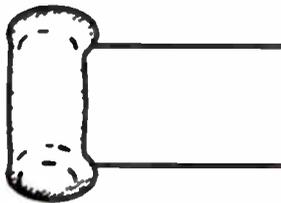


Figure 15. A silver mica capacitor.

### Electrolytic Capacitors

Electrolytic capacitors are widely used in electronic equipment because you can get a higher capacitance for a given physical size than in any other type of capacitor. There are two types of electrolytic capacitors: aluminum capacitors, which use aluminum for the plates, and tantalum capacitors, which use tantalum for

the plates. Of the two, the aluminum capacitor is more widely used because aluminum is much less expensive than tantalum.

An electrolytic capacitor is made up of two long strips of metal with an electrolyte in paste form placed between the two plates, as shown in Fig.16(A). The anode plate is treated before the capacitor is assembled to produce a coating of oxide on the surface of the plate. The oxide, which is very thin, acts as the dielectric. A gauze-type material soaked with the electrolyte is then laid in contact with the oxide. The other plate is then placed on top of the gauze. The gauze, saturated with the electrolyte, and the top plate form the cathode or negative plate of the capacitor. The whole assembly is then rolled up with the negative plate on the outside, then encased in a metal container.

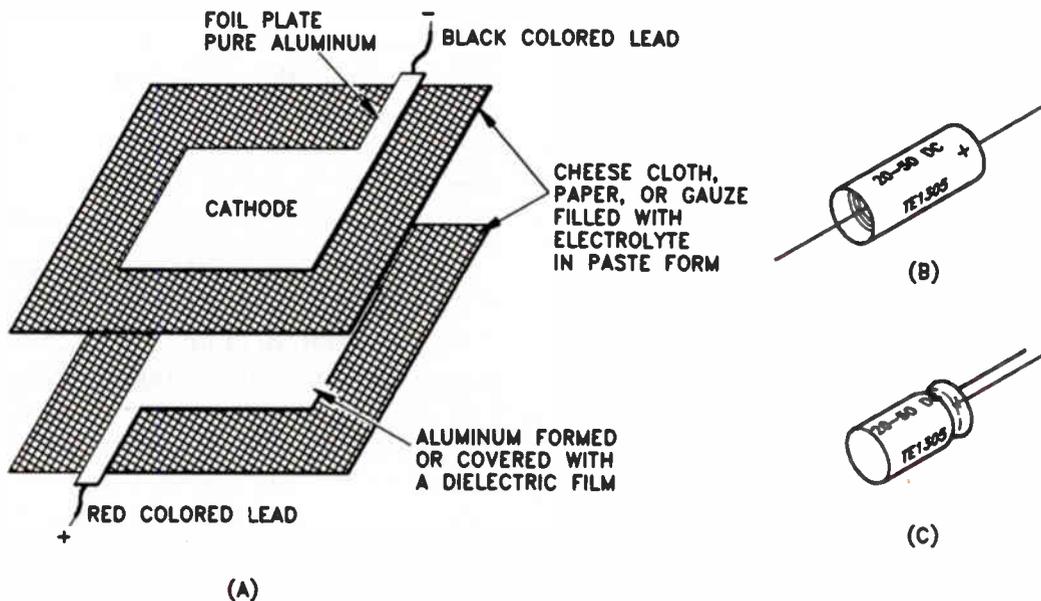


Figure 16. (A) Electrolytic capacitors are made of two plates with an electrolytic paste form placed between the two plates. The assembly is then rolled and placed in a tubular metal can. (B) The leads are then brought out of the two ends of the capacitor, or as shown at (C), the leads are brought out of one end of the capacitor.

## HOW CAPACITORS ARE USED

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In the double-ended electrolytic capacitor shown in Fig.16(B), the lead from the negative plate comes out one end of the capacitor and is in contact with the metal container. The lead from the positive plate, or anode, comes out the other end and this end is sealed with an insulating material. In the single-ended electrolytic capacitor shown in Fig.16(C), the two leads come out of the same end of the capacitor.

Electrolytic capacitors can be made with very high capacitances because the dielectric, which is an oxide coating on one of the plates, is very thin. Since the other plate consists of the aluminum and the gauze saturated with electrolyte, the two plates are very close together. You find some very small electrolytic capacitors with very high capacitances.

As we mentioned earlier, aluminum is more widely used in electrolytic capacitor because it is less expensive than tantalum. However, tantalum capacitors are better capacitors and are used in applications where the superior performance of the capacitor justifies the additional expense.

**Polarity.** Electrolytic capacitors can only be used in dc or pulsating dc circuits. The plate called the anode must always be connected to the positive side of the voltage source, and the plate called the cathode must always be connected to the negative side of the voltage source. If you connect an electrolytic capacitor into the circuit backwards, or use it in an ac circuit, a very high current flows through the capacitor, destroying it.

In some electrolytic capacitors, the anode is marked with a + sign and the cathode with a - sign. In most electrolytic capacitors, however, only one of the two leads is marked. Once you've

found the - sign indicating the cathode or the + sign indicating the anode, you can identify the unmarked lead.

**Voltage Rating.** The thinner the dielectric oxide coating in an electrolytic capacitor, the higher the capacitance; but the thinner the dielectric, the lower the voltage that can be applied to the capacitor. Manufacturers specify the maximum voltage that can be applied to an electrolytic capacitor. If you use an electrolytic capacitor in a circuit where the operating voltage is higher than the voltage rating of the capacitor, the capacitor will most likely break down.

**Defects.** Electrolytic capacitors are among the most troublesome components in electronic equipment because they deteriorate, particularly if they are not used. You should not buy a large stock of electrolytic capacitors. Avoid keeping unused capacitors longer than six months. If you do have a capacitor longer than six months before using it, you should place a small operating voltage across the capacitor and gradually increase it until the voltage applied to the capacitor slightly exceeds the rated voltage of the capacitor. Electrolytic capacitors also deteriorate as they are used. The moisture in the electrolyte slowly escapes so that the capacitance of the capacitor decreases.

The dielectric in an electrolytic capacitor is not a perfect insulator. Some electrons can cross from the negative plate to the positive plate. In a good capacitor this leakage current is very low, but in time the leakage current may become excessive. When this happens, the capacitor becomes warm. Anytime you find a warm or hot electrolytic capacitor, you should replace it.

## TYPICAL CAPACITORS

### Review

In this section we have discussed a number of different types of capacitors. In general, you can classify them into two types: those in which the capacitance is variable and those in which the capacitance is fixed.

It is not important that you remember how the various types of capacitors are made. It is important to remember that capacitors can open, short, and develop intermittent defects. A low resistance reading across a capacitor indicates that the capacitor is shorted or has developed excessive leakage.

### Self-Test Questions

- 11 What do we mean when we say that the dielectric of a variable capacitor is air? *they are separated by air*
- 12 Why are capacitors such as paper or mylar capacitors molded in a ceramic type of material? *Keep out moisture & dirt*
- 13 Why aren't mica capacitors more widely used in electronic equipment? *expensive*
- 14 What does Z5F stamped on a ceramic disc capacitor indicate? *HAS a temperature coefficient of only 7.5% & tolerance of ± 5% at +55°C*
- 15 Name two metals used in electrolytic capacitors. *Aluminum & Tantalum*
- 16 What do we mean when we say an electrolytic capacitor has polarity? *one plate is always connected to positive side & the other to negative side*
- 17 Can an electrolytic capacitor with a dc voltage rating of 10 V be used in a circuit where the operating voltage is 15 volts? *NO*
- 18 If you notice that an electrolytic capacitor is getting hot, what should you do? *replace it*

## HOW CAPACITORS ARE USED

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### CAPACITORS IN AC CIRCUITS

Capacitors are rarely used in purely direct current circuits. Once a capacitor is placed in a dc circuit and charged, there is no further current flow in the circuit. Capacitors are most important when used in ac circuits and in circuits that have both ac and dc.

#### How AC Flows in AC Circuits with Capacitors

Figure 17 shows a simple circuit with a capacitor connected across an ac generator. There is a current flow in this circuit, and the exact amount of current depends upon the voltage of the generator, its frequency, and the capacitance of the capacitor.

When terminal 1 of the generator is negative and terminal 2 is positive, electrons flow from terminal 1 into the side of the capacitor marked A. Electrons are forced out of the side marked B to terminal 2 of the generator, which attracts these electrons because it is positive. During the next half-cycle, the polarity of the generator reverses so that terminal 1 is positive and terminal 2 is negative. Now electrons on the side of the capacitor marked A are pulled out by terminal 1 which is positive, and electrons are



Figure 17. A capacitor connected across a generator.

forced into side B of the capacitor by terminal 2 of the generator, which is negative.

Electrons flow back and forth in the circuit as the generator goes through first one half-cycle and then the other. They flow first into one side of the capacitor, forcing electrons out of the other side, then the opposite. Notice that electrons do not flow through the capacitor. The plates of the capacitor are separated by a dielectric and the dielectric is a nonconducting material. However, because the capacitor stores the charge in each direction of current flow, and discharges in the opposite direction when the polarity changes, we have the effect of the current flowing in the circuit.

Refer to Fig.18. At the start of the ac cycle when the voltage is zero, there are electrons in both plates of the capacitor. The electrons in each atom of the dielectric revolve around the nucleus, as shown in Fig.18(A). However, when electrons begin to move into one plate, as shown in Fig.18(B), and out of the other plate, the electrons in the dielectric are forced out of their normal path as shown. Thus, although an electron flowing into plate 1 does not reach plate 2, it does force another electron in the dielectric over near plate 2, and this in turn forces an electron out of plate 2.

If the ac voltage decreases and finally drops to zero, the electrons in the dielectric return to the normal position, as shown in Fig.18(C). During the next half-cycle, when the polarity of the generator reverses, an electron is forced into plate 2. This in turn forces an electron in the dielectric out of its normal position and toward plate 1. This action pushes an electron out of plate 1. Thus, we have the effect of current flowing through the capacitor in the opposite direction, although the electrons flowing into one plate never actually go through the dielectric into the other plate of the capacitor.

## CAPACITORS IN AC CIRCUITS

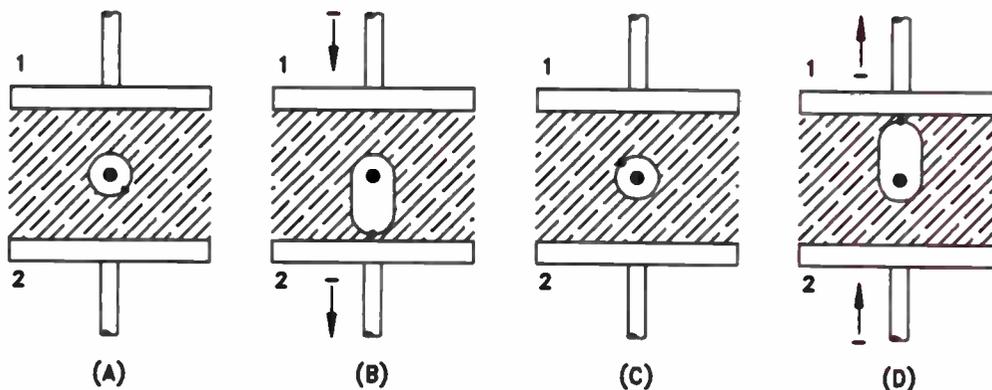


Figure 18. When ac is applied to a capacitor, the bound electrons in the dielectric move first one way, then the other. As a result, the effect is that of alternating current flowing through the capacitor.

You can see that there is a back and forth motion of electrons through the conductors connected to the capacitor. Because the electrons in the dielectric move back and forth, we can say that ac current flows through a capacitor, even though the electrons never get through the dielectric into the other plate. Because of this current continuity, capacitors can be used in ac circuits. They are also very useful in circuits where there is both ac and dc. The capacitor can be used to block the dc, while at the same time allowing the ac to flow through the capacitor.

In allowing electrons to flow back and forth, the capacitor's action serves as a good demonstration of what ac is. The actual movement of each electron is very small, but there may be a large number of electrons moving back and forth over a very short distance. The distance of the electron's travel is unimportant; the important thing is the number of electrons in motion. If we have a large number of electrons in motion, we have a large current.

### Capacitive Reactance

The capacitor does not allow electrons to move back and forth without offering opposition.

Capacitors offer opposition to the flow of ac current through them. This opposition is called capacitive reactance. This opposition is measured in ohms, just as the inductive reactance of a coil is measured in ohms. However, there is a great deal of difference between inductive reactance and capacitive reactance.

Capacitive reactance is represented by the symbol  $X_C$ . It can be expressed by the formula:

$$X_C = \frac{1}{6.28 \times f \times C}$$

The 6.28 is the value of  $2\pi$ . Remember, this appeared in the formula for inductive reactance. Notice that the formula is similar to the formula for inductive reactance except that it is inverted. In other words, the expression is divided into 1.

In this formula,  $f$  is the frequency expressed in hertz and  $C$  is the capacitance in farads. We know that the farad is too large a unit for practical use in electronics, so we can write the formula in another way by expressing  $C$  in microfarads. To do this we divide 6.28 into 1 and multiply the result by 1,000,000. We get:

$$X_C = \frac{159,000}{f C}$$

## HOW CAPACITORS ARE USED

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In this expression  $f$  is the frequency in hertz, and  $C$  is the capacitance in microfarads.

There are several important things that you can learn from this formula. For example, let's find the reactance of a  $1\ \mu\text{F}$  capacitor at a frequency of 10 Hz.

$$X_C = \frac{159,000}{10 \times 1} = \frac{159,000}{10} = 15,900\text{ohms}$$

If we increase the frequency to 100 cycles, we get:

$$X_C = \frac{159,000}{100 \times 1} = 1590\text{ ohms}$$

when we increase the frequency from 10 Hz to 100 Hz (in other words increase the frequency 10 times), we reduce the capacitive reactance by a factor of 10. We say that the reactance varies inversely as the frequency. This simply means that as the frequency increases, the reactance decreases. This is opposite to the effect that an increase in frequency has on inductive reactance.

The same thing happens if we increase the capacitance. At the frequency of 100 Hz, if we increase the capacitance from  $1\ \mu\text{F}$  to  $10\ \mu\text{F}$ , we get:

$$X_C = \frac{159,000}{100 \times 10} = 159\text{ ohms}$$

Thus, an increase in capacitance has the same effect on the capacitive reactance as an increase in frequency. And increasing either the frequency or the capacitance reduces the capacitive reactance. Even a very small capacitor can have a low reactance if the frequency is high enough. For example, a  $1\ \text{pF}$  capacitor has a reactance of 1590 ohms at a frequency of 100 MHz. This is within the FM broadcast band. At a frequency of 1000 MHz, which is only slightly higher than the

frequency used by some UHF TV stations, the reactance is only 159 ohms.

### Capacitors in Series and Parallel

When you connect two capacitors in series, you are connecting two capacitive reactances in series. It is like connecting two resistances in series. The total capacitive reactance is the sum of the two reactances. Since the reactance increases, the capacitance must decrease. As a matter of fact, if you connect two  $10\ \mu\text{F}$  capacitors in series, the total capacitance of the series combination is exactly half of  $10\ \mu\text{F}$ , or  $5\ \mu\text{F}$ .

When two capacitors are connected in series, you can find the total capacitance by using the formula:

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

If there are more than two capacitors, you can find the total capacitance of two at a time by using the same formula that we use to find the total resistance when more than two resistors are in parallel.

When capacitors are connected in series, the total capacitance is always less than the capacitance of the smallest capacitor. Remember that this is the same as resistors in parallel where the total resistance is always less than the resistance of the smallest resistor.

When you connect two capacitors in parallel, you are connecting two reactances in parallel. If you connect two  $10\ \mu\text{F}$  capacitors in parallel, you have half the capacitive reactance of either capacitor alone. Since the capacitive reactance goes down, the capacitance must increase. To find the total capacitance of capacitors connected in parallel, you simply add the capacitances.

## CAPACITORS IN AC CIRCUITS

### Time Constant

When you connect a capacitor across a battery, it takes a certain amount of time for the capacitor to charge. The length of time depends on the capacitance of the capacitor and the resistance in the circuit. Even if you connect a capacitor directly across the battery, the battery has internal resistance, so some time is involved in charging the capacitor.

If we connect a capacitor in series with a resistor across a battery, as shown in Fig.19, the voltage across the capacitor builds up following a curve as shown in Fig.20. Notice that at first the capacitor charges quite rapidly and then, as it is charged, the rate at which the voltage builds up decreases. This is because when you first connect the capacitor across the battery, the capacitor voltage is zero and the full battery voltage is forcing electrons into the one plate and out of the other. As the capacitor begins to charge, the voltage forcing the current flow decreases because the voltage causing the current to flow is the battery voltage minus the capacitor voltage. Since the effective charging voltage decreases, the rate at which the charge builds up decreases.

The length of time it takes the capacitor to charge is known as the time constant of the R-C

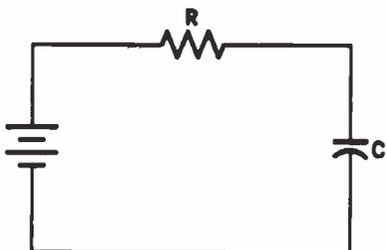


Figure 19. A resistor and a capacitor connected in series across a battery.

However, by definition, one time constant is the length of time it takes the capacitor to charge to approximately 63% of the source voltage, not to the full source voltage. This value is shown in Fig.20. The time constant in seconds of any R-C circuit can be found by multiplying the resistance of the resistor in megohms times the capacitance of the capacitor in microfarads. A capacitor is considered, again by definition, to be fully charged (100%) after five time constants have elapsed.

By this formula, a  $2 \mu\text{F}$  capacitor in series with a 1-megohm resistor has a time constant  $2 \times 1 = 2$  seconds. This means that it takes two seconds for the capacitor to charge up to 63% of the source voltage. Ten volts applied to this combination will charge the capacitor to 6.3 V in two seconds. If we apply 100 V, the capacitor voltage rises to 63 V in two seconds. Decreasing the size of either the resistor or the capacitor decreases the time constant. Increasing the size of either the resistor or the capacitor increases the time constant.

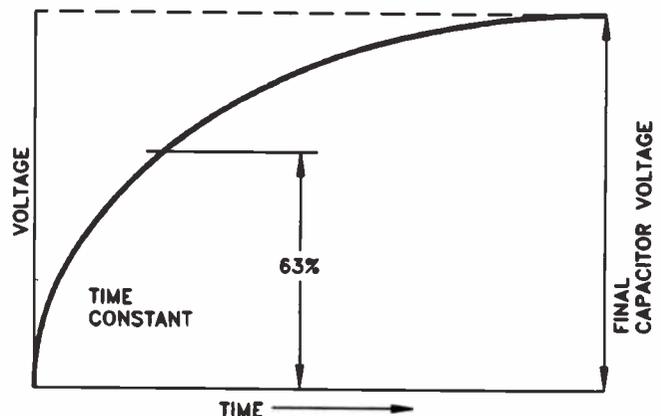


Figure 20. How a capacitor charges.

## HOW CAPACITORS ARE USED

### Voltage-Current Phase

In the preceding example, notice that when the capacitor and resistor combination is first connected across the battery, a very high current flows in the circuit. However, at this first instant when the combination is connected across the battery, there is no voltage across the capacitor. The current is at a maximum and the voltage across the capacitor is at a minimum, or zero, voltage.

As the voltage across the capacitor builds up, the current flow in the circuit decreases until finally, when the capacitor is fully charged to a value equal to the battery voltage, the current drops to zero. At this point, the source voltage is unable to force any additional electrons onto the one plate of the capacitor or to pull electrons off the other plate.

Essentially, the same thing happens on a continuing basis when a capacitor is used in an ac circuit. When the ac voltage across the capacitor builds up, the current decreases until, by the time the capacitor is fully charged, the current has dropped to zero. When the voltage across the capacitor peaks and begins to reverse in polarity with the phase change in the applied ac voltage, the current must reverse to flow in the opposite direction.

During the second quarter of the ac cycle, the capacitor voltage drops from maximum to zero while the discharge current flowing in the circuit increases from zero to maximum. As the voltage across the capacitor builds up in the opposite direction, the current begins to decrease until, at the instant when the capacitor is fully charged with the opposite polarity, the current flow in the circuit has dropped to zero again.

The relationship between the current and voltage in a capacitive ac circuit is shown in Fig.21. Notice that in this circuit the current is

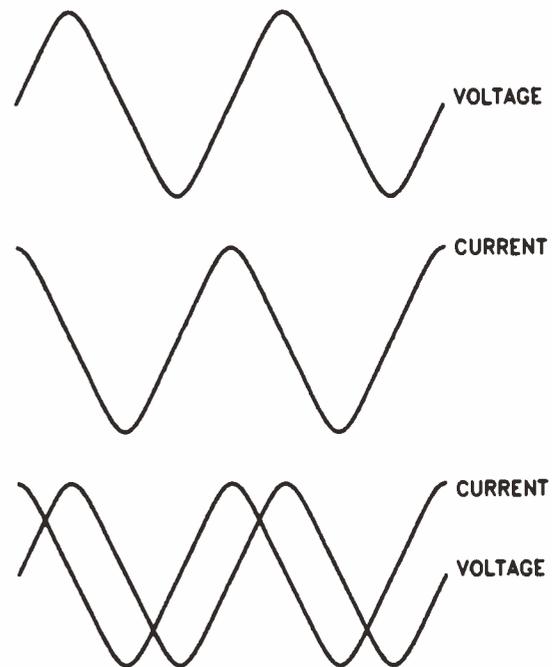


Figure 21. The phase relationship between current and voltage in a capacitive circuit.

leading the voltage by 90 degrees. In other words, it is always one-quarter cycle ahead of the voltage. Remember that this is the opposite of what happens in an inductive circuit where the current lags the voltage by 90 degrees.

### Voltage Distribution

When a resistor and a capacitor are connected in series across an ac generator, as shown in Fig.22, we cannot measure the resistor voltage, then the capacitor voltage, and add them directly together to get the generator voltage. This is because the voltage across the resistor is in phase with the current, but the voltage across the capacitor lags the current by 90 degrees. To add them, we must use a formula very similar to the one we used for inductive circuit voltages:

$$E_G = \sqrt{E_R^2 + E_C^2}$$

## CAPACITORS IN AC CIRCUITS

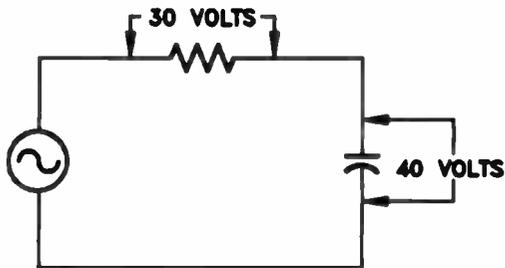


Figure 22. The voltage across the resistor.

Substituting the values shown in Fig.22 we get:

$$\begin{aligned} E_G &= \sqrt{30^2 + 40^2} \\ &= \sqrt{900+1600} \\ &= \sqrt{2500} = 50 \text{ V} \end{aligned}$$

We can also find the generator voltage by means of a vector addition of the two voltages, as shown in Fig.23. First, draw the current vector  $I$ . Since the resistor voltage is in phase with the current, draw the resistor voltage  $E_R$  over top of the current vector. Using a scale of 1"= 10 V, draw the resistor vector 3" long to indicate 30 volts. Now draw the capacitor voltage vector  $E_C$  lagging by 90° and 4" long to represent 40 V, as shown. Next, draw a dotted line parallel to the capacitor voltage vector from the end of the resistor vector and another dotted line from the end of the capacitor voltage vector parallel to the resistor voltage vector. Where the two intersect, draw a line representing the generator voltage at  $E_G$ . If you measure this line, you'll find that it is 5" long, which indicates that the generator voltage is 50 volts.

### Impedance

We can use the same type of formula to find the impedance in an R-C circuit that we used to find the impedance in an RL circuit.

$$Z = \sqrt{R^2 + X_C^2}$$

If, in the circuit shown in Fig.22, the resistance is 300 ohms and the capacitive reactance is 400 ohms, we can substitute these values in the formula to find the impedance.

$$\begin{aligned} Z &= \sqrt{300^2 + 400^2} \\ &= \sqrt{90,000+160,000} = \sqrt{250,000} \\ &= 500 \text{ ohms} \end{aligned}$$

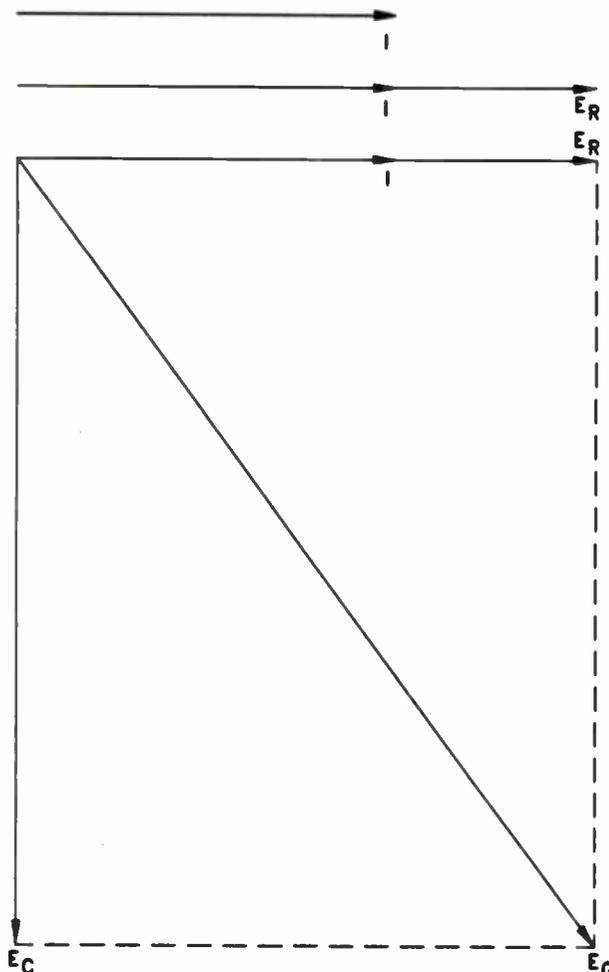


Figure 23. Vector addition of resistor and capacitor voltage in Fig.22.

## HOW CAPACITORS ARE USED

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We can also use a vector diagram to find the impedance, as shown in Fig.24. Using a scale of 100 ohms = 1", we draw a current vector first. Then we draw the resistor vector  $R$  3" long as shown. Next, we draw the capacitive reactance vector  $X_C$  4" long and then complete our vector diagram. The impedance vector  $Z$  is equal to 5", which represents 500 ohms.

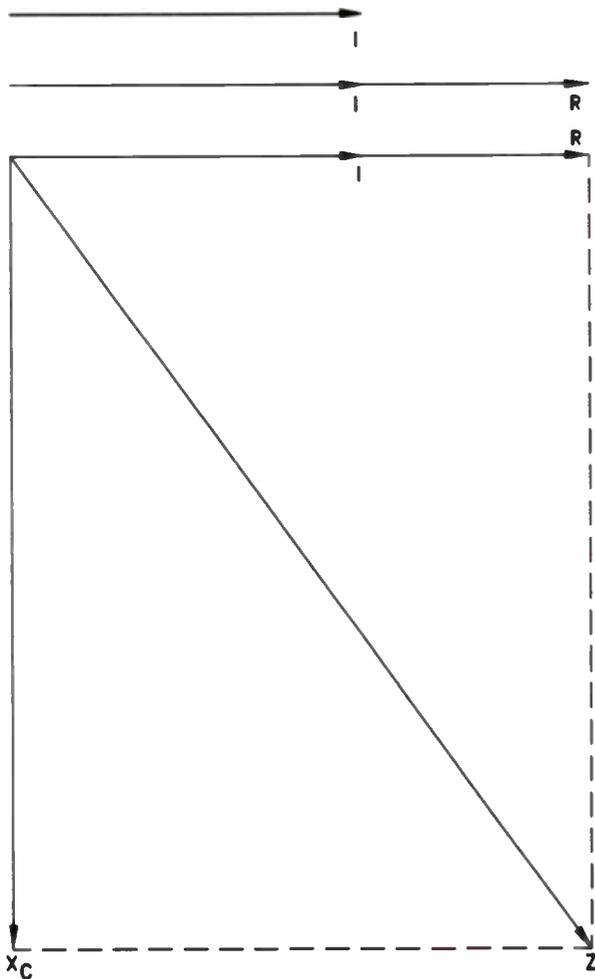


Figure 24. Vector addition of impedance.

### Review

It is important for you to remember that increasing either the frequency or the capacitance of a circuit reduces the capacitive reactance. Though you seldom have to calculate the actual reactance of a capacitor, you should remember the formula in order to remember that increasing frequency or capacitance reduces reactance. You should remember what we mean by the time constant of an R-C circuit. It is the time it takes a capacitor to charge to 63% of the applied voltage. Increasing the resistance or the capacitance of the circuit increases the time constant, whereas reducing the resistance or the capacitance reduces the time constant.

Remember that in a capacitive circuit the current leads the voltage by 90 degrees. We can also say that the voltage lags the current by 90°; both mean the same thing. Remember that in an R-C circuit, you cannot arithmetically add the voltage across a resistor and the voltage across a capacitor to get the source voltage. You must add them vectorially or by means of the formula. The same is true of impedance in an R-C circuit.

## CAPACITORS IN AC CIRCUITS

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### Self-Test Questions

- 19 When a capacitor is connected across an ac generator, does current flow from the generator?
- 20 When a capacitor is connected across a generator, does current flow through the capacitor?
- 21 What is the name given to the opposition that a capacitor offers to the flow of ac?
- 22 If either the frequency of the applied ac or the capacitance of a capacitor is increased, what happens to the capacitive reactance?
- 23 What do we mean by the time constant of an R-C circuit?
- 24 What is the time constant of a  $0.02\ \mu\text{F}$  capacitor charging through  $2.2\text{M}$  resistor?
- 25 If the time constant of an R-C circuit is two seconds when it is charged across a  $10\ \text{V}$  battery, what is the time constant when it is connected across a  $100\ \text{V}$  battery?
- 26 If a generator is connected across a resistor and a capacitor in series, what is the generator voltage if the voltage across the resistor is  $9\ \text{V}$  and the voltage across the capacitor is  $12\ \text{volts}$ ?
- 27 If a  $6\text{-ohm}$  resistor is connected in series with a capacitor having a capacitive reactance of  $8\ \text{ohms}$ , what will the impedance of the combination be?

## HOW CAPACITORS ARE USED

---

### ANSWERS TO SELF-TEST QUESTIONS

- 1 When we say a capacitor is charged, we mean there is a surplus of electrons on one plate and a shortage of electrons on the other.
- 2 The length of time it takes to charge a capacitor is affected by the resistance in the circuit and the capacitance of the capacitor.
- 3 The capacitance of the capacitor.
- 4 The microfarad, which is a millionth of a farad, and a picofarad, which is a millionth of a microfarad.
- 5 3300 pF. To convert microfarads to picofarads, you multiply by 1,000,000 or move the decimal point six places to the right.
- 6 0.00068  $\mu$ F. To convert picofarads to microfarads, you move the decimal point six places to the left.
- 7 The area of the plates, the spacing between the plates, and the dielectric of the medium between the plates.
- 8 The dielectric constant of a material tells you how many times the capacitance of the capacitor increased by substituting the material between the plates of a capacitor in place of air.
- 9 It has the effect of reducing the spacing between the plates of the capacitor.
- 10 This is the maximum dc voltage that can be applied across a capacitor.
- 11 We mean the plates are separated by air; there is no solid dielectric between the plates.
- 12 To seal the capacitor so moisture can't seep into the capacitor.
- 13 They are expensive.
- 14 Z5 indicates that the capacitor is designed for operation between 10°C and 85°C. The F indicates that the capacitance should not change more than  $\pm 7.5$  within the capacitor's normal temperature range.
- 15 Aluminum and tantalum.
- 16 One plate must always be connected to a positive voltage and the other to a negative voltage.
- 17 No.
- 18 Replace it.
- 19 Yes. Current flows from the generator to charge the capacitor with one polarity during one half-cycle and then flows to the opposite direction to charge the capacitor with the opposite polarity during the next half-cycle.
- 20 No. While electrons do flow in the circuit, they do not flow through the capacitor.
- 21 Capacitive reactance.
- 22 It is reduced.
- 23 It is the length of time it takes the capacitor to charge up to approximately 63% of the applied voltage.
- 24 0.044 second. The time constant equals  $2.2 \times 0.02 = 0.044$  second.
- 25 Two seconds. The time constant is exactly the same because the charging voltage has no effect on the time constant.
- 26 15 V. Use the formula:
$$E_G = \sqrt{E_R^2 + E_C^2} = \sqrt{9^2 + 12^2}$$
$$= \sqrt{81 + 144} = \sqrt{225}$$
$$= 15 \text{ V}$$
- 27 10 ohms. Use the formula:
$$Z = \sqrt{R^2 + X_C^2}$$
$$= \sqrt{6^2 + 8^2}$$
$$= \sqrt{36 + 64} = \sqrt{100}$$
$$= 10 \text{ ohms}$$

## Lesson Summary

Some of the important facts that you should remember about this lesson are:

- A capacitor is basically no more than two flat pieces of conductor, separated by an insulator.
- A capacitor charges at a rate determined by its capacitance and by the total resistance in the circuit.
- Capacitors are usually measured in microfarads, and have peak voltage ratings.
- Capacitors can be fixed or variable, and polarized or nonpolarized in nature.
- Current leads voltage in a capacitive circuit by as much as 90 degrees.



## LESSON QUESTIONS

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7. The total capacitance of two  $8\ \mu\text{F}$  capacitors connected in series is:
- $2\ \mu\text{F}$ .
  - $4\ \mu\text{F}$ .
  - $8\ \mu\text{F}$ .
  - $16\ \mu\text{F}$ .
8. The time constant of an R-C circuit made up of a  $50\ \mu\text{F}$  capacitor and a  $100\text{K}$  resistor is:
- 5000 seconds.
  - 500 seconds.
  - 50 seconds.
  - 5 seconds.
9. A resistor is connected in series with a capacitor and these are connected across an ac generator. The voltage measured across the resistor is 40 V and across the capacitor 30 volts. What is the generator voltage?
- 70 volts.
  - 60 volts.
  - 50 volts.
  - 45 volts.
10. A  $2.5\ \mu\text{F}$  capacitor is connected in series with a 300 ohm resistor. The two are connected across the generator operating at 159 hertz. What is the impedance of the circuit?
- 300 ohms.
  - 400 ohms.
  - 500 ohms.
  - 600 ohms.

## NOTES

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*Please use this page to record any notes  
you may want to review during your studies.*



## HOW TO BUILD CONFIDENCE

Self-confidence — an active faith in your power to accomplish whatever you try to do — is a personal asset that can do big things for you.

Nothing builds confidence like success. Each lesson you successfully complete builds your confidence. The more you accomplish, the more confident you become, and the more you are able to achieve.

Success is habit-forming. Once you get started, you'll find yourself doing something successful every day. Before you know it, your little successes will have built up to that big success you've dreamed of. Get into the success habit as fast as you can, by resolving to study every day, even if only for a few minutes.

Another confidence builder is a deep, firm faith in yourself — in your ability to get ahead. If you believe in yourself and are willing to back up this faith with hard work, you can safely let the rest take care of itself. With self-confidence grounded in hard work, you can look forward to success in any field you choose.

Act as if you cannot possibly fail, and you will surely succeed.





# How Coils and Capacitors Work Together



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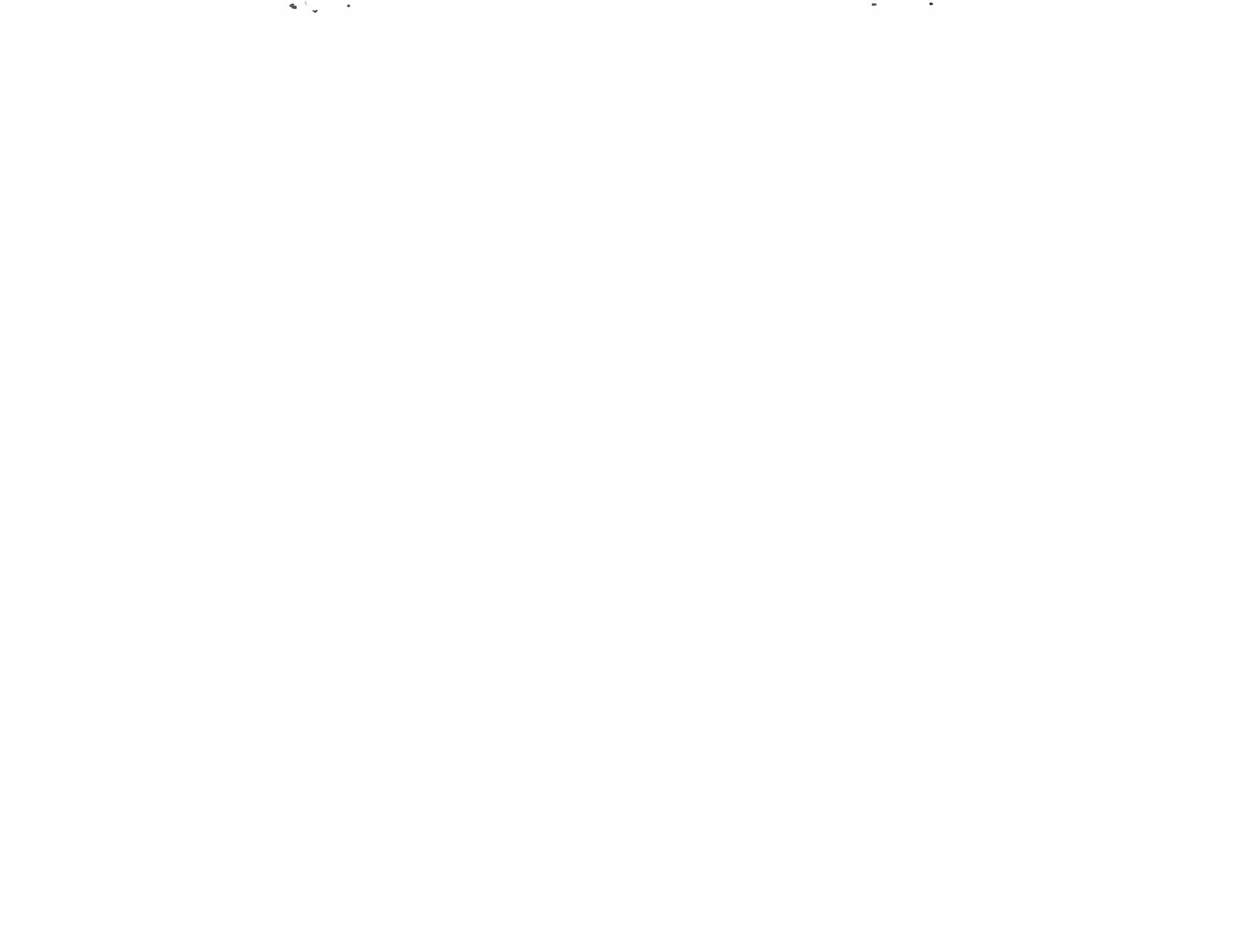


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# **How Coils and Capacitors Work Together**



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# Table of Contents

<b>Introduction</b> .....	1
<b>Series Resonant Circuits</b> .....	2
Series Circuits .....	2
Resonant Circuits .....	3
Varying C, L, f, and R .....	4
Review .....	8
Self-Test Questions .....	8
<b>Parallel Resonant Circuits</b> .....	9
Current Flow .....	9
Varying C, L, f, and R in a Parallel Resonant Circuit .....	11
Review .....	13
Self-Test Questions .....	13
<b>Comparison of Resonant Circuits</b> .....	14
Resonance Curves .....	14
Identifying Resonant Circuits .....	14
Review .....	17
Self-Test Questions .....	17
<b>How Resonant Circuits Are Used</b> .....	19
Selecting a Desired Signal .....	19
How Filters Are Used .....	20
Review .....	22
Self-Test Questions .....	22
<b>Answers to Self-Test Questions</b> .....	23
<b>Lesson Questions</b> .....	26

## HOW COILS AND CAPACITORS WORK TOGETHER

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# Lesson Objectives

In this lesson you will . . .

- Learn how coils and capacitors are combined into series resonant circuits.
- Discover the characteristics of series resonant circuits and the factors affecting them.
- Continue on to learn about how coils and capacitors can be combined into another form, parallel resonant circuits.
- Learn how series and parallel resonant circuits have practical applications as frequency filters.

### INTRODUCTION

In your study of resistors, coils, and capacitors, you were primarily concerned with the individual part. In electronic equipment, however, these parts are seldom used alone; in most cases, two or more parts are used together. Circuits that use resistors and coils together are called *R-L circuits*. Circuits that combine resistors and capacitors are called *R-C circuits*. Circuits using coils and capacitors are *L-C circuits*. When all three are used together, we call it an *R-L-C circuit*.

Coils and capacitors have basically opposite effects. For example, in a circuit having only inductance, the voltage leads the current by 90 degrees. On the other hand, in a circuit having only capacitance, the voltage lags the current by 90 degrees.

In circuits where coils and capacitors are used together, the two work against each other. Sometimes the circuit may act more like a coil, in that the voltage will lead the current by some angle less than 90 degrees. In other circuits capacitive effects might dominate, so that circuit voltage lags the current by some value less than 90 degrees. It is also possible for the inductive effect to cancel the capacitive effect so that the voltage and current will be in phase. Circuits of this type are called *resonant circuits*.

There are two types of resonant circuits: series resonant and parallel resonant. Whether a circuit is one or the other depends upon how the voltage is applied to the coil and capacitor in the circuit. Both types of resonant circuit are important. We will study them both so that you will learn to distinguish one type from the other. Series resonance is somewhat easier to understand than parallel resonance, so we will start with the series resonant circuit.

# HOW COILS AND CAPACITORS WORK TOGETHER

## SERIES RESONANT CIRCUITS

In a resonant circuit, the inductive reactance is equal to the capacitive reactance. When the voltage is applied to the coil and the capacitor in series, we call the circuit a *series resonant circuit*. To help you get a clear understanding of what happens in a series resonant circuit, let's start with two simple series circuits that are not resonant.

### Series Circuits

In the circuit of Fig.1, the capacitive reactance is 60 ohms at the frequency applied to the circuit. The inductive reactance of the coil is 100 ohms. Since the wire used in the circuit has resistance, we know that there must be some small resistance in the circuit. Let's represent this resistance with a 30-ohm resistor. First, find the impedance of the circuit, then find the current flow in the circuit and the voltage across each part in the circuit.

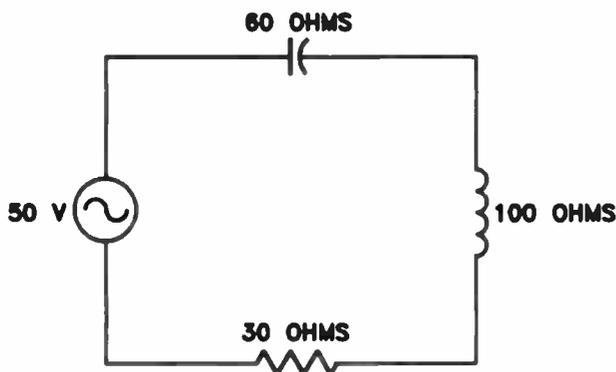


Figure 1. A series circuit where the inductive reactance is greater than the capacitive reactance.

Inductive reactance has the opposite effect of capacitive reactance. In any circuit where both exist, they tend to cancel each other out. The total reactance in this circuit is  $100 - 60 = 40$  ohms, which appears as inductive reactance because the coil reactance is greater. Therefore, the impedance of the circuit can be found using this formula:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Substituting 30 for R, 100 for  $X_L$ , and 60 for  $X_C$ , we get:

$$Z = \sqrt{30^2 + (100 - 60)^2}$$

$$= \sqrt{900 + 1,600}$$

$$= \sqrt{2,500}$$

$$= 50 \text{ ohms impedance}$$

Since the voltage applied to the circuit is 50 volts (V), we know that the current, I, must be:

$$I = \frac{E}{Z} = \frac{50}{50} = 1 \text{ ampere (A)}$$

This means that the voltage across the resistor  $E_R$  will be:

$$E_R = IR = 1 \times 30 = 30 \text{ V}$$

The voltage across the coil  $E_L$  will be:

$$E_L = IX_L = 1 \times 100 = 100 \text{ V}$$

And the voltage across the capacitor  $E_C$  will be:

$$E_C = IX_C = 1 \times 60 = 60 \text{ V}$$

The important thing for you to notice in this example is that only 50 V are applied by the generator, but there are 60 V across the capacitor and 100 V across the coil. If we take an ac voltmeter and measure the voltage across these components, these are the voltage readings we get.

## SERIES RESONANT CIRCUITS

However, since the phase of the voltage across the coil leads the current phase, and since the voltage phase across the capacitor lags the current phase, we would measure 40 V total across the coil and capacitor together, because they cancel each other. Since the coil voltage is greater than the capacitor voltage, the voltage phase leads the current. This is the effect we get when the net reactance is inductive.

To add the reactive voltage across the coil and capacitor to the voltage across the resistor, we must use this formula:

$$\begin{aligned} E_T &= \sqrt{E_R^2 + (E_L - E_C)^2} \\ &= \sqrt{30^2 + 40^2} \\ &= \sqrt{900 + 1,600} \\ &= \sqrt{2,500} \\ &= 50 \text{ V} \end{aligned}$$

Figure 2 is the same as Fig.1, except that the capacitive reactance is 100 ohms and the inductive reactance is 60 ohms. We use the same formula to find the impedance, but we subtract the inductive reactance from the capacitive reac-

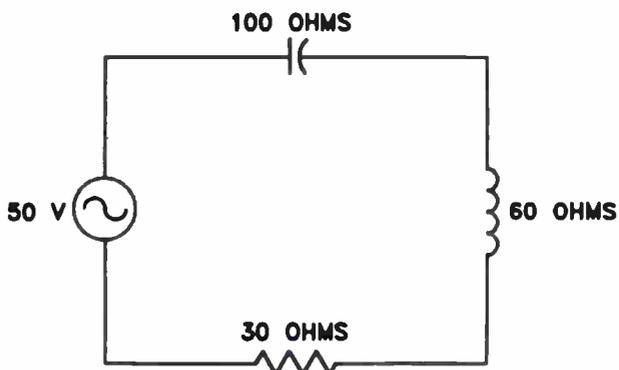


Figure 2. A series circuit where the capacitive reactance is greater than the inductive reactance.

tance. The net reactance is again 40 ohms, the impedance 50 ohms, and the current 1 ampere.

There are 100 V across the capacitance and 60 V across the inductance. The net voltage across the two is 40 V, but since the capacitive voltage is larger, the voltage phase lags the current. Remember from these two examples that the voltage across the larger reactance determines whether the current phase leads or lags the voltage phase.

### Resonant Circuits

In the series circuit shown in Fig.3, we again have a voltage of 50 V and a resistance of 30 ohms, but capacitive and inductive reactances are equal at 100 ohms. In this circuit, the inductive reactance of the coil exactly cancels the capacitive reactance of the capacitor. The only opposition to current flow is the 30-ohm resistor; thus, the impedance of the circuit is 30 ohms. The current flow through the circuit is:

$$I = \frac{E}{Z} = \frac{50}{30} = 1.67 \text{ A}$$

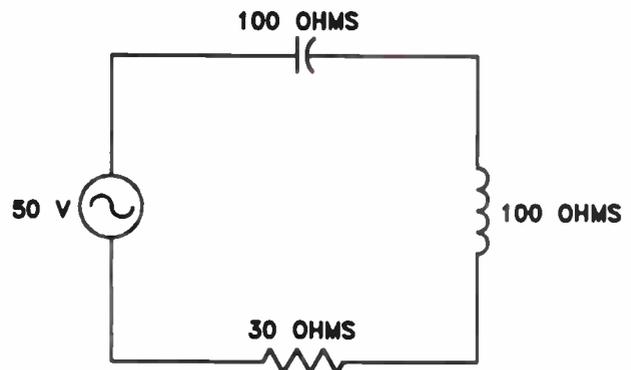


Figure 3. A series resonant circuit where the capacitive reactance is equal to the inductive reactance.

## HOW COILS AND CAPACITORS WORK TOGETHER

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The voltage across the resistor is:

$$E_R = IR = 1.67 \times 30 = 50 \text{ V}$$

The voltage across the coil is:

$$E_L = IX_L = 1.67 \times 100 = 167 \text{ V}$$

The voltage across the capacitor is:

$$E_C = IX_C = 1.67 \times 100 = 167 \text{ V}$$

Notice that in this resonant circuit we have a voltage of 167 V (more than three times the generator voltage) across the coil, and across the capacitor. This step-up in voltage, called a *resonant-voltage step-up*, occurs in all series resonant circuits. The lower the resistance in the circuit, the higher the resonant-voltage step-up.

Reducing the resistance value in the circuit from 30 ohms to 15 ohms will cause the circuit current to double and will also double the voltages across the coil and the capacitor. Remember, however, that these two voltages are 180° out of phase. The voltage across the coil leads the circuit current by 90°, and the voltage across the capacitor lags the circuit current by 90 degrees. In combination, they cancel. A measurement of the total voltage across the coil and the capacitor will show 0 volts.

In the circuit shown in Fig.3,  $X_L = X_C$ , because we know that:

$$X_L = 2\pi fL \text{ and } X_C = \frac{1}{2\pi fC}$$

We also know that:

$$2\pi fL = \frac{1}{2\pi fC}$$

We can rearrange this formula to get this:

$$f^2 = \frac{1}{4\pi^2 LC}$$

If we take the square root of both sides of the equation, we get the formula for calculating the resonant frequency of an L-C circuit:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

(Where  $f$  is the frequency in hertz (Hz) at which the circuit is resonant,  $L$  is the inductance in henrys (H),  $C$  is the capacity in farads (F), and  $2\pi =$  approximately 6.28, a constant.)

The relative position of the three parts in Fig.3 has no effect on the resonant circuit. As long as the inductive reactance is equal to the capacitive reactance, we have a series resonant circuit. In Fig.4(A), the positions of the coil and the resistor are interchanged, but the circuit is still a series resonant circuit. With a generator voltage of 50 V, a 30-ohm resistor, and the reactance of the coil and the capacitor each at 100 ohms, we have the same situation as in Fig.3.

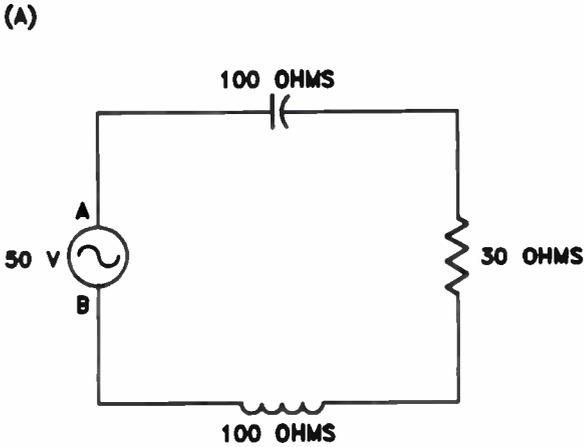
Figure 4(B) shows the current waveform. The voltage across the resistor will be in phase with the current. Figure 4(C) shows the waveform of the voltage across the coil. Notice that it is leading the current by 90 degrees. In Fig.4(D), the waveform of the voltage across the capacitor is shown. Notice it is lagging the current by 90° and is 180° out of phase with the voltage across the coil. This is why the two voltages cancel.

### Varying C, L, f, and R

In the examples shown in Figs.1, 2, and 3, the lowest circuit impedance and the highest circuit current occurred at resonance. At resonance the circuit also acted like a purely resistive circuit, because the inductive and capacitive characteristics canceled out.

Both above and below resonance, circuit impedance is greater than at resonance. In Fig.1,

# SERIES RESONANT CIRCUITS



where the inductive reactance is higher than the capacitive reactance, the circuit acts like a series circuit made up only of resistance and inductive reactance. In Fig.2, where the capacitive reactance is higher than the inductive reactance, the circuit acts like a series circuit made up of resistance and capacitive reactance. In either case, where the two reactances do not cancel completely, they add to the total impedance, making it higher than at resonance.

**Varying C.** Look at the circuit shown in Fig.5. At a frequency of approximately 500 Hz, the coil will have an inductive reactance of 314 ohms. If we start with zero capacitance in the circuit and begin increasing it in steps, the current varies as shown in Fig.6 on the next page.

When capacitance is zero, there is an open circuit, so the current will be zero. As we add capacitance, the capacitive reactance decreases, until it reaches 314 ohms with a value of 1 microfarad ( $\mu\text{F}$ ). At this point, capacitive reactance equals inductive reactance, causing both

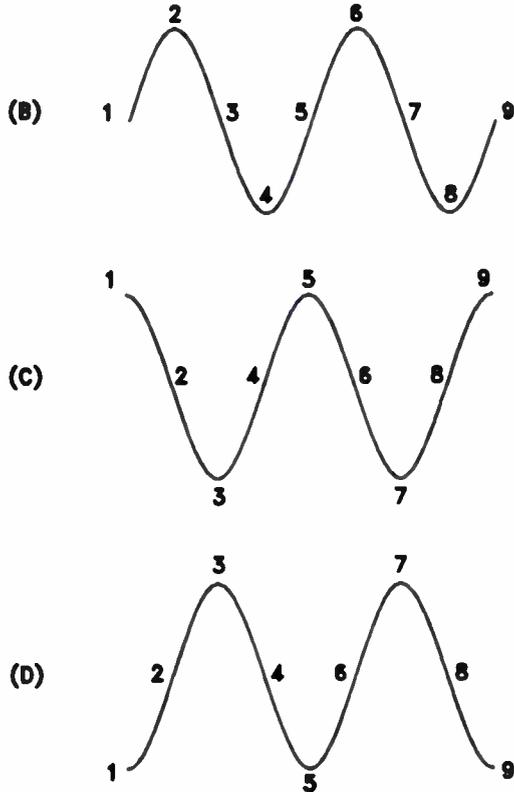


Figure 4. (A) Circuit. (B) Waveform of current and voltage across the resistor. (C) Waveform of voltage across the coil. (D) Waveform of voltage across the capacitor.

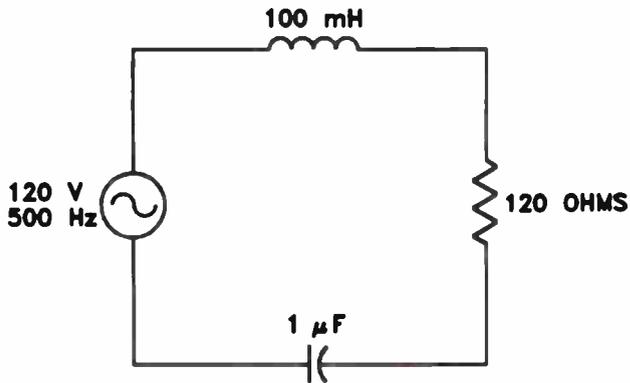


Figure 5. At 500 Hz, the 100 mH coil will have an inductive reactance of 314 ohms and the 1  $\mu\text{F}$  capacitor will have a capacitive reactance of 314 ohms, so it is a series resonant circuit.

## HOW COILS AND CAPACITORS WORK TOGETHER

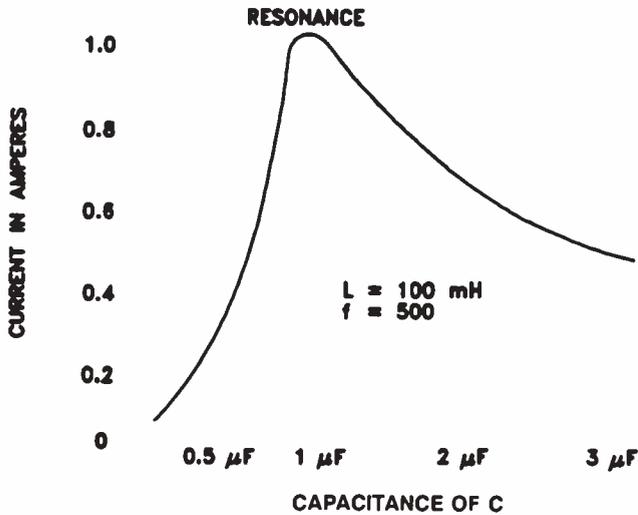


Figure 6. How current varies in a series resonant circuit when L is 100 mH, f is 500 Hz, and C is varied from 0 to 3 microfarads.

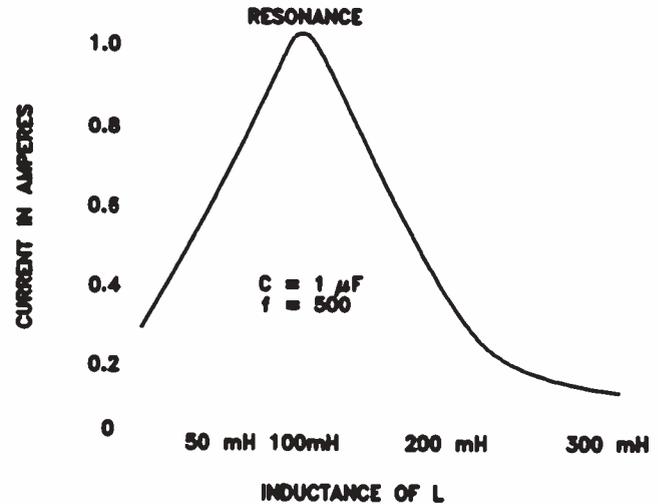


Figure 7. How current varies in a series resonant circuit when C is 1  $\mu$ F, f is 500 Hz, and L is varied from 0 to 300 millihenrys.

to cancel. The current is limited only by the 120-ohm resistor in the circuit, making a current of 1 ampere.

As we increase capacitance beyond 1  $\mu$ F, capacitive reactance continues to decrease. It becomes too small to cancel inductive reactance, leaving only resistance and inductive reactance in the circuit. The impedance increases above 120 ohms, and the current decreases as shown.

In either case, when capacitance is too little or too great for resonance, circuit impedance is greater than it is at resonance. The larger value of impedance reduces current flow in the circuit. Notice also that below resonance, capacitive reactance is greater than inductive reactance, so the current phase in the circuit leads the voltage. Above resonance, inductive reactance is greater than capacitive reactance, so the current phase lags the voltage.

**Varying L.** If we return to Fig.5 and insert a 1  $\mu$ F capacitor in the circuit, then vary the inductance from 0 to 300 millihenrys (mH), the current

will vary as shown in Fig.7. When the inductance is zero, the capacitor has a reactance of 314 ohms in series with the 120-ohm resistor. There is a current flow of approximately 0.3 ampere.

As inductance increases in the circuit, the inductive reactance subtracts from the capacitive reactance until it reaches 100 mH, the point at which inductive reactance completely cancels capacitive reactance. The only limit on current under these conditions is the 120-ohm resistor, so current is maximum for the circuit. If inductance increases above 100 mH, inductive reactance exceeds capacitive reactance, impedance increases, and current decreases as shown.

For inductance values below 100 mH, the inductive reactance is not high enough to cancel the capacitive reactance, so the circuit acts capacitive, and the current phase leads the voltage phase. For inductance values above 100 mH, inductive reactance is greater than capacitive reactance, the circuit is inductive, and current phase lags the voltage.

## SERIES RESONANT CIRCUITS

**Varying Both L and C.** If we double the inductance to 200 mH, the inductive reactance doubles, increasing to approximately 630 ohms. If we reduce the capacitance to 0.5  $\mu\text{F}$ , capacitive reactance also doubles to 630 ohms. The inductive reactance is again equal to the capacitive reactance, making the circuit resonant at 500 hertz.

Many different values of coils and capacitors can be combined to obtain a circuit that is resonant (sometimes we say that it "resonates") at 500 hertz. Any value of coil that we might select will have a certain inductive reactance at a frequency of 500 hertz. We would need a capacitor with an equal capacitive reactance at 500 Hz to give us a circuit resonant at 500 hertz.

**Varying f.** If we vary the frequency applied to the combination of 100 mH coil and 1  $\mu\text{F}$  capacitor, circuit current varies like the curve shown in Fig.8. At zero frequency there is no current flow because dc will not flow through the capacitor. As frequency increases, current increases. This happens because, even though capacitive

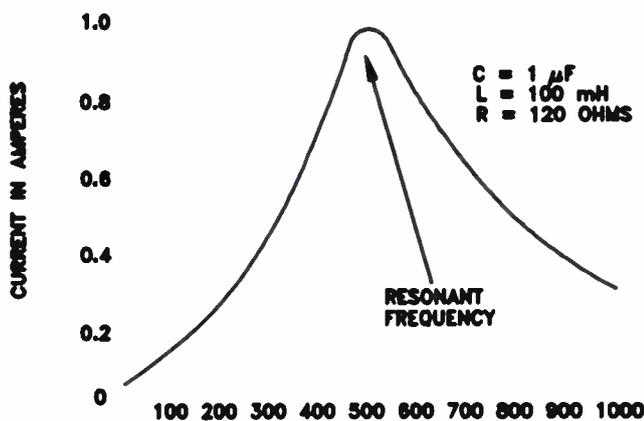


Figure 8. How current varies in a series resonant circuit when C is 1  $\mu\text{F}$ , L is 100 mH, R is 120 ohms, and f is varied from 0 to 1,000 hertz.

reactance decreases at the same rate that inductive reactance increases, greater proportions of each type of reactance cancel out, thereby reducing the total reactance in the circuit. At resonant frequency (500 Hz), the inductive reactance equals the capacitive reactance, and the two cancel completely, leaving minimum impedance and maximum current flow.

