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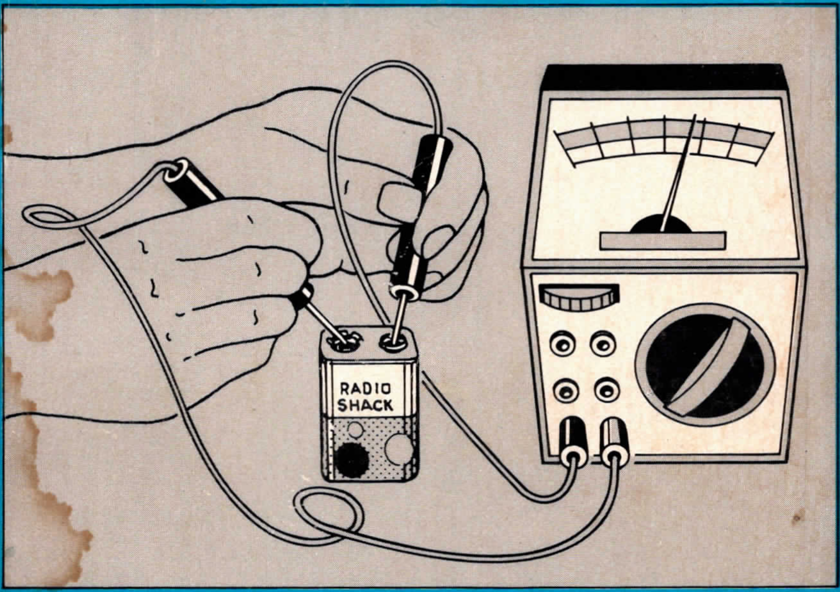

BASIC DC CIRCUITS

50¢

PRACTICAL ELECTRONICS SERIES

Volume 1

Basic DC Circuits

by

Frank Swan

and

Warren Palmer

Radio Shack®

A TANDY CORPORATION COMPANY

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CONTENTS

INTRODUCTION

Here is a practical approach to the fascinating field of electronics—a series of books with a combination of basic electronic theory and numerous practical projects to provide you with an understanding of basic electronics and introduce you to the complex circuits which make up so much of the world around us.

This series is written by two men, each of whom has been involved with electronics and education for nearly 25 years. They have a deep practical knowledge of electronics and the necessary experience to communicate this knowledge to others.

There are many practical projects and experiments included as a vital part of this series. These projects and experiments help you to understand more easily the concepts being discussed. If you perform all of the projects and experiments as you go through this series you will gradually obtain electronic components and test equipment which you can use for your own enjoyment and profit. This series provides a good foundation for continuing studies in electronics and gives the hobbyist a good working knowledge of electronics.

You will enjoy learning about electronics as you go through this clearly written and well illustrated series. Each book introduces new concepts and you will gradually cover a broad range of topics. This series is recommended for individual as well as group study. Each book in the series is not only a text-book and a work book, but can be kept as a valuable reference book as well.

A brief quiz is included at the conclusion of each chapter. Answers are provided in Appendix C for instructors using this book in a school or group study situation.

VOLUME I—BASIC DC CIRCUITS

This first book in the series introduces you to the concepts of voltage, current, resistance and power. It familiarizes you with the use of a VOM (volt-ohm-milliammeter) to measure voltage, current and resistance. Ohm's law, one of the most basic and important relationships in electronics, is learned and applied.

Basic series and parallel circuits are studied including the relationships among voltage, current, resistance, and power.

Included are a number of practical experiments which you should perform to obtain maximum benefit from your study. You may want to purchase the components and other necessary items as you go along. If you would prefer to purchase all the necessary items at one time there is a list of materials following. These materials can be obtained from your local Radio Shack store. You may even have some of these parts on hand already, which will save you some of the cost involved.

Materials List for Experiments

Quantity	Description
1	Volt-ohm-milliammeter (22-202)
1	Battery holder (270-1439)
1 set	9-volt battery clips (270-325)
1 set	Test lead jumper cables (278-1156)
2	1.5-volt D cell (23-466)
1	9-volt Battery (23-464)
1	Selenium solar cell (276-115)
1	Resistor kit (271-306)
1	Panel lamp indicators, 12-volt (272-322)
1	Variable DC power supply (22-126)
1	Experimenter's P-box (270-105)
1 set	Solderless spring terminals (270-1547)

Radio Shack catalog numbers shown in parentheses.

CHAPTER 1

DC VOLTAGE

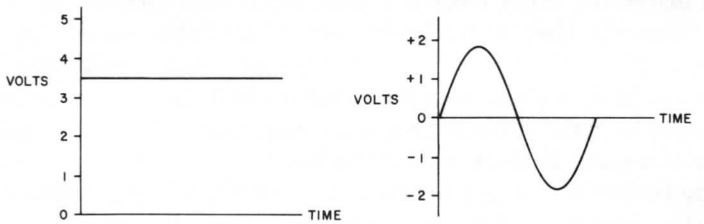
In order for most electrical and electronic circuits to function properly they must be connected to some source of DC voltage. Your flashlight doesn't give any light until you put batteries in it. You have to have a good battery in your transistor radio to make it work properly. Your can won't start, unless there is a good battery under the hood.