Above the resonant frequency, capacitive reactance continues to decrease, while inductive reactance continues to increase. The percentage of reactance cancellation decreases, because the amount of cancellation can only be as high as the smaller value of reactance. Therefore, the total reactance in the circuit increases. This means that the impedance in the circuit increases and, as a result, current flow in the circuit decreases.

**Varying R.** Under certain circumstances, the total resistance in the circuit can vary. As the resistance in the circuit changes, the Q of the circuit changes, as does current flow. The Q of a resonant circuit is equal to the inductive or capacitive reactance divided by the resistance in the circuit. In most resonant circuits, the only resistance in the circuit is the resistance in the wire used to wind the coil, so, in most cases, the Q of a resonant circuit will be equal to the Q of the coil. Remember that the Q of a coil is equal to its inductive reactance divided by its resistance.

Figure 9 on the next page shows three current curves where resistance is varied. Curves A and B have the same capacitor and inductor values with different resistances. Notice that Curve B, where dc resistance is lower, has a higher current and a sharper peak at resonance. Since the resistance in the circuit is lower, the circuit Q is higher. These are two characteristics of a high Q circuit: high current and a sharp resonance peak.

A series resonant circuit can be used to select one frequency and reject all others. This is a form

## HOW COILS AND CAPACITORS WORK TOGETHER

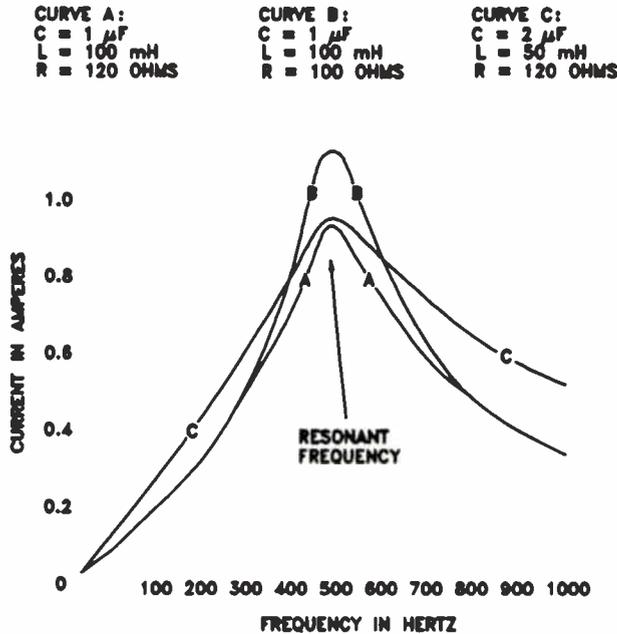


Figure 9. How the current varies in a series resonant circuit when  $f$  is varied. In each case the product of  $L$  and  $C$  is the same, and resonance occurs at 500 hertz.

of tuning to a frequency. A high- $Q$  circuit does a much better job than a low- $Q$  circuit. Sometimes, however, a series resonant circuit is used to select a band (range) of frequencies rather than one particular frequency. In this case, a low- $Q$  series resonant circuit will do a better job than a high- $Q$  circuit, since the low- $Q$  output current over a range of frequencies is higher, rather than a sharp peak of current over a narrow range.

The curve marked "C" in Fig.9 is the one we would obtain for a 50 mH coil, a 2  $\mu$ F capacitor, and a series resistance of 120 ohms. Compare Curve C with Curve A. Notice that Curve A is considerably sharper than Curve C. This is because the inductance in Curve A is greater than the inductance in Curve C, even though the resonant frequency is the same. The ratio of inductance to capacitance in a resonant circuit

is called the  $LC$  ratio. In a series resonant circuit, a high  $LC$  ratio provides a sharper resonance curve than a low  $LC$  ratio.

### Review

The most important thing to remember about a series resonant circuit is that at resonance the inductive and capacitive reactances will cancel. The circuit acts like a low resistance and draws a high current, and the current will be in phase with the generator voltage. The voltage across the coil and the voltage across the capacitor can be several times the generator voltage. This increased voltage is called a resonant-voltage step-up.

Below resonance, the voltage across the capacitor is greater than the voltage across the coil, so the current phase leads the voltage phase. Above resonance, the voltage across the coil is greater than the voltage across the capacitor, so the phase of current lags that of the voltage.

### Self-Test Questions

- 1 What is a resonant circuit?
- 2 Why is the current maximum at resonance in a series circuit consisting of a coil, a capacitor, and a resistor?
- 3 In a series resonant circuit, how will the phase of the voltage across the various components compare with the phase of the current flow in the circuit?
- 4 When a coil and a capacitor are connected in series and the frequency of the voltage applied to them is varied, at what point will the current flow through the circuit reach its maximum value?
- 5 What effect will reducing the resistance in the circuit have on the current flow in a series resonant circuit?

## PARALLEL RESONANT CIRCUITS

In a parallel resonant circuit, the coil and capacitor are in parallel. Like the series resonant circuit, the inductive reactance and the capacitive reactance are equal, and one cancels the other. However, the similarity ends at this point, because in most respects, the behavior of a parallel resonant circuit is opposite to that of a series resonant circuit. The energy stored in the capacitor and the coil circulates back and forth in the resonant circuit, alternately charging and discharging the capacitor, and building and collapsing the magnetic field of the coil.

### Current Flow

Figure 10 shows the waveforms for a typical parallel resonant circuit, such as the one shown in Fig.11 on the next page. When the coil and capacitor are in parallel, resonance occurs when the branch currents through the parallel capacitor and coil are equal and opposite. Minimum current flows in the main line, as compared to maximum current for series-resonance, as the reactances cancel each other. Because the values of inductive and capacitive reactance are essentially equal at resonance, the currents in the branches of the parallel network are also equal. Since line current is minimum, total circuit impedance is at maximum, by definition.

Let's perform some useful calculations, using the values listed for the coil, capacitor, and voltage given in Fig.11. The resonant frequency for a 0.1  $\mu$ F capacitor and a 100 mH coil is equal to:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

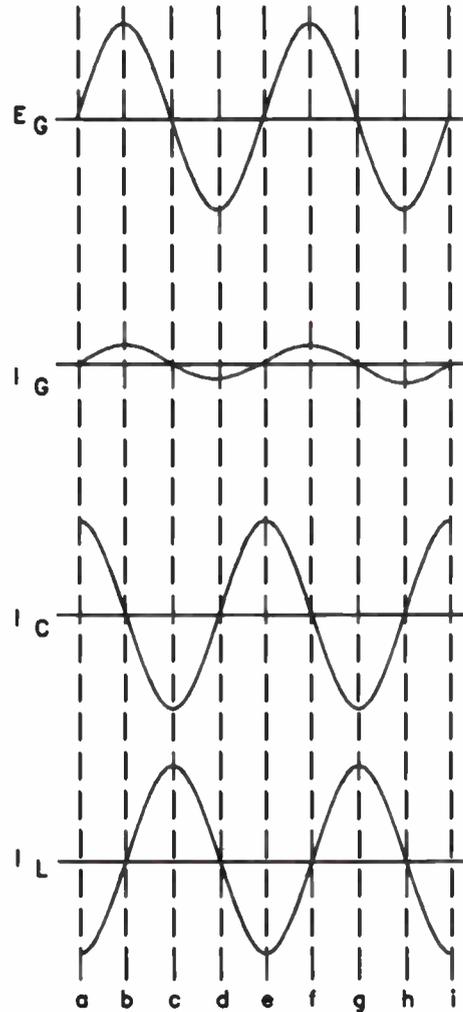


Figure 10. Voltage and current waveforms for parallel resonant circuit in Fig.11.

$$= \frac{1}{6.28 \times 0.0001}$$

$$= 1,592 \text{ Hz}$$

The resonant frequency is rounded off to the nearest hertz. At resonance, the capacitive and inductive reactance values should be equal.

## HOW COILS AND CAPACITORS WORK TOGETHER

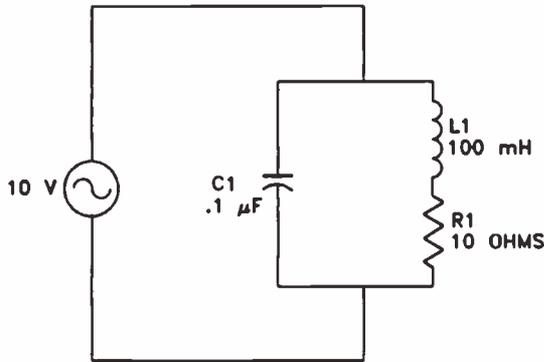


Figure 11. A parallel resonant circuit.

Again, we will round off the decimal places in the calculation and obtain these measurements:

Capacitive reactance:

$$X_C = \frac{1}{2\pi fC}$$

$$= \frac{1}{6.28 \times 1,592 \times 0.0000001}$$

$$= 1,000 \text{ ohms}$$

Inductive reactance:

$$X_L = 2\pi fL$$

$$= 6.28 \times 1,592 \times 0.1$$

$$= 1,000 \text{ ohms}$$

We can use these reactance values to calculate the branch currents. That is, current in the inductive branch is equal to the source voltage divided by the reactance, or  $10/1,000 = 10$  milliamperes (mA). (We will ignore the 10 ohm resistance since it is so low it will not have a significant effect.) We get the same current in the capacitive branch.

We have equal currents, but are they opposite? Well, since this is a parallel ac circuit, the current

phase in the capacitive branch leads the source voltage phase by  $90^\circ$ , while the current phase in the inductive branch lags the source voltage by  $90$  degrees. A series circuit would show a cumulative phase difference, but in the parallel circuit the source voltage is applied equally across the network of the two reactive elements, producing a total phase difference of  $180^\circ$ , or directly opposing. Thus, the reactance currents cancel each other in the main line, although they circulate in the parallel network at a flow of 10 mA, as calculated above.

Below resonant frequency, there is more current in the main line and more current in the inductive branch because of the lower reactance of the coil at lower frequencies. Above the resonant frequency, reactance in the capacitive branch decreases, and current in the main line and in the capacitive branch increases.

What is the current in the main line at the resonant frequency of the parallel network? In theory, a perfect capacitor and a perfect coil would retain 100% of the circuit energy, charging and discharging each other back and forth, indefinitely. Theoretically, the main line current would be zero because such a perfectly resonant circuit would create an infinite impedance.

There is no such thing as a perfect coil, however. There are losses due to the resistance of the wire used to wind the coil and for other reasons. These small losses are represented by the 10-ohm resistor shown in series with the inductive branch. As you know, this resistance determines the  $Q$  of the coil. There are also some very small losses in the capacitor, but normally the circuit  $Q$  is considered to be equal to the  $Q$  of the coil.

The shortcut way to calculate the line impedance presented by the parallel resonant network is to multiply the  $Q$  of the circuit times the inductive reactance. For the circuit shown in

## PARALLEL RESONANT CIRCUITS

Fig.11, the  $Q$  is equal to the inductive reactance divided by the resistance, or:

$$\begin{aligned} Q &= \frac{X_L}{R} \\ &= \frac{1,000}{10} \\ &= 100 \end{aligned}$$

The parallel resonant total impedance is then:

$$\begin{aligned} Z_T &= X_L \times Q \\ &= 1,000 \times 100 \\ &= 100,000 \text{ ohms} \end{aligned}$$

If you are reasonably confident that you know the  $Q$  of the circuit, the shortcut method provides a usable ballpark figure for total impedance. However, the resonant impedance may be directly and accurately measured by making a rough calculation according to the  $Q$  of the circuit, then placing a variable resistor of comparable range in series with the resonant circuit, as shown in Fig.12. Tune the circuit to resonance

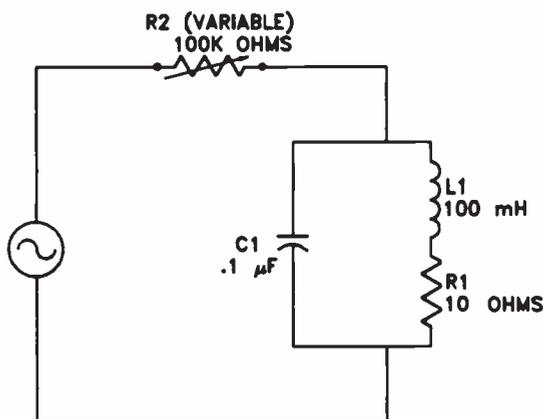


Figure 12. Using variable resistor to calculate impedance of L1-C1 resonant network.

by varying the frequency of the applied voltage and watching for a sharp dip in the main circuit current, indicating that the impedance of the parallel resonant circuit is maximum. Carefully adjust the variable resistor so that the voltage drop across it is equal to the voltage drop across the parallel resonant network. Disconnect the variable resistor from the circuit and measure its resistance. The resistance is equal to the impedance of the resonant network, since equal voltage drops in a series circuit mean equal resistance values.

### Varying C, L, f, and R in a Parallel Resonant Circuit

When we speak of resistance in a parallel resonant circuit, we are usually referring to losses in the circuit that act like a resistor connected across the circuit (sometimes called *shunt resistance*), or a small resistance in series with the coil, as discussed previously. This resistance is sometimes called *ac resistance* and is a result of eddy currents, flux leakage, skin effects, hysteresis losses, and other factors that we will discuss in a later lesson.

**Varying C.** At resonance, the inductive reactance is equal to the capacitive reactance in the parallel resonant circuit, just as in a series resonant circuit. What if the generator shown in Fig.11 had a frequency of 500 Hz and the coil had an inductance of 100 millihenrys? Figure 13 on the next page shows the effect on line current of different capacitor values. When capacitance is zero, the only limit to the flow of current is the coil impedance and coil ac resistance.

With zero ac resistance, the inductive reactance is 314 ohms. With a generator voltage of 120 V, the current is 0.38 ampere. As capacitance increases toward 1  $\mu\text{F}$ , current decreases to a

## HOW COILS AND CAPACITORS WORK TOGETHER

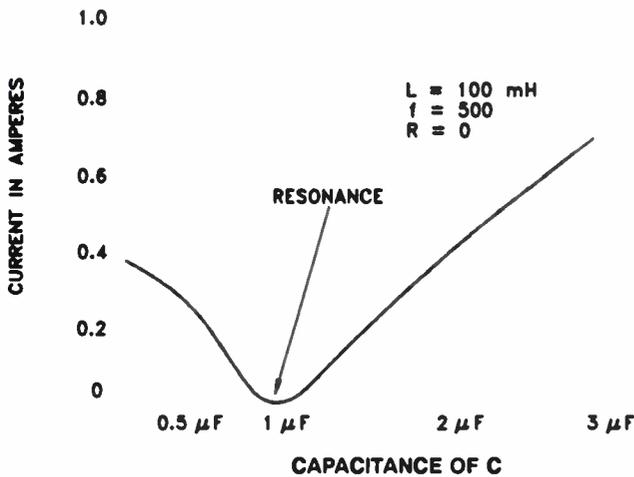


Figure 13. How the line current varies when the capacitance of the capacitor in a parallel resonant circuit is varied.

minimum because the circuit resonates at that point, and main circuit impedance is maximum.

As capacitance increases beyond 1  $\mu\text{F}$ , circuit impedance goes down and line current goes up. In the example shown, when the capacitance is less than 1  $\mu\text{F}$ , most of the current flows through the coil. With zero capacitance, the current should lag the generator voltage by an angle close to 90 degrees. As we approach resonance, the current begins to fall into phase with the voltage, until at resonance the main line current is in phase with the voltage.

**Varying L.** If we change only the inductance in the circuit, we will find that we get an effect similar to that of changing the capacitance. The line current increases when the inductance is either too large or too small for resonance. If the inductance is below the value needed for resonance, the circuit acts exactly as it does when too low a capacitance is used. Similarly, when the inductance is too high for resonance, the circuit acts as it does when the capacitance is too high.

**Varying f and R.** What if the resistance R in Fig.11 were zero? Curve A in Fig.14 shows how the current will vary as the frequency applied to the resonant circuit is changed. When the frequency is zero, we have dc. No current will flow through the capacitor. At the same time, the inductive reactance of the coil is zero, so the only limit to current flow will be the resistance of the coil. As the frequency is increased beyond the resonant frequency, the current rises slowly. The increased line current is due to the drop-off in the capacitive reactance of the capacitor. Current flow through the coil will continue to decrease as the frequency is increased because the inductive reactance of the coil will increase with the frequency.

At a frequency below the resonant frequency of the circuit, most of the current flows through the coil, and the parallel resonant circuit is inductive. At resonance the circuit acts like a

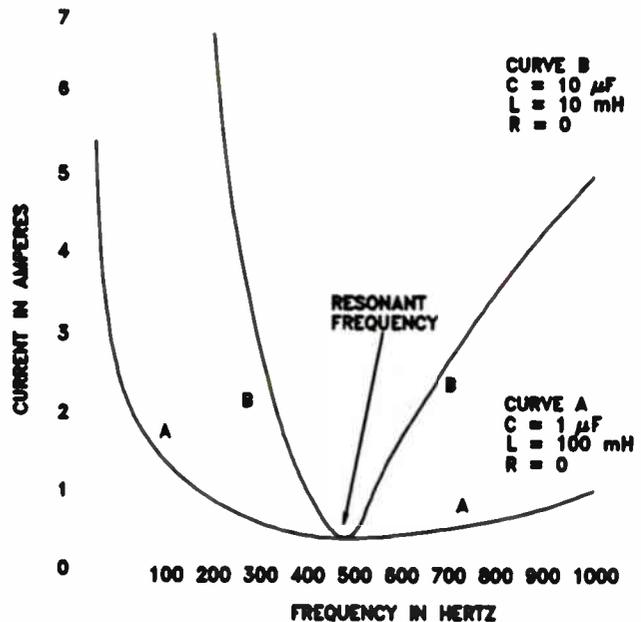


Figure 14. How the line current varies when the frequency is varied in a parallel resonant circuit.

## PARALLEL RESONANT CIRCUITS

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high resistance. Above the resonant frequency, the current flow through the capacitor is greater than the current flow through the coil, so the circuit is capacitive.

Curve A in Fig.14 is for a circuit composed of a 100 mH coil and a 1  $\mu$ F capacitor. This circuit resonates at 500 hertz. If we reduce the inductance to 10 mH and increase the capacitance to 10  $\mu$ F, the resonant frequency remains 500 Hz, because the product of the inductance and capacitance is the same. A 20 mH coil and a 5  $\mu$ F capacitor also resonate at a frequency of 500 Hz, for the same reason, as are a 10 mH coil and a 10  $\mu$ F capacitor.

Curve B of Fig.14 shows the line-current curve for a parallel resonant circuit made up of a 10 mH coil and a 10  $\mu$ F capacitor. Notice that the current rises much faster on both sides of resonance and drops to zero much more sharply than the curve for the 100 mH coil and the 1  $\mu$ F capacitor. Curve B is sharper than curve A because the circuit of curve B has a lower ratio of inductance to capacitance. The L/C ratio for curve A is 10 times higher than the L/C ratio for curve B. A low L/C ratio gives a sharp curve.

Parallel resonant circuits with a low L/C ratio are used to separate signals on frequencies that are close together. Parallel resonant circuits with a high L/C ratio are used to pass a band of frequencies. As you can see from Fig.14, if we want to pass a band of signals from 300 Hz to 800 Hz, the higher L/C-ratio resonant circuit is more suitable. On the other hand, if we want to separate a 500 Hz signal from a 300 Hz signal, the low L/C-ratio circuit would be better.

The Q of a coil is another factor that affects the sharpness of the resonant curves. A high-Q coil will yield a much sharper curve than a low-Q coil.

In a series resonant circuit, we obtain a sharp response curve with a high L/C ratio. We have the opposite situation in a parallel resonant circuit,

where we obtain a sharp curve with a low L/C ratio.

### Review

The parallel resonant circuit acts like a high resistance. The line current is low and in phase with the generator voltage. The current flowing back and forth between the capacitor and the coil in the resonant network is much higher than the generator current. Below resonance, the inductive reactance is less than the capacitive reactance, so more generator current flows through the coil, and the current phase lags the generator voltage. Above resonance, the capacitive reactance is less than the inductive reactance, so more generator current flows through the capacitor than the coil, and the current phase leads the voltage.

### Self-Test Questions

- 6 How do you distinguish between a series resonant and a parallel resonant circuit?
- 7 What does a parallel resonant circuit act like at resonance?
- 8 Does the generator supply a current of high value or of low value to a parallel resonant circuit?
- 9 In circuits such as the one shown in Fig.11, why will the voltage across the 10-ohm resistor be small?
- 10 Does a current of high value or low value flow in the coil and capacitor in a parallel resonant circuit?
- 11 Will increasing the resistance of the coil in a parallel resonant circuit cause the generator current to increase or decrease?
- 12 If a parallel resonant circuit is used in a radio receiver to select one signal and reject others, do you want a high L/C ratio or a low L/C ratio?

## HOW COILS AND CAPACITORS WORK TOGETHER

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### COMPARISON OF RESONANT CIRCUITS

Series resonant and parallel resonant circuits are found in most electronic equipment that requires tuning or filtering. Table I compares and summarizes the important characteristics of series resonant and parallel resonant circuits. Notice that in many cases the series resonant circuit acts opposite to a parallel resonant circuit.

The resistance, or impedance, at resonance and the current at resonance are very important factors. A series resonant circuit acts as a low resistance at resonance, and the current flowing through it is relatively high. On the other hand, a parallel resonant circuit acts as a very high resistance at resonance, and the current flowing through it is very low.

The combination of the coil and the capacitor in a resonant circuit is often called a *tank circuit*. A tank circuit stores electricity just as a water tank stores water. The current flowing between the coil and capacitor is called the *tank current*. In a series resonant circuit, the tank current is the line current, and it is high. In a parallel resonant circuit, even though the line current is low, the tank current will be high.

#### Resonance Curves

In Fig.14, we used a small coil and a large capacitor to obtain a sharp resonance curve with a parallel resonant circuit. This gave us a low L/C ratio. For a sharp resonant curve in a series resonant circuit, you use the opposite: a large inductance and a small capacitance. This is simply another example of the difference between series resonant and parallel resonant circuits. As a technician, you will not be called upon

to design a series resonant circuit or a parallel resonant circuit, but the more you understand about the circuits, the better you will be able to maintain equipment for which you might be responsible.

#### Identifying Resonant Circuits

Sometimes, it is not easy to distinguish between a series resonant and a parallel resonant circuit. Figure 15(A) on page 16 shows a series resonant circuit. Remember that a series resonant circuit is a resonant circuit in which the source voltage is applied across the coil and the capacitor in series. There is no doubt that this is a series resonant circuit.

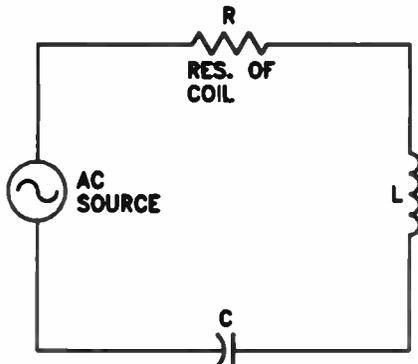
In Fig.15(B) is a parallel resonant circuit. A parallel resonant circuit is a resonant circuit in which the source voltage is applied to the coil and capacitor in parallel. It is easy to see that this is a parallel resonant circuit.

In Fig.15(C) there are two resonant circuits that look like parallel resonant circuits. The voltage from the generator is applied to the first circuit, which we call the *primary*. The second resonant circuit is arranged so that the coil is inductively coupled to the coil of the first or primary circuit. This circuit is called the *secondary* circuit.

Now, looking at the primary, we see that the generator is connected across both the coil and the capacitor. There is no doubt that the voltage is applied to the two in parallel and that therefore the circuit must be a parallel resonant circuit. But what about the secondary? Since the coil and capacitor are connected in parallel, you might jump to the conclusion that the secondary also is a parallel resonant circuit.

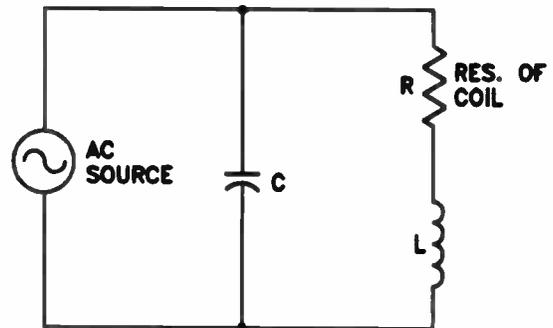
**TABLE I**  
**COMPARISON OF RESONANT CIRCUITS**

**SERIES RESONANT CIRCUITS**



1. The coil, the capacitor, and the ac voltage source are all in series.
2. Resonance occurs when the reactance of L is equal to the reactance of C.
3. At resonance, source current is at a *maximum* (very high).
4. At resonance, a series resonant circuit acts like a *resistor of low ohmic value*.
5. At resonance, the voltages across L and C are equal in magnitude but 180° out of phase with each other.
6. At resonance, the same current flows through the entire circuit.
7. At resonance, the voltage across either L or C may be greater than that of the source, giving resonant voltage step-up.
8. At resonance, increasing the value of coil resistance R lowers the circuit current, thereby *lowering* the resonant-voltage step-up.
9. Off resonance, the circuit acts like that part which has the *higher* reactance.
  - a. Increasing C above its at-resonance value makes the circuit act like a coil.
  - b. Reducing C below its at-resonance value makes the circuit act like a capacitor.
  - c. Increasing L above its at-resonance value makes the circuit act like a coil.
  - d. Reducing L below its at-resonance value makes the circuit act like a capacitor.
  - e. Applying a *higher* frequency than the resonant one makes the circuit act like a coil.
  - f. Applying a *lower* frequency than the resonant one makes the circuit act like a capacitor.
10. The product LC is constant for any given resonant frequency.
11. Increasing L or increasing C lowers the resonant frequency.
12. Decreasing L or decreasing C raises the resonant frequency.
13. The Q factor of the circuit is essentially equal to the coil reactance divided by the ac resistance of the coil.

**PARALLEL RESONANT CIRCUITS**



1. The coil, the capacitor, and the ac voltage source are all in parallel.
2. Resonance occurs when the reactance of L is equal to the reactance of C.
3. At resonance, source current is at a *minimum* (very low).
4. At resonance, a parallel resonant circuit acts like a *resistor of high ohmic value*.
5. At resonance, the voltages across L, C, and the source are all the same in magnitude and phase.
6. At resonance, the currents through L and C are essentially equal in magnitude but are 180° out of phase.
7. At resonance, the current through either L or C is greater than the source current, giving resonant-current step-up.
8. At resonance, increasing the value of coil resistance R increases the current, thereby *lowering* the resonant-current step-up.
9. Off resonance, the circuit acts like that part which has the *lower* reactance.
  - a. Increasing C above its at-resonance value makes the circuit act like a capacitor.
  - b. Reducing C below its at-resonance value makes the circuit act like a coil.
  - c. Increasing L above its at-resonance value makes the circuit act like a capacitor.
  - d. Reducing L below its at-resonance value makes the circuit act like a coil.
  - e. Applying a *higher* frequency than the resonant one makes the circuit act like a capacitor.
  - f. Applying a *lower* frequency than the resonant one makes the circuit act like a coil.
10. The product LC is constant for any given resonant frequency.
11. Increasing L or increasing C lowers the resonant frequency.
12. Decreasing L or decreasing C raises the resonant frequency.
13. The Q factor of the circuit is essentially equal to the coil reactance divided by the ac resistance of the coil.

## HOW COILS AND CAPACITORS WORK TOGETHER

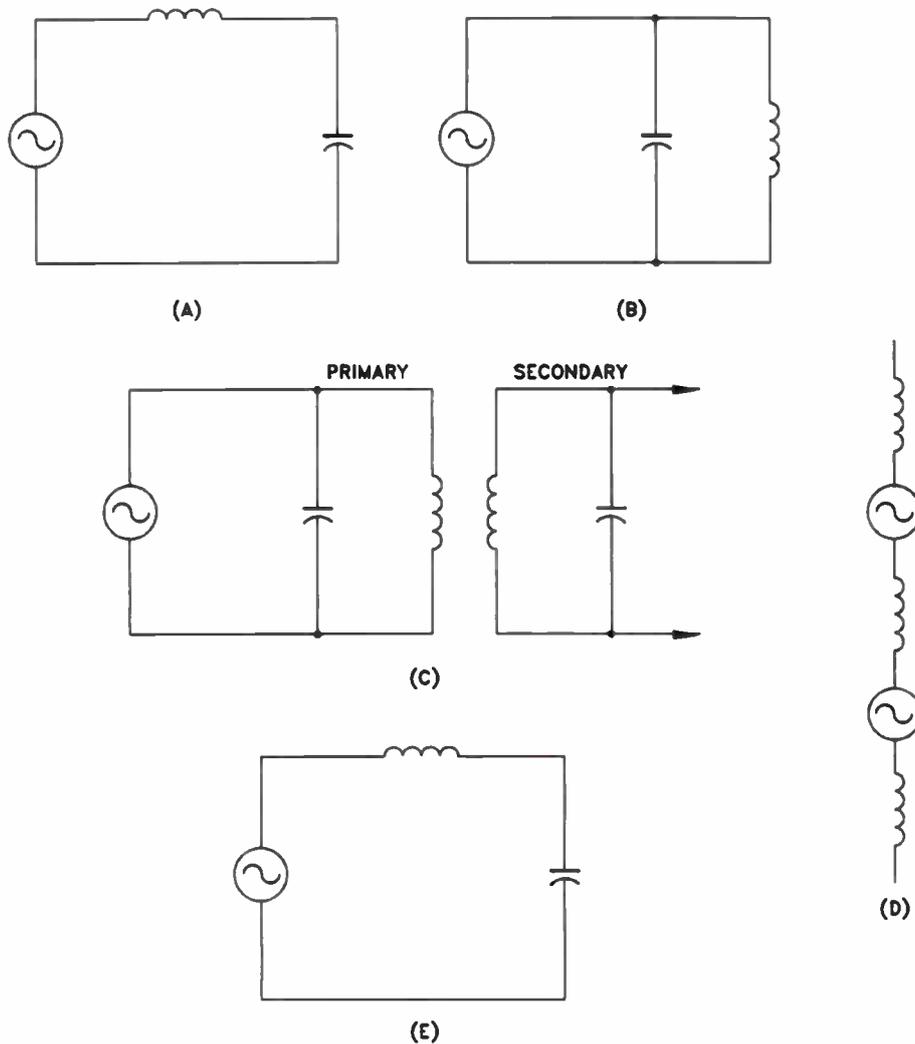


Figure 15. (A) A series resonant circuit. (B) A parallel resonant circuit. (C) The primary of the transformer and the capacitor across it form a parallel resonant circuit, and the secondary of the transformer and its capacitor form a series resonant circuit. (D) Generators and coils connected in series. (E) The equivalent of the secondary circuit.

Actually, how the coil and capacitor are connected has no bearing on whether the circuit is series resonant or parallel resonant. Remember, we said that in a parallel resonant circuit the voltage is applied across the coil and the capacitor in parallel, and in the series resonant circuit the voltage is applied to the coil and capacitor in

series. This is what distinguishes a series resonant circuit from a parallel resonant circuit.

In the secondary circuit shown in Fig.15(C), the voltage is induced in the secondary. Actually, some voltage is induced in each turn of the coil, and the coils act as if they are connected in series, so that the total voltage induced in the secondary

## COMPARISON OF RESONANT CIRCUITS

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is the sum of the voltages induced in each turn. We can compare this to a number of small generators connected in series with the various turns of the coil, and the coil might look like Fig.15(D).

The voltage induced in the coil is actually applied in series with the turns of the coil, rather than in parallel with the coil and capacitor. The circuit could be represented by Fig.15(E), which is the same as Fig.15(A). Therefore, the secondary of the transformer shown in Fig.15(C) is a series resonant circuit and not a parallel resonant circuit.

You will find this type of double-tuned circuit in many pieces of electronic equipment. In these circuits, the voltage is always applied across the primary winding in parallel with the coil and capacitor, so the primary circuit is always a parallel resonant circuit. The voltage in the secondary is always induced in the turns of the secondary winding, and this circuit is always a series resonant circuit.

When we discussed parallel resonant circuits, we pointed out that the tank circuit current will be much higher than the generator current. This is called a *resonant-current step-up*. In series resonant circuits, there is a *resonant-voltage step-up*. Therefore, in double-tuned transformers like the one shown in Fig.15(C), there is resonant-current step-up in the primary and a resonant-voltage step-up in the secondary.

Resonant-current step-up causes the primary winding to produce more flux, and more lines of flux cut the secondary winding on the transformer, inducing a higher voltage in it. At the same time, the resonant-voltage step-up occurring in the secondary circuit creates a voltage across the output of the transformer that is much higher than the generator voltage. In the input stages of electronic equipment, we often deal with signals of only a few microvolts. Resonant-current

step-ups and resonant-voltage step-ups help amplify these weak signals to strong, useful levels.

### Review

Both series resonant and parallel resonant circuits act like pure resistances. However, the series resonant circuit acts like a low resistance. The current flowing through the generator, coil, and capacitor is the same, but the voltage across the coil and the voltage across the capacitor will be much higher than the generator voltage.

The parallel resonant circuit acts like a very high resistance, and the voltage across the generator, coil, and capacitor is the same. However, the current flowing in the coil and capacitor is much higher than the generator current.

Below resonance, a series resonant circuit acts like a capacitor, and the current leads the applied voltage. A parallel resonant circuit, on the other hand, acts like an inductance below resonance, and the current lags the generator voltage. Above resonance, a series resonant circuit acts like an inductance, and the current lags the generator voltage. In the same condition, a parallel resonant circuit acts like a capacitor and the current leads the generator voltage.

### Self-Test Questions

- 13 Explain the difference between the current flowing in a coil and capacitor in a series resonant circuit, and the current flowing in the coil and capacitor in a parallel resonant circuit.
- 14 Explain the difference between the voltage across the coil and capacitor in a series resonant circuit and the voltage across the coil and capacitor in a parallel resonant circuit.

## HOW COILS AND CAPACITORS WORK TOGETHER

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- 15 What is the difference between the generator current in a series resonant circuit and in a parallel resonant circuit?
- 16 How can the voltage across the coil or capacitor in a series resonant circuit be greater than the source voltage?
- 17 Will the voltage across the coil or the capacitor in a high-Q series resonant circuit be greater than the voltage across the coil or capacitor in a low-Q series resonant circuit?

### HOW RESONANT CIRCUITS ARE USED

Resonant circuits are used in most radio and TV receivers, where these circuits select the broadcast signal from a station operating on a specific frequency but reject signals from other stations operating on different frequencies. Resonant circuits are also used as frequency filters in many applications.

There are three basic types of filters. A *low-pass filter* can pass frequencies up to a certain level, but block higher frequencies. A *high-pass filter* allows signals above a certain frequency to pass through it readily. The third type of filter, a *band-pass filter*, passes a group of frequencies that lie between a defined low and high extreme, but rejects frequencies above or below the limits.

#### Selecting a Desired Signal

Every coil and capacitor combination is resonant at some frequency. For example, we found that a 100 mH coil will form a resonant circuit with a 1  $\mu\text{F}$  capacitor at a frequency of 500 Hz, because at that frequency the inductive reactance of the coil is equal to the capacitive reactance of the capacitor.

Suppose, however, that instead of using a 1  $\mu\text{F}$  capacitor, we use a 0.5  $\mu\text{F}$  capacitor. The 0.5  $\mu\text{F}$  capacitor will have twice the reactance of the 1  $\mu\text{F}$  capacitor, so the capacitor coil combination will not be resonant at 500 hertz. If we increase the frequency of the signal applied to the circuit, the reactance of the capacitor will start coming down and the reactance of the coil will start going up. At a frequency of about 712 Hz, the two will be equal, and the circuit will be resonant at that frequency. Therefore, to be able to select

signals over a band of frequencies, all we have to do is use either a variable coil or a variable capacitor.

Figure 16 shows a typical circuit found in the input section of a radio receiver designed for use in the standard AM broadcast band. Notice that two coils are placed close together so that they are inductively coupled. They actually form a transformer. The triangular symbol connected to the primary winding is the symbol used for an antenna.

The antenna picks up signals from many stations operating in the standard broadcast band and signals from stations operating outside the band. The radio waves striking the antenna cause a very small current to flow through the primary winding L1 of the transformer, setting up a varying flux that cuts the turns of L2 and induces a voltage in series with it. At some frequency, the combination of L2 and the capacitor will form a series resonant circuit. There will be a high circulating current at this frequency and a resulting resonant-voltage step-up across L2 and across C.

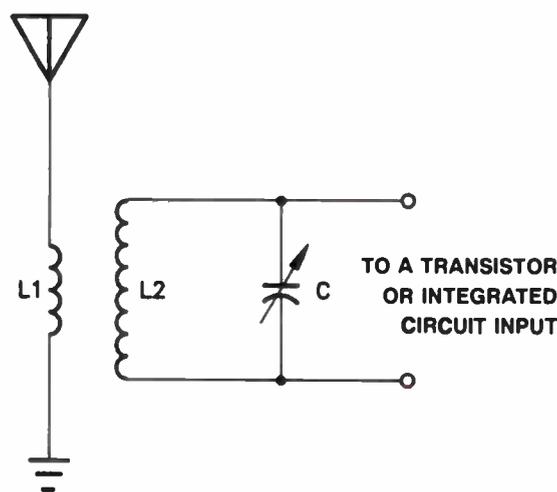


Figure 16. Input circuit of a radio receiver.

## HOW COILS AND CAPACITORS WORK TOGETHER

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The signal you tune in will be much stronger than other signals because of this resonant-voltage step-up. Radio frequency signals of a higher frequency will be bypassed by the low reactance of the capacitor. Radio frequency signals below the resonant frequency will be bypassed by the low reactance of L2. The one signal operating at the resonant frequency will be much stronger than all others.

In the crowded commercial broadcast bands, one resonant circuit is not sufficient to select a single signal frequency and reject all others. Additional resonant circuits are used to provide additional selectivity. Selectivity is defined as the ability of a circuit to select a signal while rejecting all others.

### How Filters Are Used

Two important terms related to filters are attenuation and cutoff frequency. *Attenuation* tells you how much a filter reduces the signal strength. The *cutoff frequency* tells you the frequency at which the filter becomes effective.

**Low-Pass Filters.** An example of a low-pass filter is shown in Fig. 17. This filter is designed to pass frequencies below the cutoff frequency and to

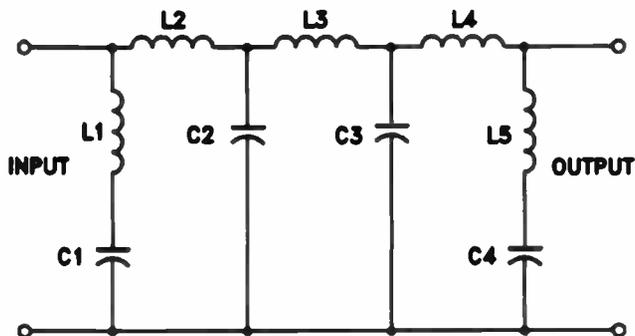


Figure 17. A low-pass filter.

attenuate frequencies above the cutoff frequency. At the input of the filter is a series circuit made up of L1 and C1. This circuit is resonant above, but very close to, the cutoff frequency.

C1 and L1 are in parallel to the incoming signal voltage. Any signal voltage that is developed across L1 and C1 is passed on; it is not filtered out. Sometimes we say that voltage dropped across a parallel resistance or reactance is *developed*, as compared to a series component, where the voltage drop tends to attenuate the voltage, or use it up.

Below the cutoff frequency, the reactance of C1 is higher and signal voltage is dropped, or developed, across the capacitor. This voltage appears at the filter output; that is, the voltage is not filtered out. If the voltage is not developed across the capacitor or the coil, it disappears into the internal resistance of the circuit or antenna from which it came.

L2 is in series. Signal voltage dropped across L2 is reduced to some degree; it is attenuated, filtered. At frequencies below resonance, the reactance of L2 is low and the reactance of C2 is high, so that very little signal is lost across L2. Since C2 is in parallel, signal voltage that is dropped across C2 *does* appear at the output and is not filtered out by C2.

L3 and C3 are also resonant at some frequency above the cutoff frequency. Below the cutoff frequency, the reactance of L3 is low and the reactance of C3 is high, so there is very little attenuation of signals below the cutoff frequency. Above the cutoff frequency, the reactance of L3 becomes high and the reactance of C3 goes down, so that the signal is greatly attenuated because it is not dropped, or developed by C3 in parallel, while at the same time it is dropped and reduced by L3 in series.

L4 provides additional attenuation for signals above the cutoff frequency. The combination of

## HOW RESONANT CIRCUITS ARE USED

L4, L5, and C4 forms a series resonant circuit at a frequency somewhat above the cutoff frequency. L5 and C4 form another series resonant circuit at a frequency still higher, to further attenuate signals above the cutoff frequency.

**High-Pass Filters.** Figure 18 is a diagram of a high-pass filter. This filter is designed to pass signals above the cutoff frequency and to attenuate signals below the cutoff frequency.

Here we have L1 and C1 resonant at some frequency below the cutoff frequency to attenuate signals close to, but below, the cutoff frequency. Since they are in parallel to the signal path, they attenuate frequencies by having low reactance, so that the signal frequency does not appear, or develop across the coil or capacitor. Above the cutoff frequency, the reactance of L1 becomes high, so that high-frequency signals are not attenuated.

Above the cutoff frequency, the reactance of C2 and the reactance of C3 is low and the reactance of L2 and L3 is high, so they pass signals with little attenuation. Below the cutoff frequency, the reactance of C2 and C3 is high and the reactance of L2 and L3 is low, so they greatly attenuate signals.

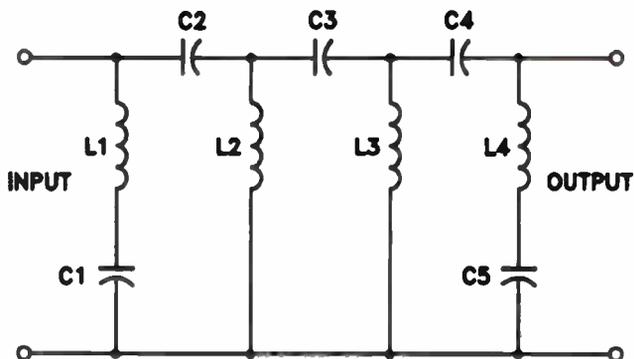


Figure 18. A high-pass filter.

C4, L4, and C5 form a series resonant circuit that is resonant below the cutoff frequency. L4 and C5 also form a series resonant circuit that is resonant below the cutoff frequency. These two series circuits attenuate signals below the cutoff frequency. Above the cutoff frequency, the reactance of L4 is high, so signals are not attenuated.

**Band-Pass Filters.** Figure 19 is a diagram of a band-pass filter. This type of filter is designed to pass a band of frequencies. Suppose, for example, we want to pass a band of frequencies between 9 and 11 megahertz (MHz). This filter would be designed to pass frequencies within this band with little or no attenuation and to attenuate signals below 9 MHz and above 11 megahertz.

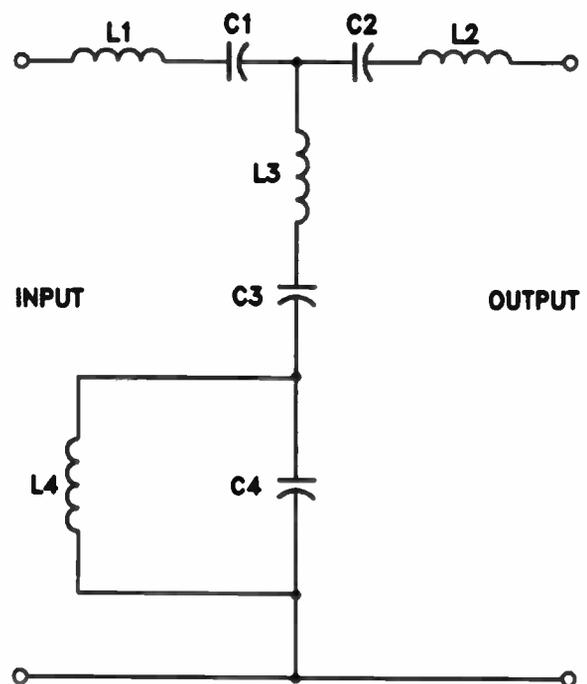


Figure 19. A band-pass filter.

## HOW COILS AND CAPACITORS WORK TOGETHER

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In this filter, L1 and C1, L2 and C2, L3 and C3 all form series resonant circuits resonant at 10 megahertz. L4 and C4 form a parallel resonant circuit also resonant at 10 megahertz. The series resonant circuits are designed with a fairly low LC ratio to pass signals above 9 MHz and below 11 megahertz. The parallel resonant circuit is designed with a high LC ratio to produce a broad curve, which offers a high impedance to signals within the pass-band.

Below 9 MHz, the reactance of C1 and the reactance of C2 begin to increase and offer considerable opposition to signals below these frequencies. Since L3 and C3 are a low L/C ratio, they don't offer much opposition to signals immediately below 9 megahertz. However, the impedance of the parallel resonant circuit decreases below 9 MHz and much of the signal would pass through C4 and L4.

Above 11 MHz, L1 and L2 begin to offer considerable opposition to the signal. Again, with the low LC ratio and the combination of L3 and C3, the signal passes through this combination and then through C4, whose reactance has decreased. Thus, signals above and below the desired pass-band are attenuated, while signals within the pass-band would pass easily.

### Review

Resonant circuits are used to select one signal frequency and reject all others. Resonant circuits are also used in filters. Remember that a low-pass filter is a filter that will pass all signal frequencies below the cutoff frequency and block all signals above it. A high-pass filter is a filter that will block all signal frequencies below the cutoff frequency and pass all signal frequencies above the cutoff frequency. A band-pass filter is a filter that will pass a band of frequencies. It will reject all signals below or above the pass-band.

### Self-Test Questions

- 18 Is the resonant circuit made up of L2 and C in Fig.16 a series resonant circuit or a parallel resonant circuit?
- 19 What is a low-pass filter?
- 20 What is a high-pass filter?
- 21 What is a band-pass filter?

## ANSWERS TO SELF-TEST QUESTIONS

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### ANSWERS TO SELF-TEST QUESTIONS

- 1 A resonant circuit is one in which the inductive reactance equals the capacitive reactance.
- 2 The current is maximum because the inductive reactance cancels the capacitive reactance and the impedance of the circuit is at a minimum.
- 3 Across the resistor the voltage will be in phase with the current; across the coil it will lead the current by  $90^\circ$ ; across the capacitor it will lag the current by 90 degrees.
- 4 The current will reach its maximum value when the inductive reactance of the coil cancels the capacitive reactance of the capacitor. When this happens we have a series resonant circuit.
- 5 Reducing the resistance in a series resonant circuit will cause the current flow in the circuit to increase. A higher resonant voltage will appear in turn across the coil and the capacitor. The voltage that appears across the resistor will remain the same, because the increase in current will be counteracted by the reduction in the resistance.
- 6 The distinction between a series resonant and a parallel resonant circuit lies in the way in which the voltage is applied to the coil and capacitor. If it is applied to the coil and capacitor in series, this circuit is series resonant; if it is applied to the coil and capacitor in parallel, the circuit is parallel resonant.
- 7 A high resistance.
- 8 The generator connected across a parallel resonant circuit will supply a current of low value because the high resistance of this type of circuit limits the current that can flow.
- 9 The voltage across the resistor will be small because the resistor is in series with the parallel resonant circuit. A parallel resonant circuit has a very high resistance at resonance and most of the voltage will be dropped across it. Consequently, there will be little voltage across the resistor.
- 10 A high-value current flows in the coil and in the capacitor.
- 11 Increasing the resistance of the coil in a parallel resonant circuit causes the generator current to increase. More losses occur as a result of the increased resistance, and the generator supplies more current to make up for these losses.
- 12 A low L/C ratio gives a sharper curve, such as curve B in Fig.14.
- 13 In a series resonant circuit, the same current flows in the coil and in the capacitor. Since the generator, resistance, coil, and capacitor are all in series in a series resonant circuit, the same current must flow through all these components. On the other hand, in a parallel resonant circuit, the currents through the coil and capacitor are essentially equal in magnitude but are  $180^\circ$  out of phase.

## HOW COILS AND CAPACITORS WORK TOGETHER

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- 14** In a series resonant circuit, the voltage across the coil will be equal to, but  $180^\circ$  out of phase with, the voltage across the capacitor. In a parallel resonant circuit, the coil and capacitor are connected in parallel and the voltage across the two will therefore be the same.
- 15** The generator current in a series resonant circuit will be very high because this circuit acts like a low resistance. The generator current in a parallel resonant circuit will be very low because this circuit acts like a high resistance.
- 16** The inductive reactance of the coil in a series resonant circuit cancels the capacitive reactance of the capacitor. Therefore, the only factor that limits current flow in the circuit is the resistance in the circuit. This results in a very high current flow. The current flowing through the coil and through the capacitor produces a voltage drop across these components that will be equal to the product of the current times the reactance of the part. This voltage may be greater than the source voltage.
- 17** Yes, the voltage across the coil and capacitor in a high-Q series resonant circuit will be greater because there will be a higher current flow.
- 18** The resonant circuit is a series resonant circuit because the voltage is induced in series with the turns of L2. Therefore, the voltage is applied in series with the coil and the capacitor.
- 19** A low-pass filter is a filter designed to pass signals below a certain frequency and reject signals above that frequency.
- 20** A high-pass filter is a filter designed to pass all signals above a certain frequency and to reject signals below that frequency.
- 21** A band-pass filter is a filter designed to pass a certain band of frequencies with little or no attenuation. It will reject or offer considerable opposition to frequencies above and below the band it is designed to pass.

## Lesson Summary

Some of the important facts that you should remember about this lesson are . . .

- Current in a series resonant circuit is maximum at the resonant frequency.
- Impedance in a series resonant circuit increases as frequency increases *or* decreases above and below the resonant point.
- Current in a parallel resonant circuit is minimum at the resonant frequency, except in the tank network, where current is maximum.
- Impedance presented by a parallel resonant circuit decreases as frequency increases *or* decreases above and below the resonant point.
- Both series and parallel resonant circuits can be carefully combined into filters that shunt (remove) or pass selected frequencies from a signal path.



## LESSON QUESTIONS

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6. Below the resonant frequency, a series resonant circuit acts like:
  - a. A resistor.
  - b. A coil.
  - c. A capacitor.
  - d. A low impedance.
7. Below the resonant frequency, a parallel resonant circuit acts like:
  - a. A resistor.
  - b. A coil.
  - c. A capacitor.
  - d. A low impedance.
8. At resonance, both a series resonant and a parallel resonant circuit:
  - a. Act like a high resistance.
  - b. Act like a low resistance.
  - c. Act like a resistance.
  - d. Draw a low generator current.
9. When comparing series resonant and parallel resonant tank circuits, the current in the tank will be:
  - a. High only in the series circuit.
  - b. High only in the parallel circuit.
  - c. High in the series circuit, but low in the parallel circuit.
  - d. High in both types of resonant circuits.
10. A high-pass filter:
  - a. Passes frequencies below the cutoff frequency.
  - b. Attenuates frequencies above the cutoff frequency.
  - c. Attenuates frequencies below the cutoff frequency.
  - d. Attenuates frequencies above and below the band of frequencies it passes.

## NOTES

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## GET ALONG WITH PEOPLE

A national magazine recently published the results of a survey in which it asked several hundred successful men and women: "What single ability have you found to be most essential to your success?" Almost unanimously, the answer was: "The ability to get along with people."

I'm sure you are already aware of the importance of this often undervalued ability. But did you think of getting along with others as a skill? It *is* a skill; one that you can learn like any other.

To be successful in any field — technical, artistic, or commercial — you must be able to get along with other people. You must have the ability to work with others to achieve your common goals. You can only profit from your special talents and skills if other people are willing to come to you for your services, and people won't seek you out if they don't like you.

Keep this in mind in your daily life. Practice getting along with people. Notice the things people respond to and the things that "turn them off." There is always room for improvement in this area. As you go along, you will learn what many happy and successful people already know — that getting along with others is the single most important factor in gaining or keeping success.





# Semiconductors

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# Semiconductors



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# Table of Contents

<b>Introduction</b> .....	1
<b>Semiconductor Types</b> .....	2
N-Type Material .....	3
P-Type Material .....	4
Charges in Semiconductor Materials .....	5
Review .....	6
Self-Test Questions .....	6
<b>Current Flow in Semiconductors</b> .....	7
Diffusion .....	7
Drift .....	7
Review .....	9
Self-Test Questions .....	10
<b>Semiconductor Diodes</b> .....	11
Depletion Layer .....	11
Biased Junctions .....	13
Review .....	15
Self-Test Questions .....	16
<b>How Diodes Are Used</b> .....	17
Silicon Rectifiers .....	17
Zener Diodes .....	18
Tunnel Diodes .....	19
Pin Diodes .....	20
Varactor Diodes .....	20
Point-Contact Diodes .....	20
Light-Emitting Diodes .....	21
Review .....	22
Self-Test Questions .....	22
<b>Answers to Self-Test Questions</b> .....	23
<b>Lesson Questions</b> .....	26

## Lesson Objectives

In this lesson you will. . .

- Learn the principles of semiconductors.
- Explore how current flows in two types of semiconductor material.
- See how semiconductors can be made to form diodes.
- Learn about how different kinds of diodes work.

### INTRODUCTION

Semiconductors are the basic components of transistors. They have been around for a long time, in various forms. Semiconductors were first used in 1905, when a fine-pointed wire pressed against a lead sulphide crystal made a

detector for radio receivers. Such “point-contact” diode devices are still available today, but junction diodes are more common and perform better. We will introduce semiconductors and diodes in this lesson — their construction, operation, and characteristics. A solid understanding of semiconductors and semiconductor junction diodes will help you understand transistor operation.

# SEMICONDUCTORS

## SEMICONDUCTOR TYPES

A *conductor* is a material through which electricity can flow readily, and an *insulator* is a material through which electricity cannot flow. Between conductors and insulators lies another group of materials called *semiconductors*. Semiconductors are neither good conductors nor good insulators.

Germanium and silicon are semiconductor materials. At one time, germanium was widely used to manufacture diodes and transistors, but today silicon has replaced germanium almost entirely. However, diodes and transistors made of germanium work in the same way as diodes and transistors made of silicon. While we are going to concentrate on silicon, anything we say about the way a silicon diode works applies equally to a germanium diode.

The nucleus of the silicon atom has a charge of +14, and around the nucleus will be 14 electrons, as shown in Fig.1. Notice there are two electrons in the first ring and eight in the second. This is the maximum number of electrons that can be in each of these rings. In the third ring are four electrons

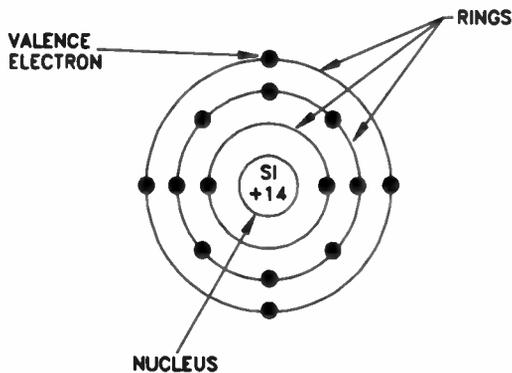


Figure 1. Silicon atom with a charge of +14 balanced by 14 electrons. The four electrons in the outer ring are called valence electrons.

called valence electrons, giving the atom a total of 14 electrons to balance the charge of +14 on the nucleus.

The outer shells of silicon and germanium are not completely filled with electrons. As a result, the chemical nature of these atoms is to acquire additional electrons. However, one atom cannot pull electrons away from another atom. Instead, nearby atoms will share electrons. Two silicon atoms will share two electrons by *bonding*, one from each atom, as shown in Fig.2(A) on the next page. By sharing electrons in this way, each atom partly fills its outer shell. This pair of shared electrons is called a *covalent bond*.

This bonding process goes further. To fill its outer ring with electrons, a single silicon atom will establish covalent bonds with four other atoms so that each atom's outer ring has 8 electrons. This arrangement of atoms in a piece of silicon is shown in Fig.2(B). Billions of silicon atoms bond into crystal form and arrange themselves into a lattice structure. Each atom shares its four valence electrons with one valence electron from each of its four neighboring atoms to form these covalent bonds.

Even at low temperatures, there is some level of heat energy in all materials. This energy is sufficient to cause a few of the electrons to move out of their proper places in the lattice structure of the silicon crystal and become *free electrons*. When an electron moves out of its position in the lattice structure, it leaves an empty space, or *hole*, in the crystal lattice. An electron from a nearby atom can move into this hole, creating a new hole at the place it left. Another electron may move out of still another atom to fill this new hole, leaving behind it another new hole.

The electrons in a piece of silicon are in a constant state of motion within their atoms. In its movement, if an electron comes closer to a hole than to its own atomic nucleus, it will be strongly attracted to the hole and will leave its

## SEMICONDUCTOR TYPES

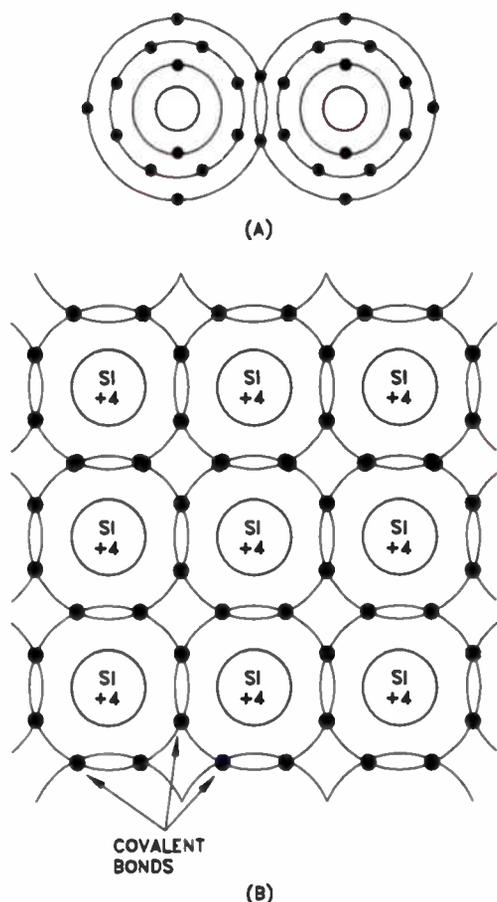


Figure 2. (A) Sharing of two electrons by two silicon atoms and (B) covalent bonds produced in a silicon crystal.

atom. When there is no voltage applied across the crystal, this movement of holes and electrons is infrequent and in random directions.

When the movement of an electron out of an atom forms a hole in the atom, the free electron and the hole it forms are called a *hole-electron pair*. The formation of hole-electron pairs is a continuous process, as is the filling of holes by electrons. As an electron leaves its atom and forms a hole, another electron moves in to fill that hole, leaving a new hole behind it. This action goes on continuously. The random conduction of electricity in pure silicon or germanium

caused by the continuous formation of hole-electron pairs is called *intrinsic conduction*. From an electronics standpoint, this type of conduction is undesirable, and it is much more prevalent in germanium than in silicon. This is one of the reasons silicon has generally replaced germanium in new diodes and transistors.

In its pure form, neither silicon nor germanium is useful in semiconductor devices. Neither material is a good conductor; both are fairly good insulators. But it is possible to alter the characteristics of both germanium and silicon and produce two different types of semiconductor material, both of which are useful in semiconductor devices.

To use silicon and germanium in semiconductors, controlled amounts of other selected elements called *impurities* are added to the crystals to alter their characteristics. By adding these materials, we can produce two types of silicon and germanium: n-type and p-type.

### N-Type Material

An *n-type semiconductor material* can be made by adding, as an impurity, an element that has five electrons in its outer ring. An example of this type of material is arsenic. Arsenic has a positive charge of 33 on the nucleus and has 33 electrons in the outer shells surrounding the nucleus. Of these electrons, 28 are in the first three rings and 5 are in the fourth ring.

When a small amount of arsenic is added to a silicon crystal, the arsenic atoms form covalent bonds with the silicon atoms, as shown in Fig.3 on the next page. However, only four of the five valence electrons in the outer shell of the arsenic atom can form covalent bonds with the neighboring silicon atoms. Thus, there will be one electron left over after the four covalent bonds are

# SEMICONDUCTORS

formed. This electron is free to move about within the crystal in exactly the same way a single electron is free to move about the outer shell of an atom in a good conductor. The addition of arsenic, which produces these free electrons, greatly reduces the resistance of the material.

If the silicon has had an impurity added to it, we say it has been *doped*. When a semiconductor material has been doped with a material such as arsenic, creating an excess of electrons, we call it an *n-type* material. The "n" refers to the *negative carriers*, or free electrons. Arsenic is called a *donor impurity* because it donates an easily freed electron.

In addition to arsenic, other materials can be used as donors. Phosphorous has a total of 15 electrons, and antimony has 51 electrons. Both of these elements have 5 electrons in their outer,

or valence, shells, and both have been used in place of arsenic as a donor impurity.

## P-Type Material

If we add a material with only three, instead of five, electrons in its valence shell, we have a situation where the impurity added to the semiconductor has one less electron than it needs to establish covalent bonds with four neighboring atoms. Thus, in one of the covalent bonds there will be only one electron instead of two. This will leave a hole in the bond. One material that is frequently used to create these bonds is indium. Indium has 49 electrons arranged around the nucleus in rings of 2, 8, 18, 18, and 3. When indium is added to silicon, it forms covalent bonds with neighboring atoms, as shown in Fig.4.