The source of voltage provides the energy which is necessary for the circuit to function properly. The source of voltage causes the current to flow in the circuit. The source of voltage is sometimes referred to as the "electromotive force" or EMF. Voltage can be compared to water pressure. The greater the pressure on a line, the more water will flow. The greater the voltage on a circuit, the more current will flow.

The amount of voltage is measured in units called *volts*. Voltage is measured using a voltmeter or the voltmeter function of a VOM (volt-ohm-milliammeter). The amount of voltage required for proper operation of a circuit depends on the nature of the circuit itself. A regular two-cell flashlight operates on 3 volts. Most transistor radios work on 6 or 9 volts. Circuits which use tubes require a much higher voltage, usually 150 volts or more. The picture tube in a color television set uses a source of voltage close to 25,000 volts, or more.

The basic unit of voltage is the volt. For many applications the basic units are quite convenient but there are times when it is easier to express the voltage in some other units. When the voltage is very high, over 1000 volts, we sometimes use the abbreviation kV which stands for kilovolts. Kilo is a prefix which means 1000. 1 kV is equal to 1000 volts. To change volts to kilovolts divide the number of volts by 1000 (move the decimal point 3 places to the left). For example, 25,000 volts $\div$ 1000 = 25 kV. To change kilovolts to volts, multiply the number of kilovolts by 1000 (move the decimal point 3 places to the right). For example, 2.6 kV $\times$ 1000 = 2600 volts.

When the voltage is very low, we sometimes use the abbreviation mV, which stands for millivolts. Milli is a prefix which means $\frac{1}{1000}$. One millivolt is equal to 0.001 volt. To change volts to millivolts, multiply the number of volts by 1000 (move the decimal point 3 places to the right). For example, 0.025 volt $\times$ 1000 = 25 mV. To change millivolts to 1000 (move the decimal point 3 places to the left). For example, 37.5 mV $\div$ 1000 = 0.0375 volt.



(*A*) *DC voltage.* (*B*) *AC voltage.*

Figure 1-1. Two types of voltage.

When the voltage is extremely low, we use the abbreviation μV which stands for microvolt. Micro is a prefix which means $\frac{1}{1,000,000}$. One microvolt is equal to 0.000,001 volt. To change volts to microvolts, multiply the number of volts by 1,000,000 (move the decimal point 6 places to the right). For example, 0.000,032 volt $\times$ 1,000,000 = 32 μV. To change microvolts to volts, divide the number of microvolts by 1,000,000 (move the decimal point 6 places to the left). For example 13 μV $\div$ 1,000,000 = 0.000,013 volt.

The term DC means *direct current*. When we say DC voltage we mean a source of voltage which has a steady value of voltage at all times. This is in contrast to an AC voltage or *alternating current* voltage which is constantly changing value.

The difference between a DC and AC voltage is illustrated in Figure 1-1.

You will notice that the value of DC voltage shown is always the same and always positive (+). The value of AC voltage shown is always changing and is sometimes positive (+) and sometimes negative (−). When we say that a voltage is either positive or negative, we are indicating what is called the *polarity* of a voltage. This is covered in more detail in Chapter 4.

When DC voltage is being represented in a formula, either the letter E or V is used.

There are several sources of DC voltage. Probably the most familiar source is the battery. Batteries come in a wide variety of shapes, sizes and voltage values. Some of the more common types of batteries are illustrated in Figure 1-2.

A schematic diagram (circuit diagram) is a drawing which shows how the various components in an electrical circuit are connected together. Each component is represented by a schematic symbol.

When a battery or cell is represented on a circuit diagram, one of the schematic symbols shown in Figure 1-3 is used.

Batteries develop a voltage across their output terminals due to the reaction of the chemicals on the dissimilar metal electrodes inside the battery. Most of the dry cells have a voltage of $1\frac{1}{2}$ volts. A 6-volt battery is made up of four $1\frac{1}{2}$-volt cells connected together. A 12-volt car battery is made up of six 2-volt cells connected together.

Figure 1-2. Different types of batteries.

The voltage source for most equipment using tubes is an electronic power supply. This type of supply is generally connected to the AC power line. The power supply circuit converts the 120-volt AC power line voltage to the desired value of DC output voltage. This type of supply is represented by the block diagram shown in Figure 1.4.

(*A*) *Single cell.* (*B*) *Multicell.*

Figure 1-3. Schematic representation of batteries.

Another source of DC voltage is the solar cell. This type of cell develops a voltage across its terminals by converting light energy into electrical energy. This type of cell is used on some of the satellites which are orbiting the earth and transmitting information back from space. A picture of some common solar cells is shown in Figure 1-5 along with the schematic representation.

Still another source of DC voltage is the thermocouple. In this device, the end of a strip of one type of metal is connected to the end of a strip of another kind of metal. When the junction of the two dissimilar metals is heated, a voltage is developed across the opposite ends of the two strips. This type of voltage source is used in equipment which is to be controlled by temperature, such as a hot water heater or clothes dryer. An illustration of a thermocouple is shown in Figure 1-6 along with the schematic symbol.

Some sources of DC voltage do not produce a pure steady DC voltage but contain periodic fluctuations or changes in voltage. These changes are generally from zero to some high value and back to zero again. These changes occur at a rather fast rate of speed and the meter used to measure the voltage cannot follow the fluctuations. The VOM indicates the average value for that source. This is illustrated in Figure 1-7.

You will notice that even though the voltage values are constantly changing, they are all the same polarity (positive).

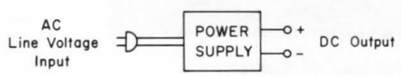


Figure 1-4. Typical power supply circuit.

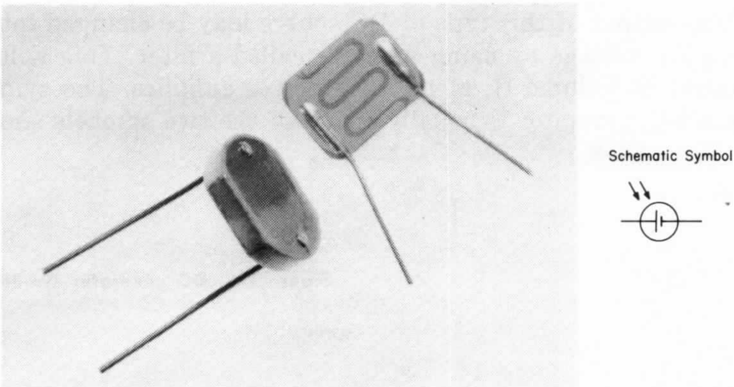


Figure 1-5. A few common solar cells.

This is different than the AC voltage shown in Figure 1-1B which has values of both polarities (positive and negative).

Some sources of the fluctuating or pulsating type DC are:

1. Automotive generator.
2. Automotive alternator.
3. DC welder.
4. Certain types of light dimmers and motor-speed controls.
5. Battery chargers.

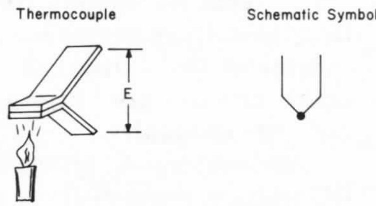
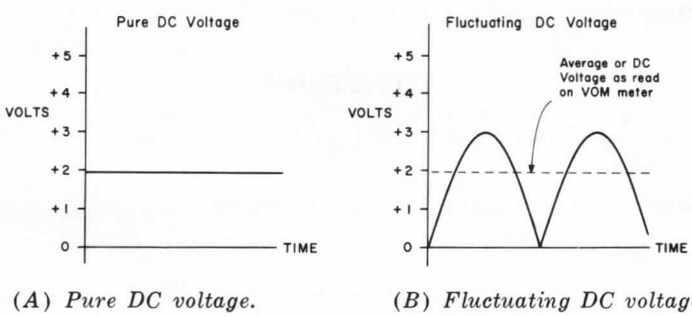


Figure 1-6. A thermocouple and schematic symbol.



(*A*) *Pure DC voltage.* (*B*) *Fluctuating DC voltage.*

Figure 1-7. Different DC voltages.

The output of this type of DC source may be changed into a pure DC voltage by using a device called a filter. This will be studied in Volume II, along with power supplies. The symbol for a DC generator is usually either of the two symbols shown in Figure 1-8.

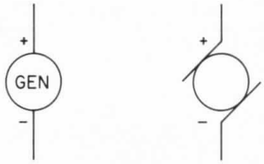


Figure 1-8. DC generator symbols.

SUMMARY

The source of voltage provides the energy to operate electronic circuits and causes current to flow in the circuit.

The amount of voltage is measured in units called *volts* and is measured using a voltmeter or the voltmeter function of a VOM. Sometimes the amount of voltage is expressed in kV, mV, or μV.

The letters E or V are used to express voltage in a formula.

The term DC stands for *direct current* which means that the voltage source has a fixed polarity, either + or −.

Some of the sources of DC voltage for operating electronic circuits are batteries, power supplies, solar cells, and thermocouples.

Some sources of voltage have a fluctuating or pulsating DC voltage. Some of these are automotive generators and alternators, welders, and battery chargers.

QUESTIONS

1. *What function does the source of voltage provide in an electronic circuit?*
2. *What is the basic unit of measure for voltage?*
3. *Change the following voltages to kV; 1500 volts, 13,500 volts.*
4. *Change the following voltages to volts; 2.3 kV, 250 kV.*
5. *Change the following voltages to mV; 0.0067 volt, 0.324 volt.*

6. *Change the following voltages to volts; 13 mV, 225 mV.*

7. *Change the following voltages to μV; 0.000456 volt, 0.0000078 volt.*

8. *Change the following voltages to volts; 27 μV, 532 μV.*

9. *Give the symbol for a single cell and a multicell battery.*

10. *How does a pulsating DC voltage differ from an AC voltage?*

CHAPTER 2

MEASUREMENT OF DC VOLTAGE

There are many times when it is necessary to make measurements of DC voltages. When you are studying a circuit, measurement of circuit voltages greatly increases your understanding of circuit operation. When you are trying to fix a defective piece of equipment, making voltage measurements helps you to locate the faulty part of the circuit. When you are building a circuit, measured voltages can indicate whether or not you have put things together properly.