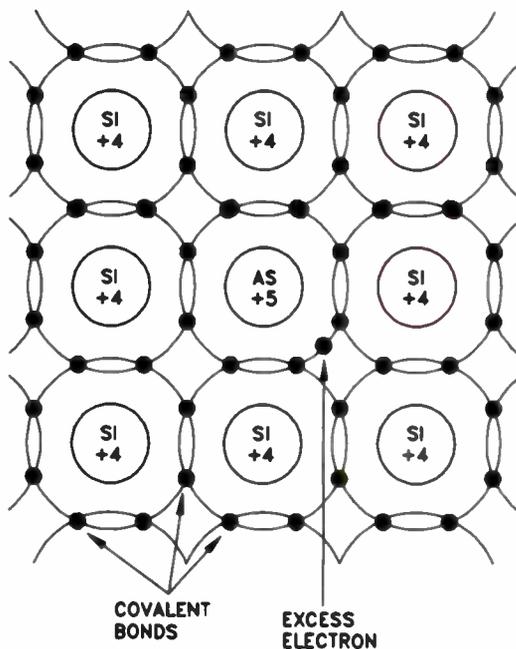


Figure 3. Silicon with arsenic added. Excess electrons are formed.

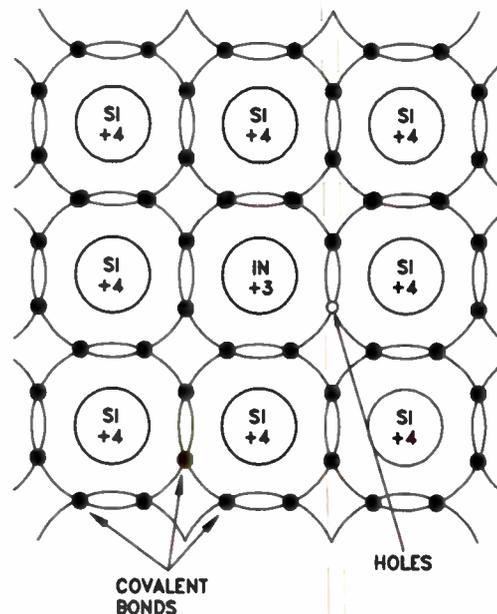


Figure 4. Silicon with indium added. A hole is formed in the covalent bond between indium and four neighboring silicon atoms because the indium atom has only three electrons in its outer ring.

## SEMICONDUCTOR TYPES

The free electrons present in the silicon (as a result of intrinsic activity) are strongly attracted to the holes in the covalent bond that are produced wherever an indium atom has displaced a silicon atom. An electron will move into a hole in the covalent bond, producing a new hole in another atom and giving the effect that the hole is moving, as shown in Fig.5.

Since a hole in the crystal is caused by an absent electron, a hole has a positive charge. Therefore, when a semiconductor material has been doped with indium, or with any material that produces holes in the lattice structure, we call the result a *p-type* material. The "p" stands for positive. Since holes represent the absence of an electron, we say they act as *positive carriers*. Indium is called an *acceptor impurity* because its atoms leave holes in the crystal structure that are free to accept electrons.

In addition to indium, boron and aluminum can be used as acceptor impurities. Boron has five electrons: two in the first shell and three in the second. Aluminum has 13 electrons: 2 in the first shell, 8 in the second, and 3 in the third.

### Charges in Semiconductor Materials

When a donor material is added to silicon, the fifth electron in the valence ring does not become part of a covalent bond. This extra electron is free to move away from the donor atom. When this happens, the donor material, such as arsenic, loses an electron, giving the arsenic atom a positive charge. At the same time, when the free electron moves to a nearby silicon atom, the silicon atom gets an extra electron and a resulting negative charge. The arsenic may then attract an electron from a nearby silicon atom to neutralize the positive charge, making a hole in that covalent bond and giving the silicon atom that loses the electron a positive charge. This is a continuous process.

The situation is comparable in a p-type material to which indium has been added. Indium has only three electrons in the outer valence ring. When an electron from a nearby silicon atom moves into the hole in the covalent bond created between the indium atom and its neighboring atoms, there will be one more electron in the indium atom than is needed to neutralize the charge on the nucleus. Thus, there will be a region of negative charge around the indium atom, and there will be a region of positive charge around the silicon atom that has given up an electron.

It is important to realize that although there may be areas of negative or positive charge throughout the crystal, the net charge on the crystal is zero. Even though electrons and holes move within the crystal, the crystal itself has not

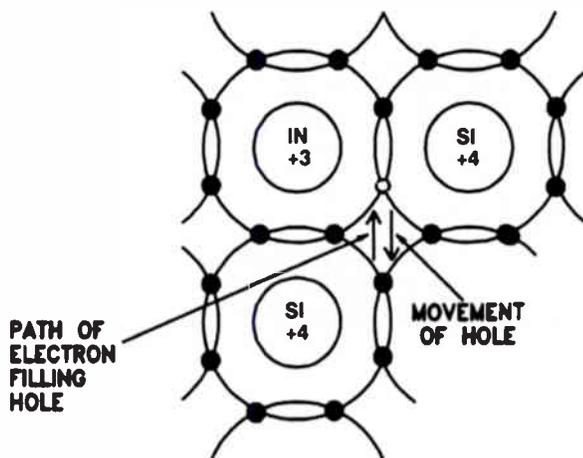


Figure 5. When an electron fills a hole, another hole will seem to move to where the electron was.

# SEMICONDUCTORS

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gained or lost any electrons, because the negative charges and the positive charges balance. The carrier that is present in greater quantity is called the *majority carrier*, while the other is called the *minority carrier*. In an n-type material, the electrons are the majority carriers and the holes are the minority carriers. In a p-type material, holes are the majority carriers and electrons are the minority carriers.

## Review

In semiconductor materials there is movement of both holes and electrons. They are involved in conduction at all times. Holes are called positive carriers and electrons are called negative carriers. In an n-type material, the electrons are the majority carriers, and in a p-type material, the holes are the majority carriers.

Both n-type and p-type semiconductor materials are used in diodes and transistors. In the next section of the lesson, we will see how current flows through these materials.

## Self-Test Questions

*Please check your answers on page 23.*

- 1 Which material, silicon or germanium, is more widely used in modern semiconductor devices?
- 2 How many electrons are there in the outer ring of the silicon atom?
- 3 How many electrons are there in the outer ring of the germanium atom?
- 4 Are pure silicon and germanium good electrical conductors?
- 5 What do we mean when we say that a silicon crystal has been doped?
- 6 What material is widely used as a donor?

# CURRENT FLOW IN SEMICONDUCTORS

## CURRENT FLOW IN SEMICONDUCTORS

When a p-type material is placed next to an n-type material, they have a *junction*. The action that occurs at the point of contact between the two different types of material is extremely important.

In this section of the lesson, you will study how current flows through semiconductor materials. You need to understand current flow through both n-type and p-type semiconductors to be able to understand how a junction works. Once you understand how a junction works, you will study a number of different types of single-junction semiconductors, or diodes. In the following lesson, you will study transistors, which have two junctions.

### Diffusion

Adding impurities to pure silicon creates either free electrons or holes. As you learned earlier, there is a certain amount of heat energy present in a crystal, even at relatively low temperatures. This energy produces some motion of free holes or electrons. The motion is random; it has no fixed direction.

When electrons and holes are in motion, they move in opposite directions. Remember that when there is a hole in one atom and an electron moves from another atom to fill that hole, a new hole appears in the second atom. The result is that the effective current flow of any one hole is canceled by the movement of an electron, and the net current flow is zero. That is, if there is a hole in atom 1 and an electron from atom 2 moves over to fill that hole, the hole moves from atom 1 to atom 2. The current flow of the electron is canceled by the movement of the hole.

This random motion of carriers is called *diffusion*. Diffusion goes on at all times in a crystal, whether or not there is a voltage applied to the crystal. Every effort is made in the design of transistors to keep this diffusion as low as possible, because random carrier motion contributes nothing to useful current flow through the device.

### Drift

Another type of carrier movement in semiconductors is known as *drift*. This type of movement is obtained when a voltage is applied across the crystal. Since the manner in which current flows through n-type and p-type materials is different, let's consider them separately.

**N-Type Materials.** Figure 6 shows an n-type crystal with a voltage applied to it. The voltage difference supplied by the battery provides a force that makes it easier for the electrons to move in one direction than in the other. The electrons are attracted by the positive terminal of the battery. Because the electrons greatly outnumber the holes, they will carry the current in the n-type material.

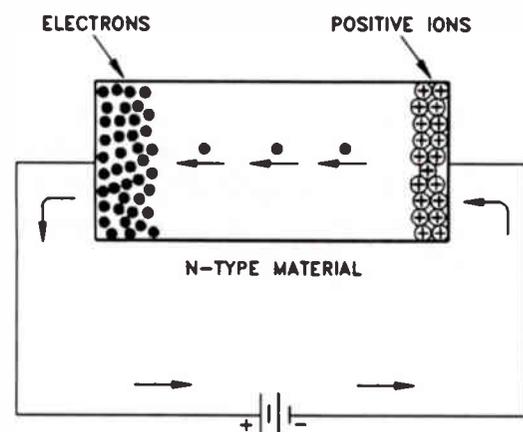


Figure 6. N-type crystal with voltage applied to it.

# SEMICONDUCTORS

When an electron moves away from its covalent bond toward the positive battery terminal, it leaves behind an atom with a positive charge, called a *positive ion*. The electrons moving toward the positive battery terminal create a region with a local negative charge, as shown in Fig.6. This negative charge establishes a *potential difference* between that end of the crystal and the positive terminal of the battery. In other words, the attraction of the positive battery terminal causes electrons to bunch up near the end of the crystal connected to the positive terminal and flow into the wire toward the voltage source.

Meanwhile, the atoms left behind are positive ions. A region of positive charge is created at the end of the crystal connected to the negative terminal of the battery. This potential difference pulls electrons from the wire into the crystal. These electrons replace the free electrons that were attracted to the positive terminal of the battery.

The number of electrons leaving the crystal through the end connected to the positive battery terminal will be exactly equal to the number of electrons entering the crystal at the end connected to the negative terminal. Since the crystal was electrically neutral before the battery was connected, and since the number of electrons in the crystal remains constant, the crystal itself remains electrically neutral.

**P-Type Materials.** Conduction through p-type material is quite different from conduction through n-type material. In the p-type semiconductor, nearly all the current is carried by holes. When a battery is connected to a p-type semiconductor, as shown in Fig.7, the voltage causes the holes to drift toward the negative terminal. They are repelled by the positive battery terminal and attracted by the negative potential applied to the other end. When a hole starts moving away from

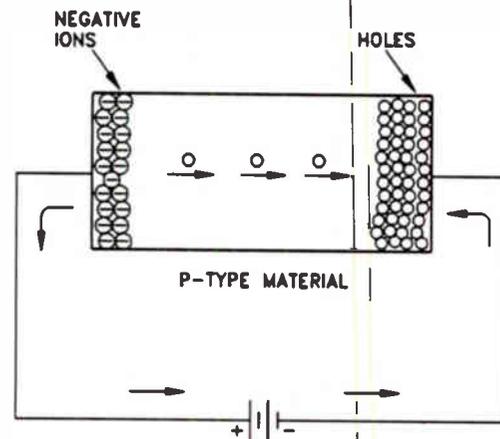


Figure 7. P-type crystal with voltage applied to it.

the end of the material connected to the positive terminal of the battery, it moves because it is filled by an electron attracted from a nearby atom.

When the hole in an acceptor-type (p-type) atom is filled with an electron, the atom has one electron more than it needs to neutralize the charge on the nucleus. Thus the atom has a negative charge; it becomes a *negative ion*. Negative ions that are formed near the semiconductor end that is connected to the positive terminal build up a region of negative charge at this end of the material. The extra electrons are drawn from these ions by the positive terminal of the battery, and new holes are formed. These holes then drift toward the end of the semiconductor connected to the negative battery terminal and build up a positive charge at this end of the semiconductor. This positive charge attracts free electrons from the external circuit. As a hole is filled with an electron, it disappears.

So, in a p-type material, we have an electron flow in the external circuit from the negative terminal of the battery to the semiconductor and

# CURRENT FLOW IN SEMICONDUCTORS

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from the semiconductor to the positive terminal. But in the semiconductor itself, current flows by means of holes, which drift from the end of the semiconductor connected to the positive terminal of the battery to the end connected to the negative terminal. Keep this point in mind: Even in p-type materials (where conduction occurs by holes, or positive carriers), the current flows in the external circuit by electrons (negative carriers) and moves in the conventional direction from the negative terminal toward the positive battery terminal.

It is important to understand that in n-type crystals, the excess electrons (produced when a donor atom forms covalent bonds with four semiconductor atoms) are free electrons that can move about the crystal. But in the p-type material, there are no extra electrons to act as free carriers; the electrons that move can only move to holes. Since a hole can capture an electron from any of its surrounding atoms, it is the hole that is free to move in any direction. For this reason, and because there are more holes than electrons in the lattice, holes are considered to be the majority carriers in p-type material.

The concept of hole-flow is simply a way of representing the action that takes place in the crystal lattice. N-type material has a lot of extra electrons, making electrons the majority carrier by which current flows in the crystal. P-type material has a lot of extra holes, so holes are the majority carrier. Actual circuit current through the p-type material still consists of electrons going in one end of the crystal and coming out at the other end. However, inside the p-type crystal itself, the mechanism of transfer depends upon hole-flow, since the electrons do move by themselves as free electrons but must move from one hole to the next.

An important practical difference between the n-type and the p-type material is that a free electron moves about twice as fast as a hole. This affects the conductivity of the two types of semiconductor material. If we have two crystals, an n-type and a p-type, and the n-type material has the same number of free electrons as the p-type material has holes, the n-type material will have a lower resistance because the free electrons can move approximately twice as fast as the holes in the p-type material.

## Review

The important thing to remember from this section of the lesson is that current flow through an n-type semiconductor is a movement of free electrons. They drift from the end of the semiconductor connected to the negative terminal of the battery to the end of the semiconductor connected to the positive terminal of the battery. In the p-type semiconductor, current flows through the crystal by means of holes. They drift from the end of the crystal connected to the positive terminal of the battery to the end of the crystal connected to the negative terminal of the battery. In both cases, current flow in the external circuit is by means of electrons flowing from the negative terminal of the battery to the crystal and from the crystal to the positive terminal of the battery.

Also, remember that the speed at which electrons move through n-type material is about twice the speed at which holes flow through p-type material. Thus, n-type material has better conductivity and lower resistance than p-type material.

# SEMICONDUCTORS

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## Self-Test Questions

- 7 In which direction do electrons move through an n-type crystal that has a voltage applied to it?
- 8 In which direction do holes move through p-type material that has a voltage applied to it?
- 9 Do electrons move through an n-type material at the same speed as holes through a p-type material?
- 10 When current is flowing through a crystal, will the crystal be charged?
- 11 If you had two identical pieces of silicon and one was doped so that it was n-type material, while the other was doped so that it was p-type material, which would have the lower resistance?
- 12 Is diffusion in a semiconductor material desirable?

## SEMICONDUCTOR DIODES

A *semiconductor diode* is made by taking a single crystal and adding opposite donor impurities to each half, making a single crystal with a p section and an n section. Where the two sections meet, they have a junction. Contacts are fastened to the two ends of the crystal so that it can be connected to an external circuit. Figure 8 shows a simple pn junction. For simplicity we have represented the crystal as a box-like structure with one half p-type material and the other half n-type material.

This type of diode is called a *junction diode*. At the junction of the p-type crystal and the n-type crystal, the actions of holes and electrons form what is called the *depletion layer*. Let us see what a depletion layer is and how it is formed.

### Depletion Layer

Remember that in an n-type crystal there are free electrons and in a p-type crystal there are free holes. Also remember that the electrons and

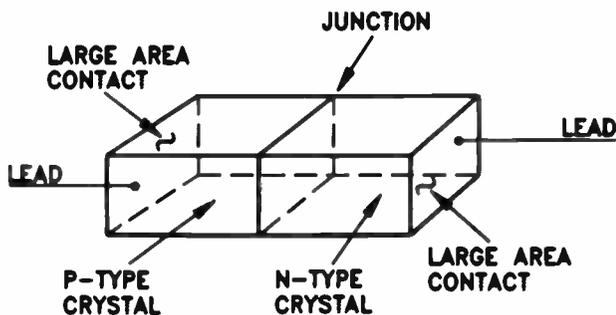


Figure 8. A simple pn junction.

holes move about a crystal in a random motion called diffusion. In the pn junction diode, holes move about in the p section and electrons move about in the n section. Some of the holes diffuse across the junction from the p section into the n section and are filled by free electrons. Similarly, some of the electrons in the n-type material diffuse across the junction and fill holes in the p section.

When an atom in the n section loses an electron, the atom becomes charged, or ionized. It has a positive charge because it has one less electron than it needs to neutralize the charge on the nucleus. Electrons diffusing across the pn junction from the n side leave behind atoms with a positive charge. At the same time, the atom on the p side gets one more electron than it needs and develops a negative charge.

Similarly, a hole diffusing across the junction from the p side moves into an atom that is, consequently, now missing an electron, giving the atom a positive charge. Over on the p side of the junction, because the hole moved, the atom that gained an extra electron gets a negative charge.

As a result of this diffusion of holes and electrons across the junction, a charged area develops on each side of the junction. On the p side is a negatively charged area, because the atoms have extra electrons. This negative charge, once established, repels free electrons in the n-type material away from the junction. At the same time, positively charged atoms on the n side repel free holes away from the junction. As a result of these charges, on the p side of the junction there is an area where there are no holes, and on the n side of the junction there is an area where there are no free electrons. This area around the junction where the majority carriers are missing is called the depletion layer.

# SEMICONDUCTORS

Figure 9(A) is a drawing showing the concentration of positive and negative ions, as well as free electrons and holes, around a pn junction. The actual depletion layer of a diode is much narrower than is shown in the picture, where the layer has been enlarged for clarification.

The charge on the ions is shown in Fig.9(B). Notice that on the p side of the junction the atoms that have lost holes by gaining electrons have a negative charge. At the junction, the potential drops to zero and then reverses on the n side where the ionized atoms have a positive charge because they have lost electrons.

Figure 9(C) shows the carrier charges that are available to neutralize the ionized atoms. At

some distance from the junction there are holes on the p side with a positive charge. But as we approach the junction, the concentration of these holes decreases because they are repelled from the junction by the positive ions on the n side of the junction. At some distance from the n side of the junction we have free electrons available, but as we approach the junction, the charge drops to zero, because these electrons are repelled from the junction by the negative ions on the p side.

As before, the crystal tends to remain neutral, having no net positive or negative charge. However, there is a region on the p side of the junction where the atoms have a negative charge and a region on the n side of the junction where the

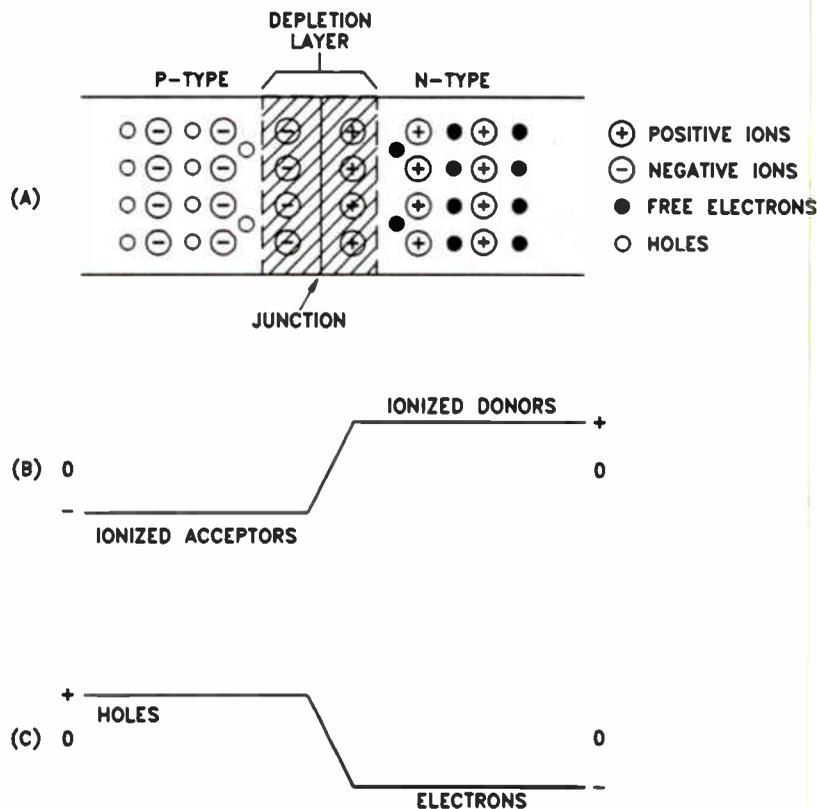


Figure 9. (A) Locations of ions and carriers at a pn junction; (B) charges at junction due to ionized impurity atoms; and (C) carrier charges.

# SEMICONDUCTOR DIODES

atoms have a positive charge. These charges exist only in the area of the junction. The crystal has neither gained nor lost electrons; the overall effect is for the crystal to remain neutral.

**Thermal Effects.** There is one other important point to consider. Remember that the thermal energy of the crystal keeps the holes and electrons in a continuous state of motion. Even at room temperature, the crystal holds a small amount of heat energy, sufficient to cause motion of both holes and electrons. In the n-type material, an electron leaving an atom creates a hole. This hole fills with an electron from another atom. There is a continuous formation of hole-electron pairs. Away from the junction, this formation of hole-electron pairs does not have any effect on the carrier concentration of the crystal.

Holes produced in the n region near the junction are attracted to the negative ions on the p side of the depletion layer, and some will cross the junction. These holes tend to neutralize the ions on the p side of the junction. Similarly, some free electrons produced on the p side of the junction will cross the junction and neutralize positive ions on the n side of the junction. This is a natural form of intrinsic conduction by minority carriers, due to thermal formation of hole-electron pairs.

The effect of minority carriers crossing the junction is to reduce the potential of the barrier created by the depletion layer. When this happens, majority carriers are also able to cross the junction at the location of the neutral atoms. The net result is that holes and electrons cross the junction in both directions. These movements tend to cancel each other, but the flow across the junction produces a certain amount of heat, which uses up a percentage of the total capacity of the junction to pass current. This lowered capacity reduces the amount of useful current that the junction can allow to pass. As we men-

tioned, this type of intrinsic conduction is not desirable, and efforts are made to minimize these effects in semiconductor components.

## Biased Junctions

When we connect a battery across a junction diode, we say that the junction is biased. This voltage bias of the diode junction is described as either a forward bias or a reverse bias, depending upon the polarity of the applied voltage. Let's see what we mean by each type of bias and what happens in each case.

**Forward Bias.** If the positive battery terminal connects to the p-type material, and the negative terminal connects to the n-type material, as shown in Fig.10, we say that the diode is forward-biased. When the battery is connected with this polarity, a current can flow through the junction.

The positive voltage on the p-type material repels holes toward the junction and attracts electrons from the negative ions in the depletion layer. In the n-type material, the negative terminal of the battery repels electrons toward the

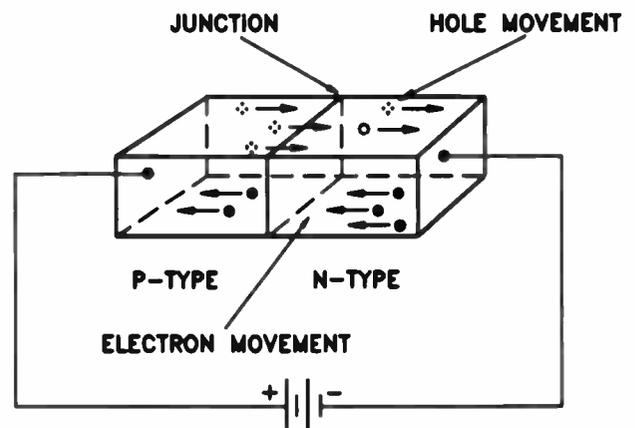


Figure 10. A forward-biased junction.

# SEMICONDUCTORS

junction and pulls holes away from the positively charged ions in the depletion layer. Holes moving toward the junction, and electrons being taken from negatively charged ions, act to neutralize the barrier charge of the depletion layer.

Reducing the potential barrier at the junction allows more majority carriers to cross the junction. More electrons flow from the n-type material across the junction to the p-type material and to the positive terminal of the battery. At the same time, holes travel from the p-type material across the junction toward the n-type material and the negative terminal of the battery.

Normally, we do not connect a battery directly across a diode, because the diode would conduct heavily, overheat, and burn out. Typically, a circuit like the one shown in Fig. 11 might be used. If the diode is a silicon diode, the voltage drop across it will be 0.6 volt. This is the voltage needed to neutralize the depletion layer "barrier charge" at the junction. The remaining 2.4 V is dropped across the resistor. If R had a resistance of 1,000 ohms, the current flow in the circuit would be 2.4 milliamperes. A 500-ohm resistor would allow current of 4.8 mA, with 2.4 V

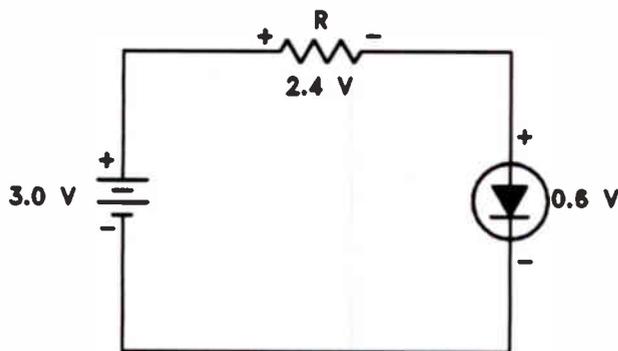


Figure 11. In the series circuit shown, the voltage drop across a silicon diode will be 0.6 volt.

dropped across the resistor and 0.6 V dropped across the diode.

Remember that the voltage drop in a forward-biased silicon diode is 0.6 volt. The actual drop varies slightly (0.6–0.7) according to the temperature, applied voltage, and amount of current through the junction. You will occasionally see references to 0.7 V as the junction potential. A germanium diode, however, drops only 0.3 volt. The depletion layer is smaller in a germanium diode because there is more intrinsic conduction in germanium.

Notice the schematic symbol for the diode. (In practice it is often drawn without the circle around it.) The arrowhead is the p-type material and is called the *anode*. The flat bar is the n-type material and is called the *cathode*. Since circuit current flows from negative to positive, diode current actually flows against the arrow in the diode symbol. When pioneer studies in the field of electronics were being made, it was not known that electrons had negative charges. Scientists believed that electrical current flowed from positive to negative. Therefore, the diode symbol was established with the arrow pointing in the direction in which early scientists thought current flowed.

When the two-element vacuum tube, which is called a diode, was invented, scientists soon realized that current was flowing through the tube from the cathode to the anode. This meant that current actually flows from negative to positive. In order to avoid a lot of confusion, however (since the diode symbol was already established in a lot of published material), the symbol was not changed.

**Reverse Bias.** Figure 12 shows a reverse bias applied to a junction diode. The negative battery terminal connects to the p-type section and attracts holes away from the junction, increasing the shortage of holes on the p side of

## SEMICONDUCTOR DIODES

the depletion layer. At the same time, the positive voltage connected to the n-type section of the crystal attracts electrons away from the junction, increasing the shortage of electrons on the n side of the depletion layer. This movement of holes and electrons increases the thickness of the depletion layer and increases the barrier potential across the junction. The increase in the barrier voltage prevents any current flow of majority carriers across the junction.

The current flow across the junction is not zero. A very small minority-carrier current is present through the junction, composed of holes from the n side and electrons from the p side. Thus, even with a reverse bias, there is a trickle of current flow from the negative terminal of the battery to the p-type material, through the material, across the junction, across the n-type material, and back to the positive side of the battery.

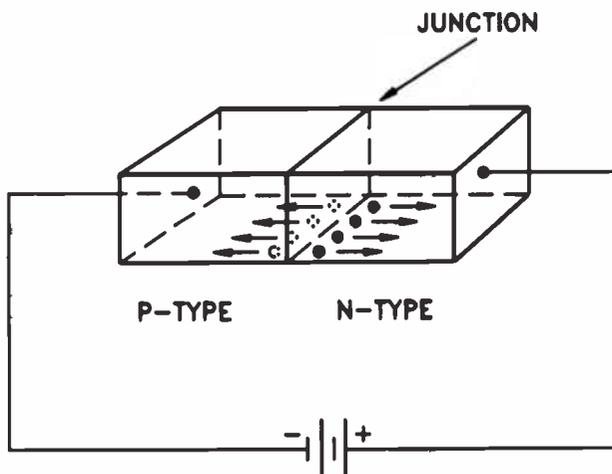


Figure 12. A reverse-biased junction.

This is called a *reverse current*, in contrast to current in a forward-biased diode, which is called *forward current*. Normally, we want the minimum possible reverse-current flow, but as you will see later, there are some applications that make use of it.

### Review

You should remember that with no voltage applied to a diode, a depletion layer forms at the junction. This depletion layer prevents the further diffusion of majority carriers across the junction. The depletion layer is also sometimes called the depletion barrier, or energy barrier.

When a diode is forward-biased, the negative terminal of the battery is connected to the n-type section and the positive terminal of the battery is connected to the p-type section. With forward bias, current can flow from the negative terminal of the battery to the n-type material, across the material and the junction, across the p-type material, and back to the positive terminal of the battery. We call the current flow in this direction through the diode a forward current flow.

When a diode is reverse-biased, the positive terminal of the battery is connected to the n-type material and the negative terminal is connected to the p-type material. No majority-carrier current flows. However, minority carriers still create a very small current through the crystal. This current is called reverse current, and in most cases we want to keep it as low as possible.

# SEMICONDUCTORS

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## Self-Test Questions

- 13 Which type of ion, positive or negative, will appear in the depletion layer on the p-type side of the junction?
- 14 Which type of ion, positive or negative, will there be in the depletion layer on the n-type side of the junction?
- 15 How do you connect a battery to a diode to forward bias it?
- 16 What is the name given to the current flowing through a diode when it is forward-biased?
- 17 How do you connect a battery to a diode to reverse bias it?
- 18 What is the name given to current flow through a diode when it is reverse biased?
- 19 What voltage drop would you expect to find across a forward-biased silicon diode?

### HOW DIODES ARE USED

All semiconductor diodes are composed of some type of pn junction created on a cut or cast segment of crystal. You might think that all diodes work the same, but in fact, there are variations in design that can accomplish a variety of purposes. By varying the amount of doping done to the n-type and p-type materials, and by varying the physical construction of the diode, we can produce diodes with radically different characteristics.

A semiconductor diode is seldom referred to simply as a diode. It usually has a specific name indicating its design type. This section reviews several different types of diodes that you will encounter in your electronics work.

#### Silicon Rectifiers

A *silicon rectifier* is a diode made for use as a rectifier in a power supply. It is used in the process of changing ac voltage into dc voltage. A typical circuit with a diode used as a rectifier is shown in Fig.13.

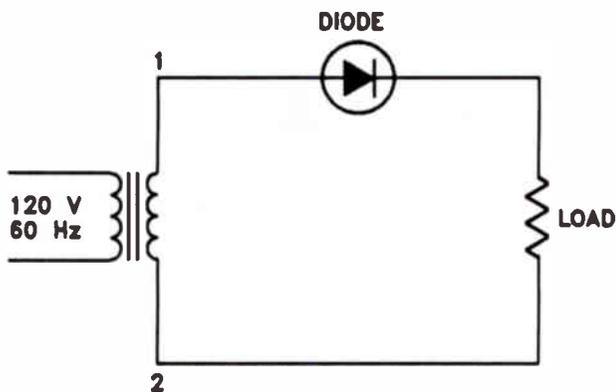


Figure 13. A diode used as a rectifier to convert ac to pulsating dc.

During the half-cycle when terminal 2 is negative and terminal 1 is positive, current flows from terminal 2 of the transformer through the load and the diode to terminal 1 of the transformer. During the next half-cycle, when terminal 2 is positive and terminal 1 is negative, current cannot flow through the diode because the diode is reverse-biased. Therefore, current flows in the circuit for one half-cycle only, in one direction only. This produces a pulsating dc output, since the negative-going half-cycle does not appear across the load.

A silicon diode is an excellent rectifier because it has very low forward-resistance; there is very little voltage drop across the diode when the current is flowing through it. At the same time, the reverse current through a silicon rectifier is very low, so low in most cases that it is not measurable.

This diode has several important characteristics. One is its current-handling capability. Diodes are designed to pass a maximum current in the forward direction. If a diode is used in a circuit where its maximum current rating is exceeded, the junction will overheat and the diode will fail.

Another important characteristic is the peak reverse voltage rating. Looking at Fig.13 again, the diode conducts when terminal 1 is positive and terminal 2 is negative. The voltage drop across it will be about 0.6 volt. But, when terminal 1 is negative and terminal 2 is positive, the entire negative-going voltage of the transformer is applied to the reverse-biased diode. If this voltage exceeds the peak reverse voltage rating, the diode will break down. For instance, if the ratio mean square (rms) voltage from the transformer is 120 V, the peak voltage is 169 volts. You need a diode with a peak reverse voltage rating of at least 200 V to allow a small safety margin.

# SEMICONDUCTORS

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Silicon rectifiers are made in many different peak reverse voltage (prv) ratings. Low-voltage diodes with a prv of 50 V are typical, as are relatively high-voltage diodes with a prv rating of 1,000 volts. Sometimes you'll see this rating written as piv. This means peak inverse voltage, the same thing as peak reverse voltage.

In the circuit shown in Fig.13, the current that flows through the load is a pulsating current that is present during one half of the ac cycle only. In a later lesson, when you study power supplies, you will learn how this current can be made to flow during both halves of the ac cycle and how it can be changed from a pulsating current to a pure dc current.

## Zener Diodes

In junction diodes designed for use as rectifiers, we must be careful not to exceed the prv of the diode. Too high a reverse voltage across the junction causes the junction to break down, conduct in the wrong direction, overheat, and fail. However, zener diodes make use of reverse current. In *zener diodes*, both the p and the n sections are specially doped and have larger junction areas for increased current-handling capacity. This type of diode is used as a voltage reference and as a voltage regulator. It is also called a *voltage-reference diode*.

In a zener diode, current remains small at low reverse voltages. At a certain voltage called the *breakdown voltage*, *avalanche voltage*, or *zener voltage*, reverse current increases rapidly with any further increase in reverse voltage.

The breakdown voltage can be varied by modifying the diode construction. Zener diodes can be made with breakdown voltages from 1 V up to several hundred volts. The amount of current that can pass through any zener diode without

damaging the diode depends upon the junction area and the methods used to keep the diode cool.

An example of how the zener diode works as a voltage regulator is given in Fig.14. The diode is in parallel with the output and is connected to the unregulated voltage input through a resistor. To obtain a regulated output voltage of 15 V, we could select a zener diode with a breakdown voltage of 15 volts. The unregulated power supply source would have a voltage of about 20 volts. The zener diode conducts enough current to maintain the voltage drop across the resistor at 5 V, keeping the voltage drop across itself at 15 V, which is the output voltage. If the unregulated voltage rises to 21 V, the diode conducts more current, increasing the voltage drop across the resistor to 6 V, leaving the regulated output at 15 volts. On the other hand, if the unregulated voltage drops to 19 V, current through the diode decreases so that the voltage drop across the resistor is 4 V, again maintaining the output voltage at 15 volts.

Zener diodes have two important ratings: the breakdown voltage and the wattage rating. The

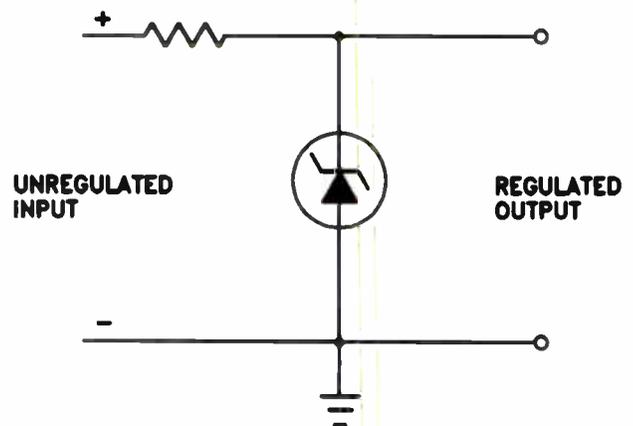


Figure 14. A circuit using a zener diode as a voltage regulator.

*wattage rating* tells you how much power a zener diode can handle. Most zener diodes are low-wattage diodes, with ratings from 1/4 watt up to 1 watt. You can replace a defective 1/4-watt zener diode with a 1-watt zener diode, but if you replace a 1-watt diode with a 1/4-watt zener diode, the low-power device will probably break down.

### Tunnel Diodes

A *tunnel diode* is a junction diode made of germanium or gallium arsenide. Both the n region and the p region of the diode are highly doped. As a result of the high doping, the depletion region around the junction is extremely narrow. Because of the narrow depletion region, holes and electrons can cross the junction by “tunneling” from one atom to another.

Current across the junction increases rapidly with either a forward or a reverse bias. When the bias is zero or very close to zero, current stops. The current across the junction increases rapidly as the forward bias increases, until a peak is reached. If the forward bias increases beyond this point, the current begins to decrease.

If the forward bias increases still further, the current across the junction continues to decrease, producing a voltage-current curve like the one shown in Fig.15. This decrease in current with increasing voltage results in what is called a *negative-resistance characteristic*.

Negative resistance is difficult to visualize, but remember from Ohm’s law that resistance is equal to voltage divided by current. In a circuit where resistance is constant and applied voltage increases, current also increases. Similarly, if applied voltage decreases, current decreases. In a tunnel diode there is a region

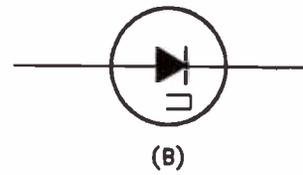
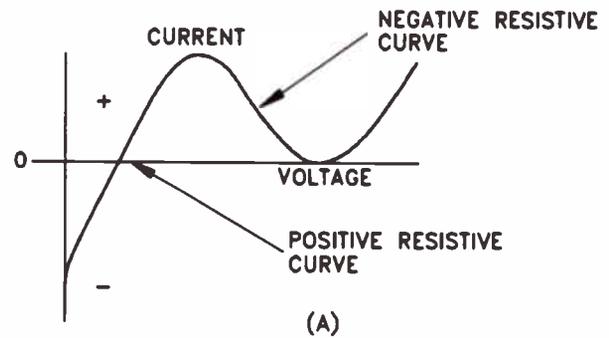


Figure 15. (A) The voltage-current relationship in a tunnel diode and (B) the schematic symbol for a tunnel diode.

of operation where the opposite happens. If the voltage increases, the current decreases. If the voltage decreases, the current increases. Something in the circuit is giving the opposite effect of resistance. We call this negative resistance.

Resistance in the circuit introduces losses. It is the resistance in a resonant circuit that keeps it from continuing to oscillate when power is removed. But if we put something with a negative resistance in the circuit — a tunnel diode, for example — the circuit should continue to oscillate, because negative resistance has the opposite effect of resistance. Tunnel diodes can be used for this purpose; they are also used in switching circuits because they can switch very rapidly. In Fig.15, we’ve also shown the schematic symbol for the tunnel diode. Compare it to the schematic symbol used for the silicon rectifier and zener diode.

# SEMICONDUCTORS

## Pin Diodes

*Pin diodes* are widely used for high-speed switching in electronic equipment. Pin is an abbreviation of positive-intrinsic-negative. This special diode is doped so that it has a very low resistance with a forward bias across the junction but a very high resistance with a reverse bias across the junction.

## Varactor Diodes

*Varactor diodes* are variable capacitors. In a varactor diode, when the diode is reverse-biased, holes on the p side and electrons on the n side of the junction move away from the junction. The higher the bias, the farther they will move from the junction. This has the same effect as separating the plates of a capacitor, decreasing the capacitance of the junction. Varactor diodes are used as small-value capacitors in specialized circuits, such as electronic tuners, particularly for high-frequency radio.

The symbol used to represent a pin diode is shown in Fig.16(A) and the symbol used to represent a varactor diode is shown in Fig.16(B).

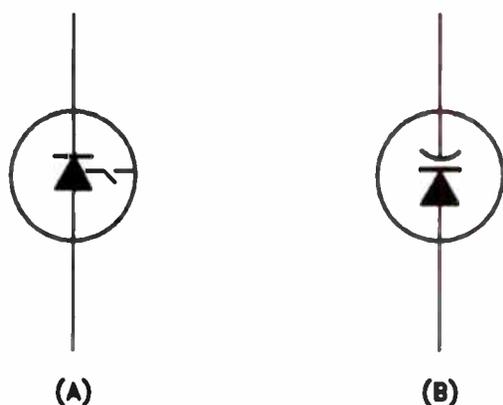


Figure 16. (A) The schematic symbol for a pin diode; (B) the schematic symbol for a varactor diode.

## Point-Contact Diodes

Another semiconductor used in radio and TV receivers is a *point-contact diode*, shown in Fig.17 with its schematic symbol. The point-contact diode is usually made with a small piece of n-type silicon. The large contact is fastened to one side of the crystal, and a thin wire, called a *cat's whisker*, is attached to the other side. When a cat's whisker is attached to the crystal, a small region of p-type material is formed around the contact, as shown in Fig.18. Thus, we have a pn junction. The point-contact diode makes a better detector than a junction diode because the junction between p-type material and n-type material is very small. The diode, therefore, has a lower capacitance and is more sensitive.

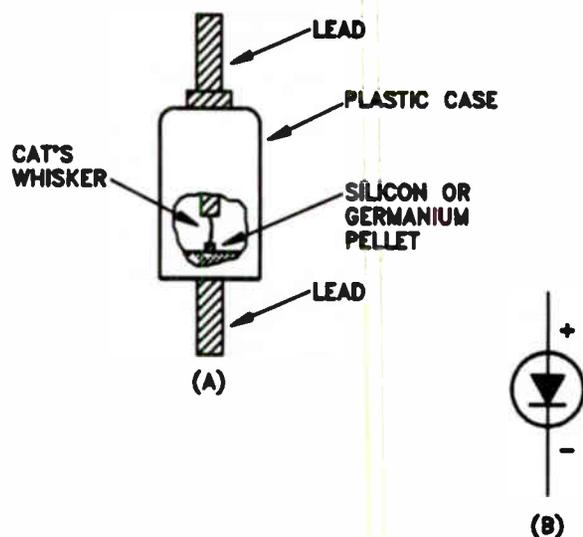


Figure 17. (A) Cutaway view of a point-contact diode and (B) its schematic symbol.

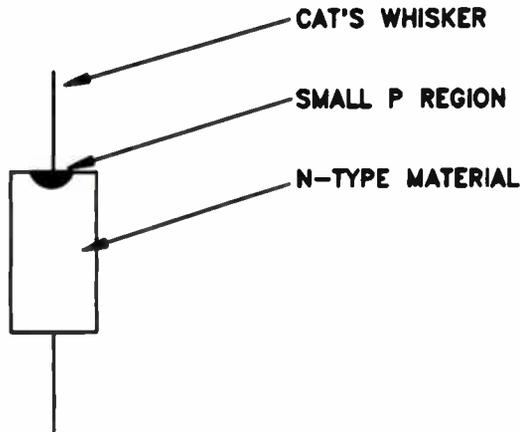


Figure 18. A point-contact diode showing where the p-type material is formed around the cat's whisker.

## Light-Emitting Diodes

Most pn junctions emit some form of radiation when they are forward-biased. In most cases, however, the radiation is very low and not easily detected. The *light-emitting diode (LED)* is a diode that has been specifically designed to emit radiation in a particular portion of the spectrum.

A photo of an LED is shown in Fig.19, along with the LED's schematic symbol. In electronic equipment, you will encounter LEDs that emit radiation in the visible spectrum in the form of red, yellow, or green light.

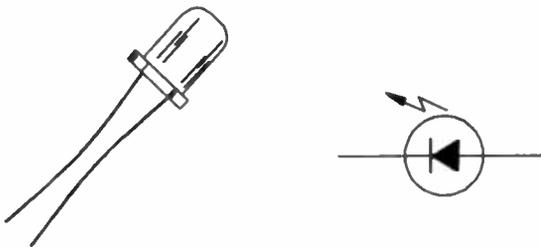


Figure 19. An LED and its schematic symbol.

LEDs that emit radiation in the infrared portion of the spectrum are also used in electronic equipment. Many remote-control devices used with TV receivers and VCRs use an LED that emits infrared radiation.

To obtain radiation from an LED, all you need do is place a forward bias across the junction. This will cause current to flow, producing radiation either in the visible or the infrared part of the spectrum.

Seven LEDs can be arranged as shown in Fig.20 to produce what is called a seven-segment display. Each of these segments is identified by a letter in Fig.20. The LEDs are in a glass or plastic tube so that the light appears as a bar rather than a point of light.

In a seven-segment display, the cathodes of all seven LEDs may be connected, as shown in Fig.21(A) on the next page. When the cathodes are connected, the display is referred to as a *common-cathode seven-segment display*. The seven-segment display can also be manufactured

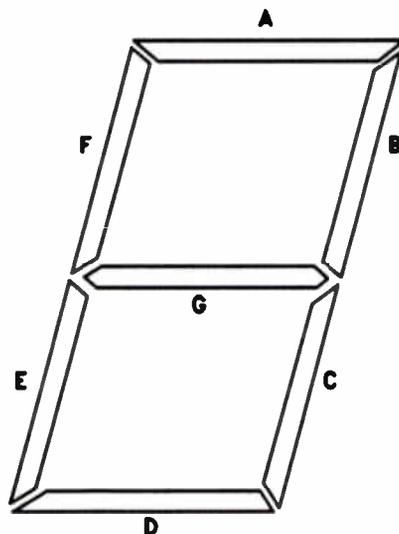


Figure 20. Seven LEDs in a seven-segment array.

# SEMICONDUCTORS

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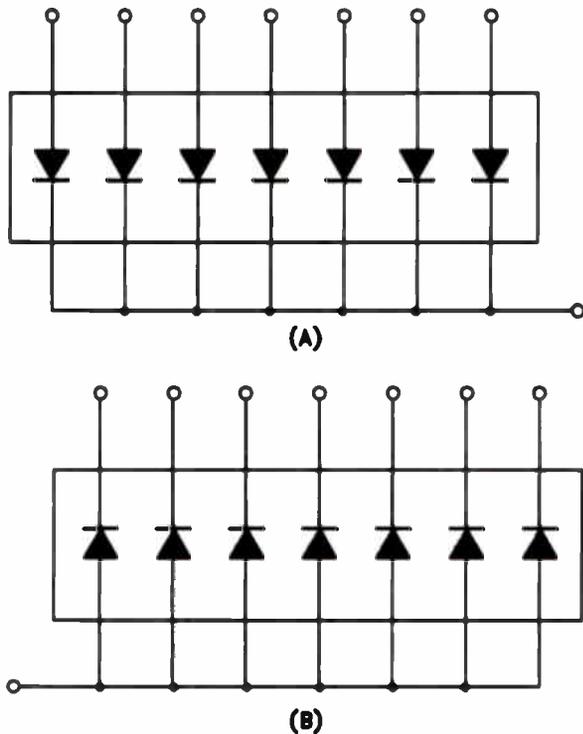


Figure 21. (A) Schematic of a common-cathode seven-segment display, and (B) schematic of a common-anode seven-segment display.

with all the anodes connected, as shown in Fig.21(B). This type of display is called a *common-anode seven-segment display*.

A seven-segment display can be used to display the numbers from 0 to 9. If all the segments except g are lit, the display will show a 0. If all seven segments are lit, it will display an 8. If segments a, b, g, c, and d are lit, it will display a 3. You can see that by lighting the segments in different combinations, any number from 0 to 9 can be displayed.

## Review

We introduced several different diode types in this section. It is important to remember that each of these diodes has an anode and a cathode. The anode is p-type material, and the cathode is n-type material. Anodes and cathodes are doped in different ways in order to get the desired characteristic from each diode.

You will find all these diodes in electronic equipment; therefore, it is important that you remember both the schematic symbol for each diode and the way in which each diode is used. In the next lesson, you will study transistors. A transistor is a semiconductor device with two junctions. Many of the electronic devices that we take for granted today were made possible by the invention of the transistor.

## Self-Test Questions

- 20 When we refer to a silicon rectifier, what does peak reverse voltage mean?
- 21 When a zener diode is used as a voltage regulator, in what direction does the current flow through the diode?
- 22 What type of diode exhibits a negative resistance characteristic?
- 23 What type of diode is widely used as a switch?
- 24 What special characteristic of a point-contact diode makes it suitable for use as a detector in radio and TV receivers?

## ANSWERS TO SELF-TEST QUESTIONS

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### ANSWERS TO SELF-TEST QUESTIONS

- 1 Germanium was once widely used, but has been replaced by silicon.
- 2 Four.
- 3 Four.
- 4 No. In its pure form, neither silicon nor germanium is a good electrical conductor.
- 5 When we say that a silicon crystal has been doped, we mean that donor or acceptor atoms have been added to the crystal.
- 6 A donor material is a material that has five electrons in the outer ring. Arsenic is widely used as a donor.
- 7 When a voltage is applied to an n-type crystal, electrons move from the end of the crystal that has the negative terminal of the battery connected to it toward the end that has the positive terminal of the battery connected to it.
- 8 Holes move through a p-type material with voltage applied to it from the end connected to the positive terminal of the battery to the end connected to the negative terminal of the battery.
- 9 No. Electrons move through an n-type material faster than holes move through a p-type material.
- 10 When current is flowing through a crystal, the crystal will not be charged, because electrons moving out of the crystal will be replaced by electrons moving into it.
- 11 The n-type material will have a lower resistance because electrons in an n-type material have a higher mobility than holes in a p-type material.
- 12 No.
- 13 Negative ions will appear in the depletion layer on the p-type side of a junction because holes drifting across the junction to the n side leave behind atoms with a negative charge.
- 14 Positive ions will appear on the n-type side of the junction because electrons that have left their atoms and diffused across the junction leave atoms with a positive charge.
- 15 To forward bias a diode, connect the negative terminal of the battery to the n-type material and the positive terminal to the p-type material.
- 16 Current flowing through a diode when the junction is forward-biased is referred to as the forward current flow.
- 17 To reverse bias a diode, you connect the positive terminal of the battery to the n-type material and the negative terminal to the p-type material.
- 18 Current flow through a diode when it is reverse biased is called a reverse current flow.
- 19 The voltage drop across a forward-biased silicon diode is about 0.6 volt.

## SEMICONDUCTORS

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- 20** The peak reverse voltage across the silicon rectifier is the maximum voltage the diode can withstand when the anode is negative and the cathode is positive.
- 21** Current flows from the anode to the cathode when a zener diode is used as a voltage regulator.
- 22** The tunnel diode exhibits a negative resistance characteristic.
- 23** The pin diode is widely used as a switch.
- 24** The point-contact diode has a very small junction and thus has very low capacitance. This makes it suitable for use as a detector.

# Lesson Summary

**Some of the important facts you should remember about this lesson are. . .**

- Silicon can be “doped” with different elements to create a semiconductor material.
- The majority carriers in an n-type semiconductor are electrons, and the majority carriers in a p-type semiconductor are holes.
- At the junction of an n-type material and a p-type material, a depletion layer, or barrier charge, is formed.
- A forward bias across a diode overcomes the barrier charge and allows current to flow from the n-type material to the p-type material.
- A reverse bias across a diode blocks current flow in the direction from the p-type material to the n-type material.
- There are many special types of diodes that have valuable characteristics for specific applications.



## LESSON QUESTIONS

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5. The minority carriers crossing a pn junction will:
  - a. Have no effect on the depletion layer.
  - b. Strengthen the depletion layer.
  - c. Weaken the depletion layer.
  - d. None of the above.
6. Which of the following diode types is used as a voltage regulator?
  - a. Zener diode.
  - b. Tunnel diode.
  - c. Pin diode.
  - d. Varactor diode.
7. Which of the following diodes is used as a switch?
  - a. Varactor diode.
  - b. Point-contact diode.
  - c. Pin diode.
  - d. Zener diode.
8. Which of the following diodes has a negative-resistance characteristic?
  - a. Varactor diode.
  - b. Tunnel diode.
  - c. Pin diode.
  - d. Zener diode.
9. If a 1/2-watt zener diode burns out, which of the following diodes *cannot* be used as a replacement?
  - a. A 1/4-watt diode.
  - b. A 1/2-watt diode.
  - c. A 1-watt diode.
  - d. A 2-watt diode.
10. The  $p_{rv}$  rating tells us the maximum:
  - a. Allowable voltage across the diode when it is conducting.
  - b. Allowable voltage across the diode when it is not conducting.
  - c. Peak current through the diode.
  - d. None of the above.

**NOTES**

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## CASHING IN ON DISCONTENTMENT

Discontentment is a good thing — if it makes you want to do something worthwhile. If you had not been discontented with your current situation, you never would have enrolled in your NRI course.

Practically everyone is discontented from time to time. If we allow ourselves to be *floored* by discontentment, we can easily become complainers who find fault with anything and everything and end up bitter and resentful failures.

If we're smart, we learn to use our discontentment to motivate us. We use it to keep us focused on the goals we have set for ourselves. We know that we are creating a better life for ourselves, so sacrifices are worth making. We are happy in our work. We face defeat squarely and come out winners.

At this moment, you may be discontented with many things — your progress in this course, your current earning ability, or your life in general.

Make that discontentment work *for* you. Don't let it get you down. If you do, you may not be able to pick yourself back up again. Keep striving to beat the causes of your discontentment. Remember that it's always darkest before the dawn. And remember, the people who are real successes in life work their hardest when they are face to face with the greatest discouragements and disappointments.





# How Transistors Work

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# How Transistors Work



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# Table of Contents

<b>Introduction</b> .....	<b>1</b>
<b>Junction Transistors</b> .....	<b>2</b>
NPN Transistors .....	3
PNP Transistors .....	5
Alloy-Junction Transistors .....	9
Review .....	11
Self-Test Questions .....	12
<b>Field-Effect Transistors</b> .....	<b>13</b>
Junction-Gate Field-Effect Transistors .....	13
Insulated-Gate Field-Effect Transistors .....	14
Review .....	17
Self-Test Questions .....	17
<b>Answers to Self-Test Questions</b> .....	<b>18</b>
<b>Lesson Questions</b> .....	<b>20</b>

# Lesson Objectives

In this lesson you will . . .

- Learn how transistors are manufactured, and how they work.
- Discover the different types of junction transistors.
- Investigate some special types of junction transistors.
- Learn the operation of field-effect transistors.
- Study the two basic types of field-effect transistors.

### INTRODUCTION

Invented in 1948, transistors have replaced vacuum tubes in all but a few, special cases. They were developed in the Bell Telephone Laboratories for use as amplifiers of voice signals. The first transistors had very limited capabilities and could be used only at audio frequencies. Transistors have improved over the years, and today they outperform vacuum tubes in every application except video displays.

Transistors have many advantages over vacuum tubes. Tubes have cathodes which must be heated to give off electrons. The energy that heats the cathode does not contribute to the signal amplification, and therefore, is considered wasteful. In operation, vacuum tubes get very hot and this heat spreads to other parts in the equipment, contributing to part failure. Transistors consume much less energy and produce less heat.

Transistors are also smaller and more rugged than vacuum tubes. A sharp blow to a vacuum tube could break the glass envelope or cause the tube to short, making it useless. A transistor is a solid device, so a sharp blow is not likely to cause a problem.

You will find transistors in radio receivers, telephone receivers, video cassette recorders, transmitters, and all types of computers. Many of the devices we accept as commonplace today would not exist if it were not for transistors.

The transistor is very important in electronic equipment. It is essential that you understand how it works. This lesson is probably the most important one so far. If there is something you do not understand after the first reading, read that section over until the subject is clear. If you still need assistance, take advantage of the NRI consultation service and write to us. We'll be glad to help you.

## JUNCTION TRANSISTORS

In the preceding lesson you studied diodes. A diode is a two-element device. A transistor is a three-element device. The junction-transistor is the most widely used type, so you will study it first.

Early transistors were made of germanium, but most modern transistors are silicon. In our discussion we'll be talking about silicon transistors, but germanium transistors work in basically the same way.

The two-junction transistor is made from a single crystal having three regions. The center region is made of either n-type or p-type material. The two end regions are made of the opposite type material. Figure 1(A) shows one type of transistor where the center region is made of n-type material. The center region is called the *base*. At one end is the *emitter*, and at the other end is the *collector*. Both ends are made

of p-type material. This type of transistor is called a *pn<sub>p</sub> transistor*.

Figure 1(B) shows another transistor where the base is made of p-type material and the emitter and collector are made of n-type material. This type of transistor is called an *np<sub>n</sub> transistor*.

Figure 1 also shows the schematic symbols used to represent both types of transistors. Notice that in the pnp type, the arrow on the emitter points toward the base, while in the npn transistor, the arrow on the emitter points away from the base. It is important that you remember the names of the three parts of the transistor, as well as the schematic symbols used for pnp and npn transistors.

In some electronic equipment, all the transistors are either npn or pnp transistors. In other equipment, both types are used. The npn transistor is the more widely used of the two; and it is also easier to understand how it operates. We'll discuss this type first.

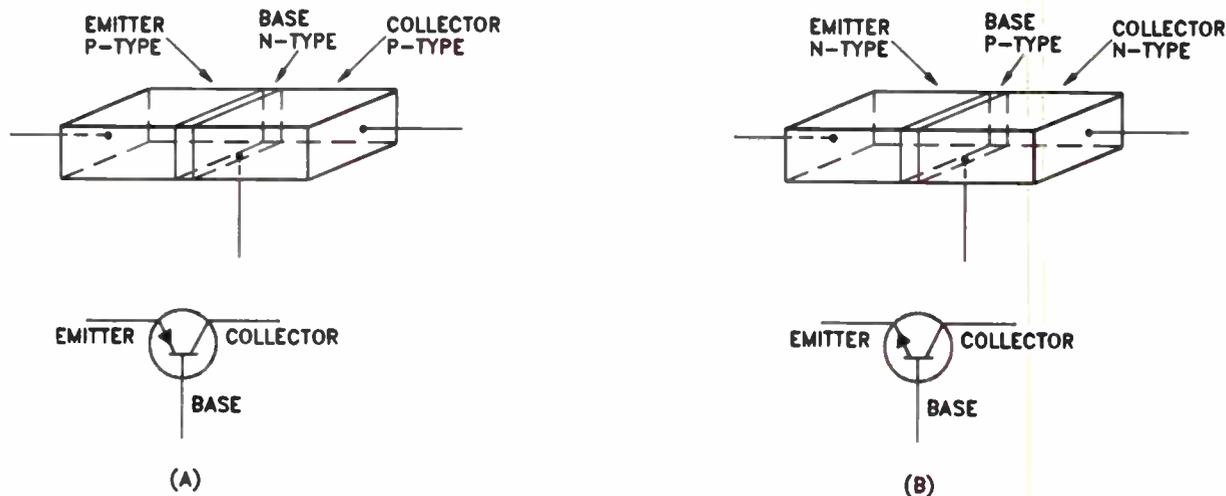


Figure 1. (A) A pnp junction transistor and its schematic symbol. (B) An npn junction transistor and its schematic symbol.

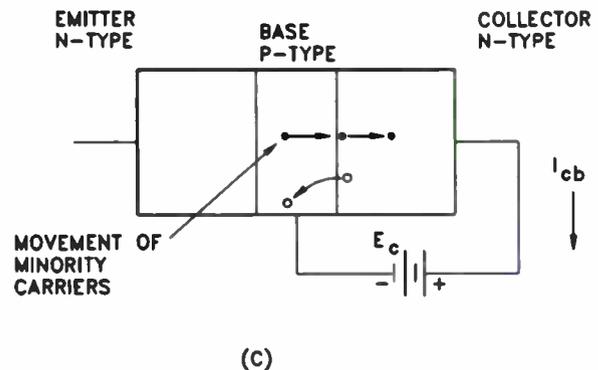
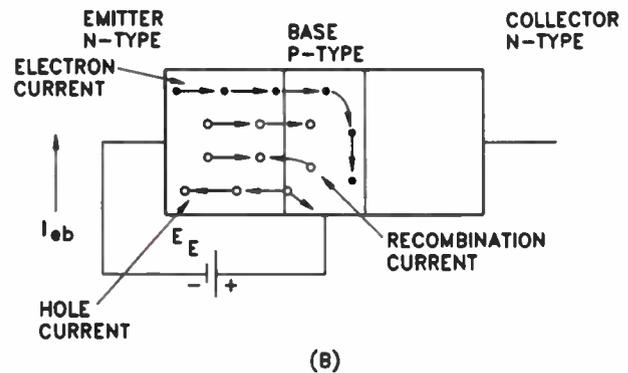
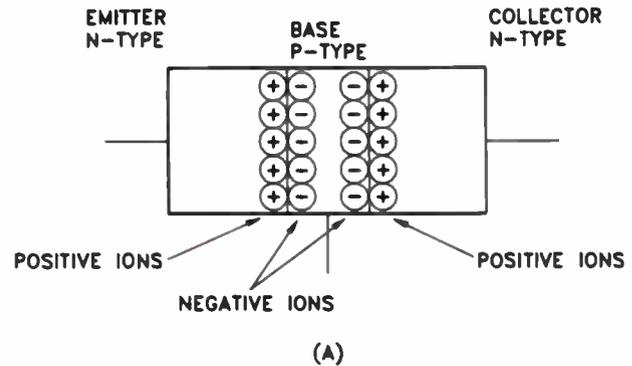
## NPN Transistors

The junctions of a junction transistor act just like the junctions in a junction diode. Between the emitter and base of the transistor, shown in Fig.2(A), there is a junction. Electrons diffuse from the emitter across the junction into the base of the transistor. When an electron leaves an atom in the emitter, it leaves a hole behind, creating a positive ion. At the same time, an electron moving into a hole in an atom in the base region creates a negative ion. A positive charge builds up on the emitter side of the junction and a negative charge builds up on the base. These charges prevent further diffusion of holes and electrons across the junction.