Voltages are measured using an instrument called a *voltmeter*. The voltmeter function is included in a very useful instrument called a VOM (volt-ohm-milliammeter). The VOM can be used to measure DC voltage, AC voltage, DC current, and resistance. A typical VOM is shown in Figure 2-1. If you do not own a VOM we suggest you purchase one before proceeding through this book. The VOM listed in the material list is recommended as an excellent first choice. This meter, although low in price, will provide you with many of the features found on the more expensive meters. If you continue in your study and use of electronics you will probably wish to buy a more expensive and versatile VOM but this one will get you off to a good start without having to spend a lot of money.

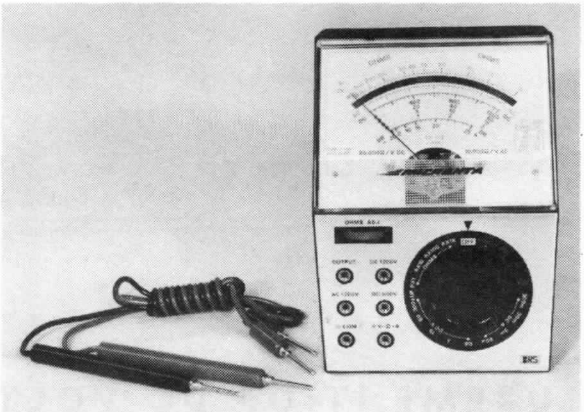


Figure 2-1. A typical VOM (volt-ohm-milliammeter).

The following features are typical of most VOM's:

1. At the lower left of the VOM are several holes called jacks (Figure 2-2). The test leads are inserted in these jacks. For most applications the black test lead is inserted in the jack marked COM or (−). The red test lead is inserted in the jack marked VΩA or (+). These colors are commonly

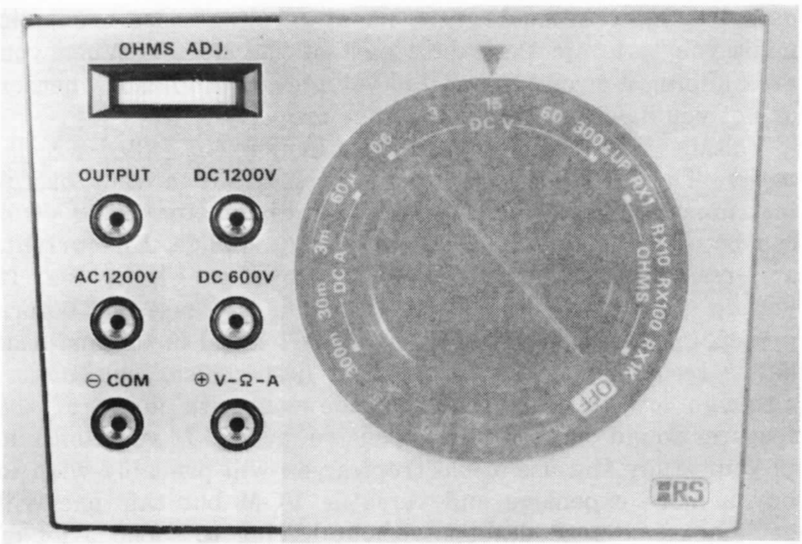


Figure 2-2. Test leads are inserted in the appropriate jacks.

used to indicate (+) and (−) in electronics. For other special measurements the red lead may be changed to one of the other four jacks.

2. To the right of the jacks is the range switch (Figure 2-3). This switch selects the function of the meter—DC voltmeter, AC voltmeter, DC milliammeter or ohmmeter. It also selects the range of these functions. Notice that on the DCV (DC voltage) portion of the switch there are full-scale ranges of 0.6, 3, 15, 60, and 300 and up. By full-scale range we

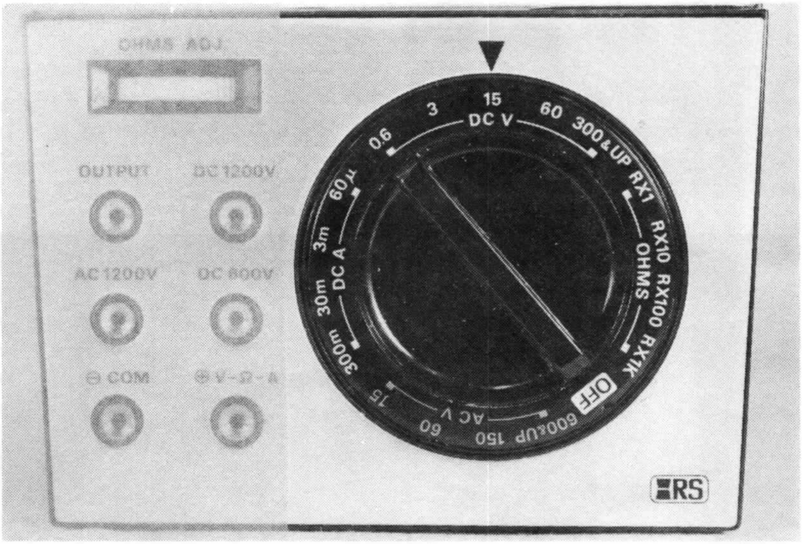


Figure 2-3. The range switch.

mean the highest value of voltage which can be measured without having the pointer on the meter go past the right end of the meter scale. In order to have a full-scale range of 600 volts, the red test lead is placed in the DC 600 V jack and the range switch is set in the 300 and up position.

In order to have a full-scale range of 1200 V the red test lead is placed in the DC 1200 V jack and the range switch is set in the 300 and up position.

On some of the lower priced VOM's the range switch is not used. Instead, different jacks are used for the various functions and ranges. A meter of this type is shown in Figure 2-4. For measuring DC voltages the black test lead

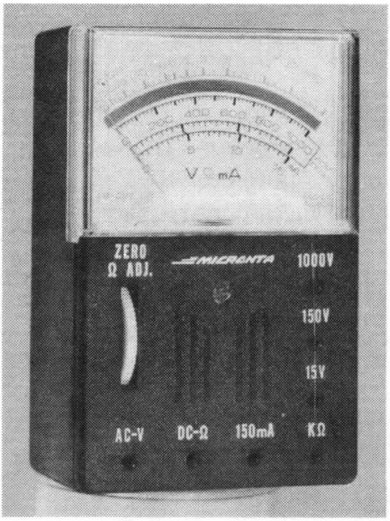


Figure 2-4. A lower-priced VOM without a range switch.

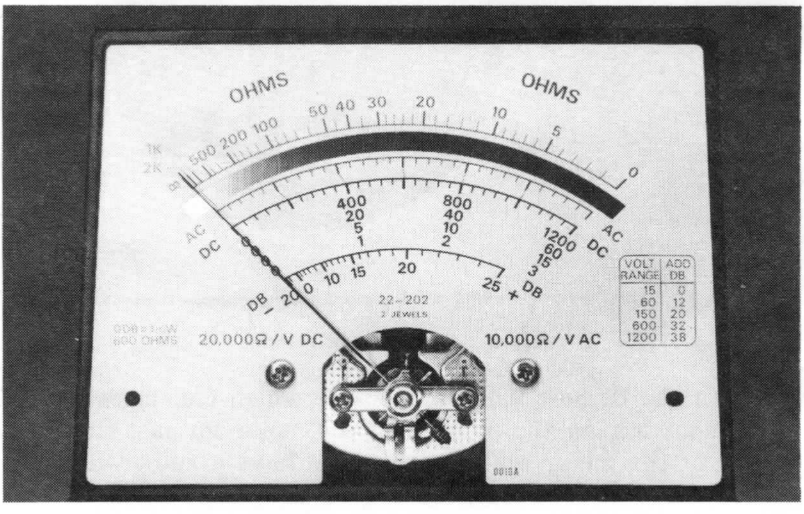


Figure 2-5. The scale of a typical VOM.

is inserted in the common jack and the red test lead is placed in the jack for the desired function and full-scale range.

3. The third major part of the VOM is the meter. The meter part of the VOM consists of the meter scales with various ranges and a movable pointer. The scale of our typical meter is shown in Figure 2-5.

Notice that there are several different scales. The top scale is marked OHMS, and is used for measuring resistance. The next lower scale is marked AC and is used for measuring AC voltages. The next lower scale is marked DC and is used for measuring DC voltages and currents. The calibrations to be used for both AC and DC depend on the position of the range switch. The bottom scale is marked DB and is used for making a special type of AC measurement.

For now, we will consider just DC voltage measurements. We will take up the other functions later.

When making DC voltage measurements the calibrations used depend on the position of the range switch. When the range switch is in the 0.6 V position the third range (0 to 60) is used but each scale value must be divided by 100. When the range switch is in the 3 V position, the lowest of the four DC ranges is used. This scale is marked with values from 0 to 3. When the range switch is in the 15 V position the second range, marked from 0 to 15 is used. When the range switch is in the 60 V position the third range, marked 0 to 60, is used. When the range switch is in the 300 V position the bottom range is used, but now you have to mentally multiply each of the scale values by 100. With the red test lead in the DC 600 V jack, the range switch in the 300 and up position, the third range (0 to 60) is used with a multiplying factor of 10. With the range switch is the 300 and up position and the red test lead inserted in the DC 1200 V jack the top DC range is used with values from 0 to 1200.

One of the common difficulties encountered when first using a VOM is proper interpretation of the meter scale markings. Only one set of line markings is used for all four ranges, so obviously each small division on the scale represents a different value of voltage for each range. On the 3 V range (Figure 2-6) the first labeled major division is 1 volt. There are 10 small calibration spaces between 0 and 1. Thus, each small division represents $1 \div 10 = 0.1$ volt. Since there are 5 small divisions in each major division, then each major division represents $5 \times 0.1 = 0.5$ volt. With the pointer in the position shown the voltage indicated would be 1.8 volts.

For 300-volt operation the 3 V scale is used but we simply mentally multiply each scale value by 100. The first labeled

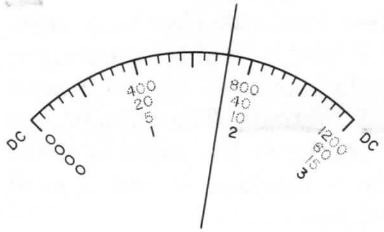


Figure 2-6. Interpreting the 3-volt range.

Each Major Division = 0.5 V
Each Small Division = 0.1 V

major division then becomes 1 × 100 = 100 volts. Each small division then represents 100 ÷ 10 = 10 volts and each major division represents 5 ×10 = 50 volts. The voltage indicated by the pointer is 180 volts.