Meanwhile, the same thing happens at the junction between the base and the collector. Electrons diffuse across the junction into the base region, and holes diffuse across the junction into the collector, building up a negative charge on the base side and a positive charge on the collector. Once established, these charges prevent any further diffusion of electrons and holes across the junction.

Look at what happens when a forward bias is placed across the emitter-base junction, as shown in Fig.2(B). Notice that the negative terminal of the battery connects to the emitter and the positive terminal of the battery connects to the base, which places a forward bias across the emitter-base junction.

The negative potential applied to the emitter forces electrons toward the junction, and attracts holes away from the junction. Both actions tend to neutralize the positively charged ions on the emitter side of the junction. The positive terminal of the battery attracts electrons away from the base side of the junction, while it repels holes toward it at the same time. These two actions tend to neutralize the charge on the base side of the junction.



**Figure 2.** (A) The formation of ions at the junctions of an npn transistor. (B) The current flow in the emitter-base circuit, and (C) in the collector-base circuit.

# HOW TRANSISTORS WORK

With the weakening of the barrier potential at the junction, electrons flow from the negative side of the battery, through the emitter, across the junction, into the base, and from the base to the positive terminal of the battery. At the same time, the positive terminal pulls electrons from the base, forming holes. These holes are repelled across the junction, through the emitter toward the end connected to the negative terminal of the battery. In the emitter, holes pick up electrons and disappear. Thus, we have a current flow through the emitter-base circuit as shown in Fig.2(B).

Not all the electrons crossing the emitter-base junction reach the positive terminal of the battery. Some of them fill holes in the p-type base material. Similarly, not all the holes crossing from the base into the emitter reach the negative terminal of the battery. Some are filled by electrons in the emitter. This current, made up of electrons that fill holes in the base and holes that are filled by electrons in the emitter, is called a *recombination current* and the transistor is designed to keep this current as low as possible because it serves no useful purpose. To maximize transistor efficiency, we want the holes and electrons crossing the junction to reach the ends of the crystal.

Now let's see what happens when a reverse bias is placed across the base-collector junction by connecting the negative terminal of a battery to the base, and the positive terminal to the collector, as shown in Fig.2(C). This increases the negative charge on the base of the junction and the positive charge on the collector side of the junction, so the potential barrier across the junction increases. This prevents current flow across the base-collector junction due to majority carriers.

At the same time, electrons, which are minority carriers in the base, break loose from their atoms and from the depletion layer on the

base side of the junction. These electrons are attracted by the positive potential applied to the collector. They cross the junction and flow through the collector to the terminal connected to the positive side of the battery, as shown in Fig.2(C).

Simultaneously, holes formed in the depletion layer on the collector side of the junction move toward the negative terminal of the battery, cross the junction, and flow over into the base and toward the negative terminal of the battery. Here they pick up electrons and disappear. Thus, we have a current flow in the base-collector circuit due to the minority carriers.

Now look at what happens when bias voltages are applied across both junctions of the npn transistor, as shown in Fig.3. Considering first the emitter-base circuit, we have electrons flowing from the negative terminal of the battery, through the n-type emitter, across the junction and into the base. Some electrons reaching the base recombine with holes. However, most

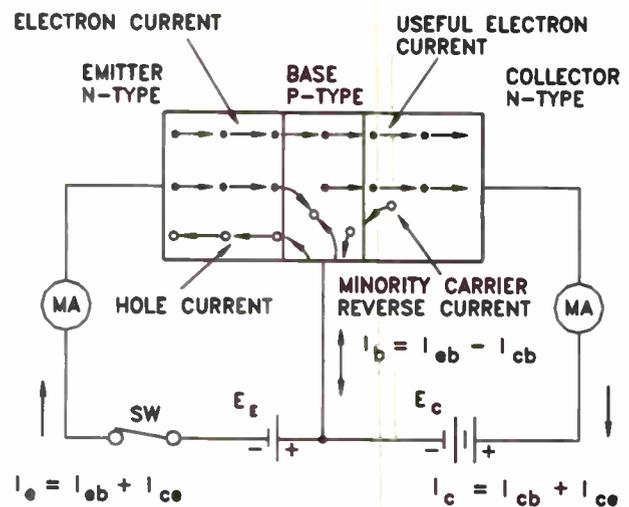


Figure 3. Current flow and carrier movement in an npn junction transistor.

electrons reaching the base are attracted to the positive potential applied to the collector and flow through the base, across the positive terminal of the battery.

At the same time, the positive potential applied to the p-type base pulls electrons out of the crystal, producing holes. These holes cross the junction into the emitter, drawn by the applied negative voltage. These holes flow through the emitter to the end connected to the battery, where they pick up electrons and disappear.

In the base-collector circuit, a reverse current flows due to the minority carriers. Holes appearing in the collector side of the depletion layer cross the junction into the base and flow toward the negative terminal of the battery, biasing the base-collector junction. Electrons in the depletion layer on the base side of the junction are attracted toward the positive potential applied to the collector. They cross the junction and flow toward the positive terminal of the battery connected between the base and the collector.

With all these currents flowing, the most important, useful current flow is that of electrons from the emitter, through the base, and to the collector. Since this is the useful current, we are interested in making it as large as possible in comparison to the other currents. Recombination current is kept as low as possible by adding more donor atoms to the emitter than acceptor atoms to the base. In this way, there will be more free electrons in the emitter than there will be holes in the base, so the recombination current will be quite small. In a good transistor, over 95% of the electrons that cross the emitter-base junction will flow to the collector.

## PNP Transistors

Now let's see how the pnp transistor functions. In this transistor the emitter and the collector are both made of p-type material and the base is made of n-type material. First, let's consider what happens at the two junctions before any voltages are applied to the transistor.

At the junctions, holes from the p-type emitter section and the p-type collector section diffuse across the junctions into the base. The holes diffusing into the base place a positive charge on the atoms near the junctions. At the same time, electrons from the n-type base diffuse across the junctions into both the emitter and collector. These electrons diffusing from the base into the emitter, on one side of the base, and the collector, on the other side of the base, place a negative charge on the atoms on the emitter and collector sides of the junctions. These charged atoms, or *ions*, will repel the electrons and holes from the region of the junction to prevent any further diffusion across the junctions. Thus we will have two depletion layers formed, as shown in Fig.4(A) on the next page.

Before going any further, you should compare Fig.2(A), which shows the depletion areas in an npn transistor, with Fig.4(A), which shows the depletion areas in a pnp transistor. Notice that the depletion areas have opposite polarities. In the npn transistor, at the emitter-base junction, there are positive ions on the emitter side of the junction and negative ions on the base side of the junction. With the pnp transistor, there are exactly the opposite: the negative ions are on the emitter side of the junction and the positive ions are on the base side of the junction.

# HOW TRANSISTORS WORK

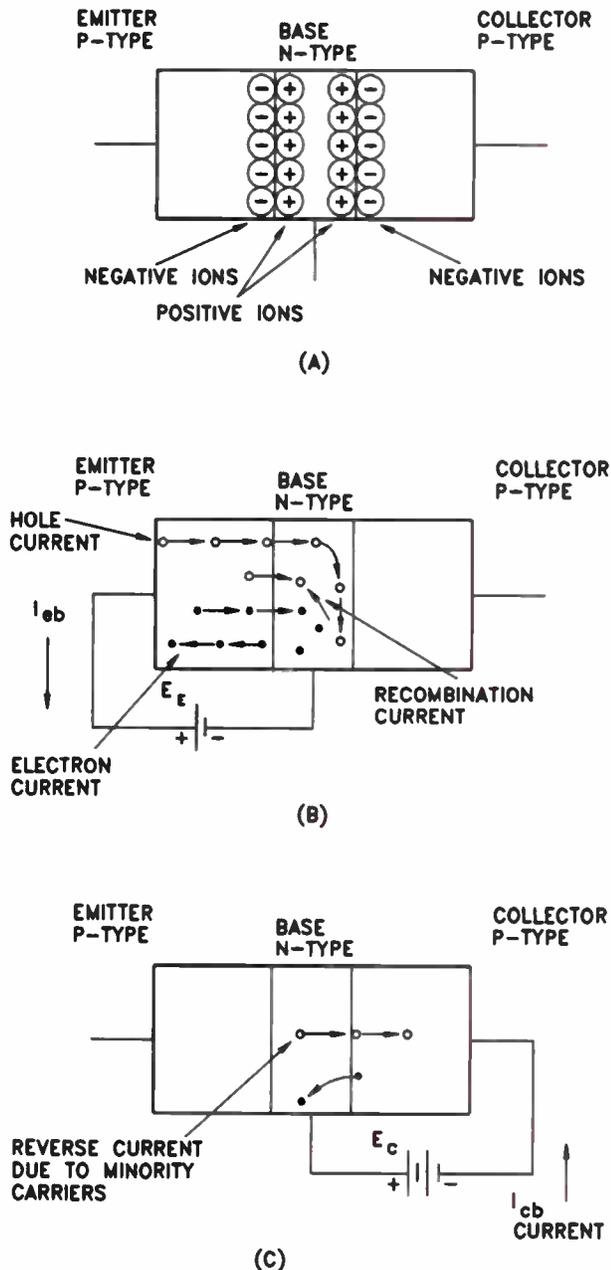


Figure 4. (A) The formation of ions at the junction of a pnp transistor. (B) The current flow in the emitter-base circuit, and (C) in the collector-base.

Notice that the polarity of the depletion layers in the base-collector junctions is also reversed. In the npn transistor there are negative ions on the base side of the junction and positive ions on the collector side. In the pnp transistor, on the other hand, there are positive ions on the base side of the junction and negative ions on the collector side of the junction.

Getting back to the pnp transistor, when a forward bias is placed between the emitter and the base, an arrangement is formed like that shown in Fig.4(B). Here the positive voltage applied to the end of the p-type emitter repels holes toward the junction. These holes tend to neutralize the negatively charged ions on the emitter side of the junction. The holes are formed at the end of the p-type section by electrons attracted out by the positive potential applied to this section. At the same time, the positive potential applied to the emitter attracts the electrons that have given the ions on the p-side of the junction their negative charge. This also weakens the negative charge on the emitter side of the junction.

At the base, the holes are attracted toward the negative terminal of the battery, while the electrons are pushed toward the depletion layer. The pulling of holes away from the depletion area and the pushing of electrons into it tend to neutralize the charge on the base side of the junction. The net effect of biasing in the forward direction is to neutralize the charges on each side of the junction and to allow current flow across the junction. Current flow is by *majority carriers*: electrons on the n-type base region and holes from the p-type emitter region.

Thus in the emitter-base circuit, we have electrons flowing from the negative terminal of the battery to the base, through the base, across the junction, and through the emitter to the positive terminal of the battery. At the same

time, we have holes being produced because electrons are being pulled out of the p-type emitter by the positive potential applied to it. The holes move through the emitter, across the junction, into the base, and to the point where the base is connected to the negative terminal of the battery. At this point, the holes pick up electrons and disappear.

Not all the electrons going from the base to the emitter reach the positive terminals of the battery. Some of these electrons recombine with holes in the emitter. Similarly, some of the holes traveling from the emitter into the base pick up an electron in the base. Once again, this is a recombination current and must be kept as low as possible.

Now consider the base-collector junction. This junction is reverse-biased as shown in Fig.4(C). Here we have a depletion layer at the junction. We also have minority carriers being formed in the depletion layer. Holes that are formed in the base region cross the junction, and, instead of neutralizing a negatively charged atom near the junction on the collector, are attracted by the negative potential applied to the collector. Similarly, electrons formed in the depletion layer of the p-type collector cross the junction and are attracted by the positive potential applied to the base. Thus, we have a current flow due to minority carriers.

Now let's see what happens when both junctions are biased as shown in Fig.5. Electrons flow from the negative terminal of the battery into the base, across the emitter-base junction, and through the emitter to the positive terminal of the battery. Some holes are formed in the p-type emitter section due to the electrons being pulled out of the section by the positive terminal of the battery.

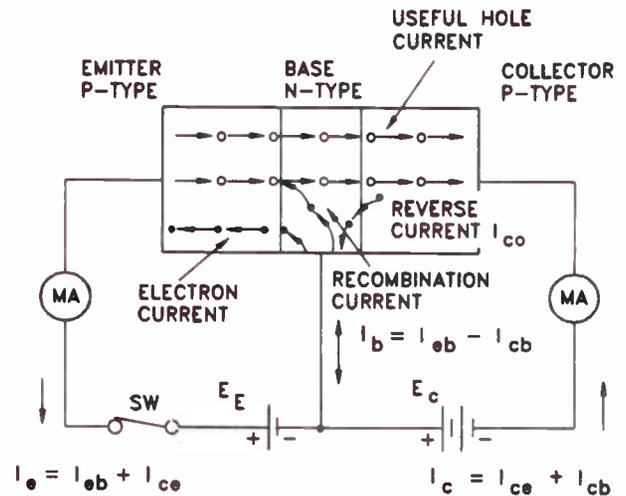


Figure 5. Current flow and carrier movement in a pnp junction transistor.

Some of these holes cross the junction into the n-type base where they pick up an electron and disappear. This is the recombination current.

Most of the holes produced in the emitter cross the emitter-base junction into the base where they are attracted by the negative potential applied to the collector. These holes cross the base, the base-collector junction, and flow to the collector terminal connected to the negative terminal of the battery. Here the holes pick up electrons and disappear.

There is another current crossing the base-collector junction due to minority carriers found in the depletion layer. Electrons formed on the collector side of the junction cross over and are attracted by the positive terminal of the battery, which connects to the base-collector junction. Similarly, holes formed on the base side of the depletion layer are attracted by the negative terminal of the battery connected to the collector.

## HOW TRANSISTORS WORK

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All in all, there are four currents flowing in the pnp transistor, just as in the npn transistor. The largest of these currents is due to the movement of holes from the emitter through the base, into the collector, to the negative terminal of the battery connected to the collector. In addition to this current, there are three small currents flowing. One is the current created by the electron movement from the negative terminal of the emitter-base battery into the base, across the base, across the junction, and through the emitter to the positive terminal of the battery. Another is the recombination current due to the holes combining with electrons in the base. And the last one is the reverse current due to the hole-electron pairs being formed in the depletion layer of the base-collector junction. Directions of movement of holes and electrons are shown in Fig.5.

In the pnp transistor, the recombination current is kept as low as possible because it serves no useful purpose, just like the npn transistor. In the npn transistor, the recombination current is kept to a minimum by adding more acceptor atoms to the emitter than donor atoms to the base. This makes more free holes in the emitter than there are free electrons in the base, so the recombination current will be quite small. In a good pnp transistor, over 95% of the holes that cross the emitter-base junction flow to the collector.

Note the similarities and differences between the pnp and npn transistors. In both transistors, useful current comes from majority carriers in the emitter of the transistor. In the npn transistor, electrons flow from the negative terminal of the battery, through the emitter, across the emitter-base junction and the base, across the base-collector junction, and through the collector to the positive terminal of the battery.

In the pnp transistor, electrons flow from the negative battery terminal to the collector, where

they fill holes arriving at the collector terminal. The positive terminal of the emitter-base battery attracts electrons from the emitter, and these electrons flow through the battery over to the positive terminal of the base-collector battery. Meanwhile, the holes produced by the emitter terminal of the battery move across the emitter, the emitter-base junction, the base, the base-collector junction, and the collector to the terminal connected to the negative terminal of the battery. There they are filled by electrons.

Notice that in both types of transistors, current flows by majority carriers; and that in both cases the majority carriers move from the terminal of the battery connected to the emitter, across the emitter, across the emitter-base junction, across the base, across the base-collector junction, and through the collector to the terminal of the battery connected to the collector. In the external circuit of the npn transistor (the circuit made up of the batteries), the electrons are flowing in the same direction as the majority carriers in the transistor. In the pnp transistor, since the majority carriers in the transistor are holes, the electrons in the external circuits are flowing in a direction opposite that of the majority carriers.

We have covered a great deal in this section on transistors, and it would be a good idea to review this section again. The important thing to remember is that the useful current through a transistor is by majority carriers. In the npn transistor the majority carriers are electrons and in the pnp transistor the majority carriers are holes.

You should also notice the polarity of the batteries used to forward bias the emitter-base junction and reverse bias the base-collector junction. To forward bias the emitter-base junction to an npn transistor, you connect the negative terminal of the battery to the emitter and the positive

terminal to the base. To forward bias a pnp transistor, connect the positive terminal of the battery to the emitter and the negative terminal of the battery to the base. To reverse bias the base-collector junction of an npn transistor, you connect the negative terminal of the battery to the base and the positive terminal to the collector. To reverse bias the base-collector junction of a pnp transistor, you connect the positive terminal of the battery to the base and the negative terminal of the battery to the collector.

## Alloy-Junction Transistors

The first transistors were germanium grown-junction transistors. This transistor is made from a small rectangular bar cut from a germanium crystal that has been grown. Suitable impurities are added so that the npn regions shown in Fig.6 are formed. The base of the transistor, which is kept as thin as possible, is located midway between the two ends. Suitable contacts are welded to the emitter, base, and collector regions.

The disadvantage of this type of transistor is that it is not particularly well-suited for operation at high frequencies. In addition, it is temperature-sensitive and can become quite unstable at high temperatures.

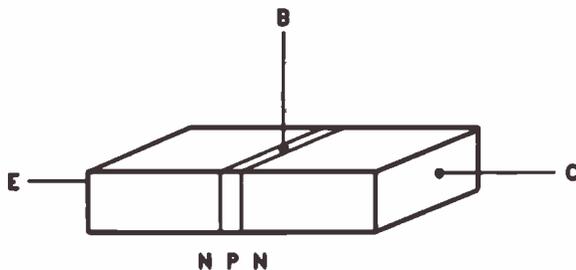


Figure 6. A grown-junction transistor.

Modern transistors are silicon alloy-junction transistors. There are a number of different types of alloy-junction transistors. In this section of the lesson we are going to discuss these transistors briefly. You do not have to remember the name of each type; they are all junction transistors and work in basically the same way.

A pnp *alloy-junction transistor* is made by taking a small rectangular piece of n-type semiconductor material and fusing small dots of indium into it on opposite sides, as shown in Fig.7. This results in p-type material being formed at the points where the dots are fused into the wafer, making a pnp transistor.

An npn transistor can be made by taking a piece of p-type semiconductor material and fusing a lead antimony alloy into the two opposite sides. It is possible to get more uniform penetration of the lead antimony alloy into the semiconductor material in this type of transistor, and thus better junction spacing. This cuts down on the width of the material between the emitter and the collector and gives improved high-frequency performance.

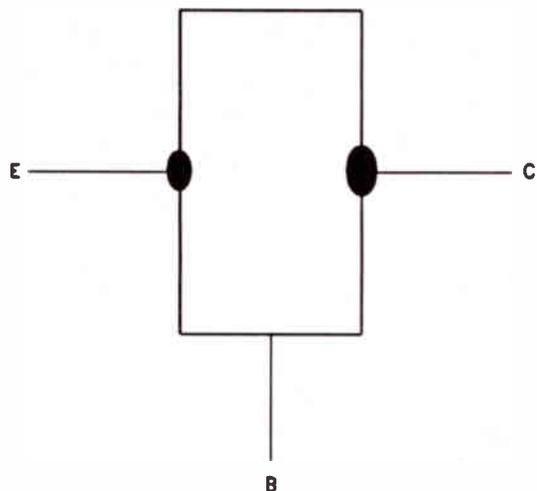


Figure 7. An alloy-junction transistor.

# HOW TRANSISTORS WORK

This type of transistor operates better at higher frequencies than the grown-type junction transistor. It has a higher potential for amplification, and remains stable as the temperature increases.

The *surface-barrier transistor* is an alloy-junction transistor in which pits are etched into the silicon, as shown in Fig.8, before adding the impurities that form the emitter and collector. Surface-barrier transistors perform well at high frequencies.

Notice that in both Fig.7 and Fig.8 the collector is larger than the emitter. In Fig.8(B) we have shown the way in which the majority carriers spread out as they cross the base, traveling from the emitter to the collector.

**Diffusion Transistors.** Diffusion is the passage of one material through another. Although a material might look and feel solid, there is a lot of space between its atoms. If you filled a sealed glass jar with hydrogen and allowed it to sit for several days, you would find that the hydrogen had escaped and that the glass was filled with air. Hydrogen atoms are very small and very active, and simply diffuse through the glass. This technique is used in the manufacture of the drift transistor, the mesa transistor, and

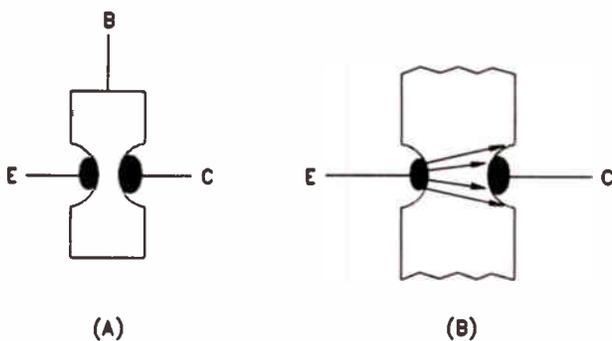


Figure 8. (A) Sketch of a surface-barrier transistor. (B) Hole movement across the base.

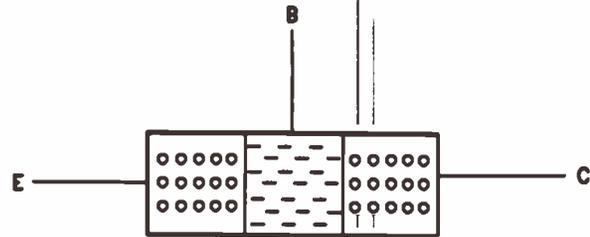


Figure 9. Diagram showing how a large number of donor impurities increases the electron concentration in the base.

the planar transistor, all of which are classified as diffusion transistors.

In the *drift* type of pnp transistor shown in Fig.9, the emitter-base and the collector-base junctions are formed by the alloy technique, but the base region is made by the diffusion process in which the impurities in the base region are varied. In a typical transistor of this type, the concentration of the donor impurities added to the base is controlled so that concentration is highest at the region of the emitter-base junction, then drops off quickly, and finally reaches a constant value which it maintains over to the base-collector junction.

The pnp *mesa* transistor starts with a piece of p-type material, to which donor impurities are added to form the base region, as shown in Fig.10. After the base is formed, acceptor impurities are added to form the emitter and emitter-base junction.

The advantages of the mesa transistor are good high-frequency response and very consistent performance. It is possible to control the manufacturing techniques quite closely so that the characteristics of mesa transistors of the same type are quite similar. This is not necessarily true of other transistors; their characteristics often vary over a wide range.

An npn *planar* transistor is formed from n-type silicon. Acceptor impurities are diffused

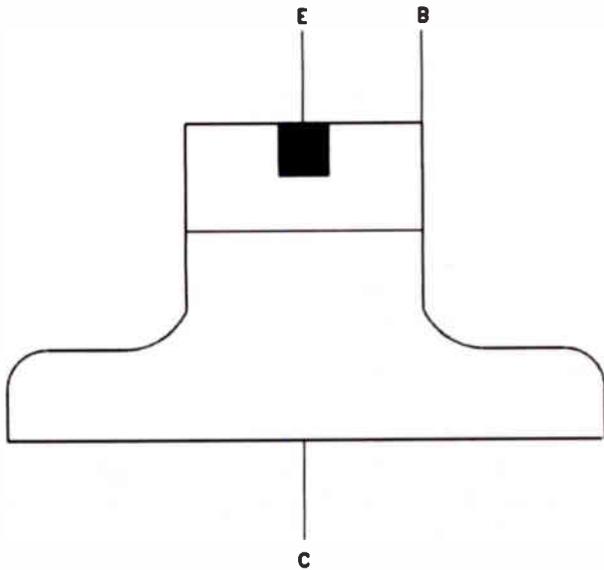


Figure 10. A mesa transistor.

into a region to form the base, as shown in Fig.11. The donor impurities are then diffused into a small region in the center of the base to form the emitter. Notice that because all junctions are brought back to the same plane, this type of transistor is called *planar*. Planar transistors usually have a very low reverse current.

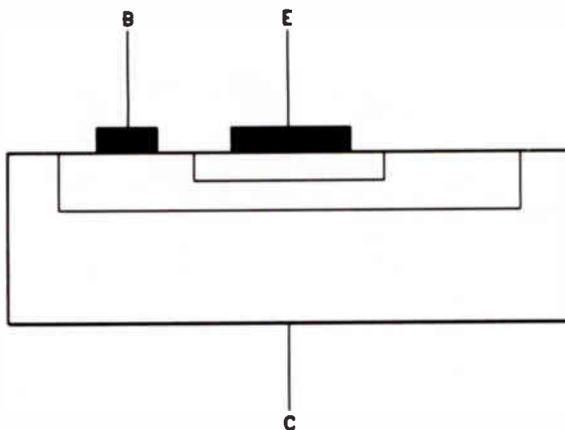


Figure 11. A diffused planar-type transistor.

**Epitaxial Transistors.** One disadvantage of the diffusion-type transistor is the relatively high resistance of the collector. This limits its usefulness at high frequencies. If we reduce the resistance of the collector, we introduce the possibility of a collector-base or a collector-emitter short, which destroys the transistor. Both these problems can be overcome with an epitaxial transistor, shown in Fig.12. In this type of transistor, the collector region immediately adjacent to the base-collector junction is doped to have a high resistance. The remainder of the collector is doped to have a low resistance. This technique improves the high-frequency performance of the transistor and at the same time reduces the possibility of a collector short.

## Review

Remember that in an npn transistor the majority carriers are electrons. They cross the emitter to the emitter-base junction. A few electrons leave the transistor at the base, but most cross the base-collector junction and flow through the collector to the positive voltage source. In a good npn transistor, over 95% of the

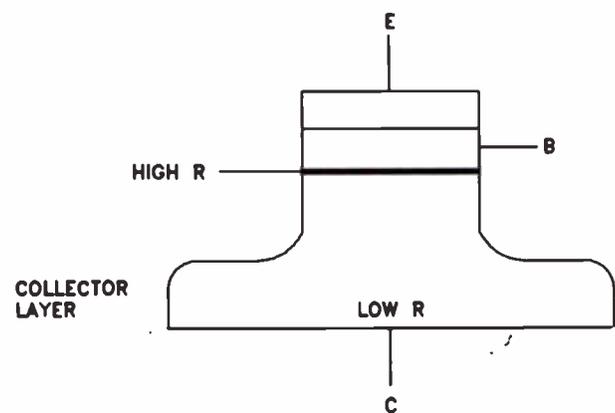


Figure 12. A double-diffused epitaxial transistor.

## HOW TRANSISTORS WORK

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electrons crossing the emitter-base junction eventually reach the collector.

In a pnp transistor the majority carriers are holes. They are produced in the emitter because electrons are pulled out of the emitter by the positive terminal of the voltage source connected to the emitter. The holes cross the emitter and the emitter-base junction and enter the base. A few of the holes travel over to the base terminal where they are filled by electrons, but most of the holes cross the base, the base-collector junction, and the collector. Here they are filled by electrons from the external voltage source. In a good pnp transistor, over 95% of the holes produced in the emitter cross the base to the collector.

### Self-Test Questions

*Please check your answers on page 18.*

- 1 What two materials have been used in the manufacture of transistors?
- 2 What two types of junction transistors are widely used?
- 3 What type of bias is used across the emitter-base junction of a transistor?
- 4 What type of bias is used across the collector-base junction of a transistor?
- 5 Draw a diagram of a pnp transistor and show how the batteries are connected to place the correct bias across the two junctions.
- 6 Draw a diagram of an npn transistor and show how the batteries are connected to place the correct bias across the two junctions.
- 7 What are the useful current carriers in a pnp transistor?
- 8 What are the useful current carriers in an npn transistor?

## FIELD-EFFECT TRANSISTORS

So far, you have studied npn and pnp transistors. These transistors are called *bipolar* devices because their operation depends on the interaction of holes and electrons. The *field-effect transistor* is a unipolar device, whose operation depends on either holes or electrons, but not both.

Field-effect transistors can be divided into two types: the *junction-gate field-effect transistor* and the *insulated-gate field-effect transistor*. Let's look at the junction-gate field-effect transistor first.

### Junction-Gate Field-Effect Transistors

One type of junction-gate field-effect transistor is made from a piece of n-type material, as shown in Fig.13. If the negative terminal of a battery is connected to one end of the material and the positive terminal to the other end, electrons flow through the material from one end to the other. If we attach a piece of p-type material to one side so that a pn junction is

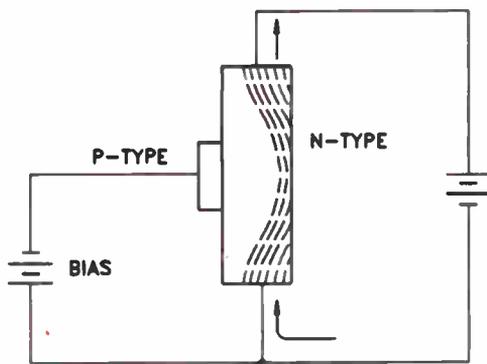


Figure 13. Drawing showing the basic operation of a field-effect transistor.

formed, and place a negative voltage on the p-type material, as shown in Fig.13, there can be no current flow across the junction, because the junction is reverse-biased.

However, the negative voltage applied to the p-type material creates a field that extends into the n-type material. This field blocks the flow of electrons through the n-type material, forcing them to one side, as shown in Fig.13. We call the n-type material a *channel*. The p-type material is called the *gate*. The effect of the gate is to narrow the channel and increase its effective resistance. A very high negative voltage applied to the gate can completely block the flow of electrons through the n-type channel. This type of transistor is called an *n-channel junction field-effect transistor*, or *n-channel JFET*.

Figure 14 shows the schematic diagram of the circuit in Fig.13. The end at which the electrons enter the channel is called the *source*, *S*. The other end, where electrons exit the channel, is called the *drain*, *D*. Notice the direction in which the arrow is drawn; this indicates a p-type gate, which means that the transistor is an n-channel JFET.

A p-channel JFET is created by using p-type material as the channel and n-type material as the gate. Figure 15, on the next page, is the schematic of a circuit similar to Fig.14 using a p-channel JFET. Notice that the direction in

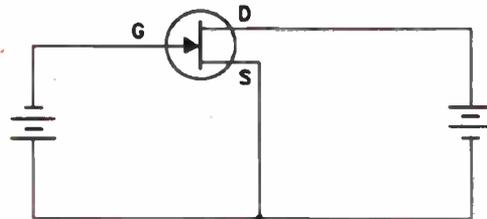


Figure 14. Schematic representation of the n-channel FET circuit shown in Fig.13.

## HOW TRANSISTORS WORK

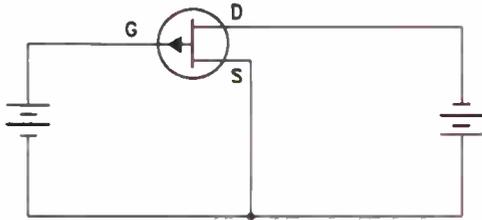


Figure 15. Schematic of a circuit using a p-channel JFET.

which the arrow is pointing is reversed to indicate an n-type gate and a p-channel JFET.

In the p-channel JFET, the battery connections to source and drain are reversed. Electrons in the p-channel material move toward the positive terminal of the battery, leaving holes behind them. At the circuit connection to the drain, the holes are filled by electrons from the negative terminal of the battery. Thus, there are holes moving through the channel from the source to the drain, but electrons are flowing in the external circuit in the opposite direction.

Notice that the battery connected between the gate and the source is also reversed. This battery is called the *bias battery*. The holes traveling through the channel are repelled by the positive voltage on the gate. Increasing this positive voltage can reduce, or cut off the flow of holes through the channel completely.

As you can see, in the n-channel JFET the number of electrons flowing through the channel depends upon the amplitude of the bias voltage. Similarly, in the p-channel JFET, the number of holes traveling through the channel depends upon the bias voltage. When this voltage varies, the carriers traveling through the channel vary. This characteristic of a JFET allows a relatively small signal voltage on the gate to control a much larger, or amplified, voltage in the output circuit. We will discuss amplification in a later lesson.

## Insulated-Gate Field-Effect Transistors

In addition to the junction-gate field-effect transistor, there is an *insulated-gate field-effect transistor*, or *IGFET*. In the IGFET, the gate is completely insulated from the channel by a thin insulating material. For example, a very thin piece of glass or mica might be placed between the conducting channel and the gate. Thus, there is no actual junction formed between the semiconductor materials in the channel and gate.

To make an n-channel IGFET, we start with a lightly doped p-type material called the *substrate*. Donor atoms are diffused into the top of the substrate to form an n-channel as shown in Fig. 16. A glass insulator placed on the side of the channel insulates the gate. When a battery is connected across the n-channel as shown in Fig. 17, electrons leave the battery and flow to the source, through the channel, to the drain, and back to the positive terminal of the battery. When a negative voltage is placed between the gate and the source as shown in Fig. 17, the channel is effectively narrowed so that the

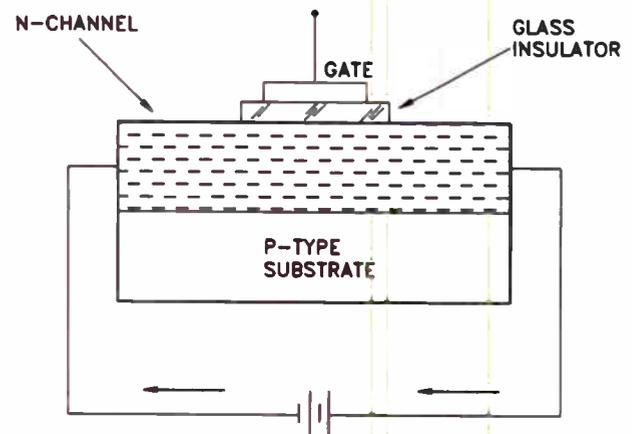


Figure 16. Current flow through an n-channel IGFET with no bias applied.

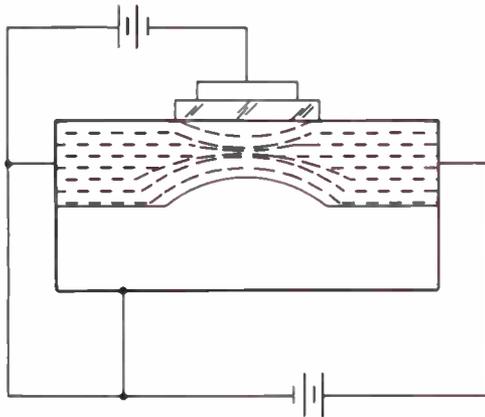


Figure 17. Current flow through an n-channel IGFET with bias applied.

resistance of the channel increases according to the magnitude of the gate voltage.

Instead of using an n-type material for the channel and a p-type material for the gate in an IGFET, a thin piece of metal that has been oxidized on one side is used for both the gate and the insulator. Metal oxides can be used as insulators because they do not conduct electricity. The advantage of this arrangement is that the oxide of the metal can be made very thin, putting the metal gate much closer to the channel. This type of device is called a *metal oxide, semiconductor field-effect transistor*. Sometimes you'll see this abbreviated as *MOS field-effect transistor*, but more often you see it abbreviated *MOS-FET* (pronounced Mossfet).

Both n-channel and p-channel MOSFETs are manufactured. The schematic symbols used to represent the two types are shown in Fig.18. Figure 18(A) shows the symbol for an n-channel type, and Fig.18(B) shows the symbol for a p-channel type. They work essentially the same way as JFETs, except that there is no current flow at all from the channel to the gate or from the gate to the channel. In the JFET, there may

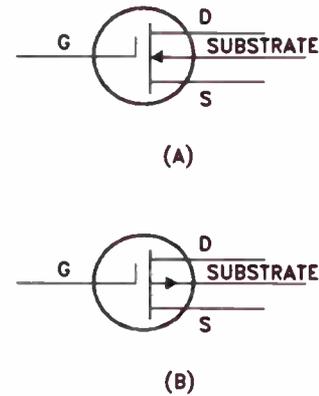


Figure 18. Insulated-gate, field-effect transistors. (A) Schematic symbol for an n-channel unit, and (B) the symbol for a p-channel unit.

be a very small leakage current across the junction. In the MOSFET, however, there is no current flow between the gate and the channel.

Both the JFET and the IGFET (MOSFET) discussed so far use a reverse bias between the junction and the channel. This reverse bias reduces the number of carriers passing through the channel. If the bias is made high enough, it prevents the flow of carriers through the channel, or is said to deplete the carriers in the channel. Thus, these FETs are known as *depletion types*. There is another type of FET called an *enhancement type*. Let's see how it works.

All enhancement-type FETs are insulated-gate FETs. In the enhancement type, there is no channel. The channel is formed between the source and drain when we place a forward bias between the gate and the substrate. You cannot have an enhancement type JFET because the forward bias would cause a high current to flow through the gate.

A sketch of an n-channel enhancement type of IGFET is shown in Fig.19, on the next page. We start with a p-type substrate and diffuse two n-type regions into it, one for the source and one

# HOW TRANSISTORS WORK

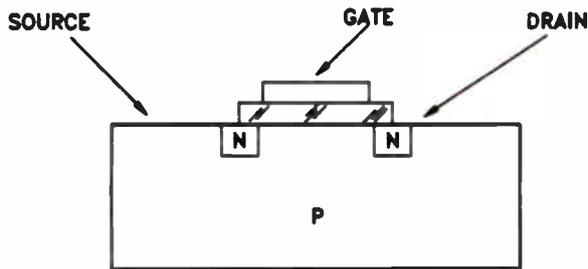


Figure 19. Sketch of an enhancement-type IGFET.

for the drain. Notice that there is a space between them and no direct channel from the source to the drain. The gate is placed so that it is opposite part of both the source and the drain.

When the negative terminal of a battery is connected to the source and the positive terminal to the drain, there is no current flow because there is no channel. If we add a second battery with its negative terminal connected to the source and its positive terminal connected to the gate, the positive voltage applied to the gate forces holes out of the p-type region between the source and the drain. At the same time, the negative voltage applied to the source forces electrons out of the source into the region between the source and the drain where they are attracted by the positive voltage applied to the drain. This creates a channel.

The higher the positive voltage applied between the source and the gate, the more holes are forced out of the p-type region between the source and the gate, and the more electrons are forced from the source into the channel and across the channel to the drain. Thus, increasing the voltage between the source and gate has the effect of reducing the resistance between the source and drain by creating a larger channel.

Figure 20 shows the schematic symbols for the enhancement-type IGFETs. The one shown in Fig.20(A) is for an n-channel and the one shown in Fig.20(B) for a p-channel. Compare these symbols with those shown in Fig.18. Notice that in Fig.18 there is a direct line between the source and drain in each case. This indicates that the channel exists, or in other words, that these are depletion-type IGFETs. In Fig.20, a direct line between the source and drain is not shown because the channel does not exist unless the correct voltage is applied to the gate. Thus, these are enhancement-type IGFETs.

In this discussion, we have referred to both the depletion-type and enhancement-type insulated-gate transistors as IGFETs since they are both insulated-gate field-effect transistors. However, you'll see them referred to as MOSFETs in almost every case because the gate of most IGFETs is a piece of metal and the insulation is an oxide formed on the metal. Don't let this confuse you; a MOSFET is a kind of IGFET. However, the term IGFET covers all insulated-gate field-effect transistors regardless of the materials used to insulate the gate.

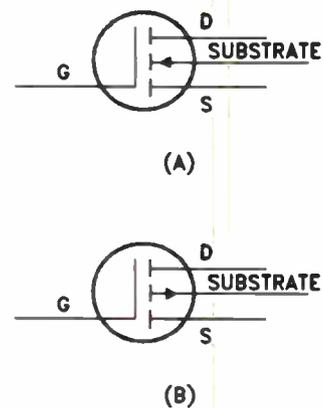


Figure 20. The schematic symbol for (A) an n-channel enhancement-type IGFET and (B) a p-channel unit.

## Review

Field-effect transistors are widely used in electronic equipment. There are two basic types, the junction-gate field-effect transistor (JFET) and the insulated-gate field-effect transistor (IGFET). Remember that in most IGFETs the gate is a piece of metal oxidized on one side. The oxide is the insulator between the gate and the channel. This type of field-effect transistor is usually called a MOSFET.

Also, remember that field-effect transistors can be made in both n-channel types and p-channel types. In a depletion-type IGFET, a channel is present and the voltage applied to the gate reduces the width, and hence, increases the resistance, of the channel. In the depletion-type field-effect transistor, the gate is always reverse-biased so there is no current flow between the gate and the channel except a small leakage current that might exist.

An IGFET can be either depletion-type or enhancement-type. In the enhancement-type IGFET, the channel between the source and drain does not exist until a voltage is applied to the gate.

## Self-Test Questions

- 9 What is the difference between a junction-gate field-effect transistor and an insulated-gate field-effect transistor?
- 10 What is a depletion-type field-effect transistor?
- 11 What is an enhancement-type field-effect transistor?
- 12 Is a MOSFET a junction-gate field-effect transistor or an insulated-gate field-effect transistor?

### ANSWERS TO SELF-TEST QUESTIONS

- 1 Germanium and silicon.
- 2 NPN and pnp.
- 3 Forward bias is used across the emitter-base junction. To forward bias the emitter-base junction in an npn transistor, the base is made positive with respect to the emitter. To forward bias the emitter-base junction in a pnp transistor, the base is made negative with respect to the emitter.
- 4 Reverse bias is used across the collector-base junction. To reverse bias the collector-base junction in an npn transistor, the collector is made positive with respect to base. To reverse bias the collector-base junction in a pnp transistor, the collector is made negative with respect to base.
- 5 See Fig.5.
- 6 See Fig.3.
- 7 The useful current carriers in a pnp transistor are holes.
- 8 The useful current carriers in an npn transistor are electrons.
- 9 In a junction-gate field-effect transistor, the gate is in contact with the channel. In the insulated-gate field-effect transistor the gate is insulated from the channel.
- 10 A depletion-type FET is a unit in which the channel is present between the source and the drain.
- 11 An enhancement-type FET is a unit in which there is no channel between the source and drain until the operating bias is applied to the gate.
- 12 A MOSFET is an insulated-gate field-effect transistor where the gate is made of a metal and the insulator is an oxide of the metal.

## Lesson Summary

Some of the important facts you should remember from this lesson are:

- Junction transistors are three-element semiconductor devices.
- The two basic types of junction transistors are npn and pnp.
- Forward bias allows conduction of electrons through a transistor, from emitter to collector.
- Reverse bias prevents current flow from emitter to collector of a transistor.
- Field effect transistors utilize field energy and polarity to establish or block a "channel" through a semiconductor material.

# HOW TRANSISTORS WORK

## LESSON QUESTIONS

**This is Lesson Number 2226.**

Make sure you print your name, student number, and lesson number in the space provided on the Lesson Answer Form. Be sure to fill in the circles beneath your student number and lesson number.

**Reminder:** A properly completed Lesson Answer Form allows us to evaluate your answers and speed the results and additional study material to you as soon as possible. Do not hold your Lesson Answer Forms to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

The form is titled "Lesson Answer Form" and contains the following fields and markings:

- Name: John Smith
- Print: \_\_\_\_\_
- Student No.: XY01237894
- Lesson No.: 2226

Below the fields is a grid of 10 rows and 20 columns of circles. The first two columns are labeled "Student No." and the last two columns are labeled "Lesson No.". The circles are filled in to match the numbers in the fields above. For example, the first row has a solid black square in the first column, followed by a circle with '0' in the second column, and circles with '2', '2', and '6' in the last three columns.

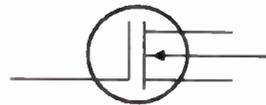
- In a correctly biased npn transistor, the base is:
  - Negative with respect to the emitter and negative with respect to the collector.
  - Negative with respect to the emitter and positive with respect to the collector.
  - Positive with respect to the emitter and negative with respect to the collector.
  - Positive with respect to the emitter and positive with respect to the collector.
- In a correctly biased pnp transistor the base is:
  - Negative with respect to the emitter and negative with respect to the collector.
  - Negative with respect to the emitter and positive with respect to the collector.
  - Positive with respect to the emitter and negative with respect to the collector.
  - Positive with respect to the emitter and positive with respect to the collector.
- Which of the following transistors is a unipolar device?
  - Alloy-junction transistor.
  - Diffusion transistor.
  - Epitaxial transistor.
  - Junction-gate field-effect transistor.
- Which of the following transistors is a bipolar device?
  - A JFET.
  - An IGFET.
  - An epitaxial transistor.
- What is a MOSFET?
  - A JFET.
  - An IGFET.
  - An npn transistor.
  - A pnp transistor.

## LESSON QUESTIONS

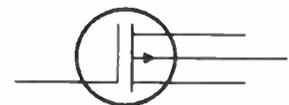
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6. In an npn transistor, what happens to an electron that crosses the emitter and the base and moves into the collector?
- It remains in the collector.
  - It fills a hole in an acceptor atom.
  - It returns to the base where it fills a hole.
  - It is attracted to the positive terminal of the battery.
7. In a pnp transistor, what happens to a hole that crosses the emitter and the base and moves into the collector?
- It remains in the collector.
  - It is filled by an electron from a donor atom.
  - It returns to the base to be filled by a free electron.
  - It is filled by an electron from the battery.
8. In a pnp transistor, electrons crossing from the base to the emitter:
- Serve no useful purpose.
  - Increase the movement of holes through the transistor.
  - Make it easier for holes to cross the base.
  - Prevent electrons from crossing the base-collector junction.

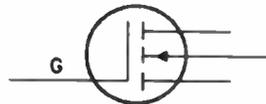
9. Which of the following is the schematic symbol for an n-channel enhancement-type MOSFET?



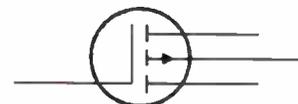
(A)



(B)



(C)



(D)

10. Which of the schematic symbols in the preceding question is the schematic symbol for a p-channel depletion-type MOSFET?

# NOTES

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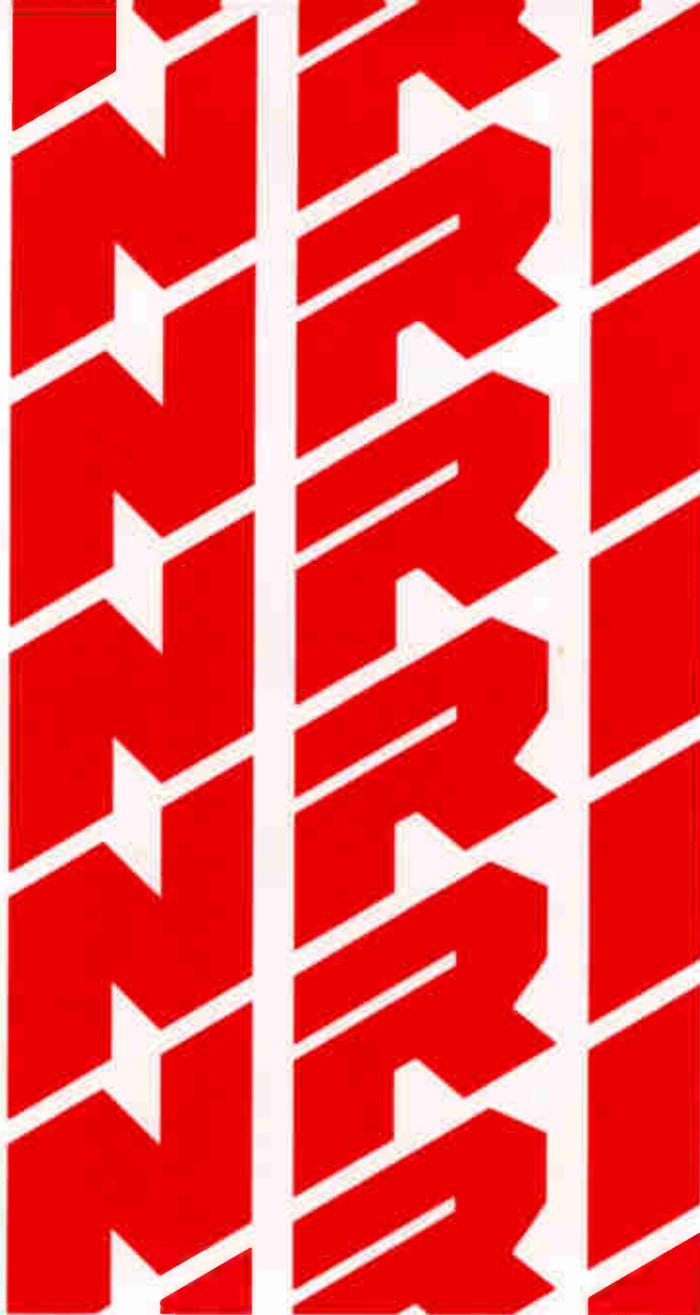
## **DIG A LITTLE DEEPER**

A poor farmer struggled for years to gain a living out of the rocky soil, then finally gave up in despair and sought fortune elsewhere. Years later, more wealth was being dug out of this rocky old farm every day than the farmer had ever dreamed existed. The farm had become a gold mine.

Many of us struggle along just like that poor farmer, never dreaming that success could be ours if we dug a little deeper right where we were. Millions of people are just barely getting along today, when they have the ability to do much better things, simply because they lack confidence in themselves. They are victims of mental defeat; they don't believe they can do anything better.

If you lack self-confidence and persistence — if you lack a sense of mastery, a consciousness of power, and a victorious mental attitude, begin now to cultivate self-confidence. How? Make your decisions with confidence and stick to them. Dig into your work a little harder, keep going a little longer, and soon you'll have the confidence that carries you speedily to success.





# How Transistors Are Used

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# **How Transistors Are Used**



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# Table of Contents

<b>Introduction</b> .....	1
<b>The Common-Emitter Circuit</b> .....	2
The Common-Emitter NPN Amplifier .....	2
The Common-Emitter PNP Amplifier .....	7
Characteristics of Common-Emitter Circuits .....	9
Review .....	11
Self-Test Questions .....	11
<b>The Common-Base Circuit</b> .....	12
The Common-Base NPN Amplifier .....	12
The Common-Base PNP Amplifier .....	15
Characteristics of Common-Base Circuits .....	17
Review .....	18
Self-Test Questions .....	18
<b>The Common-Collector Circuit</b> .....	19
The Common-Collector NPN Amplifier .....	19
The Common-Collector PNP Amplifier .....	21
Characteristics of Common-Collector Circuits .....	23
Review .....	24
Self-Test Questions .....	24
<b>Field-Effect Transistors</b> .....	25
Junction-Gate Field-Effect Transistors .....	25
Insulated-Gate Field-Effect Transistors .....	29
Dual-Gate MOSFETs .....	29
Review .....	30
Self-Test Questions .....	31
<b>Transistor Characteristics</b> .....	32
Transistor Symbols .....	32
Current Gain .....	33
Review .....	34
Self-Test Questions .....	34
<b>Answers To Self-Test Questions</b> .....	35
<b>Lesson Questions</b> .....	37

# Lesson Objectives

In this lesson you will . . .

- Become familiar with the three basic types of transistor amplifiers.
- Learn the differences in npn and pnp amplifier circuits.
- Discover how amplifier characteristics are matched for input and output circuit impedance.
- Learn how field-effect transistors are used as amplifiers.
- Learn some new symbols and abbreviations for important transistor circuit characteristics.

### INTRODUCTION

Many years ago, all electronic equipment used vacuum tubes. There were no transistors. Even giant computers were made of thousands of vacuum tubes. The invention of the transistor led to the development of the integrated circuit (IC). An *integrated circuit* is simply a device containing many transistors, usually designed to do a certain job.

As manufacturers learned how to stuff more and more transistors into relatively small integrated circuits, more sophisticated devices were developed. The grouping of many transistors into a small package is called *large-scale integration (LSI)*. LSI led to the development of the microprocessor, which is used in industry to control machines, in video cassette recorders to control the operation of the recorder, and in microcomputers. Today's desktop microcomputer can outperform computers that used thousands of vacuum tubes.

Despite the rapid developments in circuit integration, there are many places where discrete (individual and separate) transistors are used. Learning how transistors operate in these basic "building-block" circuits will help you understand other circuits that use them.

There are many ways to use a transistor, and one of the most important is to amplify a signal. A weak signal fed to a transistor amplifier produces a strong signal at the output. Junction transistors and field-effect transistors can both amplify signals. In this lesson we are going to see how transistors are used as amplifiers, beginning with junction transistors.

Junction transistors can be placed into three basic amplifier circuit configurations. These circuits are the common-emitter circuit, the common-base circuit, and the common-collector circuit. Of the three, the common-emitter circuit is the most widely used.

## HOW TRANSISTORS ARE USED

### THE COMMON-EMITTER CIRCUIT

The *common-emitter circuit* uses either an npn or a pnp transistor. Common-emitter amplifier circuits using npn transistors are a little easier to understand, so we will start the discussion with them.

#### The Common-Emitter NPN Amplifier

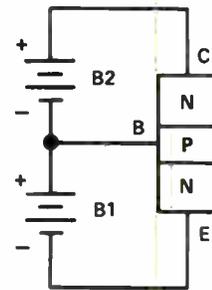
You have learned that a transistor conducts when there is a forward bias across the emitter-base junction and a reverse bias across the collector-base junction. In the case of an npn transistor, this means that the base must be positive with respect to the emitter, and negative with respect to the collector. Another way to state this is that the base must be more positive than the emitter, and the collector must be more positive than the base.

Figure 1(A) shows the battery connections to correctly bias an npn transistor. Instead of drawing the transistor horizontally, as we did in the previous lesson, we've drawn it vertically. Notice that B1 forward biases the emitter-base junction and B2 reverse biases the collector-base junction.

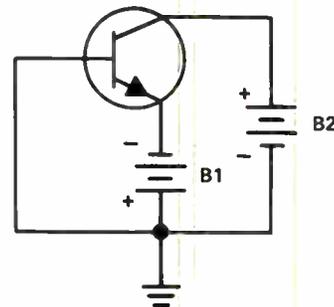
Figure 1(B) is the same circuit in schematic form. To forward bias the emitter-base junction, we connect the positive terminal of B1 to the base, and the negative terminal to the emitter. To reverse bias the collector-base junction, the positive terminal of B2 connects to the collector, and the negative terminal to the base. Figure 1(B) is an exact schematic representation of Fig.1(A).

In Fig.1(C) the circuit is rearranged, but the bias voltages applied to the transistor are unchanged. Notice that the positive end of B1 now

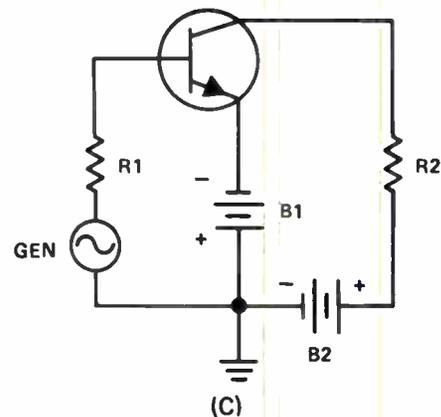
connects through an ac generator and through R1 to the base. The negative end connects to the emitter, so the emitter-base junction is still forward biased. The negative terminal of B2 connects



(A)



(B)



(C)

Figure 1. (A) and (B) Correct biasing for an npn transistor. (C) The common-emitter circuit.

## THE COMMON-EMITTER CIRCUIT

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through the generator and R1 to the base of the transistor. The positive terminal connects through R2 to the collector of the transistor. The collector-base junction is still reverse biased.

Notice that we've shown a ground symbol. This does not change the transistor biasing in any way. We've added this symbol because in the common-emitter circuit, the emitter is normally operated at what is called signal ground potential. In other words, as far as any signal is concerned, the emitter is connected directly to ground. In the circuit shown in Fig.1(C), the battery B1 will have such a low resistance to ac that, for all practical purposes, the emitter is at signal ground potential. If the battery has a high resistance we can bring the emitter to signal ground potential by connecting a large capacitor across the battery. Remember that a large capacitor will have a very low reactance to an ac signal.

The same situation exists in the collector circuit. B2 has a very low resistance, so the lower end of R2 is effectively at signal ground potential. Again, if for any reason B2 had a high resistance, we could bypass it with a large capacitor so that once again the lower end of R2 will be at signal ground potential.

As we said previously, most of the electrons crossing the emitter and the emitter-base junction will cross the base and the base-collector junction and flow through the collector to the positive terminal of B2. B2 will supply the current to the emitter that is eventually going to reach the collector.

Remember also that we said that not all of the electrons crossing the emitter-base junction will cross the base and reach the collector. Some will leave the transistor at the base. B1 will supply these electrons. The current from B1 will flow to the emitter, cross the emitter-base junction, and leave the transistor at the base lead. It will then

flow through R1 and the generator back to the positive terminal of B1.

Transistor current supplied by B2 also flows through R2. The current flowing through R2 results in a voltage drop of the polarity shown in Fig.1(C). Normally the value of R2 is selected so that the voltage drop across it will be approximately half the voltage of B2. In other words, if battery B2 has a voltage of 9 volts (V), R2 should drop about 4.5 volts. The voltage drop across R2 subtracts from the B2 supply voltage, so that the voltage between the collector of the transistor and ground is the balance of the supply voltage, about 4.5 volts. Of course, the exact voltage drop across R2 depends on its value and the current flowing through it. The current through the combination of resistor and transistor is also affected by R1 and the voltage applied to the base of the transistor. However, the rule of thumb for common-emitter amplifiers is that half the supply voltage is dropped across the collector resistor, R2 in this case.

Thus, with no signal applied (with the ac generator voltage equal to zero), current flows from the negative terminal of B1 across the emitter-base junction, through R1 and the generator, and back to the positive terminal of B1. This is a small current, referred to as the input current. There is also current flow from the negative terminal of B2, through B1 to the emitter, across the emitter-base junction, and out of the transistor at the collector terminal, through R2, to the positive terminal of B2. This current is much larger than the input current, and is called the *output current*.

Figure 2(A), on the next page, is a graph representing the collector voltage with zero signal input. That is, in the circuit of Fig.1(C), the generator voltage is 0 volts. The only voltages applied to the transistor are B1 and B2. Under these circumstances, the voltage between the

## HOW TRANSISTORS ARE USED

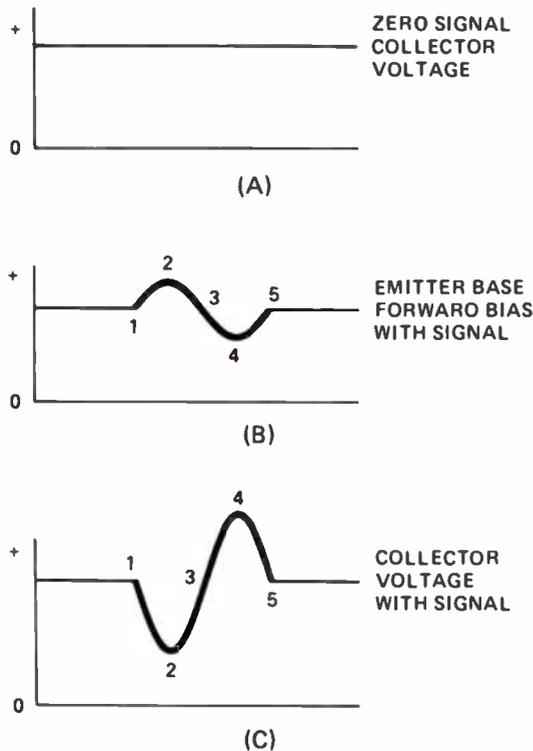


Figure 2. Waveforms for Fig.1(C).

collector of the transistor and ground is constant. This is represented by the straight, horizontal line. If  $B_2$  has a voltage of 9 V, as we mentioned previously, the voltage between the collector and ground will be constant at about 4.5 volts.

Looking again at Fig.1(C), you can see that  $B_1$ , the generator, and  $R_1$  are all connected in series between the emitter and the base. This means that any voltage created by the generator will be in series with the  $B_1$  voltage, causing the forward bias across the emitter-base junction to vary.

Figure 2(B) shows what happens to the forward bias across the emitter-base junction when the generator begins to create a signal. The straight line represents the forward bias sup-

plied by  $B_1$ . Let's suppose that starting at point 1 in Fig.2(B), the generator voltage adds to the voltage of  $B_1$ . Starting at point 1, the signal begins swinging in a positive direction until it reaches a maximum at point 2, then drops to 0 at point 3. At point 3 the polarity of the signal from the generator reverses, and begins subtracting from the voltage of  $B_1$ . The forward bias then begins decreasing from point 3 to point 4 where it reaches its lowest value. Then, as the generator voltage begins increasing again, so does the forward bias from point 4 to point 5.

When the positive generator voltage adds to the voltage of  $B_1$ , between points 1 and 3, the emitter current increases because of the increased forward bias. Not only does the current leaving the base and flowing through  $R_1$  increase, but the current reaching the collector and flowing through  $R_2$  increases. This means that the voltage drop across  $R_2$  increases, causing the voltage between the collector and ground to decrease as shown in Fig.2(C). Notice that the relatively larger current flowing through the collector causes the change in voltage between the collector and ground to be much greater than the change in voltage between the base and ground.