On the 15-volt range (Figure 2-7) the first major labeled division is 5 volts. Each small division then represents 5 ÷ 10 = 0.5 volt. Each major division represents 5 × 0.5 = 2.5 volts. With the pointer in the position shown, the voltage indicated would be 6.5 volts.

The 60-volt range is shown in Figure 2-8. Let's see if you can use the procedure we have used above to figure out this scale. The first labeled major division is __________ volts. Each small division represents __________ volts and each major division represents __________ volts. With the pointer in the position shown, a voltage of __________ volts is indicated. Your answers in the blanks above should be 20, 2, 10, 48. Recall that the same scale is used for 600 V. This

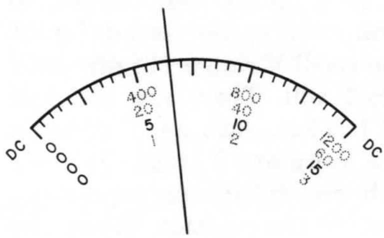


Figure 2-7. Interpreting the 15-volt range.

Each Major Division = 2.5 V
Each Small Division = 0.5 V

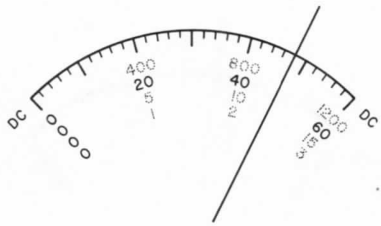


Figure 2-8. Interpreting the 60-volt range.

means that the first labeled major division is __________ volts, each small division is __________ volts, each major division is __________ volts, and the voltage indicated by the pointer would be __________ volts. Your answers for these blanks should be 200, 20, 100 and 480.

This same scale is also used for 0.6 V. For this range the first labeled major division represents 0.2 V, each small division 0.02 V, each major division 0.1 V, and the pointer indicates 0.48 V.

The 1200-volt range is shown in Figure 2-9. Use the procedure above and determine the scale calibrations.

First labeled major division __________ volts.

Small division value __________ volts.

Major division value __________ volts.

Voltage indicated by pointer ________ volts. Your answers in the blanks should be 400, 40, 200, 960.

If you have a different meter than the one we have been talking about you should study the scales carefully to be sure you know what the scale divisions represent before making any measurements.

In all our meter-scale illustrations so far we have shown the meter pointed exactly on a printed scale division. If the pointer should come to rest between two divisions you must estimate as closely as possible the relative position of the pointer. For example, look at the position of the pointer in Figure 2-10.

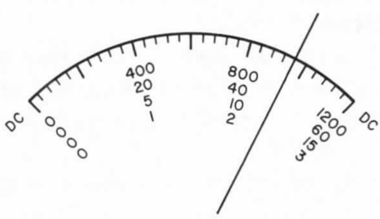


Figure 2-9. Interpreting the 1200-volt range.

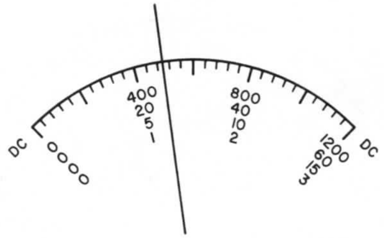


Figure 2-10. Estimating a voltage on the 60-volt range.

If the range switch is in the 60 VDC position what would you estimate the voltage reading to be? If you said 25 volts you would be correct. On the 60-volt range each small division represents 2 volts. The pointer is about half way between 24 and 26. The accuracy of the meter does not warrant any closer reading than ½ small division. The reading is then estimated as 25 V.

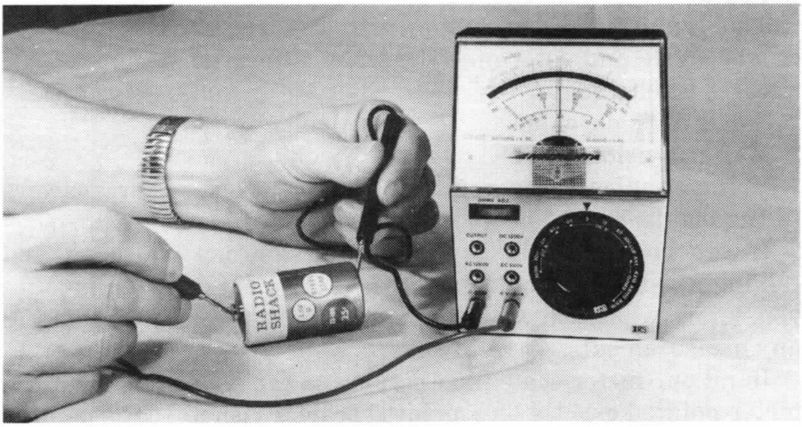


Figure 2-11. Making a DC voltage measurement.

We suggest that you spend a little time reviewing the various scales and ranges before proceeding with any measurements.

Now that you are familiar with the basic parts of your VOM let's see how to go about using it to make DC voltage measurements. Basically the procedure is this (Figure 2-11).