When the generator voltage reverses polarity, it subtracts from the voltage applied between the base and emitter by  $B_1$ . Thus the net input voltage goes down. This causes the emitter current to decrease so that not only does the current flowing through  $R_1$  decrease, but the total current flowing through the transistor and through  $R_2$  decreases. When this happens, the voltage drop across  $R_2$  decreases so that the voltage between the collector and ground increases, as shown between points 3 and 4 in Fig.2(C). Again, notice that the change in voltage between the collector and ground is much greater than the change in voltage between the base and ground.

## THE COMMON-EMITTER CIRCUIT

There are two very important things to remember: First, the small signal voltage applied to the input (base) of the transistor is reproduced in the form of an amplified or larger signal in the output (collector) circuit. Second, notice that when the input swings positive, the output swings negative. Similarly, when the input signal swings negative, the output signal swings positive. In other words, the input signal has been inverted. The output signal is  $180^\circ$  out of phase with the input signal.

One other important thing to notice about this circuit is that the base current is small and that the generator voltage, when added to the fixed emitter-base forward bias, causes only a small change in base current. That is, the current change in the input circuit is relatively small. There is a large change in current in the output circuit, however. Since the changing output current is much greater than the changing input current, we say that we have a current gain. Notice also that the current change in the output is in phase with the current in the input.

To summarize the important points about the common-emitter circuit, we have a voltage gain in the circuit and the amplified voltage is  $180^\circ$  out of phase with the input voltage. We also have a current gain in the circuit and the amplified current appearing in the output circuit is in phase with the input signal current.

A disadvantage of the circuit shown in Fig.1(C) is that it requires two batteries. However, by adding resistor R3, as shown in Fig.3, we can eliminate B1. Current from the negative terminal of B2 flows through R1 and R3 to the positive terminal of B2. The current flowing through R1 develops a voltage across it having the polarity shown. This places a forward bias across the emitter-base junction of the transistor. At the same time, the voltage drop across R3 will be greater than the voltage drop across R2.

Thus, the base is negative with respect to the collector and there is a reverse bias across the collector-base junction.

We've also added capacitors C1 and C2 to the circuit. These capacitors are used to isolate the input and output circuits from the transistor's dc circuits. If the input happened to be a low-impedance microphone, without C1 in the circuit, the low-impedance microphone would be in parallel with R1 and upset the forward bias across the emitter-base junction. By putting the capacitor in the circuit, the forward bias will be equal to the voltage drop across R1. The audio signals produced by the microphone are actually ac voltages, which the capacitor will pass.

**Bias Stabilization.** There is still one problem with the circuit shown in Fig.3. The forward bias across the emitter-base junction of the transistor can change due to minority carriers crossing the collector-base junction. These carriers cause a current flow through R1 in the external circuit that will increase the voltage drop across it. This increases the number of majority carriers crossing the emitter-base junction, which in turn

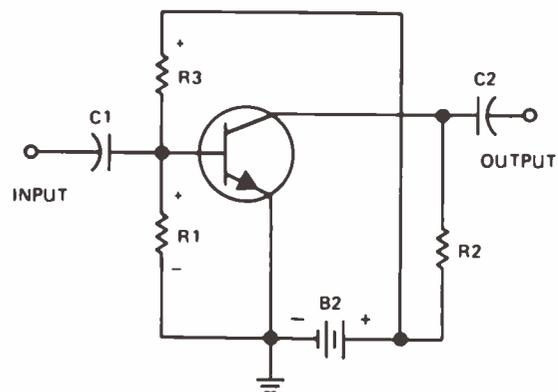


Figure 3. A common-emitter circuit with a single battery.

## HOW TRANSISTORS ARE USED

heats the junction. As the junction heats, more minority carriers will cross the junction causing the forward bias on the transistor to increase still further. This action can continue until the transistor gets so hot it literally destroys itself.

This problem can be avoided by adding R4, as shown in Fig.4. Notice that current flowing through R4 develops a voltage so that the emitter is slightly positive with respect to ground. If the minority carriers crossing the emitter-base junction cause the voltage drop across R1 to increase, any increase in majority carrier flow through the transistor increases the voltage drop across R4. Thus, both the base and the emitter of the transistor become more positive. The increase in positive voltage between the emitter and ground effectively cancels the increase in voltage between the base and ground, and stabilizes the bias. This prevents further increases in non-signal current through the transistor.

Capacitor C3 prevents variations in emitter voltage when a signal is applied to the input. Without the capacitor, if the input signal causes the emitter current to increase, the voltage drop

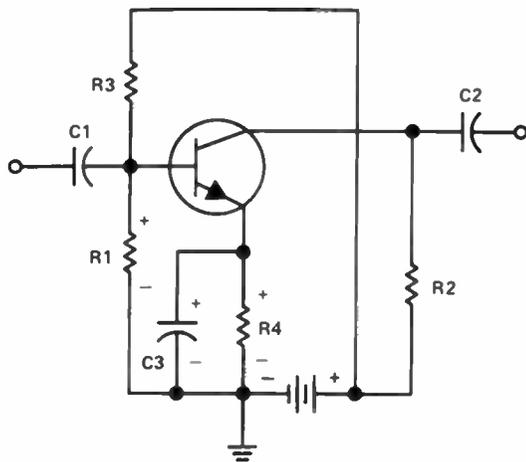


Figure 4. A common-emitter circuit with bias stabilization.

across R4 will increase. Thus, we have a positive-going signal at the base and a positive-going signal at the emitter. The positive-going signal at the emitter tends to cancel or reduce the net change in voltage between the base and emitter.

Similarly, if the input signal swings in a negative direction, the current through the transistor will decrease and this will decrease the voltage drop across R4. Again, this will tend to reduce the net change in voltage between the base and emitter.

This type of signal reduction is called *degeneration*. In some circuits, degeneration is used to reduce distortion. However, degeneration also reduces the amplification of the stage because it reduces the net change in input voltage applied between the base and the emitter. With capacitor C3 added to the circuit, the emitter voltage will remain constant when the emitter current changes due to the input signal voltage. C3 is usually an electrolytic capacitor that has a high capacitance, so its reactance is a very small percentage of the resistance of R4.

Another variation of the basic circuit is shown in Fig.5. Notice that we've eliminated the battery

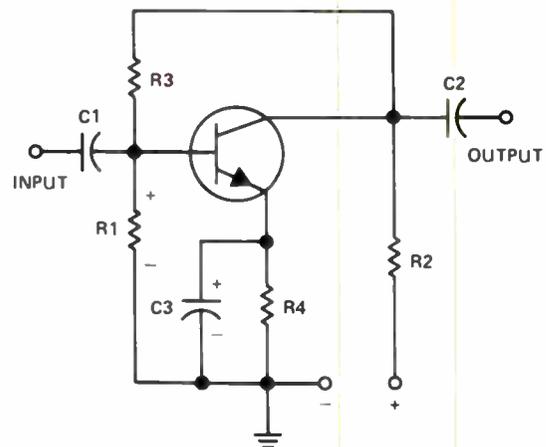


Figure 5. A common-emitter with degeneration.

## THE COMMON-EMITTER CIRCUIT

and simply indicated the two terminals as + and -. This is common practice in drawing schematic diagrams. The equipment could be battery powered and actually use a battery, or if the equipment is operated from the ac power line, the voltage source would be a dc power supply rather than a battery. As far as the circuit is concerned, it doesn't matter whether the stage is operated from a battery or a power supply; it is going to work in exactly the same way.

Another change we have made is that we've moved R3 so that, instead of connecting it directly to the positive voltage input, we've connected one end of it to the collector. This will introduce some minor degeneration into the circuit, which will reduce distortion.

Remember that when the signal voltage applied to the base swings positive, the current through the transistor increases so the voltage drop across R2 increases. This means that the voltage between the collector and ground swings in a negative direction. This reduces the voltage across the series combination of R1 and R3 so that the voltage at the junction of R1 and R3 will decrease. It will still be positive, but it will go down slightly. Similarly, when the input signal swings in a negative direction, current through the transistor decreases. The voltage drop across R2 will decrease so that the collector voltage will swing in a positive direction. This means that the dc bias voltage at the junction of R1 and R3 will swing in a positive direction.

We can see that, as the amplified signal voltage between the collector and ground swings positive or negative, the voltage at the junction of R1 and R3 will swing in the same way. This voltage change will oppose the input signal voltage and will slightly reduce the stage gain. But it is often worthwhile to accept this slight reduction in the gain of the stage because it reduces

distortion so that the amplified output signal is a faithful reproduction of the input signal.

It is important to notice that even though the voltage at the collector of the transistor is about half the voltage at the positive input terminal, we can still maintain a forward bias across the emitter-base junction simply by changing the values of R1 and R3. For that matter, just reducing the value of R3 will reduce the voltage drop across it so that we could maintain the base voltage in the circuit of Fig.5 at exactly the same value as the base voltage in the circuit of Fig.4.

### The Common-Emitter PNP Amplifier

The common-emitter pnp amplifier works in essentially the same way as the npn amplifier except that the electron current in the external circuit flows in the opposite direction, and the conduction through the transistor is by means of holes.

Figure 6 shows the schematic diagram of a common-emitter amplifier using a pnp transistor.

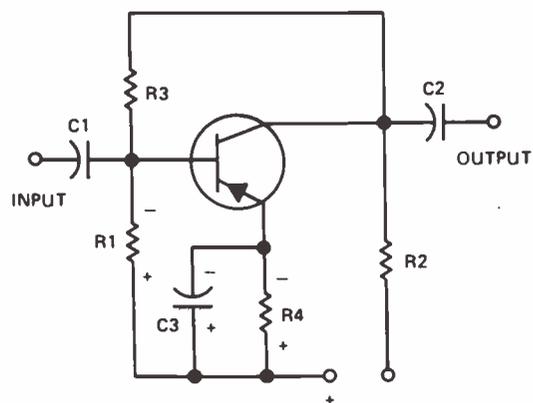


Figure 6. A common-emitter circuit using a pnp transistor.

## HOW TRANSISTORS ARE USED

Notice that the polarity of the voltage source is reversed so the positive terminal is grounded and negative voltage goes to the collector through R2. This reverses the polarity of the voltage across R1, so the base is negative with respect to the emitter, a necessary condition to forward bias the emitter-base junction of a pnp transistor. The polarity of the voltage across R4 indicates that electrons are leaving the emitter and flowing through the resistor to ground. Capacitor C3 is also connected with opposite polarity. R4 serves the same purpose as in the circuit of Fig.5. It stabilizes the forward bias across the emitter-base junction. R3 connects to the collector to introduce degeneration and reduce distortion.

Figure 7 shows waveforms for Fig.6. With zero signal input, the voltage between the collector and ground is negative and constant, and the base voltage is also constant. Figure 7(B) shows an input signal on the base of the transistor. When the input signal swings in a positive direction as it goes from point 1 to point 2, the negative polarity between the base and ground is reduced. This reduces the number of holes flowing across the emitter, across the emitter-base junction, across the base and base-collector junction to the collector. The number of holes reaching the collector decreases so the electron current flowing through R2 decreases. The voltage drop across R2 decreases, and the voltage between the collector and ground swings in a negative direction, as shown in Fig.7(C).

As the input signal drops from point 2 to point 3, the number of holes flowing through the transistor increases. Thus the current through R2 increases as the number of electrons flowing to fill the holes at the collector terminal increases. The net result is that the negative voltage between the collector and ground decreases as shown between points 2 and 3 of Fig.7(C).

When the input signal swings in a negative direction as it goes from point 3 to point 4 in Fig.7(B), the negative voltage between the base and ground increases. This increases the forward bias across the emitter-base junction so the number of holes crossing the junction increases. The number of holes reaching

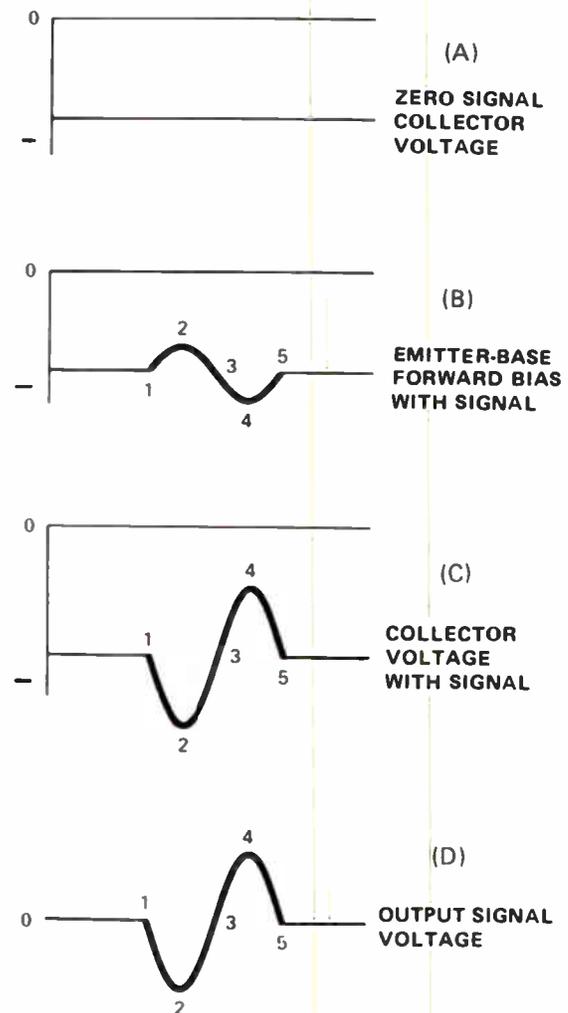


Figure 7. Waveform for Fig.6.

## THE COMMON-EMITTER CIRCUIT

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the collector increases, so the number of electrons flowing through R2 to the collector to fill these holes increases. When this happens, the voltage drop across R2 increases and the net voltage between the collector and ground becomes less negative. This is shown between points 3 and 4 of Fig.7(C).

Finally, as the input signal voltage swings from point 4 to point 5, the forward bias across the emitter-base junction decreases. This means that current flow in the transistor and through R2 decreases; the voltage drop across it decreases, and the collector voltage swings in a negative direction, as shown between points 4 and 5 in Fig.7(C).

If we measure the output voltage at the output end of C2, we see the waveform shown in Fig.7(D). The capacitor, C2, keeps the dc voltage present on the collector from appearing at the output. As the input signal goes through its cycle, it appears in amplified form on the collector, where it is superimposed on the dc collector voltage. However, the capacitor blocks dc voltage at the output, so we have only the amplified ac signal voltage.

Although conduction through the npn transistor in Fig.5 is by electrons, and conduction through the pnp transistor in Fig.6 is by holes, there are many similarities in the two circuits. First, in both cases we have a voltage gain, because the amplified output voltage is greater than the input voltage. Secondly, we have a current gain, since the amplified output current flowing in the collector circuit is much larger than the input current flowing in the emitter-base circuit. Further, notice that in both cases, the amplified output signal voltage is 180° out of phase with the input signal voltage.

### Characteristics of Common-Emitter Circuits

The common-emitter circuit is the most important of all junction transistor circuits because it is by far the most widely used. It is easy to get relatively high gain using the common-emitter circuit. Voltage gains from 80 to 100 are quite easily obtained. This means that the amplified output signal is from 80 to 100 times the amplitude of the input signal.

We mentioned earlier that the collector resistance is selected so that the collector voltage is about half the supply voltage. This allows maximum output signal from the stage. For example, suppose that the supply voltage is 9 V and the collector resistor is selected so that the collector voltage is 4.5 volts. This means that as the current through the transistor varies with the input signal, the collector voltage can swing from 4.5 V to 9 V in one direction and from 4.5 V to 0 V in the other direction, as shown in Fig.8(A) on the next page. Actually, you couldn't go quite that far because the peaks would flatten out and you would introduce distortion, but this is the maximum *theoretical* swing that you can get in the output voltage.

On the other hand, if the collector voltage were 7 V, then it can only swing to 9 V maximum, for a signal peak of 2 V in the positive direction. A corresponding swing in the negative direction would put the collector voltage at 5 V, leaving 5 V of unused potential. If the transistor is driven harder, there is no additional increase or decrease in collector voltage, so one half of the signal flattens, as shown in Fig.8(B).

Similarly, if the collector resistor is chosen so that the voltage on the collector is only 3 V, you

## HOW TRANSISTORS ARE USED

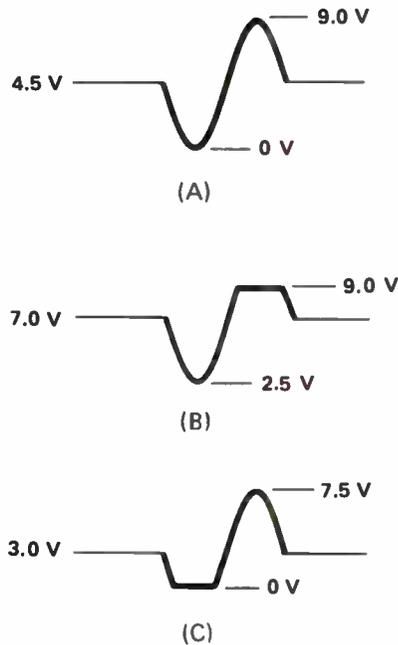


Figure 8. (A) Waveform showing how the output signal can swing from 0 to 9 V with a supply voltage of 9 V and a zero signal collector voltage of 4.5 volts. (B) and (C) Waveforms showing how the same input signal will result in distortion if the zero signal collector voltage is too high or too low.

would have the situation shown in Fig.8(C). Driving the transistor too hard would result in the other half of the output signal wave being flattened. This flattening of the output signal is one form of distortion.

The changing input signal to the common-emitter circuit causes a change in the base current. This, in turn, causes the collector current to change. The changing current is represented by the Greek letter delta, which is written as  $\Delta$ . Thus, the changing base current is  $\Delta i_b$  and the changing collector current is  $\Delta i_c$ . The ratio of the change in collector current to the change in base current is represented by the Greek letter beta,

which is written  $\beta$ . We can represent this by the formula:

$$\beta = \frac{\Delta i_c}{\Delta i_b}$$

Since the base current is relatively small, the change in base current produced by the applied signal is small. On the other hand, collector current is much greater than base current, and therefore, the change in collector current is much greater than the change in base current. This means that beta is always greater than 1, and the common-emitter circuit always has a current gain. In other words, the changing current in the output is greater than the changing current in the input.

Two other important characteristics of a transistor amplifier are the input impedance and the output impedance. The *input impedance* is simply the ratio of the input signal voltage to the input signal current. The *signal voltage* is the signal applied to the base and the *signal current* is the part of the base current caused by the signal voltage. If we represent the signal voltage by  $e_1$ , the signal current by  $i_1$ , and the impedance by  $Z_1$ , then the input impedance is:

$$Z_1 = \frac{e_1}{i_1}$$

The base current in a transistor is small, therefore the change in base current (the input signal current) is also small. This means that in the common-emitter circuit, the input impedance is relatively high.

*Output impedance* is the ratio of the output signal voltage to the output signal current. If we represent the output signal voltage by  $e_2$ , the output current by  $i_2$ , and the impedance by  $Z_2$ , then the output impedance is:

$$Z_2 = \frac{e_2}{i_2}$$

## THE COMMON-EMITTER CIRCUIT

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The output signal current consists of the increases and decreases in collector current produced as the input signal varies the flow of current through the transistor. Even though it is much greater than the change in base current, it also is comparatively small. On the other hand, the change in output current produces a relatively large change in the *voltage* across the collector load resistor. Therefore, the ratio of the output signal voltage to the output signal current is comparatively high. The common-emitter circuit has a fairly high output impedance — usually about 20,000 ohms.

### Review

The common-emitter circuit is the most frequently used junction transistor circuit, and therefore is also the most important. It would be a good idea to read over this section of the lesson again. You should remember that a common-emitter circuit provides a voltage gain of about

80–100, and a comparable current gain. Also remember that there is a 180° phase reversal in the signal voltage. This means that the output signal is 180° out of phase with the input signal. You will see later that there are other junction transistor circuits where this phase reversal does not occur.

### Self-Test Questions

*Please check your answers on page 35.*

- 1 Is it possible to get a current gain using the common-emitter circuit?
- 2 What is the relationship between the input signal voltage and the amplified output signal voltage in the common-emitter circuit?
- 3 Draw schematic diagrams of common-emitter circuits using npn and pnp transistors. You should try to do this from memory since it is important to remember these circuit configurations.

## HOW TRANSISTORS ARE USED

### THE COMMON-BASE CIRCUIT

In a common-emitter circuit, the input signal is applied between the base and ground. The output signal is taken from between the collector and ground. The emitter is operated at signal ground potential and is common to both the input and output circuits. In the common-base circuit, the input signal is applied between the emitter and ground and the output signal is taken from between the collector and ground. The base is operated at signal ground potential, and therefore, is common to both the input and output circuits.

NPN and pnp transistors can be used in the common-base circuit. The circuit using the npn transistor is a little easier to understand, so we will study it first.

#### The Common-Base NPN Amplifier

Figure 9 is a schematic diagram of a basic common-base npn amplifier. B1 supplies the forward bias for the emitter-base junction. The negative terminal of B1 connects to the emitter

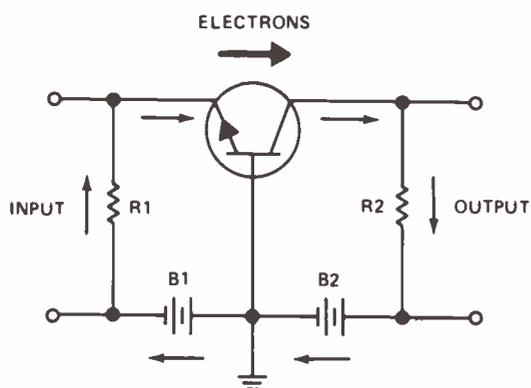


Figure 9. An npn transistor in a common-base circuit.

through R1. The positive battery terminal and the transistor base are both grounded and therefore connected. In this configuration, the emitter is negative with respect to ground. Since the base is grounded, it is positive with respect to the emitter, which is the condition we need in order to forward bias an npn transistor.

B2 supplies the reverse bias across the collector-base junction. Notice that the negative terminal of B2 is grounded and the positive terminal connects to the collector through R2. This makes the collector positive with respect to the base, reverse biasing the collector-base junction.

With no signal applied, there is a small current through the base, coming from B1. Electrons leaving the battery flow through R1, the emitter, and the emitter-base junction. They leave the transistor by the base lead and flow back to the positive terminal of B1.

B2 supplies the collector current. Electrons leaving the negative terminal of B2 flow through B1 and R1 to the emitter of the transistor. They cross the emitter, the emitter-base junction, the base, the base-collector junction, and the collector. They exit through the collector terminal, then flow through R2 back to the positive terminal of B2.

The circuit shown in Fig.9 is functional, but has several disadvantages. Neither the input nor the output is isolated from the transistor. Another drawback is that the circuit requires two batteries. The modified circuit in Fig.10 eliminates these disadvantages.

Although it looks very different, Fig.10 shows a common-base amplifier, and works like the circuit in Fig.9. There is one voltage source, which could be a battery or other dc source. Forward bias for the emitter-base junction is created by a voltage divider composed of the resistors R3 and R4. The resistor values are selected to make the base more positive than the emitter. Capacitor C2 keeps the base at signal

## THE COMMON-BASE CIRCUIT

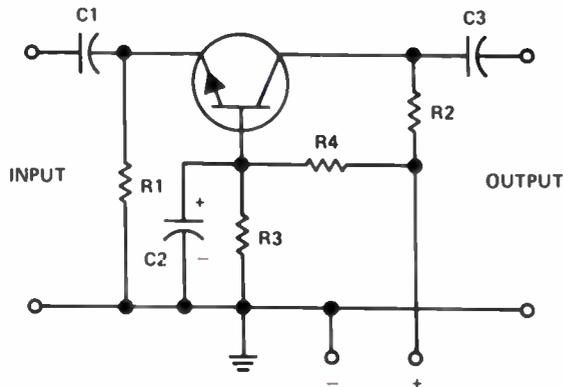


Figure 10. An npn common-base amplifier using a single voltage source.

ground potential by having a reactance that is practically zero at the operating frequency. Capacitor C1 isolates the input signal from the emitter circuit and C3 isolates the collector from the output signal.

In operation, current flows from the voltage source through R1 to the emitter, creating a voltage drop across R1 that makes the emitter positive with respect to ground. Resistors R3 and R4 form a voltage divider that maintains forward bias by keeping the base more positive than the emitter. Thus, if the voltage drop across R1 is 1 V, making the emitter voltage equal to +1 V, values of R3 and R4 are selected to set the base voltage to +2 volts.

A few electrons (less than 5%) crossing the emitter and the emitter-base junction exit at the base and flow through R4 back to the voltage source. Most electrons cross the base, the base-collector junction, the collector, exit the transistor at the collector terminal, and then flow through R2 back to the voltage source. As in the case of the common-emitter circuit, the value of R2 is selected so that the collector voltage with zero signal is approximately one half the supply voltage.

With zero signal input, the collector voltage is constant as shown in the waveform of Fig.11(A). The emitter and base voltages are also constant. The emitter voltage is positive; the base voltage is positive and greater than the emitter voltage in order to forward bias the emitter-base junction. The waveform of Fig.11(B) shows what happens to the emitter voltage with a single cycle of an input signal. With the first half-cycle, when the input signal is positive, the voltage increases from the zero signal value at point 1 up to point 2 where it reaches peak positive value. Notice that the signal voltage adds to the emitter voltage.

During the next quarter-cycle, the signal voltage decreases, causing the emitter voltage to fall from point 2 to point 3. In the second half-cycle, the input signal reverses polarity and subtracts from the emitter voltage. Emitter voltage decreases until the signal voltage reaches its peak, negative value at point 4. In the last quarter-cycle the signal voltage moves back toward zero, causing the emitter voltage to increase to point 5, where once again it is at the zero signal level.

As the emitter voltage changes with the changing signal voltage, the base voltage remains constant. C2 is too large a capacitor to either charge or discharge as the signal goes through its cycle. This means that as the emitter voltage increases above the zero signal value during the positive half-cycle of the input signal, the emitter-base forward bias decreases during this part of the cycle. For example, suppose the emitter voltage is +1 V and the base voltage is +2 volts. The difference in voltage between the two is 1 V, with the base being +1 V positive with respect to the emitter. If the input signal during the positive half-cycle increases the emitter voltage from 1 V to 1.5 V, then the difference of potential between the base and emitter will drop from 1 V to 0.5 V, reducing the forward bias

## HOW TRANSISTORS ARE USED

across the emitter-base junction. This is shown in the first half-cycle of the waveform of Fig.11(C). In contrast, during the next half-cycle, as the emitter voltage decreases, forward bias of the emitter-base junction increases. If the emitter voltage emitter goes from 1 V to 0.5 V during the negative half-cycle, forward bias of the emitter-base junction increases from 1 V to 1.5 volts. This is shown in the second half-cycle of the waveform in Fig.11(C).

When the forward bias decreases, as it does during the first half-cycle of the input signal, current through the transistor decreases. Collector current decreases, and so does the voltage drop across R2. When the voltage drop across R2 decreases, the voltage measured between the collector and ground increases as shown in the first half-cycle of the waveform in Fig.11(D). During the next half-cycle, when forward bias increases, current through the transistor increases. This raises the voltage drop across R2. The voltage measured between the collector of the transistor and ground goes down as shown between points 3, 4, and 5 of the waveform in Fig.11(D).

With an input signal there exists an output signal like the one shown in Fig.11(E). Compare the output signal with the input signal. Notice that the output signal is larger, so there is voltage amplification. Also notice that it swings positive when the input signal swings positive. There is no phase reversal between the input and output signals as is the case for a common-emitter circuit. In common-base circuits, the amplified output signal is in phase with the input signal.

Notice that the input current is the emitter current, not the base current. All current in a transistor flows through the emitter. Some emitter current will split off at the base, making the collector current slightly less than the emitter current. You don't see the great differential in

input current versus output current that is present in common-emitter amplifiers, where tiny variations in base voltage and current cause large variations in the emitter and the collector

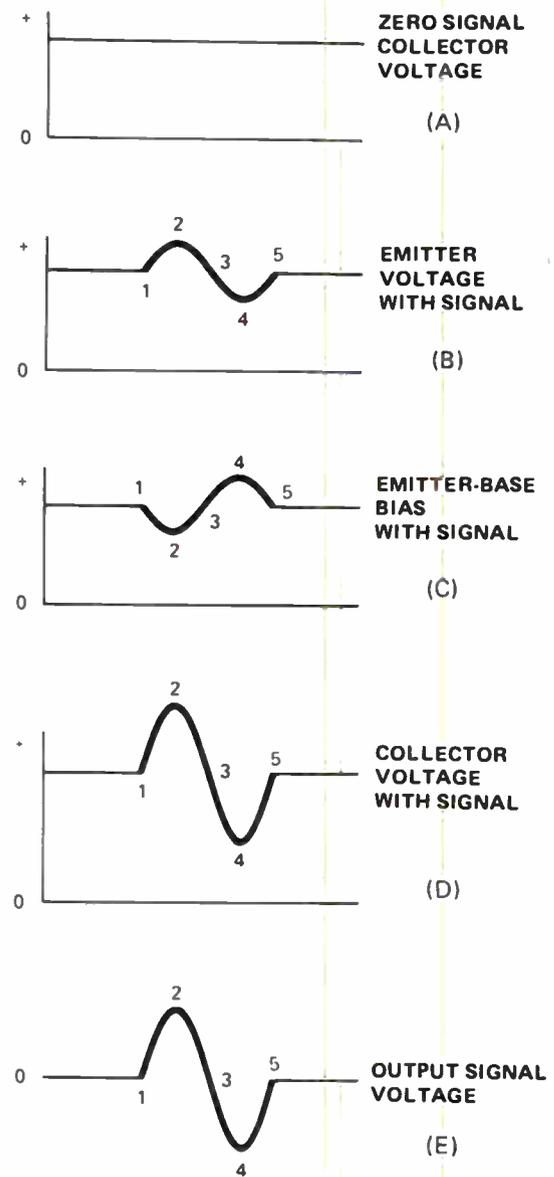


Figure 11. Waveforms for circuit shown in Fig.1.

## THE COMMON-BASE CIRCUIT

current. There is no current gain in a common-base amplifier. The collector (output) current will always be less than the emitter current.

### The Common-Base PNP Amplifier

Figure 12 shows a common-base amplifier using a pnp transistor. Compared to Fig.9, the battery polarities are reversed, and current flow in the external circuit is in the opposite direction. Conduction through the transistor is from the emitter, through the base, and to the collector by means of holes.

B1 provides forward bias for the emitter-base junction. As connected, the base is negative with respect to the emitter. This condition is required to forward bias the emitter-base junction of a pnp transistor. On the other hand, the collector is connected to be negative with respect to the base, which places the necessary reverse bias on the collector-base junction of a pnp transistor.

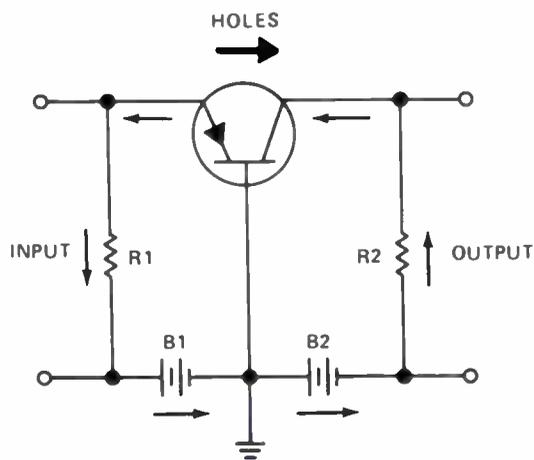


Figure 12. A pnp transistor in a common-base circuit.

B1 supplies the base current. Electrons leave the negative terminal of B1 and enter the base where they fill holes. An electron leaving the emitter of the transistor will create a hole. The electron will flow through R1 and back to the positive terminal of B1.

B2 supplies the collector current. Electrons leaving the negative terminal of B2 flow through R2 to the collector where they fill holes arriving at the collector. Electrons are pulled out of the emitter by the positive potential of B2, creating holes. The holes flow across the emitter, the emitter-base junction, the base, and the base-collector junction. They finally flow to the collector terminal where they are filled by the electrons coming from the negative terminal of B2. The electrons leaving the emitter will flow through R1 and B1 to the positive terminal of B2.

In Fig.13, we modified the basic circuit to eliminate the two batteries, and to add capacitors for isolating the input and output. Notice that the positive terminal of the voltage source is grounded. The negative terminal connects to the collector through R2. The negative terminal also connects through R4 and R3 to ground. As

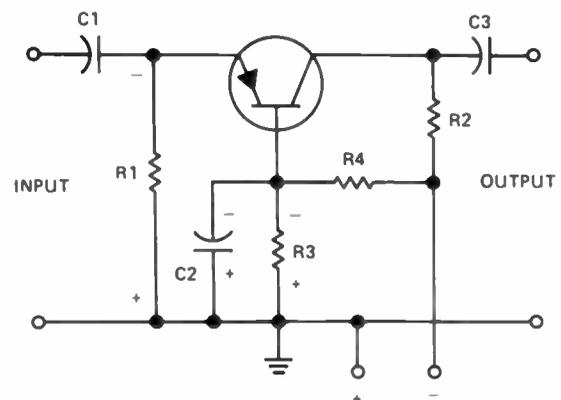


Figure 13. A pnp common-base amplifier using a single voltage source.

## HOW TRANSISTORS ARE USED

a result, there is a current flow from the negative terminal through R4 and R3 to ground. Current flowing through R3 produces a voltage drop so that the base is negative. Electrons leaving the emitter of the transistor flow through R1 to reach the positive voltage source. This sets up a voltage drop across R1 so that the emitter is negative with respect to ground.

However, by selecting the correct values for R3 and R4, we can make the voltage on the base greater than the voltage on the emitter, which makes the base negative with respect to the emitter.

The waveforms in Fig.14 show what happens when a signal is applied to the input. With no signal, the collector voltage is negative and constant, as shown in Fig.14(A), as are the emitter and base voltages. The base is more negative than the emitter; that is, if the emitter voltage is  $-1$  V, the base voltage might be  $-2$  volts.

Figure 14(B) shows what happens to the emitter voltage when a signal is applied. The emitter voltage is at its zero signal level at point 1. During the first half-cycle, as the input signal swings positive from point 1 to point 2 and back to point 3, the input signal drives the emitter voltage in a positive direction. The emitter voltage might drop from  $-1$  volt to  $-0.5$  volt. Now the forward bias across the emitter-base junction is  $-1.5$  V instead of being  $1$  V as it was with zero signal input. The forward bias across emitter-base junction increases as shown in Fig.14(C). The increase in forward bias causes the number of holes flowing through the transistor to increase. When this happens, additional electrons flow from the negative terminal of the voltage source, through R2, to the collector. The voltage drop across R2 increases so that the voltage between the collector of the transistor and ground decreases as shown between points 1, 2, and 3 of Fig.14(D).

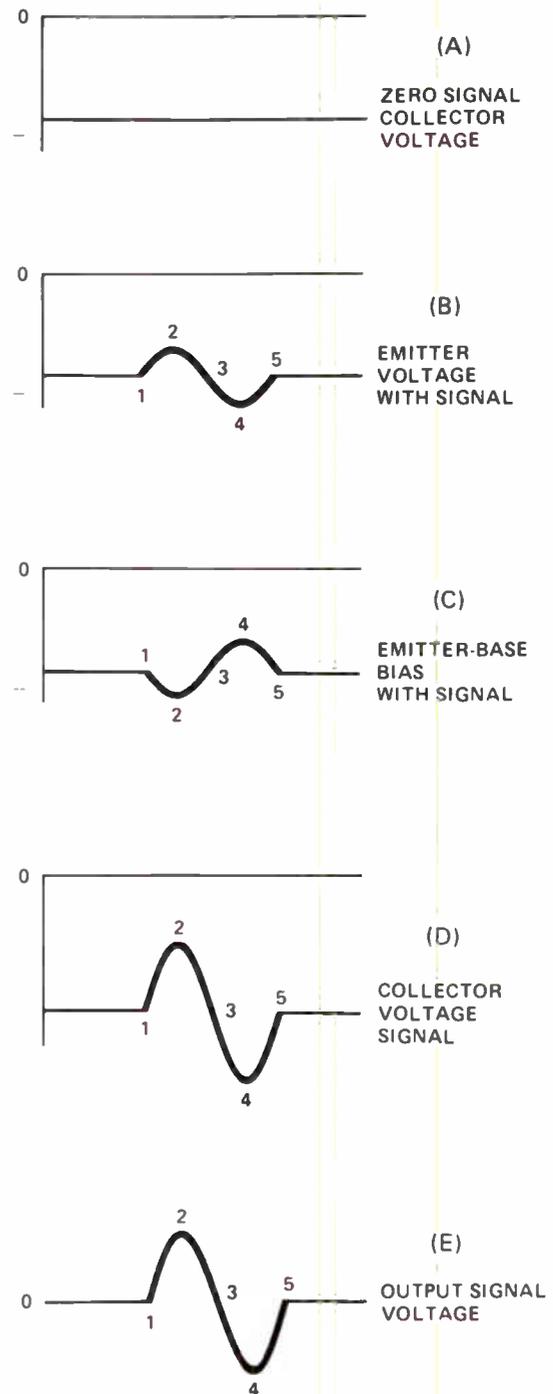


Figure 14. Waveforms for circuit shown in Fig.13.

## THE COMMON-BASE CIRCUIT

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When the input signal swings in a negative direction, as it does between points 3, 4, and 5 of Fig.15(B), the forward bias across the emitter-base junction decreases as shown in Fig.14(C). This causes the number of holes flowing through the transistor to decrease, so the number of electrons flowing through R2 to fill these holes also decreases. The voltage drop across R2 decreases so the potential between the collector and ground increases as shown in Fig.14(D). The output signal with the dc collector voltage removed is shown in Fig.14(E).

Notice that once again we have a voltage gain. Also, the output voltage is in phase with the input voltage. Furthermore, as in the npn version of the common-base circuit, current in the input circuit flowing through R1 is greater than the current in the output circuit flowing through R2. Thus, there is no current gain in the pnp amplifier either.

### Characteristics of Common-Base Circuits

Even though the action of the pnp transistor is quite different from the action of the npn transistor, the net result using the common-base circuit is the same with both types of transistors. In both cases, we have voltage amplification and the output voltage is in phase with the input voltage.

Because some of the emitter current flows to the base in the common-base circuit, the collector current must be less than the emitter current. Similarly, any change in the emitter current produced by the applied signal results in some of the changing current flowing to the base and the remainder to the collector. Therefore, the change in current in the collector circuit is less than the change in current in the emitter circuit. The ratio of the change in the collector current to the change in the emitter current is repre-

sented by the Greek letter alpha which is written as  $\alpha$ . We write this in the formula:

$$\alpha = \frac{\Delta i_c}{\Delta i_e}$$

Since the change in collector current is always less than the emitter current, alpha always has a value of less than 1. This means that for a given signal, the change in collector current is less than the change in emitter current. We say the circuit has a current gain of less than 1, which means that the changing output current is less than the changing input current. In a good transistor, alpha is 0.99 or greater.

We mentioned that the common-emitter amplifier had a relatively high input impedance. If we examine the common-base circuit shown in Fig.10 and Fig.12, we see that the input voltage is applied across R1. This causes some signal current to flow through the resistor R1. In addition, the entire emitter current drawn by the transistor must flow through R1. Therefore, even with the small signal voltage, the signal current must be quite high. Since the input impedance is determined by the ratio of the signal voltage to the signal current, a high current causes the ratio of the voltage divided by the current to be low. In other words, the common-base circuit has a relatively low input impedance.

On the other hand, since the stage is capable of giving voltage gain, the output voltage which is developed across R2 is much higher than the input voltage. And since the collector current is less than the emitter current, the signal current flowing in the output is lower than the signal current flowing in the input. Thus, the output impedance is higher than the input impedance. In fact, the output impedance is quite high. Therefore, in the common-base circuit, we have a very low input impedance and a reasonably high output impedance.

## HOW TRANSISTORS ARE USED

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### Review

The common-base circuit has a current gain of less than 1. The stage is capable of providing voltage amplification, and the amplified output signal is in phase with the input signal. The common-base circuit has a low input impedance and a reasonably high output impedance, so it is often used in applications where we want to match a low impedance to a high impedance. It is also used in some very high-frequency applications.

### Self-Test Questions

- 4 In a common-base circuit, is it possible to get a current gain?
- 5 What is the phase relationship between the amplified signal voltage and the input signal voltage in a common-base circuit?
- 6 Why is it possible to get a voltage gain in a common-base amplifier even though there is no current gain?
- 7 What are the relative input and output impedances of the common-base amplifier circuit?

## THE COMMON-COLLECTOR CIRCUIT

The third possible circuit configuration using a junction transistor is the *common-collector circuit*, frequently called an “emitter follower.” In this type of circuit, the collector is operated at signal ground potential. Although this circuit is not found as often as the common-emitter circuit, it does have some characteristics that are useful in certain applications.

As with the previous circuit configurations, either an npn or a pnp transistor can be used in the common-collector circuit. In this circuit, the input signal is applied between the base and ground and the output signal is taken from between the emitter and ground. Since the collector is operated at signal ground potential, it is common to both the input and output circuits.

### The Common-Collector NPN Amplifier

Figure 15 shows the basic common-collector circuit using an npn transistor. Battery B1 has a low impedance as far as the signal is concerned,

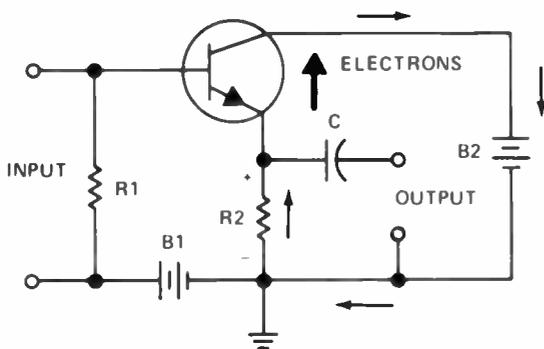


Figure 15. Basic common-collector circuit using an npn transistor.

so the signal is effectively applied between the base of the transistor and ground. Capacitor C, connected to the emitter, has a low impedance at the signal frequency, so the output signal is taken with respect to the emitter and ground.

B1 supplies forward bias across the emitter-base junction. Current flowing through R2 develops a voltage which subtracts from the bias between the base and emitter, but the voltage drop across R2 is never greater than the voltage of B1. If it were, the transistor would have no forward bias of the emitter-base junction and no current flow through the transistor. If current stops flowing in the transistor, current also stops through R2 and there would then be no voltage drop across it.

Battery B2 supplies the reverse bias across the collector-base junction. The negative terminal of this battery is connected through B1 and R1 to the base of the transistor and the positive terminal is connected directly to the collector. The voltage of B2 is much higher than the voltage at B1 so that as far as the collector-base junction is concerned, it is reversed biased.

The arrows on the diagram indicate the main direction of current flow. Electrons leaving the negative terminal of B2 flow through R2 to the emitter. They cross the emitter, the emitter-base junction, the base, the base-collector junction, the collector, and flow back to the positive terminal of B2. A few electrons leave the negative terminal of B1 and flow through R2 in the direction shown. They cross the emitter-base junction, leave the transistor by the base lead and flow through R1 back to the positive terminal of B1.

The disadvantages of the circuit shown in Fig. 15 are that it requires two batteries and the input is not isolated from the base of the transistor. We've added the capacitor C1 in Fig. 16, on the next page, to isolate the input from the base

## HOW TRANSISTORS ARE USED

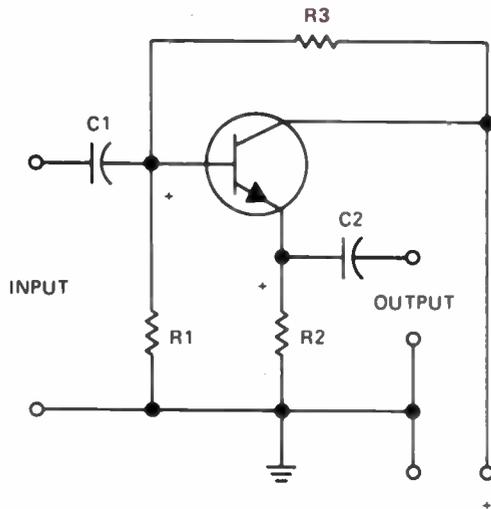


Figure 16. Common-collector amplifier using an npn transistor and a single voltage source.

circuit and also have added R3 to eliminate the need for a second voltage source. We've also simply indicated the + and - terminals where the voltage source is connected. This could be a battery or a dc power supply operated from the ac power line.

In this circuit, electrons from the negative terminal of the voltage source flow through R1, developing a voltage drop across it with the polarity shown. The electrons flow on through R3 and back to the positive terminal of the voltage source. Electrons also leave the negative terminal of the voltage source and flow through R2 to the emitter of the transistor, through the transistor, and back to the positive terminal of the voltage source. Once again, even though the emitter of the transistor is positive with respect to ground (due to the current flowing through R2), the values of R1 and R3 are selected so the base is more positive than the emitter and the transistor emitter-base junction is forward biased.

With zero input signal, the base and emitter voltages are constant. This is represented in Fig. 17 by the straight, horizontal line up to point 1 in Figs. 17(A) and (B). When a signal is applied between the base and ground during the positive half-cycle, the base voltage starting at point 1 increases to point 2, then returns to zero signal level at point 3. The increase in forward bias across the emitter-base junction causes the emitter current to increase so that the emitter voltage swings from point 1 to point 2 and then back to point 3 as shown in Fig. 17(B).

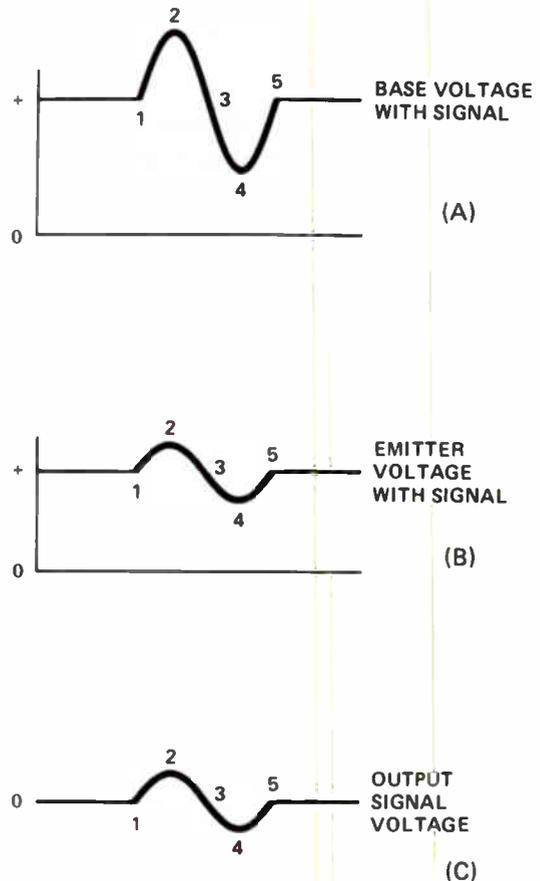


Figure 17. Waveforms for circuit shown in Fig. 16.

## THE COMMON-COLLECTOR CIRCUIT

During the negative half-cycle, as the base voltage swings in a negative direction from point 3 to point 4 and then back to point 5, as shown in Fig.17(A), the emitter voltage also swings in a negative direction. This is because the current through the transistor decreases due to the decreased forward bias across the emitter-base junction. As a result, the current through R2 decreases so that the voltage between the emitter of the transistor and ground goes from point 3 to point 4 and then back to point 5 as shown in Fig.17(B).

Notice that when the base voltage swings in the positive direction, the emitter voltage also swings in a positive direction. This swing in the positive direction reduces the net change in forward bias across the emitter-base junction.

Similarly, during the negative half-cycle, when the base is swinging in a negative direction, the emitter also swings in a negative direction, which once again reduces the net change in emitter-base junction bias. This is degeneration. Because the emitter signal is subtracting from the base signal, it can never exceed the amplitude of the base signal. If it were to exceed the amplitude it would completely cancel the change in the base voltage. If this happened, there wouldn't be any change in emitter voltage.

The output signal voltage taken between the output terminals is shown in Fig.17(C). Notice that this voltage is zero with zero signal input and then follows the emitter voltage as the signal goes through its cycle. This happens because the reactance of C2 is so low at the signal frequency that, as far as the signal is concerned, it is simply not there. However, C2 does block the dc voltage at the emitter of the transistor and prevents the output from shorting out R2.

From the waveforms in Fig.17 we see that the output voltage is originally less than the input voltage. We say that the common-collector cir-

cuit has a voltage gain of less than 1. We also see that the output voltage is in phase with the input voltage. The input signal current is the change in the base current, which is relatively small, and the output signal current is the change in the emitter current, which is relatively large; therefore, the common-collector circuit has a current gain.

### The Common-Collector PNP Amplifier

In the common-collector pnp amplifier shown in Fig.18, we have essentially the same circuit as in the case of the npn amplifier, except that the battery connections are reversed and conduction through the transistor is by means of holes instead of electrons.

Since the current through the external circuit flows the opposite of the npn circuit, the voltage drop across R2 has the opposite polarity. In other words, the end connected to the emitter is negative and the grounded end is positive.

The negative terminal of B1 connects through R1 to the base of the transistor, and the positive

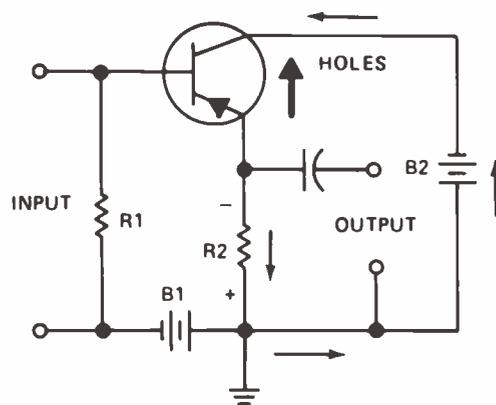


Figure 18. Basic common-collector circuit using a pnp transistor.

## HOW TRANSISTORS ARE USED

terminal connects through R2 to the emitter. This battery makes the base negative with respect to the emitter, creating the condition needed to forward bias the emitter-base junction of a pnp transistor. The positive terminal of B2 connects through B1 and R1 to the base of the transistor, and the negative terminal connects to the collector. This makes the collector negative with respect to the base, reverse biasing the collector-base junction.

During operation, electrons leave the emitter through R2 to get to the positive terminal of B2. This produces holes that cross the emitter, the emitter-base junction, the base, the base-collector junction, and the collector, where they are filled by electrons from the negative terminal of B2. At the same time, the positive terminal of B1 pulls a few electrons from the emitter. The holes produced cross the emitter and the emitter-base junction where they are filled by electrons coming from the negative terminal of B1, through R1, and to the base.

Figure 19 shows the circuit modified to eliminate the second battery. In this circuit, electrons leave the negative terminal of the voltage source and flow through R3 and then through R1 back to the positive terminal of the voltage source. The electrons flowing through R1 create a voltage drop across this resistor having the polarity shown. This drop makes the base negative with respect to ground. Electrons leave the emitter of the transistor to produce holes and flow through R2 to the positive terminal of the voltage source and set up a voltage drop across R2 having the polarity shown. This means that the emitter is negative with respect to ground. However, the voltage drop across R1 is greater than the voltage drop across R2, so the base is negative with respect to the emitter.

Waveforms for the circuit in Fig.19 are shown in Fig.20. As with the previous circuit using the

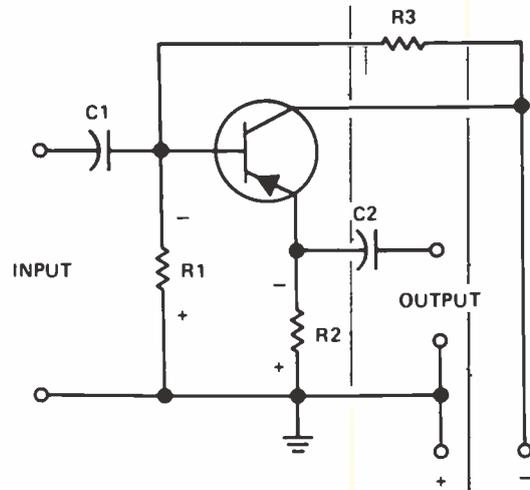


Figure 19. Common-collector amplifier using a pnp transistor and a single voltage source.

npn transistor, both the base and emitter voltages are constant with zero signal. But during the positive half-cycle of an input signal, the base voltage decreases as shown, from point 1 to point 2 and then back to zero signal-voltage level at point 3 in Fig.20(A). The decrease in the base voltage reduces the forward bias across the emitter-base junction, causing the number of holes flowing through the transistor to decrease. This means there are fewer electrons coming out of the emitter terminal and flowing through R2. The voltage drop across R2 decreases from point 1 to point 2 and back to point 3, as shown in Fig.20(B).

During the next half-cycle, when the input signal swings in a negative direction, as shown from point 3 to point 4 and back to point 5 in Fig.20(A), the base is made more negative. This increases the forward bias across the emitter-base junction so the number of holes flowing through the transistor increases. Thus, additional electrons are pulled from the emitter to create

## THE COMMON-COLLECTOR CIRCUIT

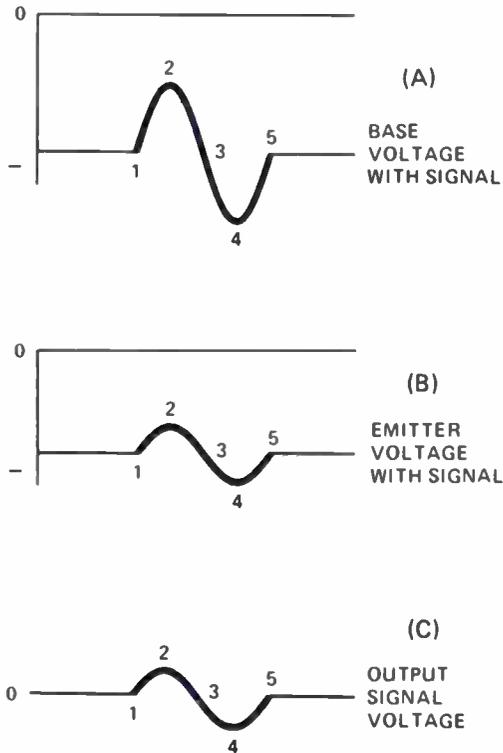


Figure 20. Waveforms for circuit shown in Fig.19.

these holes, and the voltage drop across R2 increases, as shown between points 3, 4, and 5 of Fig.20(B).

The output signal is shown in Fig.20(C). Once again, notice that the signal is the same as the signal at the emitter. The output voltage is less than the input voltage, but is in phase. Since change in the base current due to the input signal is relatively small, and changes in the emitter current are large, there is a current gain. Therefore, the common-collector circuit using a pnp transistor has essentially the same characteristics as those for the npn transistor.

### Characteristics of Common-Collector Circuits

The common-collector circuit has the highest input impedance of the three circuits. Refer to Fig.15. Input impedance is the ratio of the input voltage over the input current. The voltage applied at the input causes a flow of signal current from the emitter, through the transistor, and to the collector. Some electrons traveling from the emitter to the collector exit through the base and R1. But, since the output signal voltage is subtracted from the input signal voltage, as far as the signal voltage applied between the base and emitter is concerned, the actual signal current in the transistor is quite small. Therefore, the total input signal current is small, and this means the input impedance is high.

On the other hand, the output impedance of the transistor is low, due to the fact that the emitter signal current flows through resistor R2 and very little voltage is developed across the resistor. As a matter of fact, the voltage, as we pointed out before, cannot be equal to the input signal voltage because it would cancel the input signal voltage entirely. Since the output voltage is small, the ratio of the voltage divided by the current is small and the output impedance is low.

In the common-collector circuit, the voltage gain is always less than 1. This means that the output voltage is always less than the input voltage. All of the output voltage is fed back to the input circuit. We call this *feedback*. When all of the output voltage is fed back into the input, we call this *100% voltage feedback*. Since the output voltage that is fed back into the input circuit reduces the effective input voltage applied to the transistor, it is called *degenerative feedback*. It degenerates or reduces the effective signal voltage applied between the emitter and base of the transistor.

## HOW TRANSISTORS ARE USED

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Because the common-collector circuit has a high input impedance and a low output impedance, it is often used as an interface to match a relatively high impedance to a low impedance. An excellent example of this is found in equipment with delay lines. *Delay lines* are used in equipment where several signals must be processed and arrive at a certain point simultaneously. A signal might travel faster in some circuits than in others, so a delay line is inserted in this circuit to delay the signal, causing it to arrive at the same time as the other signals. A delay line is a comparatively low impedance device and a common-collector circuit provides an excellent method of matching from the higher impedance amplifier stages to the low impedance of the delay line.

### Review

The most widely used of the three basic transistor circuits is the common-emitter circuit. In this circuit, the emitter is common to both the input and output circuits. It is operated at signal ground potential. In the common-emitter circuit, high voltage gains can be easily obtained. There is considerable current gain in this circuit. Other important characteristics are medium input impedance (between 1000 and 2000 ohms) and an output impedance in the neighborhood of 20,000 ohms. You should also remember that this is the voltage amplifier circuit that produces a  $180^\circ$  phase shift. The output signal voltage is  $180^\circ$  out of phase with the input signal voltage.

The common-base circuit has a base common to both the input and output signals. It has a very low input impedance, but it also has the highest output impedance of the three basic circuits. The current gain is always less than 1, but this circuit is quite stable. There is no phase reversal in a voltage amplifier using this type of circuit. The

output voltage is in phase with the input voltage. Although the current gain is less than 1, you can get a voltage gain with this circuit.

The common-collector circuit is an amplifier in which the collector circuit is common to both the input and output circuits. This circuit has the highest input impedance, but the output impedance can be as low as 100 ohms. This is the only one of the three circuits with a lower output impedance than input impedance. The voltage gain is always less than 1 because there is 100% voltage feedback. There is no phase reversal when this circuit is used; the output voltage is in phase with the input voltage. Although you cannot get a voltage gain with a common-collector circuit, you can get a current gain. The input current is relatively low due to the fact that the output voltage reduces the effective value of the input voltage. Thus the input current is low, whereas the output current is high.

### Self-Test Questions

- 8 What is the phase relationship between the output voltage and the input voltage in a common-collector circuit?
- 9 What will the voltage gain of the common-collector amplifier be?
- 10 What are the relative input and output impedances of the common-collector circuit?
- 11 Which transistor circuit gives you an output signal that is  $180^\circ$  out of phase with the input signal voltage?
- 12 Which transistor circuits give you a voltage gain?
- 13 Which transistor circuits give you a current gain?
- 14 Which transistor circuits have a relatively high input impedance?
- 15 Which transistor circuit has a low output impedance?

### FIELD-EFFECT TRANSISTORS

There are two basic types of field-effect transistors — the *junction-gate (JFET)* and the *insulated-gate (IGFET)*. The JFET requires a reverse bias between the junction and the channel, otherwise the junction draws current. Furthermore, the peak signal fed to a JFET must not exceed the reverse bias across the junction for the same reason.

Field-effect transistors offer some advantages over bipolar transistors. Let's go ahead and see how field-effect transistors are used as amplifiers so we can better understand what some of these advantages may be.

#### Junction-Gate Field-Effect Transistors

There are two types of JFETs, the n-channel and p-channel. In the *n-channel transistor*, the channel between the source and the drain is made of n-type material and the gate is made of p-type material. In the *p-channel transistor*, the channel between the source and drain is a p-type material and the gate is an n-type material.

**N-Channel JFETs.** Figure 21 shows a schematic diagram of an n-channel JFET amplifier. With no signal applied to the input, electrons flow from the battery, through R2 to the source of the JFET, through the channel to the drain, through R3, and back to the battery. R2 has a voltage drop of the polarity shown. Notice that the end of the resistor connected to the source is positive with respect to ground. This means that the source is positive with respect to ground. In a typical amplifier, the value of R2 would be selected so that the voltage drop across it is about 1 volt. If the battery is a 9 V battery, and we select a value of R3 so that the voltage drop across it would be 4 V, the polarity between the source and

drain of the JFET would also be 4 volts. In other words, there would be a voltage gradient along the channel going from +1 V at the source to +5 V at the drain.

The gate of the JFET connects to ground through R1. Since the entire channel is positive with respect to ground, it is positive with respect to the gate. Therefore, the gate is negative with respect to the channel. This condition is necessary to prevent current flow from the channel to the gate. We could get the same effect by eliminating R2 and connecting a battery between the source and the gate with the negative terminal of the battery connected to the gate. However, it is more convenient to use a resistor to develop this voltage.

Capacitor C2 is usually large, with a capacitance high enough so that its reactance is practically zero at the signal frequency. This keeps the source at ground, as far as the signal is concerned, and prevents the voltage across R2 from varying as the current through the JFET varies. C1 and C3 also have almost zero reactance at the signal frequency. However, they prevent anything connected across the input or the output from affecting the dc voltages applied to the JFET.

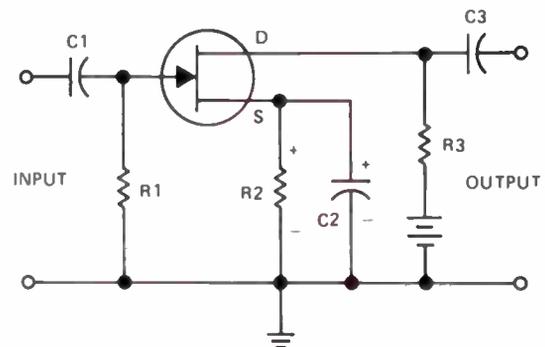


Figure 21. Schematic diagram of an amplifier using an n-channel JFET.

## HOW TRANSISTORS ARE USED

The waveforms in Fig.22 show how the circuit works. With zero input signal the drain voltage is constant, as shown in Fig.22(A). Figure 22(B) shows what happens when a signal is applied to the gate. With zero signal, the gate voltage is

zero. When the positive half-cycle arrives, it swings the gate voltage positive as shown between points 1, 2, and 3. The peak voltage at point 2 must not exceed the positive voltage on the source or current flows to the gate, introducing distortion and possible damage to the transistor. During the next half-cycle the input signal swings the gate in a negative direction, as shown from point 3 to point 4 and back to point 5.

Figure 22(C) shows what happens to the voltage between the drain and ground. When the gate voltage swings in a positive direction it reduces the negative bias between the gate and channel, permitting the channel to widen. This widening reduces the resistance of the channel. Current through the JFET increases so the voltage drop across R3 increases. When this happens, the net voltage between the drain of the JFET and ground decreases as shown from point 1 to point 2 and then back to point 3.

During the next half-cycle, when the input signal swings negative, it increases the net negative bias between the gate and the channel. This causes the channel width to decrease, effectively increasing the resistance of the channel. As a result, the current through the JFET decreases, causing the voltage drop across R3 to decrease. When this happens, the voltage between the drain and ground swings positive, as shown between points 3, 4, and 5 in Fig.22(C).

Any amplified signal appearing at the output on the drain of the JFET takes the form of an amplified ac signal superimposed on the dc drain voltage. At the output, on the other side of the blocking capacitor C3, we have the waveform shown in Fig.22(D). Here the dc is blocked so that the signal appears as an amplified signal.

Notice that the output signal is larger than the input signal. A relatively small signal applied to the input causes a variation in the current flowing through R3, which is a rather large resistor.

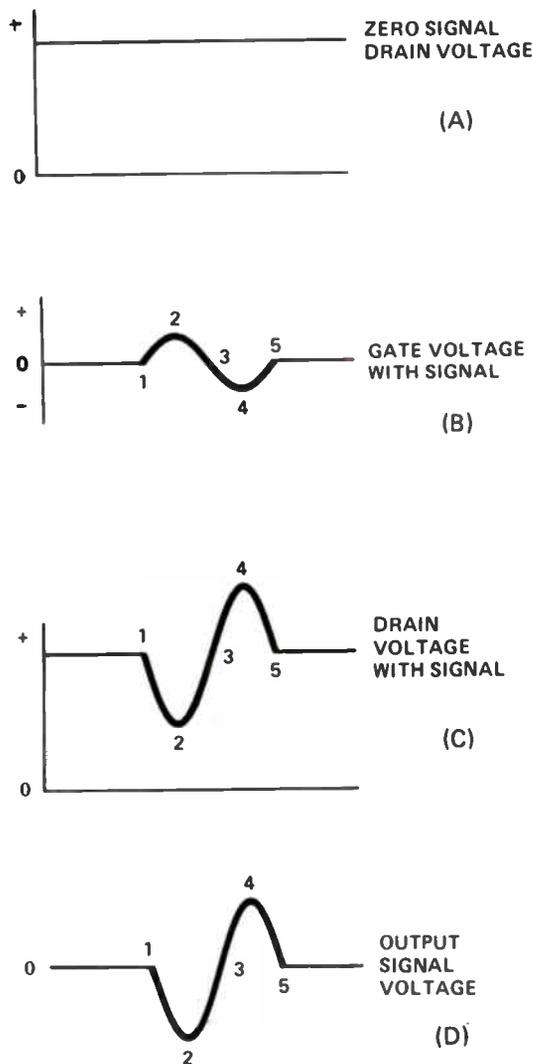


Figure 22. Waveform for the circuit in Fig.21.

## FIELD-EFFECT TRANSISTORS

This develops an amplified signal voltage in the output. Also, notice that when the input signal swings in a positive direction, the output signal swings in a negative direction, and vice versa. That is, the output signal is  $180^\circ$  out of phase with the input signal. Remember that this is the same situation that we encountered with the junction transistor in the common-emitter circuit.

**P-Channel JFETs.** In Fig.23 we've shown a schematic diagram similar to the one shown in Fig.21, but this time we've used a p-channel JFET. Remember that in a p-channel transistor, conduction through the transistor occurs by means of holes.

In this circuit, the positive terminal of the battery is connected through R2 to the source, so that electrons come out of the transistor from the source connection. This creates holes that travel through the channel to the drain, where they are filled by electrons traveling from the negative terminal of the battery through R3 to the drain.

The electrons leaving the source and flowing through R2 develop a voltage drop across R2 with the polarity indicated. This makes the source negative with respect to ground. Since the

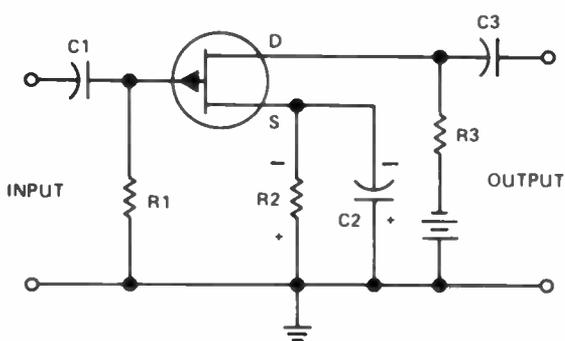


Figure 23. Schematic diagram of an amplifier using a p-channel JFET.

gate connects to ground through R1, the source is negative with respect to the gate. This is the same as saying that the gate is positive with respect to the source. If the gate is positive with respect to the entire channel, no holes flow from the channel to the gate and, therefore, no electrons flow through R1.

The waveforms in Fig.24, on the next page, show what happens when the signal is applied to the input. With zero signal, the voltage between the drain and ground is constant and negative, as shown in Fig.24(A). Figure 24(B) shows that the gate voltage is constant and zero until a signal is applied to the input. When the input signal swings in a positive direction from point 1 to point 2 and then back to zero voltage at point 3, it increases the positive voltage on the gate. The increased voltage adds to the voltage across R1, making the gate more positive. This repels the holes into a narrower channel so the resistance of the channel in the JFET increases. This reduces the number of holes traveling from the source to the drain so the number of electrons leaving the negative terminal of the battery and flowing through R3 to fill the holes arriving at the drain decreases. When this happens, the voltage drop across R3 decreases so the voltage between the drain and ground increases. In other words, the drain becomes more negative. This is shown in Fig.24(C) as the drain voltage swings from zero signal voltage at point 1 to a more negative level at point 2, and then back to zero at point 3.

During the negative half of the input signal, the gate voltage swings negative from zero at point 3 to a maximum negative value at point 4, then back to zero at point 5. This subtracts from the voltage across R1, making the net voltage between the gate and the source lower. The gate is less positive. The lower positive voltage has less repelling effect; thus the width of the channel increases, permitting more holes to flow

## HOW TRANSISTORS ARE USED

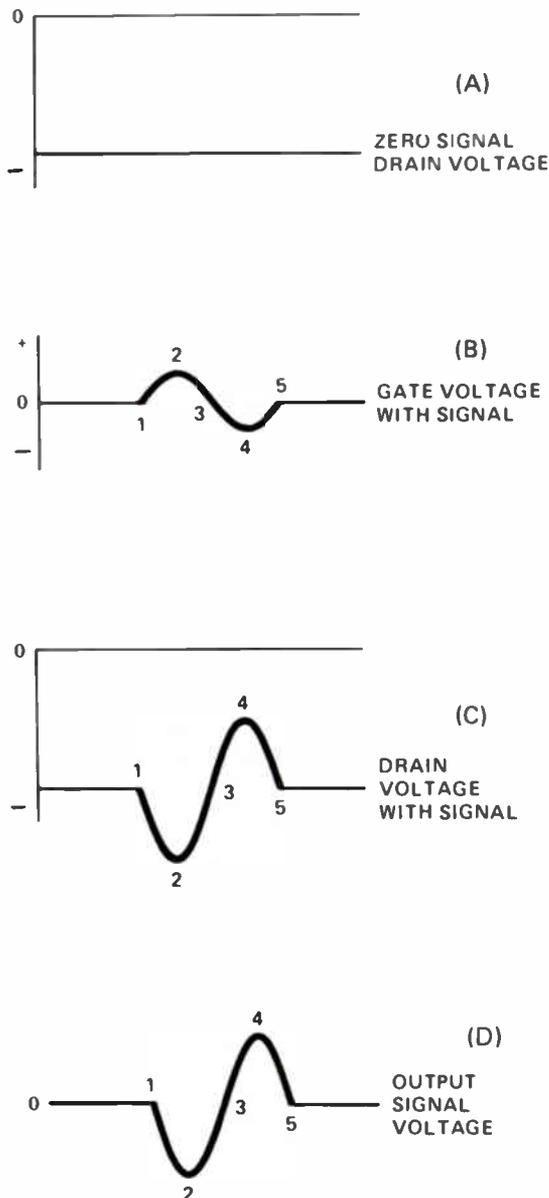


Figure 24. Waveforms for circuit shown in Fig 23.

through the channel from the source to the drain. The increase in the number of holes arriving at the drain results in an increase in the number of electrons leaving the negative terminal of the battery and flowing through R3 to fill the holes that reach the drain. The increased current through R3 results in a greater voltage drop across R3. The drain voltage becomes less negative as the drain voltage swings from point 3 to a minimum at point 4 and then back again to zero signal level at point 5, as shown in Fig.24(C).

Figure 24(D) shows the output signal once the dc voltage at the drain has been removed by the blocking capacitor C3. Compare this with Fig.22(D) and you see that the two are identical. In the p-channel JFET we have a voltage gain because the output signal is greater than the input signal. We also see that the output signal voltage is  $180^\circ$  out of phase with the input signal voltage.

**Characteristics.** There are several important characteristics of the JFET circuit that you should remember. Remember that the output signal is greater than the input signal because the small signal voltage causes a varying current to flow through a high value of load resistor developing a large output voltage. Also, remember that the output voltage is  $180^\circ$  out of phase with the input.

Consider the input circuit. Since the gate is reverse biased, there is little or no current flowing from the channel to the gate. This means that the applied signal voltage has little or no signal current flowing in the gate circuit. Therefore, the input impedance of the JFET is very high — usually several megohms. The output impedance is determined by the value of the load resistor, which is usually in the vicinity of 20k or

## FIELD-EFFECT TRANSISTORS

more. Because of its very high input impedance, the JFET is particularly useful in applications where we must avoid loading the source voltage.

### Insulated-Gate Field-Effect Transistors

Figure 25(A) shows a diagram of an amplifier using an n-channel, insulated-gate, field-effect transistor (IGFET), and Fig.25(B) shows an

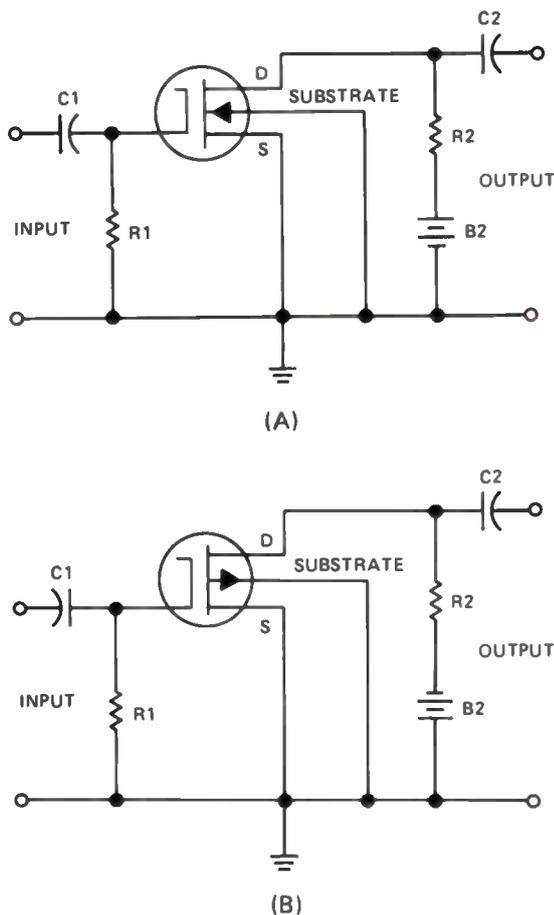


Figure 25. IGFET amplifiers using (A) an n-channel IGFET and (B) a p-channel IGFET.

amplifier using an p-channel, insulated-gate, field-effect transistor. Notice that in both circuits the source is connected directly to ground instead of to ground through a resistor. This means that in both circuits there is no reverse bias applied to the gate. The gate is insulated from the channel and therefore there is no way electrons can flow from the channel to the gate, or from the gate to the channel. Thus reverse bias is not needed.

The operation of these circuits is the same as the operation of the JFET circuits. In both cases, the output signal is  $180^\circ$  out of phase with the input signal. The IGFET has an even higher input impedance than the JFET. This is due to the fact that there is some leakage across the gate-channel junction in a JFET because of the minority carriers crossing the junction. There is no leakage across the junction in an IGFET because there is an insulator between the gate and the channel. As a matter of fact, the input impedance of these devices is so high that manufacturers usually ship them to the user with the leads wrapped in tin foil or some other conducting device. This is to keep the gate shorted to the source or the drain so the gate cannot build up a high static charge. Since there is no way for this charge to dissipate, the charge can build up to such a high value that it punctures the insulation between the gate and the channel. Once this happens, the transistor is destroyed.

### Dual-Gate MOSFETs

Earlier we mentioned that the MOSFET is a metal oxide semiconductor field-effect transistor. The metal oxide refers to the insulation used between the gate and the channel. The MOSFET can be made with a single gate or a dual gate.

## HOW TRANSISTORS ARE USED

Figure 26 is a diagram of an amplifier using a dual-gate, n-channel MOSFET. The input signal is applied to gate 1 as shown, and the output signal is taken off between the output terminals. With gate 2 grounded, the input signal applied to gate 1 causes the current flowing through the channel to vary. This varies the voltage drop across R2 so that the voltage between the drain and ground varies and an output signal is produced.

If, instead of grounding gate 2, we apply a negative voltage to it, we can vary the gain of the transistor by varying the negative voltage. With zero voltage, a signal applied to gate 1 causes a certain varying current to flow through the channel. But if we apply a negative voltage to gate 2, it restricts the channel width so that the current decreases. This reduces the amplitude of the varying current flowing through the channel and hence the varying voltage developed across R2. As a result, the output signal decreases. If we increase the negative voltage applied to gate 2 still further, the varying current continues to

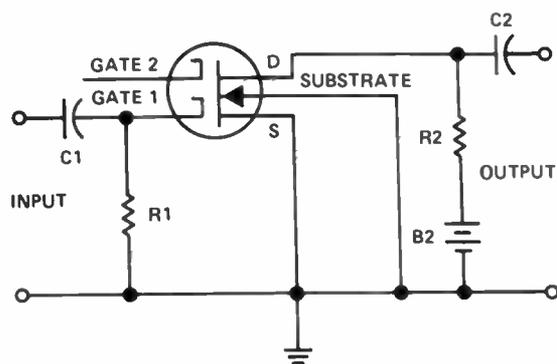


Figure 26. Amplifier circuit using a dual-gate MOSFET.

decrease and the amplitude of the output signal in turn continues to decrease. In fact, if we make a negative voltage applied to gate 2 high enough, we can cut off the flow of current through the channel so that the output signal drops to zero.

The operation of the transistor is exactly the same as that of the JFET described earlier, except here we have a means of controlling the gain by varying the voltage applied to the gate. In the case of an n-channel transistor, we would apply a negative voltage to gate 2 in order to reduce the gain of the stage. In the case of a p-channel transistor, we would apply a positive voltage to the gate. Dual-gate MOSFETs are widely used as the rf amplifier in TV tuners. It is possible to vary the gain of the stage over a wide range with this type of FET so that on strong local stations, the rf stage amplifies the signal very little. This prevents overloading the receiver with a strong signal received from the local station. On the other hand, if you tune the TV receiver to a weak distant station, then the reverse bias applied to the gate automatically decreases and the stage operates with a maximum gain in order to amplify the weak signal as much as possible to provide a satisfactory picture. There are other applications where dual-gate MOSFETs are used to control the gain of the stage.

### Review

There are two basic types of field-effect transistor — the junction-gate (JFET) and the insulated-gate (IGFET). These field-effect transistors offer certain advantages over the bipolar transistors we discussed earlier in this lesson. Both have a very high input impedance, and in any circuit using an FET there is a 180° phase reversal.

## FIELD-EFFECT TRANSISTORS

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One important type of IGFET that we have discussed is the MOSFET. Its operation is exactly the same as that of the JFET, except that, with a MOSFET, we can control the gain by varying the voltage applied to the gate. MOSFETs are widely used as rf amplifiers in TV tuners and computers.

### Self-Test Questions

- 16 Is the amplified output signal from a field-effect transistor in phase or out of phase with the input signal?
- 17 What potential must be applied to the gate of a p-channel JFET?
- 18 What important characteristic does the input impedance of a FET amplifier have?
- 19 Which has the higher input impedance, a JFET or an IGFET?
- 20 What purpose does gate 2 in a dual-gate MOSFET serve?

## HOW TRANSISTORS ARE USED

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### TRANSISTOR CHARACTERISTICS

The table in Fig.27 is a summary of both bipolar and field-effect transistor characteristics. There are a number of important characteristics that you should remember. The common-collector type has a voltage gain less than 1; all other circuits provide a high voltage gain. The common-base circuit has a current gain less than 1, whereas all others provide a higher current gain. In the common-base and common-collector circuits, the output signal is in phase with the input signal. In all the other circuits, the output signal is 180° out of phase with the input.

There are a number of symbols used in describing transistor performance. Most of these symbols are of interest to circuit designers and

engineers, but not to the technician. However, there are a few that are widely used that you should become familiar with. You may encounter them in your work.

#### Transistor Symbols

As you might expect, the letter I is used to represent current in transistor circuits. When the capital letter I is used, it indicates dc current or rms current. When the small letter i is used, it indicates the instantaneous current.

You frequently see references to the ac current in a transistor. When an ac signal is applied to the input of a transistor circuit, it causes the current in the output circuit to vary. We can consider the current in the output circuit as a dc current with an ac current superimposed on it. Remember that when we used a capacitor in the output circuit to block the dc voltage, we got a

TRANSISTOR TYPE	VOLTAGE GAIN	CURRENT GAIN	INPUT/OUTPUT SIGNAL PHASE RELATION	INPUT IMPEDANCE	OUTPUT IMPEDANCE
COMMON-BASE	HIGH	LESS THAN 1	IN PHASE	LOW	REASONABLY HIGH
COMMON-EMITTER	HIGH	HIGH	180° OUT OF PHASE	REASONABLY HIGH	REASONABLY HIGH
COMMON-COLLECTOR	LESS THAN 1	REASONABLY HIGH	IN PHASE	REASONABLY HIGH	LOW
JFET	HIGH	HIGH	180° OUT OF PHASE	HIGH	REASONABLY HIGH
IGFET	HIGH	HIGH	180° OUT OF PHASE	VERY HIGH	REASONABLY HIGH

Figure 27. Bipolar and field-effect transistor characteristics.

## TRANSISTOR CHARACTERISTICS

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signal voltage that was strictly an ac voltage. If we connect a resistor across the output terminals, we have an ac current flow. It is important for you to remember that when we refer to ac current in a transistor, we are referring to the ac current that is, in effect, superimposed on the dc current that flows through the transistor under zero signal conditions.

Currents flowing to or from the various transistor terminals are identified by means of a letter representing the terminal. For example, the emitter current is represented by the letter E or e. Base current is represented by B or b and collector current is represented by the letter C or c. Using these symbols, the dc emitter current is designated by the symbol  $I_E$ . The rms emitter current is represented by the symbol  $I_e$ , and the instantaneous emitter current is represented by the symbol  $i_e$ . Similarly, dc base current is represented by  $I_B$ , rms base current is represented by  $I_b$ , and instantaneous base current is represented by  $i_b$ . Collector dc current is represented by  $I_C$ , rms collector current is represented by  $I_c$ , and instantaneous collector current is represented by  $i_c$ .

Two characteristics that are often referred to in transistors are the forward current and reverse current. The symbol used to represent the dc forward current is  $I_F$ , and  $i_F$  is used to represent the instantaneous forward current. The dc reverse current is represented by  $I_R$ , and the instantaneous reverse current is represented by  $i_R$ .

Remember that in normal operation a transistor is operated with forward bias across the emitter-base junction and reverse bias across the base-collector junction. Thus, in an npn transistor, current can flow from the emitter, across the emitter-base junction, through the base, across the base-collector junction, through the collector, and to the positive terminal of the

battery, placing the reverse bias across the base-collector junction. However, there would be times when some minority carriers would cross the various junctions in a reverse direction. Thus, there is a current flow across the base-collector junction due to holes traveling from the collector across the junction into the base. This reverse current is kept as small as possible because it is useless current. Transistor manuals often list the reverse current across the collector-base junction. The current that is listed is the current that flows across the junction when the junction is reverse biased and the emitter is open circuited. This dc current is represented by the symbol  $I_{CBO}$ . The letters CB indicate that the current is across the collector-base junction in the reverse direction. The letter O indicates that the other electrode, the emitter, is open. This symbol is so widely used that it is often abbreviated  $I_{CO}$ .

Groups of letters are used in this manner to indicate other transistor currents. For example, the symbol  $I_{CEO}$  is used to represent the dc collector current with the collector reverse-biased and the base open-circuited.

There are other symbols used in conjunction with the transistors, but you can usually figure out what the symbols mean. Transistor manuals and data sheets are also available from electronic parts distributors. Most of these manuals list all the symbols and tell you what they mean.

### Current Gain

You already know that the current gain of a transistor used in a common-base circuit is represented by the Greek letter  $\alpha$ , and the current gain in a common-emitter circuit is represented by the Greek letter  $\beta$ .

## HOW TRANSISTORS ARE USED

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Frequently in transistor characteristics, you see the alpha cutoff frequency listed. Transistors are designed to operate up to a certain maximum frequency. The alpha cutoff frequency is the frequency at which the current gain of a transistor in a common-base circuit drops to approximately 70% of the gain that is listed in the transistor characteristics. The higher the alpha cutoff frequency, the higher the frequency at which the transistor can be used.

Manufacturers usually give either the alpha or the beta of a transistor, but seldom both. Sometimes when the alpha is given, you want to know the value of beta and vice versa. If you know the alpha of a transistor, you can find beta from the formula:

$$\beta = \frac{\alpha}{1 - \alpha}$$

If you know the beta of a transistor, you can find the alpha from the formula:

$$\alpha = \frac{\beta}{1 + \beta}$$

It is not necessary that you memorize these formulas, but try to remember where they are so you can look them up if you need them.

### Review

Because transistors are used so frequently in electronic circuitry, it is very important that you get to know all the different types and their symbols. They come up often in your electronics studies and experiences. It is also important that you understand the information given on the table in Fig.27, as well as the formulas for determining current gain in transistors.

### Self-Test Questions

- 21 What symbol is used to represent the dc base current?
- 22 What symbol is used to represent the rms collector current?
- 23 What symbol is used to represent the instantaneous-emitter current?

## ANSWERS TO SELF-TEST QUESTIONS

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### ANSWERS TO SELF-TEST QUESTIONS

- 1 Yes. In the common-emitter circuit, the signal voltage is applied across the input resistor. None of the emitter current that is flowing through the collector flows through this resistor. The actual signal current flowing in the input is comparatively small. At the same time, the collector current is equal to the emitter current minus any current loss at the base and is therefore much larger than the signal input current. As a result, a current gain is possible in the common-emitter circuit.
- 2 The amplified signal voltage is many times the input voltage and is  $180^\circ$  out of phase with it in the common-emitter circuit.
- 3 Figures 4 and 5 are schematics of a common-emitter circuit using an npn transistor. Figure 6 is a schematic using a pnp transistor.
- 4 No. In the common-base circuit, the collector current is always less than the emitter current because part of the emitter current leaves the transistor through the base.
- 5 They are in phase.
- 6 We can obtain a voltage gain in a common-base circuit because the output load resistor can be made quite large. Thus, even though the signal current flowing through the load is smaller than the input signal, the fact that the output load resistor can be made many times the input impedance of the transistor results in the output voltage being greater than the input signal voltage.
- 7 A very low input impedance and a high output impedance.
- 8 The output signal voltage is in phase with the input signal voltage.
- 9 The voltage gain of a common-collector circuit is always less than 1.
- 10 The common-collector circuit has a high input impedance and a low output impedance. Its input impedance is higher than that of the other two circuits, and it is the only circuit in which the output impedance is lower than the input impedance.
- 11 The common-emitter circuit.
- 12 The common-base circuit and the common-emitter circuit.
- 13 The common-emitter circuit and the common-collector circuit.
- 14 The common-emitter circuit and the common-collector circuit.
- 15 The common-collector circuit.
- 16  $180^\circ$  out of phase.
- 17 A positive potential.
- 18 It has a high input impedance.
- 19 The IGFET has a higher input impedance than the JFET.
- 20 It can be used to control the gain of the MOSFET.
- 21  $I_B$ .
- 22  $I_C$ .
- 23  $i_e$ .

# Lesson Summary

Some of the important facts that you should remember about this lesson are:

- The three basic amplifier configurations are common base, common emitter, and common collector.
- Either a pnp or an npn transistor can be used in any amplifier configuration.
- The current gain of a common-base amplifier circuit is an important characteristic that is represented by the Greek letter alpha.
- Current gain of a common-emitter amplifier circuit is represented by the Greek letter beta.
- Dual-gate MOSFETs provide a means of automatically controlling the gain of an FET amplifier circuit.

LESSON QUESTIONS

This is Lesson Number 2227.

Make sure you print your name, student number, and lesson number in the space provided on the Lesson Answer Form. Be sure to fill in the circles beneath your student number. Code the lesson number as shown at the right.

**Reminder:** A properly completed Lesson Answer Form allows us to evaluate your answers and speed the results and additional study material to you as soon as possible. Do not hold your Lesson Answer Forms to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

Name John Smith  
 Print  
 Student No. XY01237894 Lesson No. 2227  
 Grid of bubbles for marking answers (0-9) with some bubbles already filled in.

1. The transistor with the highest input impedance is a(n):
  - a. PNP.
  - b. NPN.
  - c. IGFET.
  - d. JFET.
2. The basic transistor circuit that does not provide a current gain is the:
  - a. Common-emitter circuit.
  - b. Common-base circuit.
  - c. Common-collector circuit.
3. The basic transistor circuit that does not provide a voltage gain is the:
  - a. Common-emitter circuit.
  - b. Common-base circuit.
  - c. Common-collector circuit.
4. Which basic transistor circuit provides a 180° phase shift?
  - a. The common-base circuit.
  - b. The common-emitter circuit.
  - c. The common-collector circuit.
5. The common-base circuit has:
  - a. The highest input impedance.
  - b. A current gain.
  - c. A low output impedance.
  - d. A voltage gain.
6. The common-emitter circuit provides:
  - a. A current gain.
  - b. A low input impedance.
  - c. A low output impedance.
  - d. An amplified in-phase voltage.

## HOW TRANSISTORS ARE USED

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7. The common-collector circuit provides:
  - a. A low input impedance.
  - b. A high output impedance.
  - c. A voltage gain.
  - d. A current gain.
8. An amplifier using a field-effect transistor has a(n):
  - a. High input impedance.
  - b. Low input impedance.
  - c. Voltage gain less than 1.
  - d. Amplified signal in phase with the input signal.
9. A MOSFET is a(n):
  - a. NPN transistor.
  - b. PNP transistor.
  - c. JFET.
  - d. IGFET.
10. The purpose of a second gate in a dual-gate MOSFET is:
  - a. To increase the gain.
  - b. To increase the input impedance.
  - c. To control the gain.
  - d. To increase the output impedance.

## NOTES

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*Please use this page to record any notes  
you may want to review during your studies.*

## NOTES

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## GET ALONG WITH PEOPLE

A national magazine recently published the results of a survey in which it asked several hundred successful men and women: "What single ability have you found to be most essential to your success?" Almost unanimously, the answer was: "The ability to get along with people."

I'm sure you are already aware of the importance of this often undervalued ability. But did you think of getting along with others as a skill? It *is* a skill; one that you can learn like any other.

To be successful in any field — technical, artistic, or commercial — you must be able to get along with other people. You must have the ability to work with others to achieve your common goals. You can only profit from your special talents and skills if other people are willing to come to you for your services, and people won't seek you out if they don't like you.

Keep this in mind in your daily life. Practice getting along with people. Notice the things people respond to and the things that "turn them off." There is always room for improvement in this area. As you go along, you will learn what many happy and successful people already know — that getting along with others is the single most important factor in gaining or keeping success.



# Integrated Circuits

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# Integrated Circuits

# INTEGRATED CIRCUITS

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## TABLE OF CONTENTS

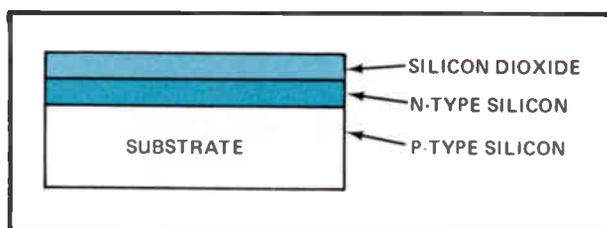
<b>Introduction</b> .....	1
<b>How Monolithic Circuits Are Made</b> .....	1
Summary .....	4
<b>Basic Circuits</b> .....	5
Voltage Regulation .....	5
The Differential Amplifier .....	6
Compound-Connected Transistors .....	10
A Dual-Differential Amplifier .....	11
Summary .....	16
Self-Test Questions .....	17
<b>Digital Circuits</b> .....	18
The Inverter .....	19
The AND Gate .....	19
The OR Gate .....	21
The NAND Gate .....	23
The NOR Gate .....	23
Negative Logic .....	24
Flip-Flops .....	27
Common ICs .....	29
Summary .....	29
Self-Test Questions .....	30
<b>Answers to Self-Test Questions</b> .....	31
<b>Lesson Questions</b> .....	33

## HOW MONOLITHIC CIRCUITS ARE MADE

The manufacturing of an IC begins with a bar of silicon to which an impurity, such as boron, is added to produce a p-type silicon material. This bar of silicon is then sliced into discs a few thousandths of an inch thick. Called the *substrate*, the p-type silicon is the foundation on which ICs are made. Each disc may be several inches in diameter so that a large number of ICs can be built on each disc. After the circuits are built, the discs are cut up to form individual ICs.

After the bar of silicon has been cut into discs, the discs are polished to a very smooth surface. On the top of the disc, a layer of n-type silicon is deposited. This layer is called the *epitaxial layer*, and it will eventually become the collector for the npn transistors that will form part of the IC.

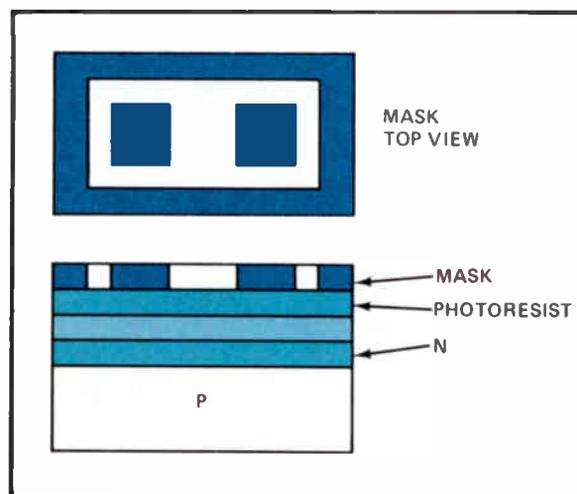
Next, we grow a layer of silicon dioxide over the top of the n-type crystal by heating the chip in an oxygen atmosphere. At this stage, a side view of the enlarged chip looks like Fig.1. (The drawing is out of scale; the



**Figure 1.** P-type silicon substrate with n-type epitaxial layer and protective layer of silicon dioxide.

chip will actually be only a few thousandths of an inch thick.) The layer of n-type silicon on top of the substrate and the layer of silicon dioxide are extremely thin.

From here on, the procedure used depends on what elements are going to be formed on the substrate. If we are going to make an IC containing two npn transistors, the next step is to coat the entire surface of the silicon dioxide with a photoresist material. This is the material that becomes chemically insolvent if it is exposed to ultraviolet light. After the silicon disc is coated with photoresist, a mask with opaque and transparent regions is made on film, as shown in Fig.2. The photoresist on the chip is then exposed to ultraviolet light through the mask. At the spots where the mask is opaque, the ultraviolet



**Figure 2.** Drawing showing mask and how it is placed over silicon dioxide.

# INTEGRATED CIRCUITS

2

light cannot go through and strike the photoresist. Where the mask is transparent, the light can get through and strike the photoresist. The chip is then rinsed in a developer. Where light has not struck the photoresist, the developer removes the photoresist and exposes the surface of the silicon dioxide. Next, the wafer is put into a chemical bath that etches or eats away holes, or windows, in the surface of the chip where it has not been exposed to the ultraviolet light. This action continues until the windows reach the n-type silicon, as shown in Fig.3. The silicon is then placed in an oven at high temperature, and the p-type silicon is diffused through the window in the n-type layer. The p-type material is diffused into the n-type material until it joins the substrate. There are now two areas of n-type material insulated from each other by the substrate and by the p-type material that has been diffused through the n-type material into the substrate. The chip now looks like Fig.4.

At this point, the entire surface of the chip is once again oxidized with silicon dioxide and then coated with photoresist. As shown in Fig.5, a new mask is then placed over the chip and once again the chip is exposed to

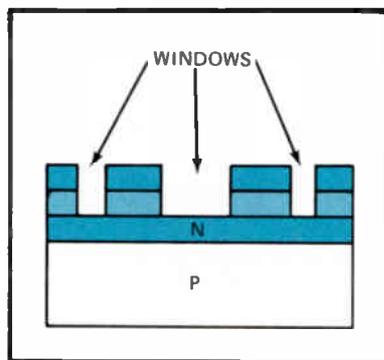


Figure 3. Windows are etched chemically down through the silicon dioxide to the n region.

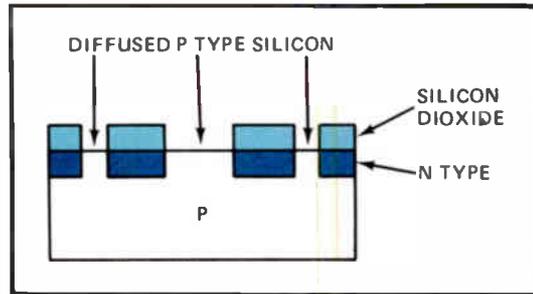


Figure 4. Drawing showing chip after p-type silicon is diffused through the windows.

ultraviolet light. Where the light strikes the chip, the silicon dioxide is protected by the photoresist, but where it is prevented from striking the chip by the opaque portion of the mask, the oxide and photoresist can be easily removed, forming new windows. P-type material is once again diffused into the windows forming the pn junctions that are shown in Fig.6.

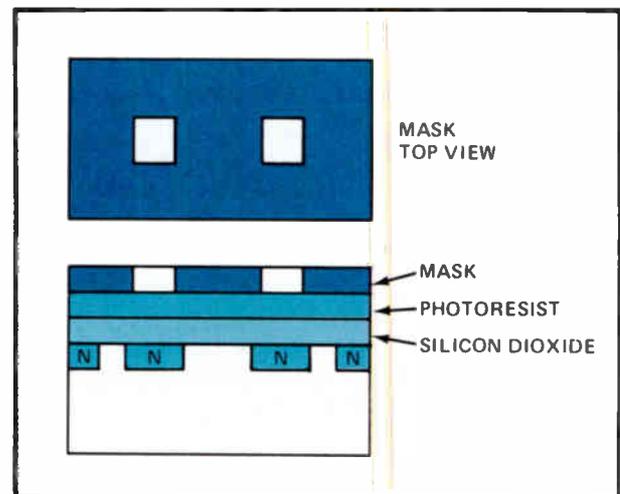
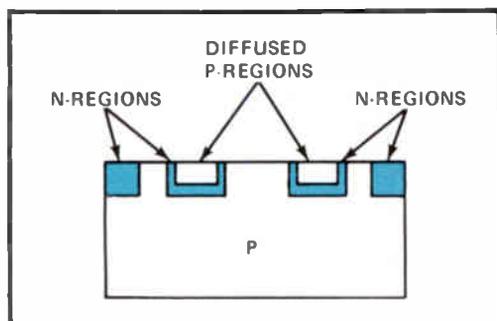
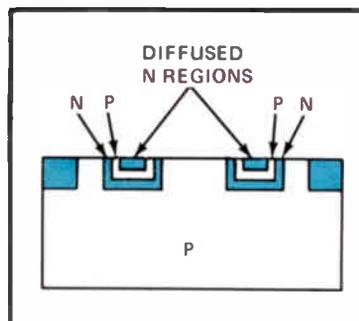


Figure 5. Drawing of the mask and chip ready for second exposure and etching.



**Figure 6.** Drawing of chip after second p-type silicon diffusion.



**Figure 8.** Drawing of chip after second n-type diffusion has formed two npn transistors.

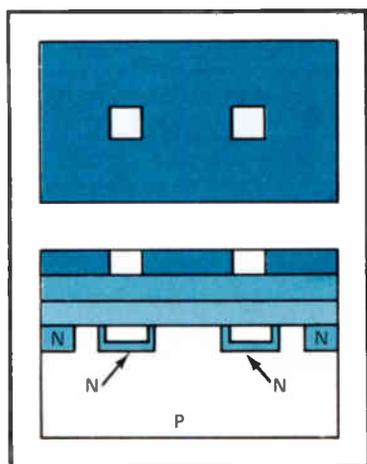
Once again the surface is oxidized with silicon dioxide and then coated with photoresist. As shown in Fig.7, another mask is placed over the chip. The chip is again exposed to ultraviolet light and the opaque area of the mask is etched away. N-type material is then diffused through the windows, as shown in Fig.8, so that we now have two npn transistors.

In the final step, windows are etched through a new mask through which alu-

minum is deposited to provide metal contacts for bonding leads to the transistor elements.

We have omitted a number of steps and many details in this description of how ICs are made, but the important thing to remember is that the transistors are formed in a series of steps, and since they are all formed at the same time, it is likely that they will have very similar characteristics. Although the transistors formed by the procedures are npn transistors, pnp transistors can also be formed using similar techniques.

You might wonder why the two transistors formed on the single p-type substrate do not short together through the substrate. This is easy to understand if you consider the operating voltages that will be applied to the transistor when it is in use. The larger n-region that is first formed will be the collector of the transistors. The collector will have a positive voltage applied to it. The substrate will be at ground or zero potential. Therefore, we have a reverse bias across the junction formed by the n-type collector and the p-type substrate, and no current can cross the junction. In other words, the n-type collector material and the p-type substrate act as a reverse-biased diode so that there will be no current flow across the junction.



**Figure 7.** Drawing of mask and chip ready for third exposure.

The two transistors are thus isolated from each other by the substrate.

The two npn transistors formed on the IC just described are bipolar transistors, so the IC is called a *bipolar IC*. There are other types of ICs that use insulated-gate field-effect transistors.

You will recall that a MOSFET is an insulated-gate field-effect transistor in which the gate is a metal and is insulated from the channel by an oxide of the metal. ICs using n-channel enhancement-type FETs are referred to as *NMOS*. ICs that use enhancement-type FETs where the channel is a p-type material are called *PMOS*.

In some ICs, both enhancement-type n-channel and p-channel FETs are used. In these ICs, the two FETs are connected in series and their gates are tied together. When the voltage applied to the gate is positive, the n-channel FET can conduct; when the voltage applied to the gate is negative, the p-channel FET can conduct. These ICs are called *CMOS*, which means complementary metal oxides semiconductors.

There is another type of insulated-gate field-effect transistor IC that uses depletion-type n-channel FETs. This type of IC is called *HMOS*.

The ICs that use insulated-gate field-effect transistors have a very high impedance. It is possible for static charges of such high values to build up on the gates that the charge will break through the insulation and short the gate to the channel. This will destroy the IC. To prevent this from happening, when the IC is not in use, it should be plugged into a foam-type conductor so that the various leads on the IC will be shorted together.

### Summary

You don't have to remember the IC manufacturing process, but remember that in a monolithic IC all the parts are formed by the same manufacturing process. An IC using npn or pnp transistors is called a bipolar IC. An NMOS IC uses n-channel enhancement-type FETs. A PMOS IC uses p-channel enhancement-type FETs. A CMOS IC uses both n-channel and p-channel enhancement-type FETs. An HMOS IC uses n-channel depletion-type FETs.

## BASIC CIRCUITS

There are two types of integrated circuits that are widely used today, *digital ICs* and *linear ICs*. In digital circuits, the various transistors are used in either the “on” or “off” state. In other words, the transistor is arranged so that it is either conducting at such a high level that it is saturated, or not conducting so that it is completely cut off.

In linear ICs, the transistors are biased at the midpoint of their characteristic curve. Thus, in a linear IC, the linear transistors are capable of amplifying signals and producing an amplified version of the original signal in the input.

### Voltage Regulation

Frequently, the successful operation of a circuit in an IC requires maintaining fairly close operating voltages on one or more stages within the IC. Often the voltage regulation is obtained by constructing one or more zener diodes within the IC. They are made at the same time, using the same processes used to form the transistors.

**Zener Regulation.** The circuit in Fig.9 shows how a zener diode can be used for voltage regulation. Here the input voltage applied to the circuit is 12 volts and the diode is maintaining the output voltage at 9 volts.

In a circuit of this type, the value of R1 is selected so that the normal current flow through it will produce a voltage drop of less than 3 volts. The current flowing through the diode supplies the additional current needed to maintain the output voltage at 9 volts. If the load current increases so that the voltage drop across R1 increases, the current through the diode decreases to maintain the output voltage at 9 volts. Similarly, if the load current decreases, the current through

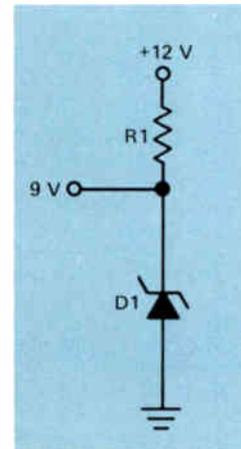


Figure 9. Zener diode voltage regulator circuit.

the diode will increase to keep the voltage constant.

The diode will also compensate for variations in the input of 12 volts. If the input voltage increases, the current through the diode will increase, so the voltage drop across R1 will increase to maintain the output voltage at 9 volts. Similarly, if the input voltage drops below 12 volts, the current through the diode will decrease, so the voltage drop across R1 will decrease to maintain the output voltage at 9 volts.

Notice that the input voltage must be greater than the required regulated voltage. If the input voltage is 9 volts or less, the diode will not conduct and as a result we will not have any regulation.

**Diode Regulation.** Forward-biased diodes can also be used as voltage regulators. A silicon diode, when it is conducting, has a voltage drop of approximately 0.6 volt across it, which remains constant over a fairly wide current range. By arranging forward-biased diodes as shown in Fig.10, the voltage regulated by the series-connected diodes will be considerably higher than the voltage that could be regulated by a single diode.

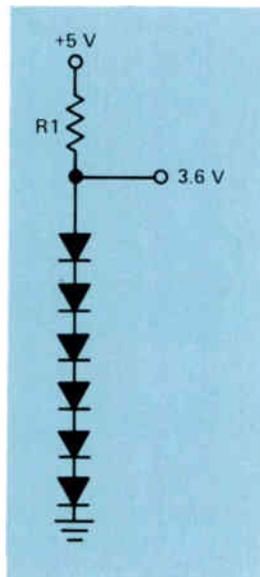


Figure 10. Forward-biased diodes used in a voltage regulator circuit.

Forward-biased diodes are widely used as voltage regulators in ICs. They are formed using the same processes that are used to form a transistor. Since the cathodes and anodes of the diodes are all formed at the same time, all of the diodes will have essentially the same characteristics. Therefore, the voltage drop across each diode is essentially the same.

In the circuit shown in Fig.10, six diodes, each with a voltage drop of 0.6 volt across it, are used to obtain a regulated voltage of 3.6 volts. You may encounter several strings of diodes, such as shown in Fig.10, in an IC where several regulated voltages are needed.

### The Differential Amplifier

One of the most widely used amplifier circuits in linear ICs is the differential amplifier shown in Fig.11. Since the amplifier uses

no capacitors, it can be used from dc up to vhf (very high frequency).

Notice that the amplifier has two inputs, input 1 and input 2, and two outputs labeled E1 and E2. The output is taken between terminals E1 and E2. The greater the difference in voltage between the two input signals, the greater the output voltage. For example, let's see what happens if the input to Q1 swings in a positive direction and the input to Q2 swings in a negative direction.

The positive input to Q1 causes the current through the transistor to increase. This causes the voltage drop across R2 to increase so that the potential at E1 will swing in a negative direction. At the same time, the negative signal applied to the input of Q2 will cause the current through the transistor to decrease. As a result, the voltage drop across R3 will decrease, causing the potential at E2 to swing in a positive direction. Thus, we have E1 swinging in a negative direction

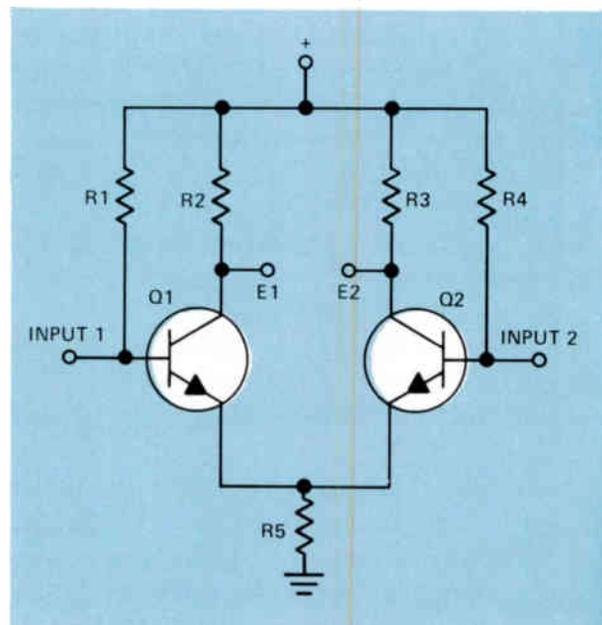


Figure 11. The basic differential amplifier circuit.

and E2 swinging in a positive direction, so that considerable output voltage is developed between these two terminals. If the positive signal fed to the input of Q1 is equal to the negative signal fed to the input of Q2, and the transistors, as well as R2 and R3, are matched, the increased current through Q1 will be exactly offset by the decrease in current through Q2. As a result, the current through R5 will remain constant and the voltage drop across it will not change.

Note what happens when the two input signals of the amplifier are equal in amplitude and phase. If the inputs to Q1 and Q2 both swing in a positive direction, the current through both transistors will increase, increasing the voltage drop across both R2 and R3. As a result, E1 and E2 will both swing in a negative direction so that the net voltage difference between E2 and E1 will be zero. At the same time, the current through R5 will increase, increasing the voltage drop across it. Thus, the emitters of both transistors will swing in a positive direction. This will subtract from the positive signals fed to the two inputs. The current increase through the two transistors will be considerably less than it would be if the emitters were connected directly to ground. This limits the current increases through R2 and R3, resulting in very little change in the voltage between E1 and ground and E2 and ground. At the same time, the increase in the voltage drop across R5 further limits the change in voltage between E1 and ground and E2 and ground so that these two voltages remain essentially constant.

At the same time, any change in the voltage between E1 and ground and the voltage between E2 and ground will be equal so that there will be no voltage between E1 and E2. Thus, the equal in-phase signals fed to the two inputs will not result in any output. This is referred to as *common-mode rejection*. It

simply means that the amplifier will not produce an output signal if there are any changes in the operating voltage or stray signals picked up at the two inputs. Thus, hum or any other noise signal picked up by the two inputs will not result in an output signal. Common-mode rejection is an important characteristic of the differential amplifier; you should remember what it is.

The differential amplifier will also produce an output if there is only one input signal. For example, if the input of Q1 swings in a positive direction, the current through this transistor will increase, causing the voltage drop across R2 to increase so that the potential at E1 will swing in a negative direction. If there is no signal at the input of Q2, the increased current through Q1 will cause the voltage drop across R5 to increase. This will reduce the forward bias across the emitter-base junction of Q2, causing the current through this transistor to decrease. As a result, the voltage drop across R3 will decrease, causing the voltage at E2 to swing in a positive direction. Therefore, we have an output signal that is once again equivalent to the difference between the voltages at E1 and E2.

When used in ICs, the basic differential amplifier circuit is usually modified as shown in Fig.12. Notice that the collector of Q1 is brought directly back to the positive power supply. The base of Q2 is operated at signal ground potential by bypassing it to ground through C1. The term *signal ground potential* simply means that insofar as any input signal is concerned, the base of Q2 is connected directly to ground. The reactance of C1 is so low that insofar as a signal is concerned, the base of Q2 is connected directly to ground.

The input signal is fed to the base of Q1 and the output signal is taken from the collector of Q2. When the input signal causes

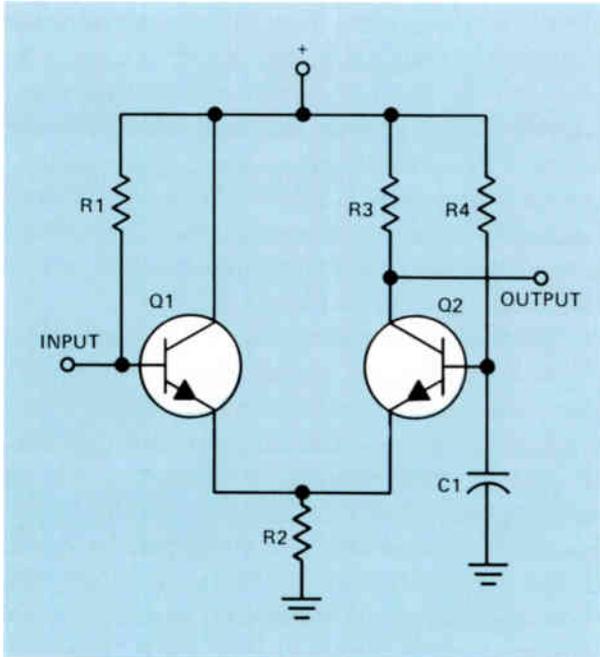


Figure 12. Modified differential amplifier circuit.

the base of Q1 to swing in a positive direction, current through the transistor will increase, increasing the voltage drop across R2. This will swing the emitter of Q2 in a positive direction, reducing the forward bias across the emitter-base junction of Q2. This will cause the current through the transistor to decrease, causing the voltage drop across R3 to decrease. Thus, the voltage between the collector of Q2 and ground will swing in a positive direction.

When the input signal applied to Q1 swings in the negative direction, it will reduce the current through the transistor, which in turn will reduce the voltage drop across R2. This will cause the forward bias across the emitter-base junction of Q2 to increase, increasing the current through the transistor and thus the voltage drop across R3. This means that the voltage between the collector of Q2 and ground will decrease or, in other words, swing in a negative direction.

Notice that there is no phase shift in this differential amplifier. For a positive-going input signal, we get a positive-going output signal; for a negative-going input signal, we get a negative-going output signal.

**Constant-Current Circuit.** Figure 13 is a diagram of an integrated circuit using a modified form of the differential amplifier. Terminals 1 through 5 are terminals of the IC. The transistor Q3 is called a *constant-current sink* or a *constant-current source*. By this we mean that the current through Q3 remains essentially constant. Let's see how this works.

Notice that the connection from R4 goes to terminal 4 of the IC. A small positive voltage is applied to this terminal. Current will flow from ground through D2, D1, and R4 to terminal 4. The voltage drop across D1 and D2

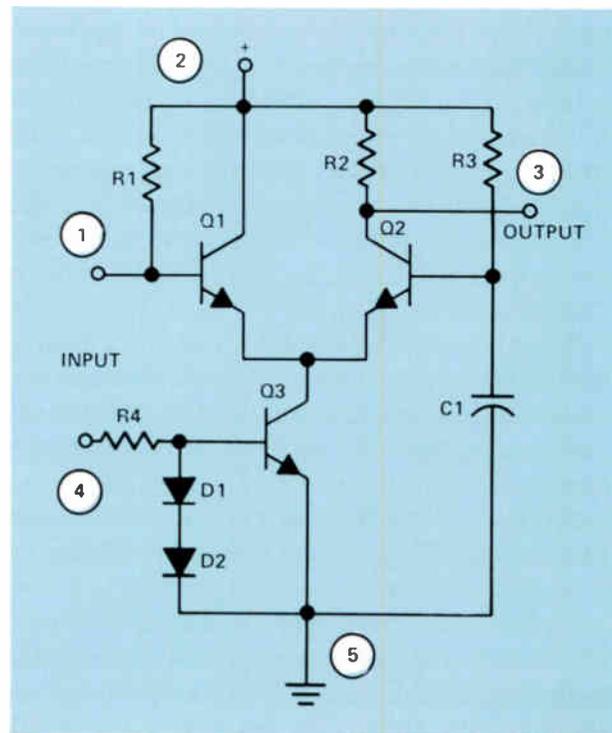


Figure 13. Differential amplifier with a constant-current sink.

will remain constant. If the voltage at terminal 4 increases slightly, the current through D1 and D2 will increase, as well as the current through R4. This will cause a greater voltage drop across R4 so that the voltage drop across the series-connected D1 and D2 will remain essentially constant. Similarly, when the voltage at terminal 4 drops slightly, the current flow in the circuit will drop, so the voltage drop across D1 and D2 will remain constant.

As long as the voltage drop across D1 and D2 is constant, there will be a constant forward bias across the emitter-base junction of Q3. As long as the forward bias across this junction is constant, the current flow through the transistor will remain constant.

If an input signal fed to terminal 1 swings positive, the forward bias across the emitter-base junction of Q1 will increase and the current through this transistor will increase. Since Q3 is supplying emitter current for both Q1 and Q2, and the current through Q3 is constant, if the current through Q1 increases, the current through Q2 must decrease. If the current through Q2 decreases, the voltage drop across R2 will decrease and the output at terminal 3 will swing in a positive direction.

If the input signal drives terminal 1 in a negative direction, the forward bias across the emitter-base junction of Q1 will decrease and the current through Q1 will decrease. Again, since the current through Q3 is constant, the current through Q2 must increase. The voltage drop across R2 will increase so that the voltage at the collector of Q2 will decrease and the voltage at output terminal 3 will swing in a negative direction. Notice that with this circuit we once again have an output signal that is in phase with the input signal.

**DC Level Shifting.** If we need more gain than we can get from a single amplifier, a

second differential amplifier can be used. However, in both Figs.12 and 13, the dc output voltage at the collector of Q2 is considerably higher than the base voltage at the input of Q1. Therefore, rather than trying to direct-couple the second differential amplifier, an emitter-follower stage is used between the two to get the dc voltage down to a lower level. Then, a second differential amplifier can be driven quite conveniently.

The circuit used to lower the dc level is shown in Fig.14. Notice that in this circuit, Q1 and Q2 form a differential amplifier that is identical to the circuit shown in Fig.12. The output from Q2 is coupled directly to the base of Q3, and the output signal is taken from the emitter of Q3. By controlling the characteristics of Q3 and the size of R5, we can obtain the correct dc voltage at the emitter of Q3 to correctly bias the base of the first stage of a second differential amplifier.

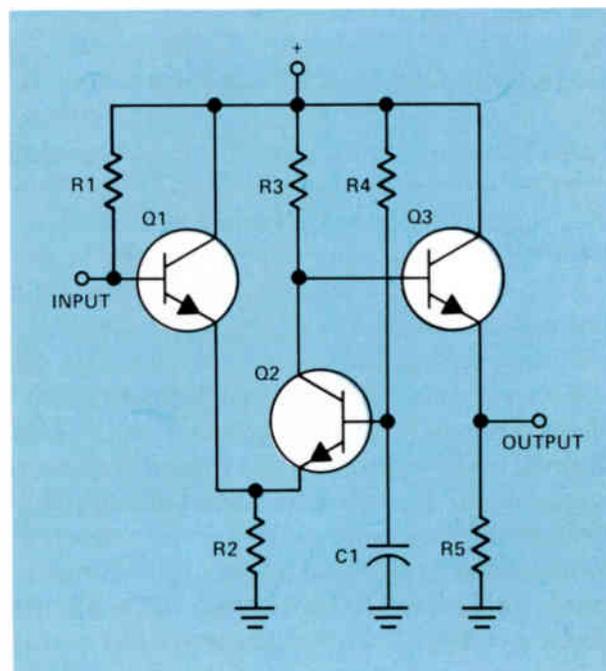


Figure 14. A differential amplifier and an emitter-follower stage.

In some integrated circuits, you will find two or three differential amplifiers and an emitter follower connected in cascade, which means that one differential amplifier is connected after another. The differential amplifiers are isolated from each other by an emitter-follower stage that lowers the dc level, so that in each case the output from the emitter follower provides the correct forward bias for the first stage of the following differential amplifier.

Very high gain can be obtained by using two, three, or more cascaded stages, as shown in Fig.14. If three differential amplifiers with an emitter-follower output are used in an integrated circuit, and each differential amplifier and emitter follower provides a gain of 10, the total gain of the three cascaded stages will be  $10 \times 10 \times 10 = 1000$ . It is relatively easy to obtain a gain of 10 in each differential amplifier and emitter-follower stage of this type.

### Compound-Connected Transistors

An example of a compound-connected emitter follower is shown in Fig.15. This type of circuit is frequently called a Darlington circuit. Two important characteristics of this type of circuit are a very high current gain and a relatively high input impedance.

Notice that in the circuit shown in Fig.15, the base current of Q2 is the emitter current of Q1. Thus, with similar transistors the base current of Q1 will be much lower than it would be if it were connected in the conventional common-emitter or emitter-follower circuit. A relatively small change in the base current of Q1 will produce a large change in the emitter current of Q2.

The relatively high input impedance of the Darlington circuit is due to the low base current of Q1. In a typical transistor, 95% of the

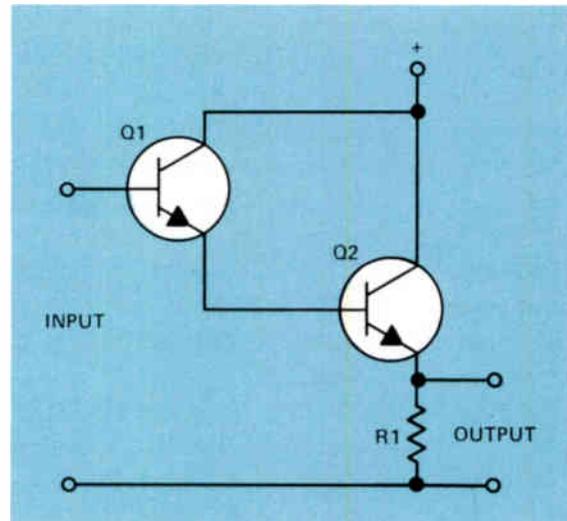


Figure 15. A compound-connected emitter-follower circuit.

emitter current will flow through the collector and 5% will flow through the base. Thus, in Q2, only 5% of the emitter current flows through the base. If Q1 has similar characteristics, 95% of its emitter current will flow through the collector. Since 95% of 5% is 4.75%, this leaves only 0.25% of the emitter current of Q2 to flow to the base of Q1. The base current of Q1 will be much lower than that of a single transistor stage. Hence, we have a higher input impedance, and since the circuit behaves as a normal emitter follower, it will have a low output impedance.

The relatively small base current of Q1, compared to the emitter current of Q2, results in a higher overall gain. Thus, the stage has two important characteristics: a high current gain and a relatively high input impedance.

Compound-connected transistors are used not only in emitter-follower circuits, but also in compound-connected differential amplifiers, as shown in Fig.16. The gain of an amplifier of this type is considerably higher

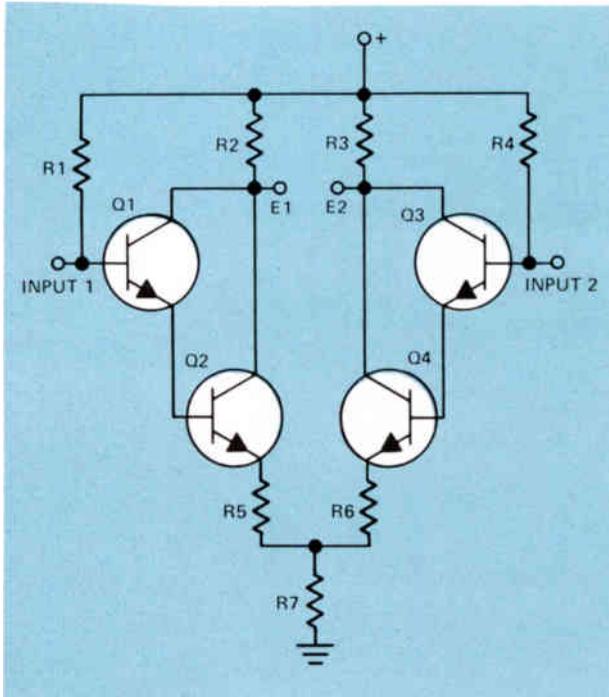


Figure 16. A compound-connected differential amplifier.

than the gain of the differential amplifier shown in Fig.11.