1. Insert the test leads in the proper meter jacks.
2. Select the proper voltage function and range.

3. Place the metal test probe tips across the voltage to be measured, observing proper polarity if it is known.
4. Notice the position of the pointer on the meter scale and read the value of voltage.

Before making any measurements let's consider each of these four steps in more detail. By observing some conventions and precautions you will be able to make your measurements more quickly and also protect your meter from possible damage.

When inserting the test leads in the jacks, the black lead is usually placed in the COM or (−) jack and the red lead is usually placed in the VΩA or (+) jack. Be sure the small plug (either a pin plug or a banana plug) on the end of the lead is clean before inserting it in the jack. Also be sure that the plug is inserted all the way into the jack so that good contact is made between the plug and the jack.

When selecting the meter function and range, keep the following suggestions in mind.

1. Select the proper function (DC V).
2. Select the proper range. If the approximate value of voltage is known, select the lowest range which includes the expected voltage.

If the value of voltage is unknown, always start with the range switch in the highest voltage position and switch downward until the proper range is reached. For best accuracy, always use the lowest meter range which includes the voltage under measurement.

To obtain a voltage measurement, the test probes must be placed across the voltage being measured. Hold the tip of the black probe firmly against the most negative terminal. Place the tip of the red probe on the positive end of the voltage being measured. If you are not sure of the polarity of the voltage, place the black probe at one terminal and momentarily tap the red probe on the other terminal. If the pointer flicks upscale the polarity is correct. If the pointer flicks down-scale, the test leads will have to be reversed. This flick test will also indicate if the voltage level is excessive for the range being used. An excessive voltage will cause a rapid and above-scale deflection of the pointer. Once you have determined the proper polarity, press both test probes firmly against the terminals to assure good contact.

Observe the position of the meter pointer on the scale and read the voltage. As an aid to lining up the pointer properly, some meters have a mirrored scale. This small mirror is located between the two AC scales on the Radio Shack meter we have been describing. Position your eye over the pointer so that the pointer reflection in the mirror is directly underneath

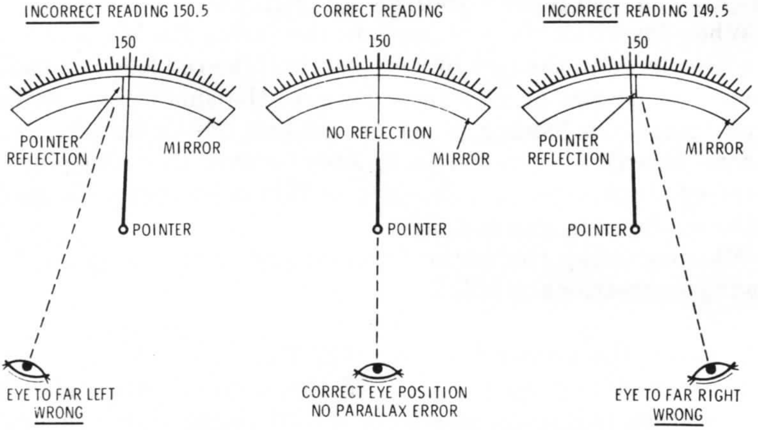


Figure 2-12. Using the antiparallax mirror.

the pointer (Figure 2-12). With your eye in this position, read the voltage on the proper scale. The error introduced by not observing the pointer from this exact position is called parallax error.

You'll get some practical experience in voltage measurements with your VOM in the following chapter.

SUMMARY

DC voltages are measured using an instrument called a voltmeter. The voltmeter function is included in a VOM (volt-ohm-milliammeter).

The major parts of a VOM are:

1. **Test leads and test jacks.**
2. **Function and range switch.**
3. **Meter with scales and pointer.**

One of the common difficulties encountered when first using a VOM is proper interpretation of the meter scale markings. Study the scale markings before attempting actual measurements.

The procedure for measuring DC voltages includes 4 simple steps:

1. **Insert test leads in proper meter jacks.**
2. **Select proper function and range.**
3. **Place the test probes *across* the voltage to be measured, observing proper polarity.**
4. **Notice the position of the pointer on the meter scale and read the value of voltage.**

If the polarity and approximate value of voltage are not known, the following precautions should be observed:

1. **Always start with the highest range switch position. Switch downward as required to obtain the most accurate reading.**
2. **Use the "flick" test to determine if meter polarity is correct and voltage is not excessive.**

QUESTIONS

1. *What type of instrument is used to measure DC voltage?*
2. *What is a VOM?*
3. *What are the major parts of a VOM?*
4. *What voltage is indicated by the pointer and scale shown in Figure 2-10 if the VOM range switch is on the 300 V position?*
5. *List the four basic steps used in measuring a DC voltage.*
6. *What are the two major precautions to use when measuring an unknown DC voltage?*
7. *What is meant by the "flick" test?*
8. *What is the purpose of the small mirror on the meter face?*

CHAPTER 3

PRACTICAL DC VOLTAGE MEASUREMENTS

In the previous chapter we discussed the basic procedures which should be followed in order to make DC voltage measurements. In this chapter we will actually have you make some measurements on a few different kinds of devices to give you some practice in making this kind of measurement. Before starting to make the measurements, check to see that you have all the necessary items listed below. If you do not have all of these you can obtain them at your nearby Radio Shack store. The catalog numbers of these items are given in the material list (page 6).