In the circuit shown in Fig.16, when an input signal drives input 1 in a positive direction, the small increase in the base current of Q1 will cause a larger increase in the emitter current of Q1. Since the emitter current of Q1 is the base current of Q2, the base current of Q2 must increase substantially. An increase in the base current causes a large increase in the emitter current of Q2 and the collector current. Thus, we have the collector current increasing, which increases the voltage drop across R2 so that E1 will swing in a negative direction.

If at the same time there is a negative voltage at input 2, the negative voltage will cause the base current of Q3 to decrease. This decrease in base current will cause a much greater decrease in the emitter current, which in turn will cause the base current of

Q4 to decrease. This will cause a large decrease in the collector current of Q4. Since both the collector currents of Q3 and Q4 decrease, there will be a considerable decrease in the voltage drop across R3 so that E2 will swing in a positive direction.

The signal voltage developed between terminals E1 and E2 of the compound differential amplifier will be much greater than it would be with a differential amplifier using only two transistors, because in this circuit all four transistors are amplifying the input change. This type of circuit can be used advantageously in an integrated circuit because we can get a nearly perfect balance in the two amplifiers. For example, since all four transistors are formed at the same time, they should have practically identical characteristics. Similarly, it is possible to make R1 equal to R4, R2 equal to R3, and R5 equal to R6. This means that a given input applied to input 1 will produce the same change in E1 that the same input signal fed to input 2 will produce at E2.

### A Dual-Differential Amplifier

The schematic diagram of an RCA type CA3026 IC is shown in Fig.17. It contains two differential amplifiers, each with a constant-current sink. Notice that there are no resistors or other parts in the IC except the transistors used in the differential amplifiers and the transistors used as current sources. The emitter of Q6, which is connected to terminal 9, is also connected to the metal case of the IC and to the IC substrate. Also notice that there are no circles drawn around the transistors. It is common practice to omit the circles around the transistors and diodes in the schematics of ICs. This indicates that they are not discrete or separate components, but are a part of an integrated circuit.

# INTEGRATED CIRCUITS

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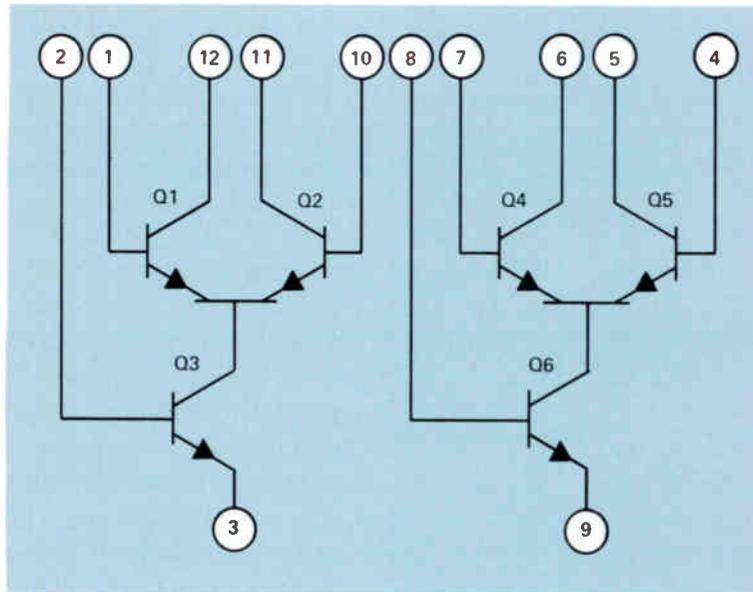


Figure 17. Schematic of a dual differential amplifier, type CA3026 IC.

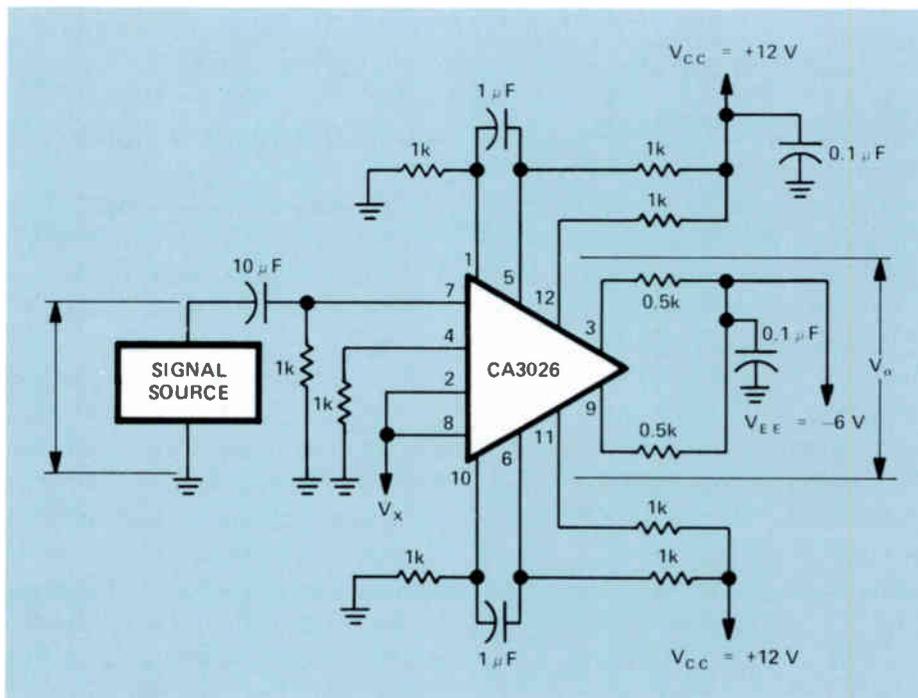
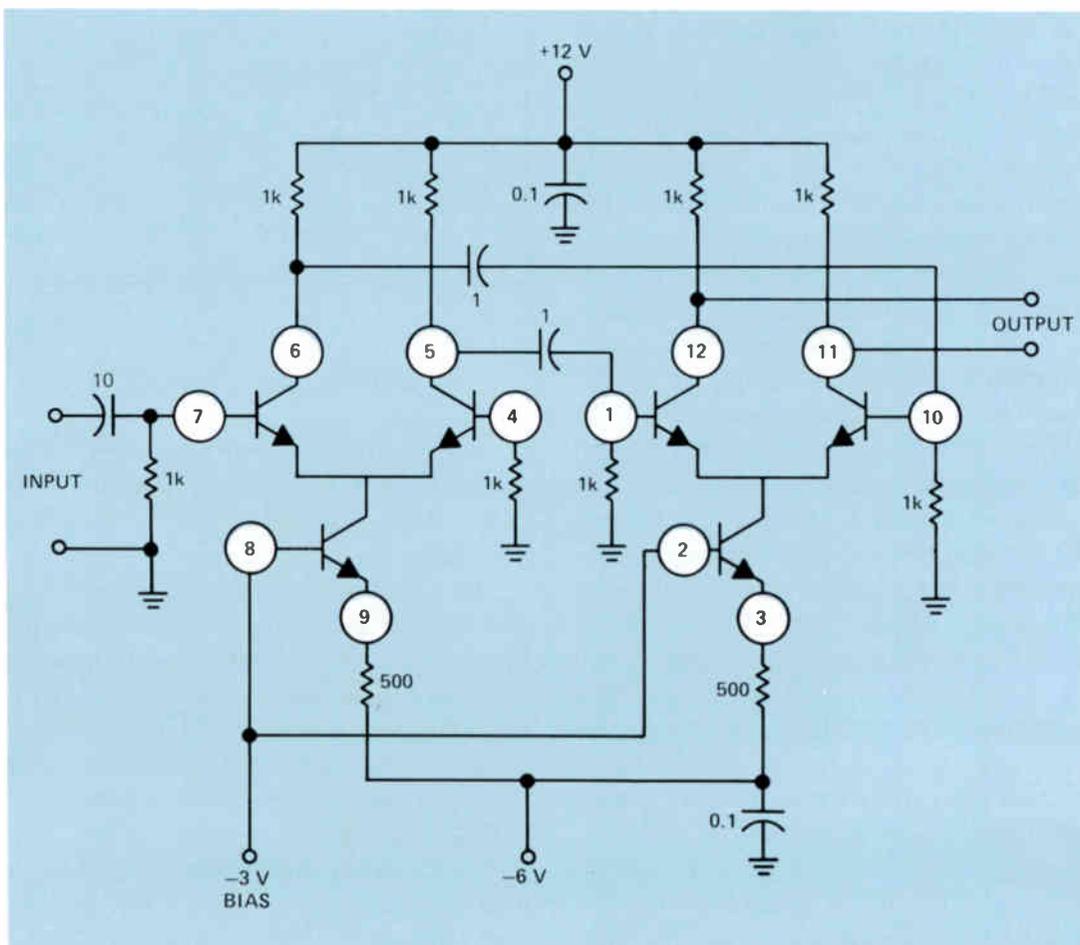


Figure 18. Using the CA3026 as a two-stage amplifier.

Figure 18 shows how this IC can be used as a two-stage amplifier. This is the type of diagram you'll see when ICs are used as two-stage amplifiers. As you can see, without knowing what is inside the IC it is difficult to trace out the circuit. However, by referring to Fig.17, which shows what is inside the IC, and to Fig.19, which shows the complete schematic of the two-stage amplifier, you should be able to trace out the circuitry shown in Fig.18.

Looking at Fig.18, we see that the input signal is fed to terminal 7. Figure 17 tells us

that pin 7 is the base of Q4. The other transistor in this differential amplifier is Q5 and the base of this transistor is connected to pin 4. We see that pin 4 is connected to ground through a 1k resistor. If the input signal fed to pin 7 swings in a positive direction, the current through the transistor must increase. Since there is a constant-current source (Q6), the current through the other transistor in the differential pair (Q5) must decrease. As a result, we have a push-pull output between terminals 5 and 6. The term *push-pull* means that as the voltage at one



Courtesy RCA

Figure 19. Complete schematic of the CA3026 two-stage amplifier.

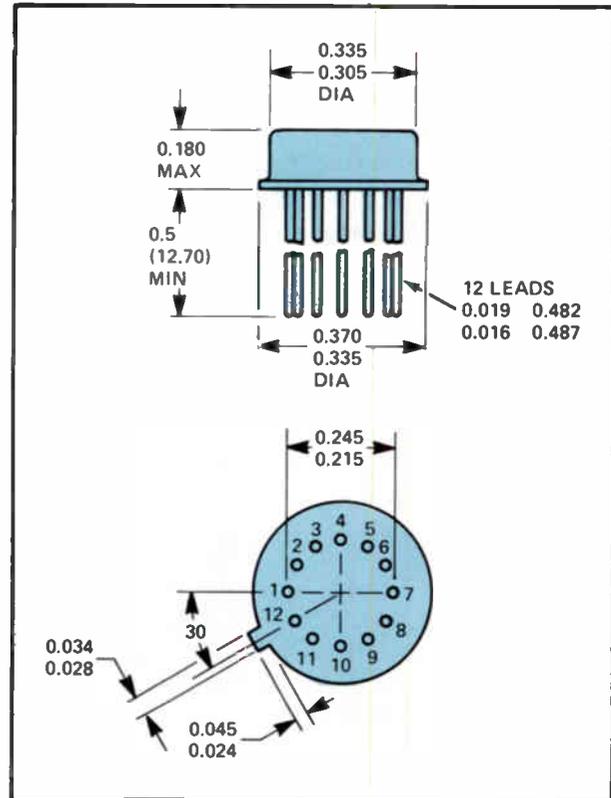
terminal swings in a positive direction, the voltage at the other terminal is swinging in a negative direction.

The outputs from terminals 5 and 6 are then fed through the  $1\mu\text{F}$  coupling capacitors to the bases of the other differential amplifier pair, where the signal is amplified further by this pair. The amplified push-pull output will be present at terminals 11 and 12 of the second differential amplifier, which is the output.

The bases of the transistors used as constant-current sources are brought to external connections, so different values of base bias can be applied to the bases, depending upon the application. In the example shown in Fig.19, a voltage of  $-3$  volts is applied to pins 2 and 8 of the IC. When the IC is used as a two-stage amplifier, there will be a voltage gain of about 1000.

To give you an idea of how much gain this actually represents, if we feed a 1 microvolt signal (in other words, a signal having an amplitude of 1 millionth of a volt) into terminal 7, we will have an amplified signal of 1000 microvolts, which is equal to 1 millivolt, between the output of terminals 11 and 12. If we take a second CA3026 and feed the output from terminals 11 and 12 of the first IC into terminals 4 and 7 of the second IC, with the circuit essentially the same as in Fig.18, we can get another voltage gain of 1000. Therefore, at terminals 11 and 12 of the second IC, the amplitude of the signal will be 1 volt. In other words, by connecting two ICs in cascade so that the signal is amplified first by one and then by the other, we can amplify the signal from 1 microvolt to 1 volt, getting a total gain of 1,000,000.

You might wonder how large the CA3026 IC actually is. This IC is housed in what is called a TO-5 case. The drawing in Fig.20(A)



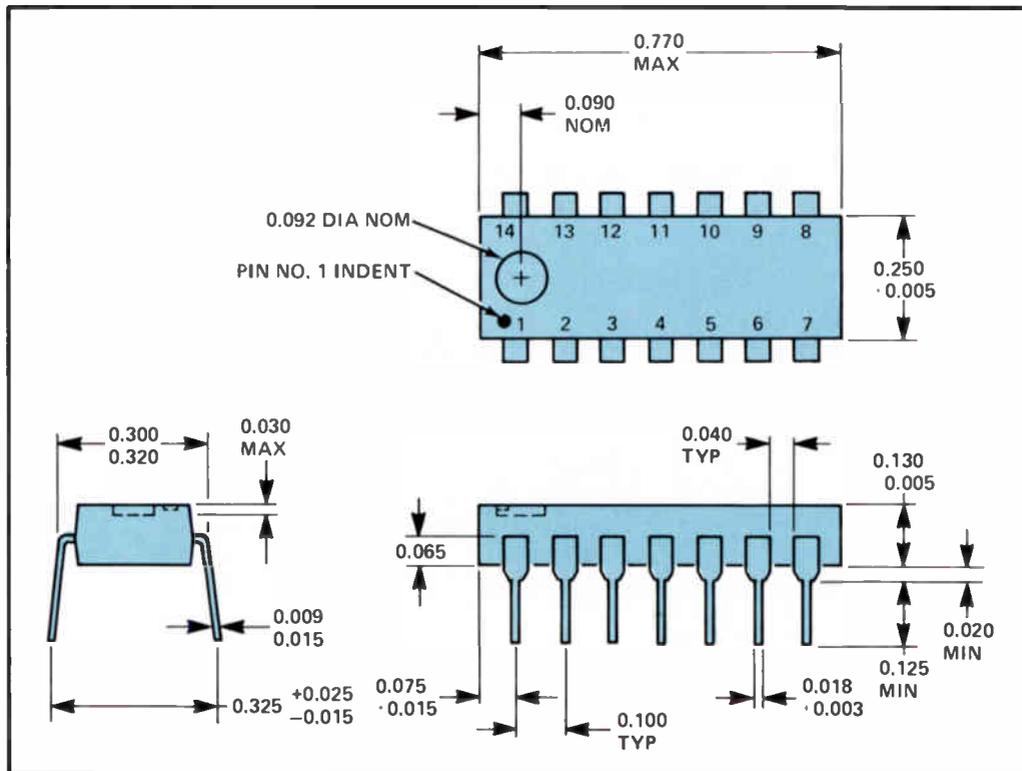
Courtesy RCA

Figure 20. Physical layout of CA3026.

gives the dimensions of the case. Notice that the maximum diameter of the rim of the case is 0.370 inch, or considerably less than one-half inch.

The various leads are identified by means of a small tip on the rim of the case adjacent to lead 12, as shown in Fig.20(B). Notice that there are 12 leads on this IC and lead No.12 is in the exact center of the tip on the rim. This is a bottom view. Counting from lead 12 in the clockwise direction, we come to leads 1, 2, 3, and so on.

The CA3026 dual-differential amplifier is also available as the type CA3054 in a package that is called a 14-lead, dual in-line



Courtesy RCA

Figure 21. TO-116 case dimensions.

package, identified as a TO-116 package. The physical dimensions of this package are shown in Fig.21. Notice that there are 7 leads on each side of the package. Also notice the notch, called an *index point*, at one end of the package. This enables us to identify the various pins. The view that shows the notch is a top view, so looking at the IC with the notch to your left, the pin below and to the left is terminal 1, and the pin above and to the left is terminal 14. Notice that the pins on one side of the IC are numbered 1 through 7, and the pins on the other side are numbered 8 through 14.

Most of the ICs you will encounter will be in dual in-line packages. The number of pins will vary from 8 on up. The same numbering scheme is used on all in-line packages. For example, in the case of a dual in-line package with 24 leads, the terminals on one side will be numbered 1 through 12 and those on the other side will be numbered 13 through 24.

Figure 22 is a drawing showing how the dual-differential amplifiers are connected in the CA3054 IC. The differential amplifiers in this IC are electrically identical to those in the CA3026 IC, but as you can see the pin connection arrangements are quite different.

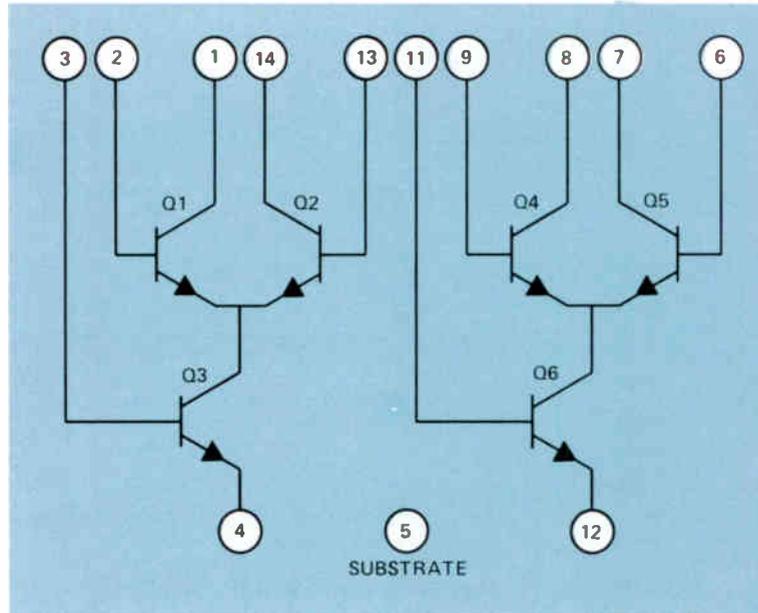


Figure 22. Pin connections for the CA3054 IC.

### Summary

Some ICs have voltage regulators built in them. The voltage regulator may be a zener diode or it may be a group of conventional silicon diodes connected in series. A forward-conducting silicon diode has a voltage drop of about 0.6 volt across it.

If you have a differential amplifier using two npn transistors and the signal fed to the base of one swings in a positive direction, the voltage at its collector will swing in a negative direction. If the signal fed to the input of the other transistor swings in a negative direction, the voltage at its collector will swing in a positive direction. The output voltage is the difference in voltage between the two collectors. If equal amplitudes in phase signals are fed to the bases of the

two transistors, the collector voltages will swing in the same direction, so the output will be zero.

The differential amplifier can be modified to use a single input and a single output. The differential amplifier is followed by an emitter-follower in order to reduce the dc voltage level at the output of the amplifier. Differential amplifiers and emitter-followers can be cascaded to obtain very high gain amplifiers. The transistor, with its base voltage held constant by means of the zener diode, forms a constant-current source. A constant-current source is often referred to as a current sink.

Two important characteristics of a compound-connected emitter-follower, often referred to as a Darlington circuit, are a very high current gain and a relatively high input impedance.

### Self-Test Questions

*Please check your answers on page 31.*

- 1 When a zener diode is used as a voltage regulator, is it forward biased or reverse biased?
- 2 If five forward-biased diodes are used as a voltage regulator and the voltage drop across one diode is 0.6 volt, what is the total regulator voltage?
- 3 When forward-biased diodes are used as a voltage regulator in an integrated circuit, why are the diodes likely to have identical characteristics?
- 4 If a differential amplifier, such as the one shown in Fig.11, is designed to provide a voltage gain of 10 in each stage, and a 1 volt positive signal is applied to both inputs, what will the output voltage be?
- 5 In the differential amplifier shown in Fig.12, will the output signal be in phase or 180° out of phase with the input signal?
- 6 What is the purpose of Q3 in the differential amplifier of Fig.13?
- 7 What purpose does Q3 serve in the circuit shown in Fig.14?
- 8 Give two advantages of the compound-connected emitter-follower circuit over the emitter-follower using a single transistor.
- 9 Why might compound-connected transistors be used in a differential amplifier?
- 10 In the ICs shown in Fig.17, which transistors are constant-current sources?
- 11 What type of circuits are contained in the ICs shown in Fig.17?
- 12 In the circuit shown in Fig.18, do we have a single-ended input or a push-pull input?
- 13 In the circuit shown in Fig.18, do we have a single-ended output or a push-pull output?
- 14 Is the maximum diameter of the type TO-5 case greater than or less than one-half inch?
- 15 How can you identify the various pins of an IC using a type TO-116 case?
- 16 In a 24-lead, dual in-line IC package, what pin will be at the same end as and opposite pin 1?

## DIGITAL CIRCUITS

Linear circuits are used to amplify the signal when we want the amplified circuit to be an exact copy of the original input. For example, if a signal like that shown in Fig.23(A) is fed to a linear amplifier, the output will be like Fig.23(B). The output is the same, but it is greater in amplitude.

A digital circuit has only two output conditions: maximum positive output and zero output. If we feed a signal such as shown in Fig.23(A) to a digital circuit that requires a *positive* signal to produce an output signal, we will get an output like that shown in Fig.23(C). If we feed a signal like that shown in Fig.23(A) to a digital circuit that requires

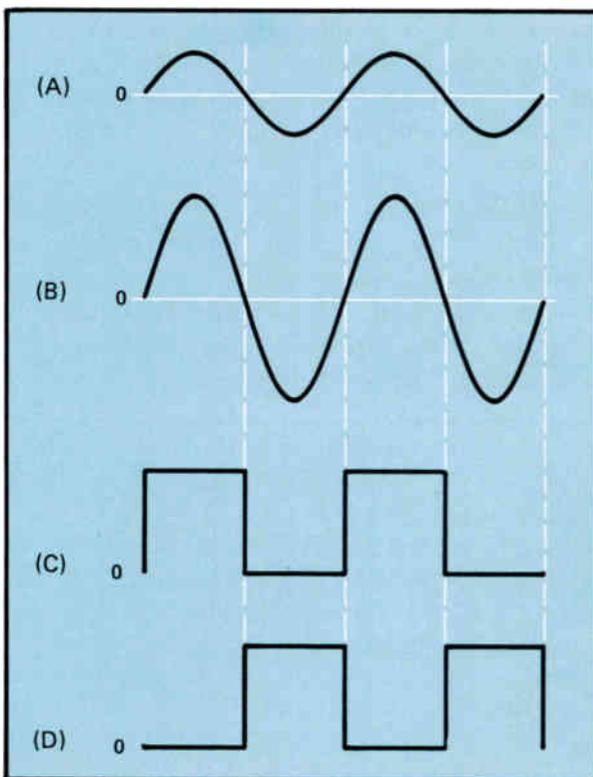


Figure 23. A comparison of signals from a linear circuit and a digital circuit.

a *negative* voltage to produce an output, we will get an output like that in Fig.23(D). Again, notice there are only two output levels: maximum positive and zero.

Digital circuits are widely used in computers and microcomputers. Both use a numbering system called a *binary system*. In this system there are only two digits, 1 and 0. Thus, in a digital system, full output can represent 1 and zero output can represent 0.

This might seem a little complex at first, but it is really quite simple. For example, look at the circuit shown in Fig.24. With the switch in the position shown, there is no forward bias across the emitter-base junction of the transistor. Therefore, there will be no current flow through the transistor or through R2. Thus, if we measure the voltage on output terminal 1, the voltage will be positive and it will be equal to the full battery voltage. This might represent binary 1.

Now, when we throw the switch into position B, the base will be connected to the positive end of the battery through R1. This places a positive voltage on the base of the transistor, so the transistor will conduct

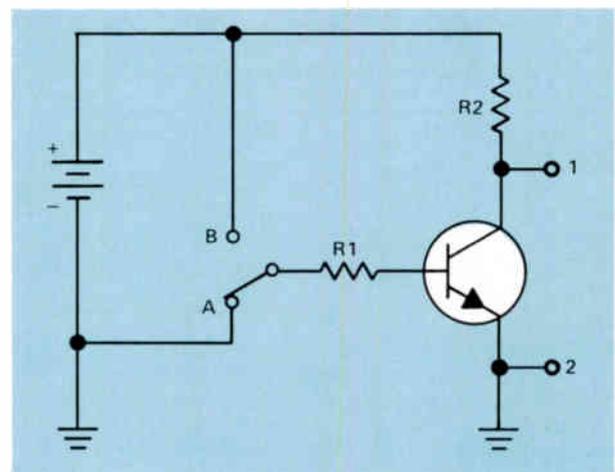


Figure 24. A transistor switch that produces binary outputs of 1 and 0.

heavily. It will go into what we call *saturation*, meaning it will conduct all the current it is capable of conducting. As a result, the transistor acts as a very low resistance between the emitter and the collector, while  $R_2$  is a comparatively large resistance. Therefore, the voltage drop across the transistor will be practically zero, whereas almost the entire battery voltage will be dropped across  $R_2$ . The voltage on terminal 1 will now drop to near zero. This condition represents a binary 0.

This system of representing the digits 1 and 0 is called *digital logic*. The circuits used for this purpose are called *digital logic circuits* or simply *logic circuits*. When 1 is represented by the most positive voltage in the circuit, we have what is called *positive logic*. In positive logic, we often refer to 1 as a high and 0 as a low.

### The Inverter

The schematic diagram of an inverter used with positive logic is shown in Fig.25(A). The inverter does exactly what the name implies: it inverts the signal. When the input is zero, the transistor will not conduct because there is no forward bias across the emitter-base junction. The output will be +5 as shown. When the input swings positive, the transistor will saturate and practically the entire 5 volts will be dropped across  $R_2$  so that the output voltage will drop to zero. When the input signal drops back to zero, the transistor will stop conducting and the output will climb again to +5 volts.

Figure 25(B) shows the symbol used to represent a logic inverter. The triangle represents some form of active circuit, such as a transistor, and the small circle indicates inversion. The input  $A$  is at either a 1 or a 0 binary level. The output is  $\bar{A}$ , which is read

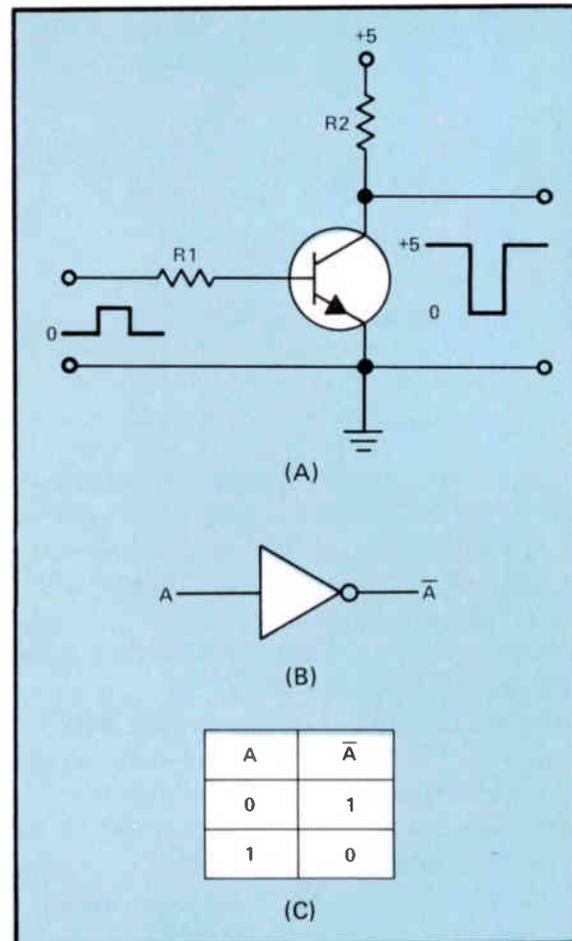


Figure 25. (A) A typical inverter circuit, and (B) its symbol. (C) A logic table.

*NOT A*. This means that if the input is  $A$ , the output is NOT  $A$ ; it is the inversion of  $A$ . We summarize this in a table called a *truth table*, which is shown in Fig.25(C). Where the input is zero, the output is NOT 0; it is 1. When the input is 1, the output is NOT 1; it is 0.

### The AND Gate

A *gate* is a circuit that looks at two or more binary signals and produces a binary output

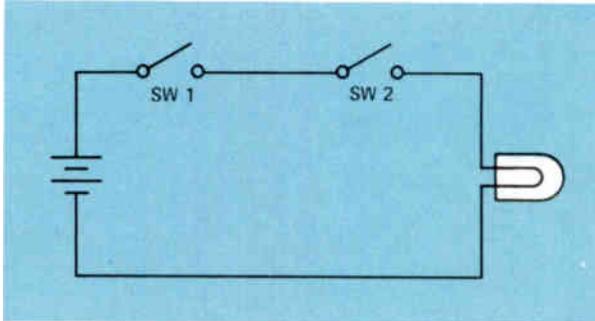


Figure 26. An example of an AND gate.

signal that depends upon the input signals. An *AND gate* is a gate with two or more inputs that will produce a binary 1 output signal only when there is a binary 1 input signal at each input.

Figure 26 is a simple example that demonstrates AND gate operation. You can see that with either SW1 or SW2 open, or with both SW1 and SW2 open, the lamp will not light. The only condition under which the lamp will light is when both switches are closed.

A semiconductor AND gate is shown in Fig.27(A). To see how this gate works, we will apply a logic level 0 to either input by grounding the input. We will apply a logic level 1 by connecting the negative terminal of a 6 volt battery to ground and the positive terminal to the input to which we wish to apply a logic level 1.

If we ground both terminals A and B to apply a logic 0 to each input, current will flow from ground to terminal A and through D1 and R1 to +12 V. Current will also flow from ground to terminal B and through D2 and R1 to +12 V. Since the conducting diodes will have practically zero resistance, almost the entire 12 volts will be dropped across R1, so the output at C will be zero.

If we connect the positive terminal of the 6 volt battery to input A, and keep input B

grounded, current will still flow from ground to input B and through D2 and R1 to +12 V. The voltage drop across D2 will be practically zero, so the voltage at output C will be zero.

If we ground input A and connect the positive terminal of the battery to input B, current will still flow from ground to input A and through D1 and R1 to +12 V. The voltage drop across D1 will be practically zero, so the voltage at output C will be zero.

If we connect a 6 volt battery between ground and each input terminal, current will flow from ground through the battery to input A and through D1 and R1 to +12 V. Current will also flow from ground through the 6 volt battery to input B and through D2 and R1 to +12 V. The voltage drop across D1 and D2 will be practically zero, but since inputs A and B are now connected to +6 volts, the voltage at C will be +6 V, which represents a binary 1.

In Fig.27(B), we've shown two signals applied to inputs A and B and the output they will produce at output C. Notice that there is a binary 1, represented by the positive voltage at the output of C, only when there is a binary 1 present at both inputs A and B. At all other times, the output at C is zero.

The symbol for an AND gate is shown in Fig.27(C). Notice that we have used the mathematical expression  $C = AB$  to designate the AND operation. The gate output is designated C and the inputs are designated A and B. The equation tells us that the output C occurs when both A and B are present.

The truth table for an AND gate is shown in Fig.27(D). Notice that when we have binary 1 at inputs A and B, we have a binary 1 at output C. With all other combinations, the output will be 0 at C. Only when we have a binary 1 at A and B will we have a binary 1 at C.

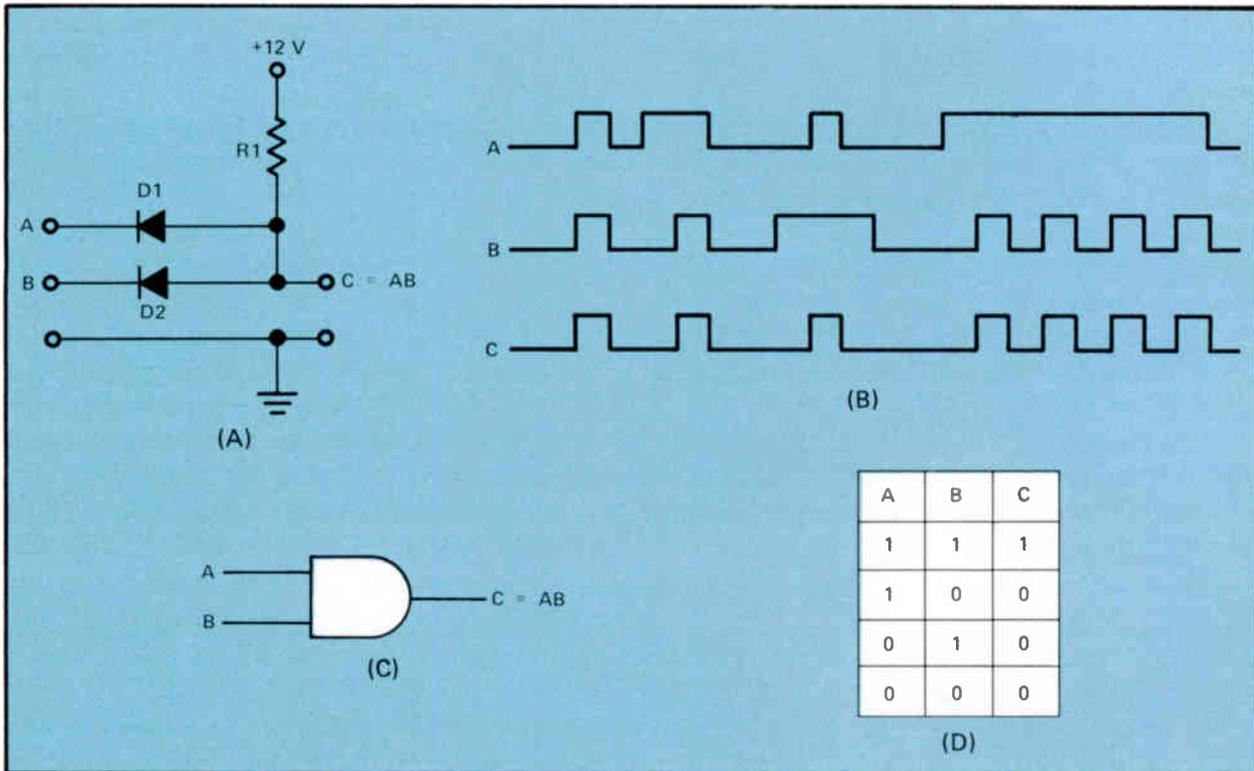


Figure 27. (A) The schematic symbol of a diode AND gate, and (B) the input and output signals. (C) The symbol for an AND gate, and (D) the truth table.

AND gates are not limited to two inputs. We could have three or more inputs. If, for example, we have four inputs, the only time we'll get a binary 1 at the output is when we have a binary 1 at all four inputs.

### The OR Gate

A simple example of an *OR gate* is shown in Fig.28. Here, if we close switch 1, the light will light. If we leave switch 1 open and close switch 2, the light will also light. In other words, the light will light if either switch is closed. The light will also light if both

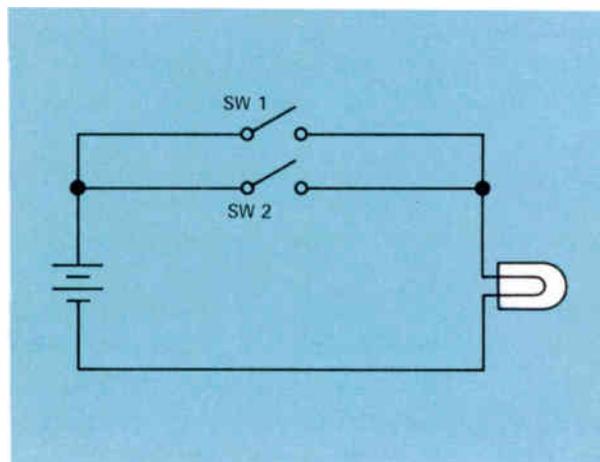


Figure 28. An example of an OR gate.

switches are closed. The important thing to note is that the light will light if either switch 1 or 2 is closed.

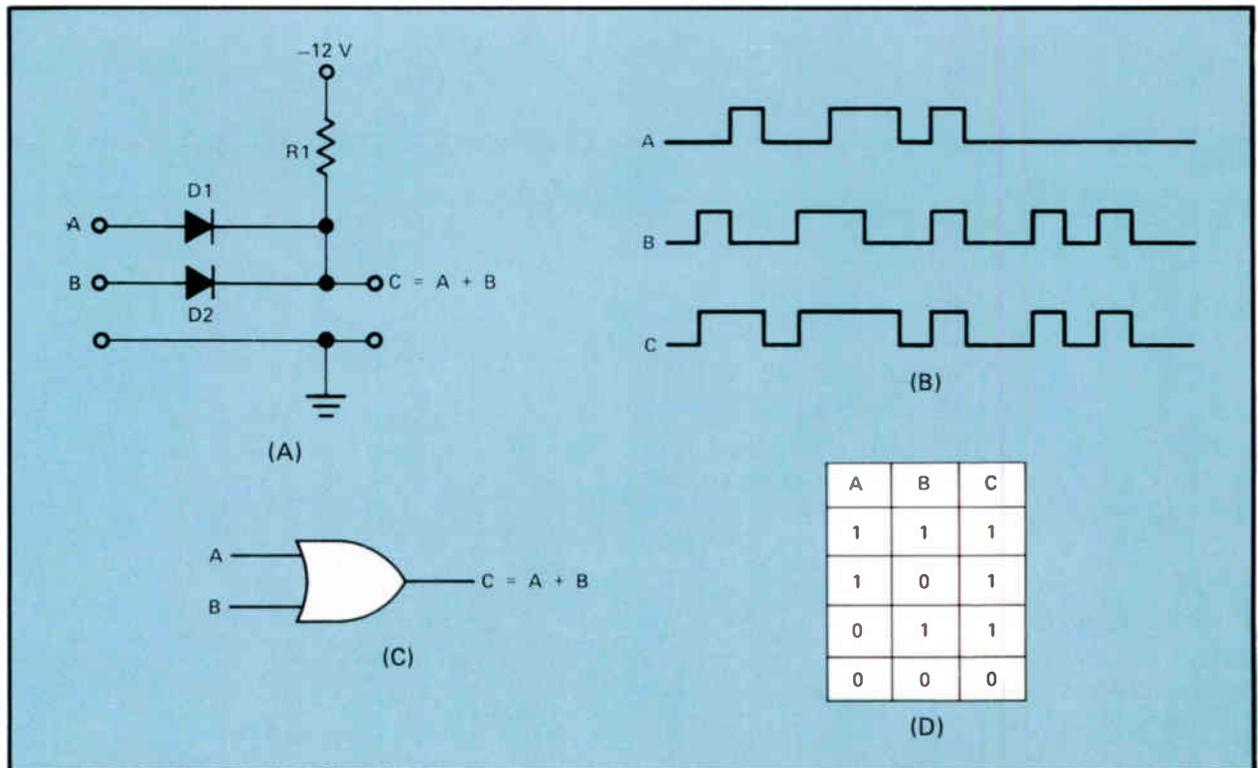
The schematic diagram of a diode OR gate is shown in Fig.29(A). To see how the circuit works, we will do the same for logic level 0 and 1 as we did with the AND gate. For 0, we'll ground the input terminal. For 1, we'll connect the negative terminal of the 6 volt battery to ground and the positive terminal to the input to which we wish to apply logic level 1.

With logic level 0 applied to both inputs A and B (that is, both inputs grounded), diodes D1 and D2 will be forward biased because their cathodes are connected to the minus

side of the supply through R1. Current flows from the negative side of the supply through R1, through D1 and D2 to ground, and to the positive terminal of the 12 volt supply. Since the resistance of the conducting diodes is practically zero, the voltage at output C will be zero, and the output is a binary zero.

With one input at ground and the other at logic level 1, the output, C, will also be at logic level 1. Let's see why this is so.

Let's apply a logic level 0 to input B by grounding it, and a logic level 1 to input A by connecting the negative terminal of the 6 volt battery to ground and the positive terminal to input A. This will place a total of 18 volts across D1 and R1 in series. D1 will con-



**Figure 29.** (A) A schematic diagram of an OR gate, and (B) input signals. (C) The symbol for the OR gate, and (D) the truth table.

duct, and since the diode is practically zero resistance when it is conducting, the junction of the cathode of D1 and the cathode of D2 and R1 will be at +6 volts. This is a binary level 1, so we'll have a binary 1 at output C. Diode D2 can't conduct because it has a reverse bias of 6 volts across it. The cathode will have +6 volts applied to it, and the anode is at zero.

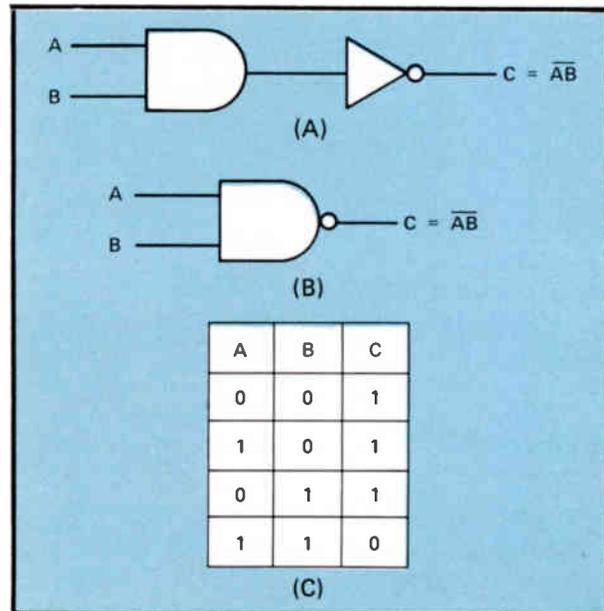
If input A is grounded and input B has +6 volts applied to it, diode D2 will conduct, bringing terminal C to +6 volts. In this case, D1 will be reverse biased and will not conduct. If +6 volts is applied to both terminals A and B, both diodes will conduct, again bringing terminal C to the +6 volt or logic 1 level.

Notice the difference between the AND gate and the OR gate. With the AND gate, we had a logic level 1 at the output only when we had a logic level 1 at A and B. With the OR gate, we had a logic level 1 when we had a logic level 1 at either A or B (or both).

Figure 29(B) shows input signals applied to inputs A and B and the output produced at terminal C. Figure 29(C) is the symbol used for an OR gate. Notice the mathematical expression  $C = A + B$  used to represent the OR gate. This is read  $C = A$  or  $B$ . The truth table for the OR gate is shown in Fig.29(D).

### The NAND Gate

When an AND gate is followed by an inverter, it becomes a *NAND gate*. The word is derived from the words NOT and AND, where the NOT refers to the inverter and the AND refers to the gate. In Fig.30(A), we have shown an AND gate followed by an inverter. Notice the mathematical output term  $\overline{AB}$ ; it means that the output produced is inverted. The schematic symbol used to represent a



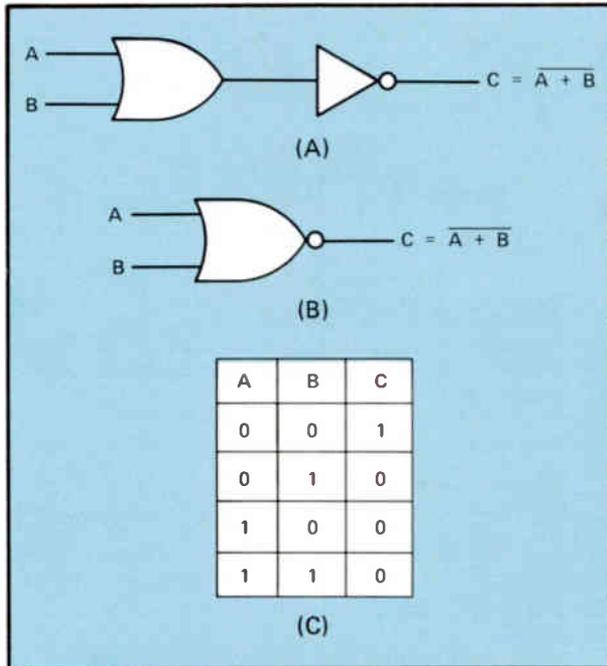
**Figure 30.** (A) An AND gate followed by an inverter becomes a NAND gate. (B) The schematic symbol, and (C) the truth table.

NAND gate is shown in Fig.30(B). The truth table for the NAND gate is shown in Fig.30(C). Notice that the NAND gate output is exactly the opposite of an AND gate. This is because the inverter inverts the output from the AND gate.

### The NOR Gate

When an OR gate is followed by an inverter, as shown in Fig.31(A), we have a *NOR gate*. As you might expect, the name is derived from the words NOT and OR. The mathematical expression for the output is read  $C = \text{NOT } A$  or  $B$ .

The schematic symbol for the NOR gate is shown in Fig.31(B). The truth table for the NOR gate is shown in Fig.31(C). The output is opposite of that of an OR gate because the gate is made up of an OR gate and its output is then inverted.



**Figure 31.** (A) An OR gate followed by an inverter becomes a NOR gate. (B) The schematic symbol for a NOR gate, and (C) the truth table.

You might wonder why we need NAND and NOR gates. One reason is that in diode AND and OR gates there is no amplification. If the logic signal has to pass through several gates, its amplitude will decrease as it goes through each gate, and the system will become unreliable. By using a diode gate followed by a transistor inverter, we can amplify the signal after it goes through the gate and thus maintain our logic level constant. Gates such as NAND and NOR gates in which diodes and transistors are used are referred to as *diode transistor logic*, abbreviated *DTL*. In some logic circuits, you will find transistor gates and transistor inverters. This configuration is referred to as *transistor transistor logic*, abbreviated *TTL*. Both DTL and TTL logic is used, but most modern logic gates use *CMOS*. We need not be con-

cerned with the type of circuitry inside the gate; the main thing to remember is the function that the gate performs.

### Negative Logic

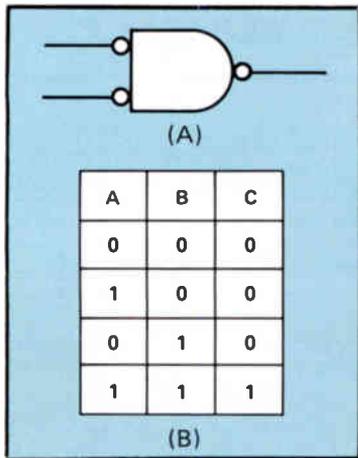
The logic we have been discussing thus far is called *positive logic*. This means that a binary 1 is represented by a voltage that is positive with respect to binary 0. In the examples we've discussed, we've used +6 V as binary 1, and 0 as binary 0.

Another type of logic that you will sometimes encounter is *negative logic*. In negative logic, the voltage representing logic 1 is negative with respect to the voltage representing binary 0. With this logic, binary 1 could be 0 volt, and binary 0 could be +6 V. Binary 0 could be 0 V and binary 1 could be -6 V.

Notice the important difference here: In both examples given, binary 1 is represented by a voltage level that is negative with respect to binary 0.

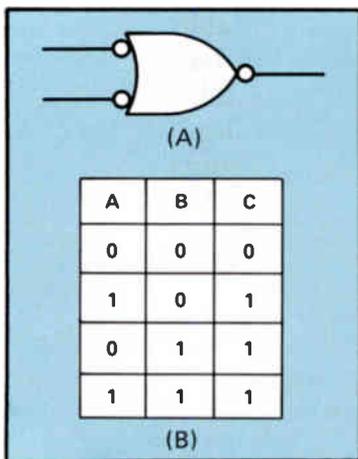
The schematic symbol for a negative logic AND gate is shown in Fig.32(A). Figure 32(B) is the truth table for the negative logic AND gate. Notice that the truth table is the same as the truth table for the positive logic AND gate. Regardless of whether positive or negative logic is being used, to get a binary 1 in the output of the AND gate you must have a binary 1 at both inputs. The circuits for the two gates will be different, but they perform the same function.

Figure 33(A) shows the schematic symbol for the negative logic OR gate, and Fig.33(B) is the truth table for the negative logic OR gate. Notice that with this gate, you'll get a binary 1 in the output if you have a binary 1 on either or both of the two inputs. This is the same as for a positive logic OR gate.



**Figure 32.** (A) The schematic symbol for a negative logic AND gate, and (B) the truth table.

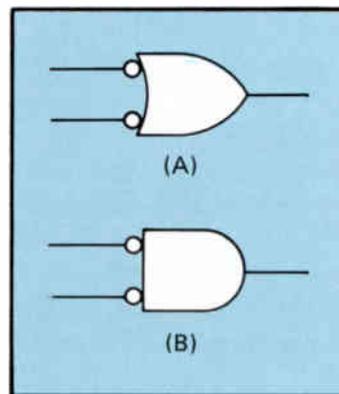
Let's go back and look at the gate shown in Fig.27. Remember that when we discussed this gate previously, we said that we'd use +6 volts as one binary level and zero volts as the other. With 0 volts at either input, we had 0 in the output. The only time we got +6 V in the output was when we applied +6 V to both inputs. With negative logic, where 1 is



**Figure 33.** (A) The schematic symbol for a negative logic OR gate, and (B) the truth table.

represented by 0 volts and 0 is represented by +6 V, we get a logic level 1 (0 volts) at C when either A or B, or both, are grounded. We get a logic level 0 (+6 volts) only when +6 volts (logic level 0) is applied to both inputs. This means that with negative logic, the diode gate shown in Fig.27, which worked as an AND gate with positive logic, will function as an OR gate with negative logic. Similarly, the diode gate shown in Fig.29, which functions as an OR gate with positive logic, will function as an AND gate with negative logic.

Negative logic can be used with the gates shown in Figs.30 and 31. When negative logic is used with the circuit shown in Fig.30, the AND gate becomes an OR gate and the inverter performs the NOT function, so we have it performing the NOR function. The symbol for the negative logic NOR gate is shown in Fig.34(A). Similarly, when the circuit shown in Fig.31 is used with negative logic, the OR gate becomes an AND gate and the output is inverted by the inverter, so the inverter performs the NAND function. The symbol for the negative logic NAND gate is shown in Fig.34(B). Table 1 is a summary of the logic symbols and truth tables for the logic gates discussed so far.



**Figure 34.** (A) The symbol for the negative logic NOR gate, and (B) the symbol for the negative logic NAND gate.

# INTEGRATED CIRCUITS

26

**TABLE I**  
**A SUMMARY TABLE OF LOGIC SYMBOLS AND TRUTH TABLES**

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## Flip-Flops

Another important logic circuit is the *flip-flop*. The circuit is called a flip-flop because it flips and flops between two stable states when trigger signals are applied.

The flip-flop can be made by connecting two logic inverters back to back as shown in Fig.35. One logic inverter is made up of Q1, R1, and R4. The output from this inverter is fed from the collector of Q1 through R3 to the base of the second inverter made up of Q2, R2, and R3. The output from this inverter is fed through R4 to the base of Q1. If the output from the flip-flop is taken from the collector of Q1, this is called the *normal output*. The output from the collector Q2 is called the *complement output*. Now let's see how the flip-flop works.

When power is first applied to the circuit, one transistor will start conducting faster than the other. Let's suppose that at the instant the equipment is turned on, a high cur-

rent begins flowing through Q2 because its collector is connected through R2 to the positive side of the supply and its base is connected through R3 and R1 to +V. Under these conditions, the transistor will quickly go into saturation so that the voltage at the collector of Q2 will drop practically to zero. When this happens, the voltage at the base of Q1 will drop to zero so that Q1 will be cut off. The output at the collector of Q1 will be +V, which with positive logic we can call binary 1. Unless something is done to the circuit, it will remain in this state with Q1 cut off and Q2 saturated indefinitely. This is called a *stable state* because it will not change of its own accord.

If we momentarily short the collector of Q1 to ground, the positive voltage applied to the base of Q2 will be removed. This will cut off Q2, and the current flow through R2 will drop to zero, so the collector of Q2 will suddenly be highly positive. Since the base of Q1 is connected to the collector of Q2 through

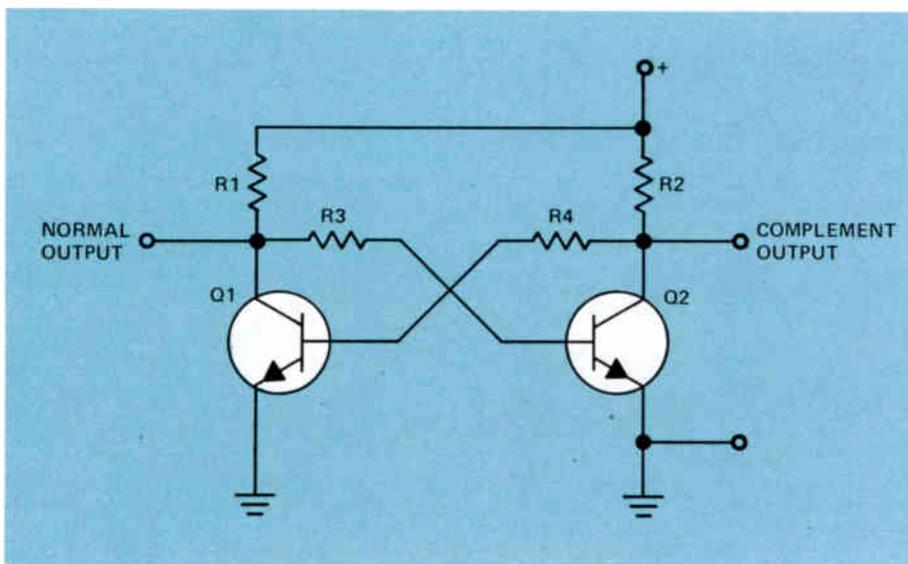


Figure 35. A flip-flop circuit.

R4, the base will swing positive and base current will begin to flow. This will cause Q1 to saturate, so the collector voltage will drop practically to zero. Since the base of Q2 is connected to the collector of Q1 through R3, the base voltage of Q2 will drop to zero, so Q2 will be cut off. This is the second stable state where Q1 is saturated and Q2 is cut off. Now the output from Q1 will be zero, and we call this a binary 0. Again, the circuit will remain in this stable state indefinitely, unless something is done to cause it to change.

Now you see how the circuit gets its name. It is called a flip-flop because one transistor is conducting while the other is cut off. When an external signal is applied, it flips over to the other state and the first transistor that was saturated is now cut off, and the second one that was cut off is now saturated. If another signal is applied, it flops back to the original state.

Another flip-flop circuit with two additional resistors and two input terminals is

shown in Fig.36. With the normal output taken from the collector of Q1 when the transistor is cut off, the collector voltage will go to +V, which will represent a binary 1 with positive logic. When Q1 is cut off, Q2 will saturate.

Let's suppose that when the flip-flop is first turned on, Q1 saturates. The collector voltage will drop to zero, so the voltage on the base of Q2 will be zero. Q2 will be cut off, so its collector voltage will be +V. Under these circumstances, the output at the normal output will be zero, which represents binary 0. Suppose, however, that we want it to represent binary 1. We can accomplish this by feeding a positive pulse into the set input. This will cause Q2 to conduct and go into saturation, so the collector voltage of Q2 will drop practically to zero. When this happens, the base voltage of Q1 will drop to zero so that Q1 will be cut off. With Q1 cut off and its collector current zero, there will be little or no voltage drop across R1. Thus the current

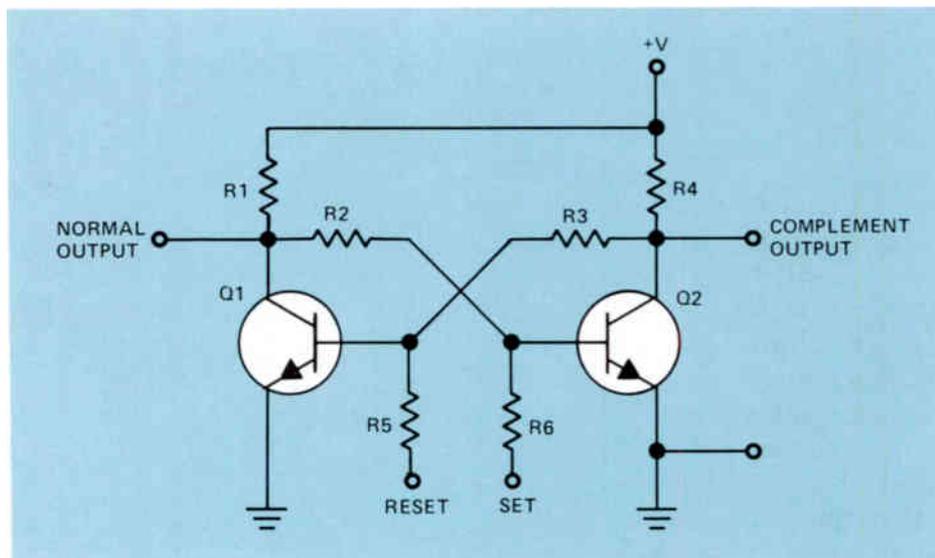


Figure 36. A set-reset flip-flop circuit.

swings to  $+V$ , so we have a binary 1 stored at the normal output.

If we want to reset the flip-flop to store a binary 0 at the output of Q1, we feed a positive pulse into the reset terminal. This causes Q1 to conduct and saturate, so the voltage at the collector of Q1 drops to zero. Once again, this causes the base voltage of Q2 to drop to zero so that Q2 will be cut off and the collector voltage will swing to a high positive value. Since the base of Q1 connects to the collector of Q2 through R3, the base of Q1 will be held at a high positive voltage, so Q1 will remain saturated.

This type of flip-flop is called a *set-reset flip-flop*. Often you will see it referred to as an *SR* or *RS flip-flop*. This circuit is also called a *latch* because the circuit latches in one of the stable states and remains there until changed by a signal fed into the set or reset inputs. The circuit latches itself in either of the two stable states: one where Q1 is cut off, representing a binary 1, and the other where Q2 is cut off and Q1 is saturated, representing a binary 0.

## Common ICs

There are a couple of terms you will see used with ICs and you should know what they mean. One is SSI; this means *small-scale integration*. This is an IC with the equivalent of less than ten gates. MSI means *medium-scale integration*. This is an IC with the equivalent of more than ten gates, but less than one hundred. LSI means *large-scale integration*. This is an IC with the equivalent of more than one hundred but less than a thousand gates. VLSI means *very large-scale integration*. This is an IC with the equivalent of more than one thousand gates.

## Summary

Linear circuits are used to amplify signals so that the output is an amplified version of the input. Digital circuits have only two conditions, on and off.

In digital circuits you are dealing with two logic levels, one of which can be called 1 and the other 0. If logic level 1 is more positive than logic level 0, we have positive logic. If logic level 1 is more negative than logic level 0, we have negative logic. Remember that an inverter is a logic circuit that inverts the logic level.

An AND gate is a gate with two or more inputs that will produce a logic level 1 in the output only when all the inputs are a logic level 1. A NAND gate is an AND gate followed by an inverter. If you have a logic level 0 on any input of a NAND gate, you'll have a logic level 1 at the output.

An OR gate is a gate that will produce a logic level 1 at the output if there is a logic level 1 on any input. A NOR gate is an OR gate followed by an inverter. A NOR gate will produce a logic level 0 in the output if you have a logic level 1 on any input.

A flip-flop is a circuit with two stable states. It will remain in one of the two stable states until some external signal causes it to flip to the other stable state.

## Self-Test Questions

- 17 How will a series of positive pulses fed into the input of an inverter appear at the output?
- 18 What is the name given to the gate where a binary 1 must be present at both inputs in order to produce a binary 1 in the output?
- 19 What is the name given to a gate where a binary 1 at either input will produce a binary 1 at the output?
- 20 If there is a binary 1 at one input of a NAND gate, will there be a binary 1 in the output?
- 21 If a binary 1 is fed into one input of a NOR gate, will there be a binary 1 in the output?
- 22 If the flip-flop circuit shown in Fig.36 is storing a binary 0 in the normal output, how do we change it to store a binary 1?
- 23 If we feed a binary 1 signal to two inputs of a 4-input AND gate, will we get a binary 1 in the output?

## ANSWERS TO SELF-TEST QUESTIONS

- 1 Reverse biased. Zener diodes pass very little current until the breakdown voltage is reached. This is the voltage that the zener maintains constant. Once this voltage is reached, if the voltage across the diode tends to increase, the current will increase rapidly to maintain the voltage constant.
- 2 3 volts. If the voltage drop across each diode is 0.6 volt, and five are connected in series, the voltage across the five will be  $5 \times 0.6 = 3.0$  volts.
- 3 The diodes are likely to have identical characteristics because they will all be formed at the same time in the manufacturing of the IC. Since they will be formed under identical conditions, it is likely that they will have identical characteristics.
- 4 Zero. If a 1 volt positive signal is applied to each input, it will cause the current through each transistor to increase, which will cause identical voltage drops across R2 and R3 so that the voltage between E1 and E2 will be zero.
- 5 In phase. The positive-going signal applied to the input of Q1 will cause the collector current to increase. This will cause the current through R2 to increase, which will swing the emitter of Q2 in a positive direction. This will reduce the forward bias across the emitter-base junction so that the current through the transistor and through R3 will decrease. If the current through R3 decreases, the voltage drop across it will decrease so that the voltage between the collector and ground will increase.
- 6 It is a constant-current source. Q3 is also called a current sink. If the current through Q1 increases, the current through Q2 will decrease because the current through Q3 remains constant.
- 7 Q3 is an emitter-follower. It is used to isolate the differential amplifier made up of Q1, Q2, and the following stage. It is also used to reduce the dc output voltage so that the output can be fed to another differential amplifier. By connecting differential amplifiers followed by an emitter-follower in this way, we can build an amplifier with a very good low-frequency response; as a matter of fact, it will even respond to dc at the input.
- 8 It has a higher gain and a higher input impedance.
- 9 A compound-connected differential amplifier will have a much higher gain.
- 10 Q3 and Q6.
- 11 Two differential amplifiers, each with a current sink.
- 12 The circuit shown in Fig.18 has a single-ended input. The input is fed into terminal 7.
- 13 We have a push-pull output. By looking at Fig.18, you see that the output is taken from terminals 11 and 12. By referring to Fig.19, you see that terminal 11 is the collector of one transistor and terminal 12 is

the collector of the other transistor in a differential amplifier.

- 14** Less than one-half inch. Figure 20 shows that the maximum diameter of the transistor is 0.370 inch, or considerably less than one-half inch.
- 15** To identify the various pins of a TO-116 case, you hold the IC with its top toward you and the index point on the left. The first pin on the lower left is pin 1. The lower pins are numbered 1 through 7. The upper pins are numbered from the right, pin 8 through pin 14.
- 16** In a 24 lead, dual in-line package, the pin at the same end as and opposite pin 1 will be pin 24.
- 17** They will appear as a series of negative-going pulses. The inverter inverts the input signal.
- 18** An AND gate.
- 19** An OR gate.
- 20** Yes. A NAND gate is made up of an AND gate and an inverter. If a logic level 1 is fed to one input of the AND gate, the output will be logic level 0. The inverter will invert this so that binary 1 will appear in the output.
- 21** No. A NOR gate is made up of an OR gate and an inverter. If a binary 1 is fed into one input of an OR gate, a binary 1 will appear in the output. The inverter will invert this so that the output will be a binary 0.
- 22** We feed a positive pulse into the set terminal. This will cause Q2 to conduct so that the voltage between the collector and ground of Q2 will drop practically to zero. This will cause the base voltage of Q1 to drop to zero, so that Q1 will cut off and the collector voltage on Q1 will swing to the +V level, which is the logic 1 or binary 1 level.
- 23** No. In a 4-input AND gate, we must have a logic level 1 at all four inputs before we'll get a logic level 1 in the output.

## LESSON QUESTIONS

### This is Lesson Number 2228.

Make sure you print your name, student number, and lesson number in the spaces provided on the Lesson Answer Form. Be sure to fill in the circles beneath your student number and lesson number.

**Reminder:** A properly completed Lesson Answer Form allows us to evaluate your answers and speed the results and additional study material to you as soon as possible. Do not hold your Lesson Answer Forms to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

Name John Smith  
 Print  
 Student No. XY01237894 Lesson No. 2228

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- In the circuit shown in Fig.11, if a positive-going signal is fed to input 1 and a negative-going signal is fed to input 2, the current flow will increase through:
  - R1.
  - R2.
  - R3.
  - R4.
- If in-phase sine wave signals, each having an amplitude of 1 volt, are fed to inputs 1 and 2 of the differential amplifier shown in Fig.11, the output between the two output terminals will be:
  - 0 volts.
  - 1 volt.
  - 2 volts.
  - 4 volts.
- If an input signal swings the base of Q1 in Fig.12 positive, which of the following statements is true?
  - The collector of Q1 will swing negative.
  - The collector of Q2 will swing positive.
  - The base of Q2 will swing positive.
  - The emitter of Q2 will swing negative.
- One of the important characteristics of the compound-connected emitter-follower circuit is:
  - High output impedance.
  - High input impedance.
  - Low input impedance.
  - None of the above.

# INTEGRATED CIRCUITS

34

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5. In the compound-connected differential amplifier shown in Fig.16, which two transistors have the highest collector current?
  - a. Q1 and Q2.
  - b. Q3 and Q4.
  - c. Q1 and Q3.
  - d. Q2 and Q4.
6. In the IC shown in Fig.17, Q3 is:
  - a. A current source.
  - b. Part of a Darlington circuit.
  - c. A voltage regulator.
  - d. None of the above.
7. In a 4-input AND gate, in order to have a logic level 1 in the output, we must have a logic level 1 at:
  - a. One input.
  - b. Two inputs.
  - c. Three inputs.
  - d. Four inputs.
8. In order to get a logic level 1 in the output of a 2-input OR gate, you need a logic level 1 at:
  - a. Input A.
  - b. Input B.
  - c. Inputs A and B.
  - d. All three of the above will produce a 1 in the output.
9. You will have a logic level 0 in the output of a 2-input NAND gate when you have:
  - a. Logic 1 at both inputs.
  - b. Logic 0 at both inputs.
  - c. Logic 1 at input A.
  - d. Logic 1 at input B.
10. If a logic level 1 is stored in the normal output of the set-reset flip-flop shown in Fig.36:
  - a. Q1 will be cut off.
  - b. Q2 will be cut off.
  - c. Q1 and Q2 will be cut off.
  - d. Q1 and Q2 will be saturated.

# NOTES

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*Please use this page to record any notes  
you may want to review during your studies.*

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you may want to review during your studies.*

## WISHERS AND DOERS

How often have you said “I wish I had more money”? Many times, possibly. But do you realize that if you are living in a town with a population of 5,000, there may be 4,999 other people saying exactly the same thing!

And yet, of these 5,000 “wishers,” only about 100 are going to do something about it. The others are going to continue dreaming.

Now, any person who shows enough self-motivation to undertake this course proves that he or she is not a mere wisher. Your job now is to keep going forward on the road you have mapped out for yourself.

Every lesson in this course and every goal you work toward is a step along the road. Don't let yourself *wish* that the lessons were easier, that you could become successful without effort, or that well-paying jobs would come looking for you. *Do* something to make your dreams a reality. Stay out of the class of the “wisher” — stay in the class of the “doer.”





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**Dedicated Access Services Offered** 56K, FracT1, T1, Frame Relay

**Other Services** FREE Web Page with every account. Dial-up Access For Huntsville, Ogden, Morgan, Layton, Kaysville, and Salt Lake. No hourly limits. Dedicated connections. ISDN.

Server Co-location. Web Site Statistics. Shell accounts. Government & non-profit organization discounts. E-mail to Fax/Pager. RealAudio. Electronic Commerce and Shopping Cart systems. Full commercial web site development. Experienced consultants available.

**Fees** All Accounts are Unlimited — Personal Accounts: \$17.95/mo. Business Accounts: from \$25.00 w/10mb disk space. Shared Virtual Server: \$39.95/mo. Virtual Server: \$49.95/mo. Premium Services include: E-mail to FAX/Alpha-Pager – Virtual Server Hosting with UNLIMITED number of E-mail addresses. Free Domain Registration.

## **Imagine Communications Corporation (Imagixx)**

**Web Site** <http://www.imagixx.net>

**Telephone** +1-304-292-6600

**Software/Hours** PC, Mac, 24/7

**Dial-Up Services Offered** 28.8, Rockwell, Lucent, ISDN

**Dedicated Access Services Offered** 56K, FracT1, T1, FracT3, Frame Relay

**Other Services** All services available.

**Fees** \$7.95/5 hours, \$2.50/hour thereafter; \$22.95/mo unmetered; \$60/quarter (three months); Students: \$65/semester (3 semester year); \$195/year – all unmetered access, 5 mb storage for your personal website included. Commercial accounts at \$35/mo. Call or e-mail [info@imagixx.net](mailto:info@imagixx.net) for further details.

## **World Wide Net, Inc.**

**Web Site** <http://www.wwnet.com>

**Telephone** 1-313-513-7707

**Software/Hours** PC, Mac, 24 hours

**Dial-Up Services Offered** 28.8, Rockwell, Lucent, ISDN

**Dedicated Access Services Offered** 56K, FracT1, T1

**Other Services** All accounts include shell access, 2 megabytes of space for a personal web page, and one e-mail account. Accounts can also be Microsoft FrontPage enabled at no additional cost.

**Fees** Personal Dial-up Accounts: \$150 Annual, \$80 Semi-annual, \$42 Quarterly, \$14.95 Monthly. 800 / 888 Toll-free Accounts: \$250 Annual, \$130 Semi-annual, \$70 Quarterly, \$24.95 Monthly. All dial-up accounts include 100 hours access per month, with additional hours billed at \$0.50/hour. Additional e-mail accounts are available for \$25/year. Dual-Channel ISDN Accounts (SouthEastern Michigan only:) \$275 Annual, \$150 Semi-annual, \$80 Quarterly, \$29.95 Monthly. Leased Lines Start at \$250 (telco charge included). Satellite Access Up to T-1 speeds at prices comparable to ISDN. (Call for more information)

## **WhyWeb Internet Services**

**Web Site** <http://www.WhyWeb.com>

**Telephone** 1-888-694-9932

**Software/Hours** PC, Mac, 24 hours a day, 7 days a week, 365 days a year

**Dial-Up Services Offered** 28.8, ISDN

**Dedicated Access Services Offered** 56K, FracT1, T1, FracT3, T3, Frame Relay

**Other Services** Custom Business Solutions, Co-Location Services, LAN-ISDN with Static IPs, Security Filtering Services, for both Intranet and Internet

**Fees** Unlimited 33.6: \$14.75/mo, 100 hrs of 64k ISDN: \$16.95/mo, 20 hrs of 128k ISDN: \$34.95/mo, 100 hrs of 128k PLUS ISDN: \$84.95/mo, Additional ISDN hours 95¢ per hour.  
\*\*\*\*\*PLEASE CALL OR VISIT OUR WEB SITE AT [www.WhyWeb.com](http://www.WhyWeb.com).

## **Quantum Communications, Inc.**

**Web Site** <http://www.q-com.com>

**Telephone** +1-888-279-4638

**Software/Hours** PC, Mac, M-F 9-6

**Dial-Up Services Offered** 28.8, Rockwell

**Dedicated Access Services Offered** FracT1, T1, FracT3, T3

**Other Services** Toll-Free Flat-Rate. Access from anywhere in the US.

**Fees** Local PPP \$19.95/mo. and \$19.95 setup. Toll-Free (Flat-Rate) PPP \$24.95/mo. and \$19.95 setup. Web Page Hosting \$50 and \$50 setup (includes dialup PPP). DNS Registration \$150. Windows NT, 95, 3.x, & Novell Networking.



## Instructions for On-line Projects 5647 and 5650

These projects are designed to demonstrate the knowledge and skills you learned from the PC Communications and Internet lessons. You will be using an FTP site to retrieve the actual exam material for Project 5647 as well as the information for Project 5650. You will be completing both projects at the same time and submitting them together in one file. They will be graded and recorded separately.

To retrieve the file:

**Step 1:** Log onto the Internet through your Internet Service Provider (ISP).

**Step 2:** Open your browser (if it is not automatically loaded).

**Step 3:** On the address line of your browser, type the address <http://www.nrischools.com>

**Step 4:** When the page is fully loaded, clear the address line on your browser and type the address <ftp://ftp.nrischools.com/pub> and press ENTER.

**Step 5:** Double click on the file labeled "exam5647-5650.doc."

**NOTE:** At this time, you will be given a choice of either opening the file, or saving the file to disk. At this time, open the file. You will be saving it later. Click the OPEN FILE button and click OK. The file will be opened in Notepad (which is part of your Windows 9X operation system) or into your word processor program if you have loaded one.

From this point on, you will be following the instruction in the file that you have just opened.



# **NRI** Schools

4401 Connecticut Avenue, NW, Washington, DC 20008  
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Dear Student:

This section of your training deals with basic computer communications and the Internet. In these lessons, you will learn how computers communicate and how to use your modem. Then, you'll apply this information by connection to the Internet. You'll explore the Internet's history, culture, and the social impact of the Web.

To complete the projects in this package you will need an Internet Service Provider (ISP). There are literally hundreds of ISPs from which to choose. We have included a list of some of the ISPs along with a description of the services provided by the ISP. When choosing an ISP, keep in mind that most ISPs require a major credit card to activate your account.

After you have selected an ISP and loaded the software from the ISP, it's time to load the Netscape software provided with this package. Refer to the Netscape Navigator Handbook for complete instructions on the installation of Netscape Navigator. Once you have Netscape Navigator loaded, be sure to visit our website at [MHCEC.COM](http://MHCEC.COM).

The lessons in this package are designed to be completed in a particular order. The recommended order for studying the material is:

<u>Lesson</u>	<u>Title</u>
✓ 5645	Using a PC for Communications
✓ 5646	Internet Basics
✓ 5647	Practical Project 1
✓ 5648	Navigating the Internet 1: Essential Internet Tools
✓ 5649	Navigating the Internet 2: The Web and Beyond
✓ 5650	Practical Project 2

If you have any questions during your studies, please don't hesitate to contact your NRI Instructor. You can use one of the "Ask Your Instructor...." forms, or you can use the Internet and send us an e-mail. To use our e-mail, log onto [MHCEC.COM](http://MHCEC.COM) and enter the "Students On-Line Connection." Click on "Mail Box" and complete the form. A reply to your e-mail will be returned to the address you enter on the form.

(over, please)



Now, review the enclosed list and select an ISP, so that you can complete these lessons and projects in this training unit.

Sincerely,  
The NRI Instruction Staff



4401 Connecticut Avenue, NW, Washington, DC 20008  
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Dear Student

The instructions in the Forefront user's manual on pages 2.2 and 2.3 tell you to make a backup to the original diskette by using the MS-DOS **DISKCOPY** command. Technology upgrades have made this instruction obsolete. If you use the copy or xcopy commands under DOS, your original disk will be corrupted and will no longer boot your computer.

To make a copy of you Troubleshooter diskette, insert a blank diskette into you're A:> drive. Double click the "My Computer" icon. Click the "3 ½" Floppy (A)" icon so that it is now highlighted. Press the right mouse button and select the *FORMAT* option from the pull down menu. Select "Full Format" from the *Format Disk* window and click *START*. After the formatting is complete, remove the formatted diskette and insert your Troubleshooter diskette in the A:> drive. Again, double click on the "My Computer" icon, and single click on the "3 ½" Floppy (A)" icon. Press the right mouse button and select *Copy* from the pull down menu. Follow the instruction on the screen and change the diskettes as necessary. Using this method both disks will remain bootable.

If you vary from this procedure, both the original and target disks will be corrupted.

Cordially,

Your NRI Instructor

NSI007394(003)



**MODULE 1635MD: Introduction to Windows 98**

In this module, you will learn the basics of the Windows 98 operating system. You'll study the Windows 98 interface, programs, and accessories. You'll learn how to personalize your system and look at how Windows 98 local and network file systems function.

**MODULE 1654MD: PII-400 Standard Computer**

This module contains your computer system, based on a Pentium II processor. The system contains 64 meg of RAM, 56K fax/modem, and a 6.8 gig hard drive. This computer also includes a 16-bit sound card, 32X cd-ROM drive and a 14" SVGA monitor.

**MODULE 1636MD: Using Windows 98**

In this module, you'll advance your knowledge of the Windows 98 operating system by examining its Web browser and communications capabilities--such as the Internet Explorer and Active Desktop. You'll also look at managing and configuring your Windows 98 system.

**MODULE 1476MD: PC Communications and the Internet**

This module covers basic computer communications concepts and Internet use. You will learn how computers communicate and how to use your modem, then apply this information to connecting with the Internet. You'll then explore the Internet's history, culture, and social impact and how to download files, join discussion groups, browse the World Wide Web, and much more. Projects show you how to access Internet resources with both text and graphical browsers.

**MODULE 1370MD: Computer Diagnostics**

This module contains your computer diagnostic software. This self-booting software tests memory, both RAM and cache, IDE drives, monitors, CPU and co-processors, monitors and video cards, and even multimedia devices such as CD-ROMs and sound cards.

**MODULE 1369MD: A+ Certification Reference**

In this module you will receive information to help you prepare for the A+ Certification Exam. You'll receive reference material on MS-DOS, Windows 3.1, Local Area Networks, and the Macintosh computer systems. Also, you will receive an interactive CD-ROM to help you prepare for the exam. This CD-ROM has sample questions and a practice test which simulates the A+ Certification exam.

## **PC Servicing**

Student: Marion D McMains Jr

STUDENT NUMBER: KW19286848

### **MODULE 1485MD: Introduction to Computers**

You will discover how PCs work and what functions they serve in today's world in this module. You'll also gain a working familiarity with fundamental PC hardware and software.

### **MODULE 1483MD: Basic Electronics**

This module introduces you to the basic concepts in electronics: voltage, resistance, and current. You'll learn the difference between series and parallel circuits. You'll also learn the difference between ac and dc voltage.

### **MODULE 1906MD: Hands-On Projects: Basic Electronics**

In this module, you will construct and observe a number of electronic circuits to demonstrate basic electronics theory. You'll also learn how to make voltage, resistance, and current measurements with your Digital Multimeter.

### **MODULE 1484MD: Intermediate Electronics**

In this module, you'll learn about coils and capacitors, and how they work together. Next, you'll learn about semiconductors, and how semiconductors are used. Finally, you'll look at transistors and their uses.

### **MODULE 1521MD: Analog Electronics**

Here, you'll explore the theory and practice of more advanced electronic circuits. You'll study and demonstrate amplifiers, oscillators, and power supply circuitry, using both discrete components and integrated circuits.

### **MODULE 1522MD: Digital Electronics**

In this module, you'll enter the world of digital electronics. You will study and demonstrate the operation of logic gates, flip-flops, and binary counters and registers.

### **MODULE 5105MD: Microcomputer Hardware and Peripherals**

This module examines the hardware and peripherals most often used in microcomputers. Achieving a solid understanding of this equipment will allow you to quickly identify core problems and execute simple solutions.

### **MODULE 4863MD: The 8085 Microprocessor**

In this module, you will extend your understanding of digital circuitry to the world of microprocessors. Here, you will demonstrate various features of a typical microprocessor as you construct and test your own 8085-based system.

### **MODULE 1494MD: Micro Troubleshooting and Servicing**

This module explores specific procedures and techniques for troubleshooting and servicing microcomputers and common peripheral devices including disk drives, monitors, and printers.

*Answers to  
Test Questions*





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Dear Student:

The A+ Certification package that you received is now a self-contained training package. This new package no longer requires reference text to supplement the information on the CD-ROM. The CD-ROM in this new package gives you all of the training that you will need to study for and pass the A+ Certification exam.

The CD-ROM contains in-depth content, practice test question, and hands-on exercises for the most effective training available. You will receive the knowledge and, most importantly, the skills required to manage current technologies.

We know that you will enjoy this new training package.

Cordially,

Your NRI Instructor

NLR007397





4401 Connecticut Avenue, NW, Washington, DC 20008  
Phone 202/244-1600 • Fax 202/244-2047

Dear Student:

Welcome to *Working with Windows 98*. In this training module, you'll explore Windows 98's Web browsing features and Internet Explorer, Active Desktop, subscriptions, and Web channels. You'll also look at how Windows 98 handles e-mail and communication, Web publishing, and mobile and remote computing. Finally, you'll learn how to better configure, manage, and optimize your Windows 98 system.

This training module is centered around the textbook *Windows 98 Made Easy: The Basics and Beyond*. You will use the *Working with Windows 98* study guide, included in this package, to navigate your way through the course. This study guide contains your assignments and important information on taking an examination after each assignment. This study guide also includes information about the hands-on project that you must submit to your instructor for grading. Be sure to carefully read and follow all the directions in your study guide.

Always remember that we're here to help you. If you have trouble with anything in your course, please let us know. You'll find some "Ask Your Instructor" forms included with your course material; you can use these forms to write to us. Or, you can phone us at (202) 244-1600 between 8:30 a.m. and 4:30 p.m. Eastern time. Our instructors will provide support for your course, and each of them has experience and training in this field to give you any help you may need.

Let's get started now. Pick up your study guide and begin!

NRI Instruction Department





## Special Instructions for 7327 – Working with Windows 98

If you received your computer as part of your NRI training, your system was supplied with Windows ME (Millennium Edition) not Windows 98. Since the basic interface of these operating systems is the same, most of the instructions for the exercises in this manual are the same for both operating systems. The following instructions will cover the areas where the instructions are different.

**Exercise 3:** When you open the Help files in **Step 1**, you'll notice that IDEX is no longer a tab as shown in Figure 1 of the manual. In Windows ME, the tabs have been changed into a tool bar. Also, the topic you will need displayed is "Connect to the Internet." Within that topic, select "from MSN." Again, the display will be slightly different than shown in Figure 1. The remaining instructions are the same for both operating systems.

**Exercise 5:** When you prepare the project diskette, you will not be able to copy the systems files as directed in **Step 1**. This feature was removed from Windows ME. In ME, the only way to create a system diskette is through "ADD/REMOVE Software" in the control panel. Since there is no practical reason to create a system diskette for this experiment, you should skip this step.

To complete this exercise, format a diskette, including your student number as the label. After the diskette is formatted, continue with copying the files as directed in **Step 2**.

Cordially,

The NRI Instruction Department

NSI007399



# **NRI** Schools

4401 Connecticut Avenue, NW, Washington, DC 20008  
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Dear Student:

In this module, the intermediate elements of basic electronics will be presented. You should find that these concepts are just a couple of steps above what you have already come to understand. Many of the principles presented during this module assume that you already possess a foundational knowledge of electronics. Upon completing these lessons, you will have been exposed to all of the elementary principles you need to understand more complex circuits. It is important to remember that you are at the start of an educational journey that will continue to challenge you, even beyond this course.

The enclosed lessons are designed to be studied and completed in a specific order. For when they are accomplished in this sequence, each will serve as a stepping stone for the next lesson. It is, therefore, recommended that they be studied in the following order:

<u>Lesson</u>	<u>Title</u>
2222	How Coils are Used
2223	How Capacitors are Used
2224	How Coils and Capacitors Work Together
2225	Semiconductors
2226	How Transistors Work
2227	How Transistors are Used

Please be sure to send in your answers for each lesson as it is completed. Additional materials are shipped to you based upon your rate of study. If you decide to hold your answers in order to send in several at once, you may exhaust your study materials before the next shipment is delivered to you.

If any difficulties or questions arise, please contact us by use of the enclosed "Ask Your Instructor" forms, or by e-mail, fax, or telephone. It is our goal to assist you as quickly and as efficiently as possible. To aid us in this effort, please be specific and detailed in presenting the difficulty that you have encountered. This will enable our staff to readily identify your problem area and address the issue thoroughly.

Sincerely,

*NRI Instruction Department*

LR6740(807)



# **NRI** Schools

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Dear Student:

Now you begin your study of the power supply, regulator, amplifier, and oscillator circuits used in modern electronic equipment. These are called *analog circuits* because they work with continuously varying voltage levels, as opposed to the discrete voltage steps associated with digital circuits. The word *analog* is used because the varying voltages are frequently used to represent other varying physical quantities such as temperature, distance, speed, and sound or light intensity. Changes in voltage are *analogous* to changes in these other quantities.

The lessons in this package have been designed for study in a particular order. This permits each lesson to serve as a foundation for succeeding lessons. Therefore, for the best results, you should study these lessons in the following sequence:

<u>Lesson</u>	<u>Title</u>
✓ 2228	Integrated Circuits
✓ 2229	Power Supplies for Electronic Equipment
✓ 2230	How Amplifiers Work
✓ 2231	How Oscillators Work

Please be sure to send in your answers for each lesson as you complete the lesson questions. Additional materials are shipped to you based on your rate of study. If you hold your answers and send several sets in at once, you may run out of study materials before the next shipment can reach you.

If you should encounter a problem or have any questions concerning your lessons, please use one of the enclosed "Ask Your Instructor" forms to request assistance. Provide as much detail as you can in your request so that we can more readily identify the specific cause of your difficulty, and can thus provide the information necessary to complete your understanding of the specific topic.

Sincerely yours,

NRI Instruction Department

LR2457 (708)



## **Special Instructions For 6629PL PC Communication and the Internet**

As you are aware, technology changes quickly. This is especially true in the computer industry. Due to changing technology, we have had to make some changes to this package. The changes we have made will in no way prevent you from completing the lessons and projects in this package.

We have removed the software that was included in this package. The software we had to remove was: Eudora Light, WinZip, Trumpet News Reader, and Netscape. These software packages were necessary during the early years of the Internet. Changes in technology have made much of this software obsolete. Below is an explanation of the function of each piece of software and the reason that it has been deleted from this package.

**Eudora Light:** This software is a simple software package for sending and receiving email. This package is an MS-DOS based package that functioned nicely under Windows 3.1 and Windows 95, but has caused some problems under Windows 98. Since your computer was shipped with Windows 98, and since most Internet Service Providers now include an email package, this program has been deleted. A large section of lesson 5646 refers to Eudora software. You can still complete this lesson without the software.

**WinZip:** This is a file compression program. Using WinZip enables you to compress files in a smaller "zipped" file that will take up less space. This utility also allows you to expand zipped files. A copy of WinZip was included in this package so that we could send you Eudora Light on one diskette. The WinZip that was included was an older version of this software. There are many newer versions available on the web as "shareware" or "freeware." These newer packages can be easily downloaded to your hard drive and offer you many new options.

**Trumpet News Reader:** During the early years of the Internet, you needed a special software package so you could view the information that was available in news groups. ISPs now include software that allows you to connect and use these news groups. The new software, as well as the advanced technology of the Internet, in general, has made Trumpet News Reader obsolete.

**Netscape:** This is one of two primary Internet browsers. The other is Microsoft Internet Explorer. At one time Netscape was commercially available on CD. Now, this software is available as a free download over the Internet. Starting with Windows 95, Microsoft has included Internet Explorer as part of the operating system. Therefore, you already have one browser installed on your computer. If

you want to download the latest version of Netscape, you can go to the Netscape.com, and download the complete software package.

Since ISPs are more sophisticated now, your provider will have all the necessary functions imbedded in their software package.

Cordially,

The NRI Instruction Department

**NSI007393(911)**

# **NRI** Schools

4401 Connecticut Avenue, NW, Washington, DC 20008  
Phone 202/244-1600 • Fax 202/244-2047

Dear Student:

In this module, the foundational elements of basic electronics will be presented. Though these topics may initially appear to be unrelated, they are the fundamentals upon which you will base all of your knowledge of electronics. Once you have an understanding of these concepts, you will be able to take on more advanced theories without much difficulty. Keep in mind that every sophisticated circuit used in today's world is based upon the simple concepts presented in these six lesson units.

These enclosed lessons are designed to be studied and completed in a specific order. For when they are done in this sequence, each will serve as a stepping stone for the next lesson. It is, therefore, recommended that they be studied in the following order:

<u>Lesson</u>	<u>Title</u>
4409	Introduction to Electronics
2217	Voltage, Current, and Resistance
2218	Series Circuits
2219	Parallel Circuits
2220	Power Sources
2221	How Resistors are Used

Please be sure to send in your answers for each lesson as it is completed. Additional materials are shipped to you based upon your rate of study. If you decide to hold your answers in order to send in several at once, you may exhaust your study materials before the next shipment is delivered to you.

If any difficulties or questions arise, please contact us by use of the enclosed "Ask Your Instructor" forms, or by e-mail, fax, or telephone. It is our goal to assist you as quickly and as efficiently as possible. To aid us in this effort, please be specific and detailed in presenting the difficulty that you have encountered. This will enable our staff to readily identify your problem area and address the issue thoroughly.

Sincerely,

NRI Instruction Department

LR7087(802)



# Examination 7325

## Web Servers, NetMeeting, and Mobile/Remote

**This is the examination for Assignment 7325.**

Make sure you print your name, student number, and lesson number in the space provided on the examination answer card. Be sure to fill in the circles beneath your student number and assignment number.

**Reminder:** A properly completed examination answer card allows us to evaluate your answers and speed the results and additional study materials to you as soon as possible. Do not hold your examination answer cards to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

Name	<i>John Smith</i>													
	Print													
	Student No.								Lesson No.					
	X	Y	0	1	2	3	7	8	9	4	7	3	2	5
	●	○	○	○	○	○	○	○	○	○	○	○	○	
	①	●	①	①	①	①	①	①	①	①	①	①	①	
	②	②	●	②	②	②	②	②	②	②	②	●	②	
	③	③	③	●	③	③	③	③	③	③	●	③	③	
	④	④	④	④	④	④	④	●	④	④	④	④	④	
	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	●	
	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	⑥	
	⑦	⑦	⑦	⑦	●	⑦	⑦	⑦	⑦	●	⑦	⑦	⑦	
	⑧	⑧	⑧	⑧	⑧	●	⑧	⑧	⑧	⑧	⑧	⑧	⑧	
	⑨	⑨	⑨	⑨	⑨	⑨	●	⑨	⑨	⑨	⑨	⑨	⑨	

**Another Option:** You can use the convenient TeleGrading service and receive your exam results immediately. The TeleGrading service can be accessed only from a touch-tone telephone. Please read these instructions before using the service.

1. Fill out your examination answer card.
2. Dial 1-202-686-5704.
3. Enter your eight-digit student number. Do not include letters that may precede the number.
4. Enter the four-digit assignment number that appears on your examination.
5. Enter your answer for each question when prompted. On your telephone keypad, number 1 equals letter A; 2 equals B; 3 equals C; and 4 equals D.
6. Listen carefully to the instructions as you receive them over the telephone. TeleGrading lets you review your answers and make changes, if necessary, before it scores your exam.
7. If you hang up before you hear that your exam has been accepted, your exam record will be deleted.

1. True or false. You can create a home page using FrontPage Express but not with Personal Web Server. PWS is used only as a desktop Web server and doesn't have the capabilities for creating a home page.
  - a. True.
  - b. False.
  
2. In PWS, folders that are located on your hard drive but appear as if they were part of the home page when visitors of your home page view them are called:
  - a. Alias directories.
  - b. Published directories.
  - c. Root directories.
  - d. Virtual directories.
  
3. Where can you keep a log of visitors to your Web site in PWS?
  - a. In the Main page, enable "Visitor Log."
  - b. In the Web site page, enable "Activity Log."
  - c. In the Advanced page, enable "Allow Activity Log."
  - d. In the Advanced page, enable "Save Web Site Activity Log."
  
4. True or false. NetMeeting can be used with a dial-up modem connection where you directly call the other party's computer, and it can also be used with an intranet or Internet connection where you locate your party on the network.
  - a. True.
  - b. False.
  
5. When you see a list of users in your NetMeeting window:
  - a. All the users listed are standing by and waiting for a call.
  - b. None of the users are standing by and waiting for a call.
  - c. It's impossible to tell who's standing by and waiting for a call because the list retains names long after users have signed off.
  - d. You can't see a list of users in NetMeeting due to privacy restrictions.
  
6. Which of the following is one way of transferring a file during a NetMeeting call?
  - a. Press the Copy during Call button.
  - b. Click and drag the file into the NetMeeting window.
  - c. Cut the file from your hard drive and paste it into NetMeeting's Share folder.
  - d. Chose File Transfer from the Edit menu.
  
7. A Windows 98 feature that automatically detects new devices and peripherals in your system and installs the necessary software drivers to support them is called:
  - a. Hot docking.
  - b. Docking.
  - c. Plug-and-Play.
  - d. Dock-and-Play.

8. The ability of your computer and operating system to control energy consumption is called:

- a. DCC support.
- b. Power management.
- c. BIOS.
- d. Hardware profiles.

9. Which Windows 98 feature uses the Update All button to synchronize files from a mobile computer with files on your desktop computer?

- a. DCC.
- b. Windows CE.
- c. Dial-Up Monitoring.
- d. Windows 98 Briefcase.

10. The Windows feature that automatically synchronizes information on H/PCs with Windows-based computers is called:

- a. InSync.
- b. ActiveSync.
- c. Windows CE.
- d. H/PC-Sync.



## Examination 7326 Configuration and Management of Windows 98

### This is the examination for Assignment 7326.

Make sure you print your name, student number, and lesson number in the space provided on the examination answer card. Be sure to fill in the circles beneath your student number and assignment number.

**Reminder:** A properly completed examination answer card allows us to evaluate your answers and speed the results and additional study materials to you as soon as possible. Do not hold your examination answer cards to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

Name	John Smith													
	Print													
	Student No.								Lesson No.					
	X	Y	0	1	2	3	7	8	9	4	7	3	2	6
	●	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	○	○	○	○	○	○	○	○	○	○	○	○	○	○

**Another Option:** You can use the convenient TeleGrading service and receive your exam results immediately. The TeleGrading service can be accessed only from a touch-tone telephone. Please read these instructions before using the service.

1. Fill out your examination answer card.
2. Dial 1-202-686-5704.
3. Enter your eight-digit student number. Do not include letters that may precede the number.
4. Enter the four-digit assignment number that appears on your examination.
5. Enter your answer for each question when prompted. On your telephone keypad, number 1 equals letter A; 2 equals B; 3 equals C; and 4 equals D.
6. Listen carefully to the instructions as you receive them over the telephone. TeleGrading lets you review your answers and make changes, if necessary, before it scores your exam.
7. If you hang up before you hear that your exam has been accepted, your exam record will be deleted.

1. If you want to take a look at the settings of devices that are installed on your computer, you can use the:
  - a. Add New Hardware utility.
  - b. Device Manager.
  - c. Resource Manager.
  - d. Properties Manager.
  
2. When you install a printer to your computer, what must you install so that other Windows applications know about the printer?
  - a. Driver files.
  - b. Printer card.
  - c. Network files.
  - d. Printer icon.
  
3. How can you view the properties of your printer?
  - a. Left-click the printer icon and select the Devices tab.
  - b. Right-click the printer icon and choose Properties from the shortcut menu.
  - c. Open the Computer Properties dialog box and click the Printers tab.
  - d. Open the System Properties dialog box and select the Performance button.
  
4. If, when you add a new modem, the Install New Modem Wizard doesn't appear, how can you access it to easily install the proper drivers?
  - a. Open Modems in the Control Panel.
  - b. Open the Install New Modem Wizard from the Edit menu in My Computer.
  - c. Right-click the System Properties icon to Modem Installation.
  - d. You can't open the wizard; it must be done automatically by Windows 98.
  
5. True or false. DVD technology brings together the computer and home-entertainment industries. With DVD, you can play movies on your computer.
  - a. True.
  - b. False.
  
6. Which Windows 98 tool should you run if you want to check your hard drive for errors?
  - a. Disk Defragmenter.
  - b. ScanDisk.
  - c. Disk Cleanup.
  - d. FAT32.
  
7. When files are broken up and scattered throughout your hard drive, this can cause Windows 98 to read the hard drive at a slower pace. What Windows 98 tool gathers up scattered file pieces and stores them together so that Windows 98 can read them faster?
  - a. Disk Defragmenter.
  - b. ScanDisk.
  - c. Disk Cleanup.
  - d. FAT32.

8. True or false. When you use the Windows 98 Backup utility, you must always back up your files to a floppy disk drive.
- True.
  - False.
9. You can check your system's performance in the:
- System Characteristics dialog box.
  - Properties file.
  - System Properties dialog box.
  - System file.
10. With \_\_\_\_\_, you can make sure that your system has the latest operating system software and device drivers.
- System Update.
  - System Information.
  - System Monitor.
  - Windows Update.



# Examination 7323

## Internet Explorer and the Active Desktop

**This is the examination for Assignment 7323.**

Make sure you print your name, student number, and lesson number in the space provided on the examination answer card. Be sure to fill in the circles beneath your student number and assignment number.

**Reminder:** A properly completed examination answer card allows us to evaluate your answers and speed the results and additional study materials to you as soon as possible. Do not hold your examination answer cards to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

— ■													
—													
—	Name <u>John Smith</u>												
—	Print												
—													
—	Student No.								Lesson No.				
—	XY	0	1	2	3	7	8	9	4	7	3	2	3
—	●	○	○	○	○	○	○	○	○	○	○	○	○
—	1	●	1	1	1	1	1	1	1	1	1	1	1
—	2	2	●	2	2	2	2	2	2	2	●	2	2
—	3	3	3	●	3	3	3	3	3	3	3	●	3
—	4	4	4	4	4	4	4	4	4	4	4	4	4
—	5	5	5	5	5	5	5	5	5	5	5	5	5
—	6	6	6	6	6	6	6	6	6	6	6	6	6
—	7	7	7	7	●	7	7	7	7	7	7	7	7
—	8	8	8	8	8	●	8	8	8	8	8	8	8
—	9	9	9	9	9	9	●	9	9	9	9	9	9

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3. Enter your eight-digit student number. Do not include letters that may precede the number.
4. Enter the four-digit assignment number that appears on your examination.
5. Enter your answer for each question when prompted. On your telephone keypad, number 1 equals letter A; 2 equals B; 3 equals C; and 4 equals D.
6. Listen carefully to the instructions as you receive them over the telephone. TeleGrading lets you review your answers and make changes, if necessary, before it scores your exam.
7. If you hang up before you hear that your exam has been accepted, your exam record will be deleted.

1. Clicking the down arrow button on the right side of the Address bar in Internet Explorer will:
  - a. Show Microsoft's suggested sites to see.
  - b. Show a list of sites that you've already visited.
  - c. Show only URL sites.
  - d. Show only HTTP sites.
  
2. If you've started to download a page in Internet Explorer and then realize that you don't want to download the page, what can you do?
  - a. Click the End button.
  - b. Click the Do Not Download button.
  - c. Click the Stop button.
  - d. Click the Escape button.
  
3. Web sites that you frequently visit in Internet Explorer are called:
  - a. Bookmarks.
  - b. Favorites.
  - c. Frequent.
  - d. Regulars.
  
4. What is the History list?
  - a. It's Internet Explorer's way of keeping track of where you've been on the Web. Internet Explorer's default is maintaining the information for 20 days.
  - b. It's Internet Explorer's way of maintaining the Favorites list.
  - c. It's Internet Explorer's way of keeping track of search engines that you've used. Internet Explorer's default is maintaining the information for 999 days.
  - d. It's Internet Explorer's way of keeping track of purging old Web site information. Internet Explorer's default is purging the information after 90 days.
  
5. True or false. You can't use plug-ins with Internet Explorer; you can only use them with Netscape Navigator.
  - a. True.
  - b. False.
  
6. What is a *subscription* in Windows 98?
  - a. It's a way of automatically receiving information from Web sites.
  - b. It's a way of joining an electronic discussion group.
  - c. It's a way of receiving a television signal over Windows 98.
  - d. It's a way of receiving electronic magazines over email.

**7. CDF files:**

- a. Provide Internet Explorer with an index of visitors who have searched a particular Web site.
- b. Are a feature of Netscape Navigator, not Internet Explorer.
- c. Provide Internet Explorer with an index of what is new and what has changed in a Web site, making it quick and easy for Internet Explorer to obtain the latest information on the site.
- d. Provide Internet Explorer with non-channel sites.

**8. You can use the \_\_\_\_\_ as a quick way to find channels on the Internet that can deliver news and information directly to your Active Desktop.**

- a. Channel Broadcasting.
- b. Offline Web Browser.
- c. TV Tuner Card.
- d. Active Channel Guide.

**9. How can you view a standard television broadcast on your computer?**

- a. With a TV tuner card.
- b. With a special Windows 98 technology called WebTV for Windows.
- c. With a special Windows 98 technology called WaveTop.
- d. With a special Windows 98 technology called DVD.

**10. True or false. All sites that provide components for the Active Desktop require that you set up a subscription.**

- a. True.
- b. False.





1. True or false. With Outlook Express, you can use non-HTML formatting, and recipients of your message will be able to view your formatting, regardless of the email software they use.
  - a. True.
  - b. False.
  
2. To pick multiple recipients from a list of names in your Outlook Express Address Book, click the \_\_\_\_\_ button or hold the CTRL key while selecting multiple addresses.
  - a. To:
  - b. Cc:
  - c. Select Recipients.
  - d. Insert Recipients.
  
3. In Outlook Express, you can use the \_\_\_\_\_ to automatically move messages from your email account at work to your email account at home.
  - a. Address Book.
  - b. Outlook Express folders.
  - c. Outbox Assistant.
  - d. Inbox Assistant.
  
4. When you subscribe to a newsgroup using Outlook Express, the available messages for that group:
  - a. Are uploaded to the Internet for you to view.
  - b. Are uploaded to your computer network.
  - c. Are downloaded to your computer.
  - d. Are downloaded to a zip drive.
  
5. After you've composed your newsgroup message in Outlook Express and verified the newsgroup address, what final step must you take to send the message to the newsgroup?
  - a. Click the Send button.
  - b. Click the Post button.
  - c. Click the Compose button.
  - d. Click the Flame button.
  
6. With Outlook Express, how can you hide your email address in your outgoing messages to newsgroups?
  - a. On the Tools menu, choose Accounts and click the News tab. Then, choose an account and click the Properties button. Under User Information in the General tab, you can specify a bogus email address.
  - b. On the Tools menu, choose Accounts and click the General tab. Open the Properties button and enter your bogus email address.
  - c. On the Tools menu, choose Accounts and click the email button. Be sure that the "Block email address" option is enabled.
  - d. It's not possible to hide your email address in your outgoing messages to newsgroups.
  
7. In FrontPage Express when you're saving your page, if you click the "As file" option, your page is saved as a(n) \_\_\_\_\_ file.
  - a. HTML.
  - b. HTTP.
  - c. FPE.
  - d. PWS.

8. True or false. FrontPage Express lets you add special formatting, such as bold and italic, but won't let you add hyperlinks. You must use PWS to add hyperlinks.
  - a. True.
  - b. False.
  
9. How can you create an email link on your home page in FrontPage Express so that visitors can send you an email message?
  - a. Type your email address in the URL field in the Open Pages tab in the Create Hyperlink dialog box.
  - b. In the Create Hyperlink dialog box, choose the World Wide Web tab, select "mailto:" in the Hyperlink Type box, and type your email address in the URL field.
  - c. Type your email address in the Target Frame field in the New Page tab in the Create Hyperlink dialog box.
  - d. You can't create an email link in FrontPage Express; you must use PWS.
  
10. In FrontPage Express, where are graphic elements stored?
  - a. In the HTM files.
  - b. In the HTTP files.
  - c. In separate files.
  - d. In Web pages on the Internet.



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# Project 7327: Working with Windows 98

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## Introduction

Welcome to your Windows 98 hands-on project. In this assignment, you will work on five exercises that you will submit to your instructor for grading. Up to this point in your course, you've been reading and learning about Windows 98. With this project, you'll practice what you've learned!

As you'll see when you begin the project, when we ask you to complete certain tasks, we don't tell you how to do them. This makes the project more challenging for you and gives you an idea of how vast your options are for performing a task in Windows 98. Basically, you can do the assigned tasks in any way that you choose. For example, if we ask you to cut and paste some text, you can use the Cut and Paste commands from the menus, the Cut and Paste buttons on the Toolbar, or the CTRL-X and CTRL-INSERT commands on the keyboard. As you know, Windows 98 provides you with many options for performing a task. The same goes for this project: Complete the task however you want. You are the one in control of Windows 98.

Furthermore, you can set up Windows 98 in any way that you'd like. You don't have to conform to any particular settings for this project. For example, you may have your Windows 98 interface set up for the Active Desktop and single-clicking. Or, you may choose to disable the Active Desktop and use the traditional double-click.

It's up to you. Your project will *not* be affected by the settings you choose for Windows 98.

As mentioned earlier, this project consists of five exercises:

- Exercise 1: Creating a New Folder
- Exercise 2: Creating Shortcuts
- Exercise 3: Copying, Pasting, and Formatting Text
- Exercise 4: Adding an Item to the Start Menu
- Exercise 5: Scanning Your Hard Disk for Possible Errors

Take your time and complete all five exercises. As you work on them, you'll be saving your work to a folder on your hard drive called My Folder. When you've finished with all five exercises, you'll copy the My Folder folder to a diskette to submit to NRI for grading. Follow the directions at the end of this project for submitting the disk to us.

Good luck, and get started now!

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# Exercise 1: Creating a New Folder

---

## Directions

In this exercise, we would like you to create a new folder on your C drive. (If your drive is designated as anything other than “C,” just substitute that drive letter when we mention “C drive.”) Create C:\My Folder on your C drive. You’ll use this folder to store the files that you’ll create in this project.

Now we are going to show you how to “take a picture” of your new folder so that you can send it to us to show us that you created My Folder on your computer. Open either Explorer or My Computer so that you can view My Folder in the window. When you can see it, press the “Print Screen” button on your keyboard. (It’s located on the top-right section of most keyboards.) This button “takes a picture” of what’s displayed on screen and pastes it to the Windows 98 Clipboard.

Next, open up the Windows 98 Paint program. Recall that the current contents of the Clipboard can be pasted into other applications. Within Paint, select the Edit menu and then the Paste option.

The graphics image from the Clipboard should be pasted in. Depending on how much memory (RAM) your PC has, you may get a message asking if you want to increase the size of the bitmap within Paint so as to contain the new image. Simply click Yes if this message box appears.

Finally, save the image as a bitmap file in My Folder. Just select the File menu and then the Save As option. Please call the file "*My Folder.bmp*". Within the Save As Type field, select the "16 Color Bitmap" option. Using this option will reduce the size of the graphics file while maintaining all essential characteristics. If you receive a message saying that you may lose some information saving the file this way, just click OK.

Now when you open up My Folder from Explorer or My Computer, you should see the one file called "*My Folder*" in the window.

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# Exercise 2: Creating Shortcuts

---

## Directions

You've already learned how shortcuts can be used to expedite your work in Windows 98. In this exercise, you'll create three shortcuts:

1. Create a shortcut on the Desktop to My Folder.
2. Create a shortcut on the Desktop to Paint.
3. Create a shortcut on the Desktop to Explorer.

We'll provide you with some tips for creating these shortcuts. The file that starts the Paint program is called "Mspaint.exe". It's located in the Accessories folder in the Program Files folder. The file that launches the Explorer program is called "Explorer.exe", and it's located in the Windows folder on your C drive. (Remember, to be able to view file extensions, go into the View menu in Explorer or My Computer, select Folder Options, click on the View tab, and uncheck the "hide file extensions for known types" option.)

As you did in Exercise 1, please "take a picture" of your Desktop with the three new shortcuts on it. Save the file as "*Shortcuts.bmp*" in My Folder. Be sure to save the file as a 16-color bitmap file.

## Exercise 3: Copying, Pasting, and Formatting Text

---

### Directions

Windows makes it easy for you to transfer information from one application to another. In this exercise, you'll first locate some information within the Windows Help system. You'll copy and paste that information into Notepad. From Notepad, you'll transfer the information to WordPad, where you'll format the text and save your WordPad document.

**Step 1.** Open up the Help option from the Start menu. Click on the Index tab and display the topics for "connections, Internet." Within the topics listed, choose "The Microsoft Network: The best way to go online." Look at Figure 1 to make sure you're accessing the correct information in Help.

**Step 2.** Windows Help will display the requested information — "The Microsoft Network: The best way to go online" — in a separate window on the right-hand side of the Windows Help dialog box. We'd like you to copy the text in this window to the Clipboard.

**Step 3.** Open up Notepad (located in Start | Programs | Accessories) and paste in the text. Within Notepad, we simply want you to eliminate some of the extra spacing that occurs between some lines within the text. To do this, just click the mouse at the beginning of an empty line and then hit the Delete key.

Do this for each blank line that's embedded within the text, but leave the blank line between the title and the first line.

When you've finished with this simple editing, save the document: Select the File menu and then Save As. Type in the following line within the File Name field:

C:\My Folder\MSN.txt

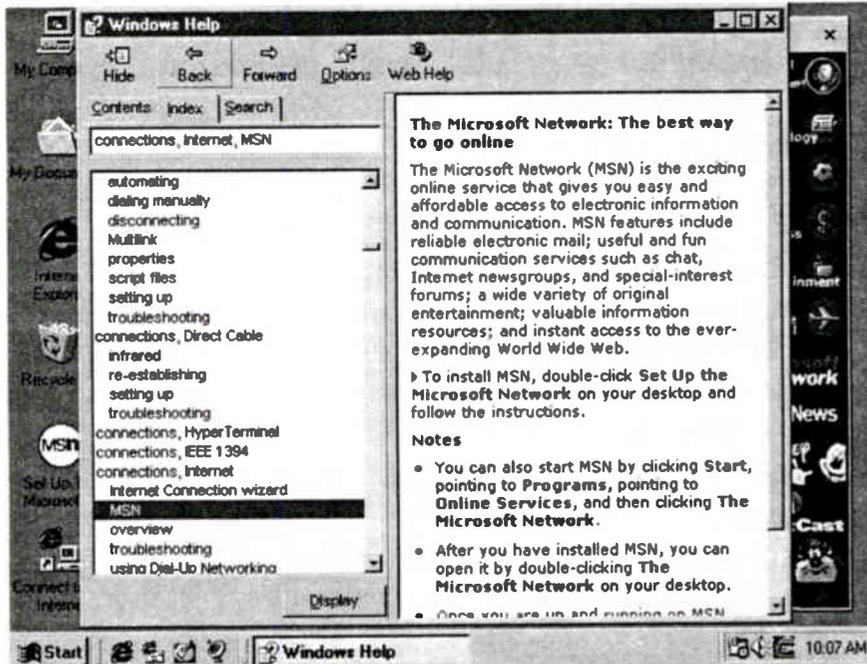


Figure 1.

**Step 4.** To better format the Help text, copy it from Notepad into WordPad via the Clipboard.

**Step 5.** We want you to format the Help text and make it look good. Although WordPad isn't as sophisticated a word processor as Microsoft Word or WordPerfect, it has enough capabilities to be very useful. You'll notice, for example, that when you pasted text into WordPad, the longer lines were automatically wrapped around so that all the text was visible. This automatic word-wrap feature is common to all word processing applications. Follow the directions in the list on the next page for formatting instructions.

- Increase the font size for the title — “The Microsoft Network: The best way to go online” — to 16 point.
- Change the title’s font to Arial. (Substitute another similar font if your computer doesn’t have Arial. You could use Helvetica or Swiss, for example.)
- Capitalize the title so that it reads: “The Microsoft Network: The Best Way to Go Online”.
- Make the title bold.
- Select all the text except the title and make it Times New Roman 12 point.
- Insert a blank line above the paragraph that begins with “To install MSN.”
- Insert a blank line above the “Notes” header.
- Insert a special arrow character in front of the line that begins with “To install MSN.” Look at Figure 2, on the next page, to see how this should look.

*Hint:* To insert a special character, you can use the Character Map program. To get the arrow, you can use any font that has an arrow character in it; we used “Wingdings.”

- Make the “Notes” header bold.
- Insert a bullet in front of each paragraph in the “Notes” section.
- Look at Figure 2 to make sure that your formatted document looks like the one that we did.

**Step 6.** Save your formatted document within WordPad as “*MSN.doc*”. Save it to My Folder. Keep in mind that the extension “.doc” will differentiate this file from the “*MSN.txt*” file that you saved in Notepad.

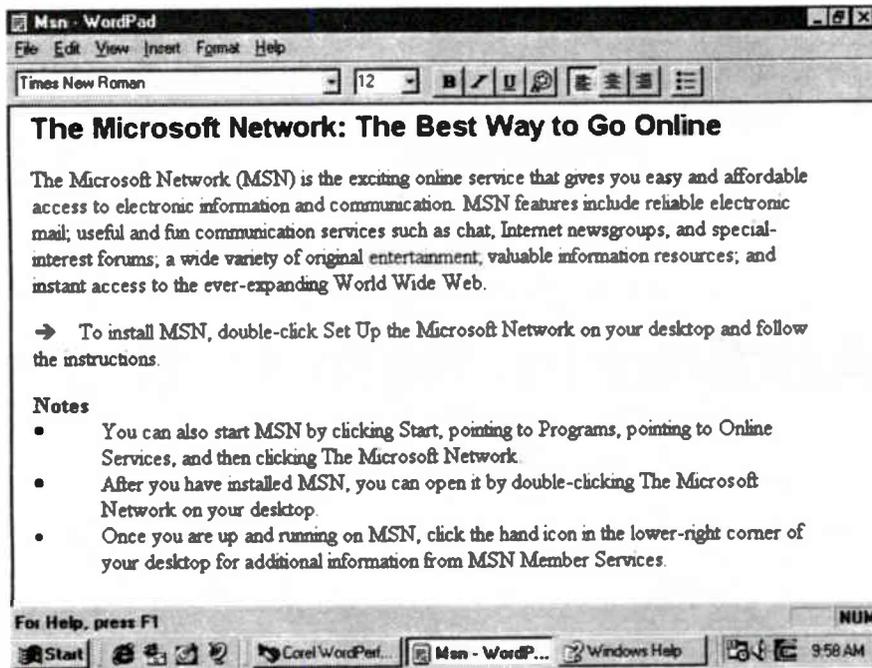


Figure 2.

## Exercise 4: Adding an Item to the Start Menu

---

### Directions

Windows 98 lets you add items and program folders to the Start menu. In this exercise, add the Clipboard Viewer program to the Start menu. The Clipboard Viewer is the program that lets you see what is currently on the Clipboard. It's currently located in Start | Programs | Accessories | System Tools. You can find the launch file in the Windows directory: Clipbrd.exe. (Note: If you can't find the Clipboard Viewer on your system, it may not be installed. You must load the Clipboard Viewer from your installation disks or CD-ROM per the bullet list instructions at the end of this exercise.)

Place the Clipboard Viewer directly in the Start menu. (That is, it shouldn't go inside another folder in the Start menu; it should be its own folder.) Keep in mind that there are several different ways to add programs to the Start menu. Feel free to use whichever way is easiest for you. Then, we'd like you to "take a picture" of your revised Start menu and save it as a bitmap file called "*Clipboard.bmp*" in My Folder so that we can evaluate your work. Be sure to save the file as a 16-color bitmap file.

---

## Installing the Clipboard Viewer

If the Clipboard Viewer isn't on your system, follow these steps to install it:

- Open the Control Panel and double-click on the Add/Remove Programs icon.
- Click the Windows Setup tab at the top of the Add/Remove Programs dialog box.
- Double-click the System Tools item that appears within a Components part of the dialog box.
- A System Tools dialog box appears with a list of applications, each with a square box in front of the application icon. If the box is checked, then the application is already installed. Find the Clipboard Viewer application in the list and click its box to insert the needed check mark. Then click the OK button at the bottom of the dialog box.
- You'll be returned to the Add/Remove Programs dialog box. Click the OK button at the bottom of this box as well.
- Another dialog box will appear prompting you to insert either a specified Windows 98 installation diskette or CD-ROM (depending on what medium was used for the original installation). Insert the specified diskette or CD-ROM and click OK. The necessary files for the Clipboard Viewer will then be copied onto your hard drive. Or, if the necessary files were loaded on your hard drive but just not installed, you won't need to insert a diskette or CD-ROM; Windows 98 will find the files for you from your hard drive.
- When the installation is complete, you can close the Control Panel.

# Exercise 5: Scanning Your Hard Disk for Possible Errors

---

## Directions

Windows 98 comes with a number of utility programs that help you to maintain your disk drives. One such program is ScanDisk, which can perform a detailed inspection of any disk within a stand-alone PC. ScanDisk can even make the needed repairs for you if a problem is found.

Although it can take up to an hour to perform a “thorough” ScanDisk operation of a large hard drive, we recommend that you do so regularly — at least once a month. The sooner that disk errors are found and corrected, the less chance that your whole hard disk will become corrupted.

In this exercise, we want you to perform a “thorough” ScanDisk operation of your primary hard drive. You’ll then copy the resulting SCANDISK.LOG file, containing the results of the operation, to My Folder.

Since the ScanDisk operation requires substantial time, you can plan to do something else — away from your PC — while the program is running.

**Step 1.** There are two ways to start the ScanDisk program, and you can choose any method that you like. One way is to right-click your C: disk drive object from the My Computer window. From the resulting menu, select the Properties option.

---

Then click the Tools tab from the resulting dialog box. The first field in the Tools tab displays how many days it's been since you last scanned that disk drive. You simply click the Check Now button to initiate a new ScanDisk operation.

The second way to start ScanDisk is via the Start menu: Click Start | Programs | Accessories | System Tools. ScanDisk should be listed among the System Tools.

**Step 2.** Make sure that the desired hard drive (C:) is selected within the first field. In the Type of Test field, we want you to click on the Thorough option. It takes longer to run than the Standard option, but it guarantees better results. We'd also like you to click the Automatically Fix Errors field. Finally, click the Start button.

Depending on the size of your hard drive and the speed of your PC, it could take anywhere from ten minutes up to an hour for the ScanDisk operation to run to completion. The program continually alerts you as to exactly how many disk clusters have been scanned so far out of the total number of clusters on the drive. When the program finishes, it displays a ScanDisk Results report, which gives a general summary of the current conditions of your designated disk drive.

**Step 3.** The ScanDisk Results report doesn't tell what the ScanDisk program may have done to diagnose and repair problem areas on your disk. For that, you need to open the SCANDISK.LOG report that is automatically produced every time the program runs. This report file is placed in the root folder of the drive containing Windows 98 — probably your C: drive.

To look at this report, first open the root folder of your primary hard drive (C:). Find the SCANDISK.LOG file object and open it. You may then be prompted as to which application to use to open this file. Select Notepad from the displayed list. That will open the Notepad program with the report file — a text file — contained inside. By default, a new SCANDISK.LOG report is generated every time that you run ScanDisk.

If no report is produced on your system, return to the ScanDisk screen and click the Advanced button. On the

ensuing ScanDisk Advanced Options window, check the Log File section and make sure that the “Replace log” option is selected.

**Step 4.** Copy your SCANDISK.LOG report file to My Folder for submission to your instructor. You can copy the file from the root folder to My Folder using any file copying method you like. Note that the report file will appear simply as “*SCANDISK*” if you haven’t specified the use of filename extensions.

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# Preparing Your Project Diskettes

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This final step requires that you format a system diskette and then copy all the files from My Folder to the floppy diskette. Then, you'll duplicate the diskette so that you can keep a copy of it for yourself. You'll send the original diskette in to your NRI instructor for a detailed evaluation of your work.

**Step 1.** Get one of the two blank, 3.5" diskettes that were included within this training package and format it. (You can use the Format command when you right-click your 3.5" drive in My Computer.) Make sure that the Capacity field at the top displays "1.44 MB (3.5)". For the Format Type, select the Full option button. Within the Label field, we want you to type in your Student Number to help us in identifying your work. This Label value will be encoded magnetically on the formatted diskette.

As for the Other Options field, we'd like you to click the Copy System Files option. This will cause the primary operating system files, including COMMAND.COM and three hidden files, to be copied from your hard disk to the diskette, allowing you to boot from your diskette. The Display Summary button should be on by default — just leave it as it is. Now you're ready to click the Start button to begin formatting. It takes a few minutes to format the diskette and copy over the system files.

When the process is complete, a summary report should be displayed for you. The report should indicate the amount of storage space, in bytes, available on the formatted diskette, along with the number of bytes occupied

by the system files. After looking briefly at the report, close its window and then close the Format window.

**Step 2.** Next, we want you to copy all the files from My Folder on your hard disk to the newly formatted system diskette. You can use any type of Copy method you like. Keep in mind that you will be copying the following files:

- *My Folder.bmp*
- *Shortcuts.bmp*
- *MSN.doc*
- *MSN.txt*
- *Clipboard.bmp*
- *SCANDISK.log*

**Step 3.** Verify that all the files from My Folder were in fact copied to the diskette. Note that COMMAND.COM and three hidden files (IO.SYS, MSDOS.SYS, and DRVSPACE.BIN) should also be present on the diskette, since it was formatted as a system diskette.

**Step 4.** Next, we want you to make an exact duplicate of the diskette you just formatted and copied your work to. The second diskette will serve as your backup in the event that the primary diskette gets lost in transit. This second diskette will also be a system diskette, which you could use to boot your PC in the event of a hard disk failure.

To duplicate the diskette, start by right-clicking the 3.5" drive object within the My Computer window. This time select the Copy Disk option. It should show that it will copy from one 3.5" floppy to another 3.5" floppy.

Verify this and then click the Start button to proceed. It takes a while to copy the contents of your diskette to the PC's memory. When this part of the operation is complete, another dialog box should appear. Following its instructions, you should proceed to insert your second diskette into the drive now so that it can receive all the information that was copied from the first diskette. Note that the second diskette doesn't have to be formatted first since this Copy Disk operation will automatically format it for you. After inserting the second diskette, hit the OK button and wait while the copying operation completes.

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When the Copy Disk operation is complete, verify that the second diskette now contains the same files as the first diskette. Then write-protect both diskettes. This is done by sliding the little square lever in the lower right corner of the diskette's rear side until a square opening appears. This opening ensures that no new files can be written to your diskettes.

**Step 5.** Get the disk mailer envelope and its NRI mailing label now (they came with this training package). Write your name, student number, and return address on the envelope. Make sure that the NRI mailing label is correctly affixed to the envelope. Next, get two of the sticky diskette labels that came with this training package. On each of them write the following information: FX7327, your name, your student number, and the current date. Make the two labels identical and place one on each of the two diskettes. Insert one of the labeled diskettes into the diskette mailer envelope. Put the other diskette away for safekeeping. Remember that you can use the backup diskette to boot your PC during a hard disk emergency.

Next, get a blank Lesson Answer card and proceed to fill out only the Name, Student Number, and Lesson Number (7327) sections. Your NRI instructor will fill out the rest of the card based on the contents of your diskette.

Place your Lesson Answer card in the diskette mailer envelope as well. Seal the envelope and take it to your nearest post office to weigh it and affix the needed postage before sending it to NRI.

We hope you have enjoyed working with these Windows 98 training materials. Windows 98 is envisioned to be the principal PC operating system of the late 1990s. By successfully completing these exercises, you'll have demonstrated that you're well on the road to becoming a proficient Windows 98 user.





**FX7327(002)**