1. VOM.
2. Battery holder for two D cells.
3. Battery clip for 9-volt battery.
4. Test lead jumper cables.
5. $1\frac{1}{2}$-volt D cell (two).
6. 9-volt transistor radio battery.
7. Selenium solar cell.

If you have a new VOM that has never been used before, it may be necessary to check a few things before you start. Some meter manufacturers place a short piece of wire across the meter terminals to minimize meter damage during shipment. If so, this jumper wire must be removed before you can use

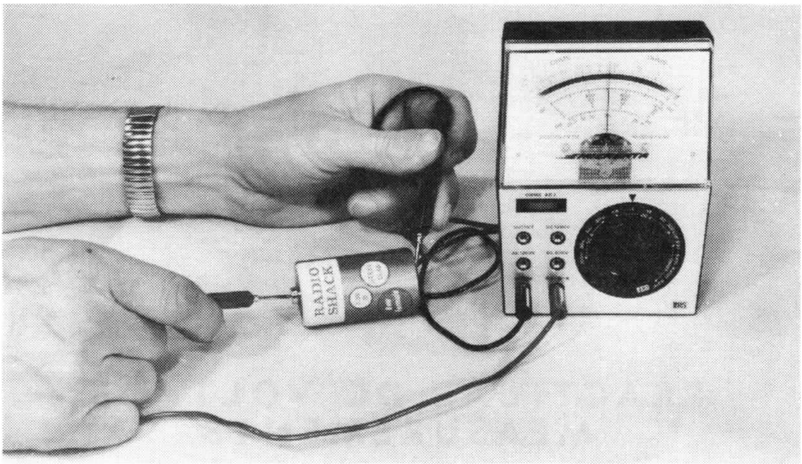


Figure 3-1. Voltage measurement of a 1.5-volt battery.

the meter. Also the battery or cell which is used for ohmmeter measurements must be installed as this is very seldom put in at the factory. Be sure that the battery is put in with proper polarity as indicated on the battery holder. Read over the booklet that comes with your meter to see if there are any other things which must be done before using the meter.

The first measurement will be made on a single $1\frac{1}{2}$-volt D cell. Place the test leads in the proper test jacks, that is, black lead in COM or (−), red lead in VΩA or (+). Place the function switch in the 3 V DC position (or the proper range position for your meter). Connect the test leads across the battery as shown in Figure 3-1. The positive terminal of the battery is the small round button. Record the voltage that you read on the meter: __________ V. For this type of cell the voltage should read approximately 1.5 volts.

The schematic representation of the measurement you have made is shown in Figure 3-2. The meter is represented by the circle with the letter V.

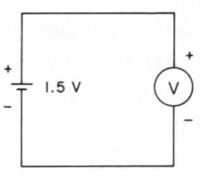


Figure 3-2. Schematic representation of measurement in Figure 3-1.

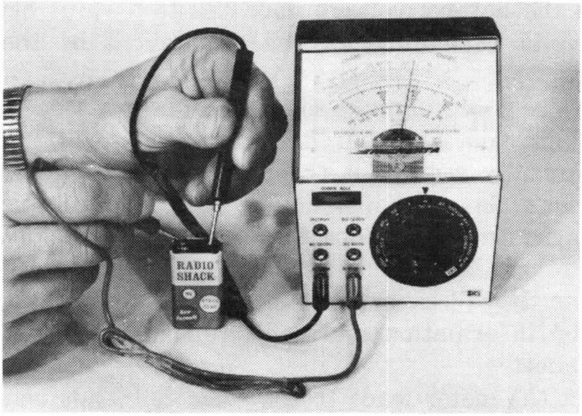


Figure 3-3. Voltage measurement of a 9-volt battery.

The next measurement will be made on a 9-volt transistor radio battery. Use a new battery or remove the battery from a radio. Place the function switch in the 15 V DC position (or the proper range position for your meter). Connect the test leads to the battery as shown in Figure 3-3. Record the voltage that you read on the meter: __________ V. For this type of battery the voltage should read approximately 9.0 volts. The schematic representation of this measurement would be similar to that shown in Figure 3-2, except the voltage source is a 9-volt battery.

Now let's try some measurements on an automobile battery. If you own a car or have access to a car battery you can proceed.

With the range switch set on the 15 V DC range (or the proper range for your meter) place the test leads across the battery terminals. Be sure to observe proper polarity. Record the voltage that you read on the meter: __________ V. For this type of battery the voltage should read approximately 12 to 13 volts. Remove the test leads from the battery and then start the car and let it run at a fast idle. Switch the meter range swich to the 60 V DC range and measure the voltage across the battery terminals. Be sure that you don't allow the meter leads to get caught in the fan blades. Voltage is: __________ V. You may be able to switch back down to the 15 volt range if the reading is below 15 volts. With the engine running the battery is receiving a charge and under this condition the battery voltage may rise to a value between 14 and 16 volts depending on the adjustment of the voltage regulator.

Next we're going to make some measurements on a selenium solar cell. If you have purchased the solar cell from Radio Shack, carefully remove it from the package and straighten out the leads. Save the instruction sheet that comes with the cell. It might be a good idea to get a folder in which to keep this and other data sheets as you gradually begin to gather more parts. It will save you some frustration later when you want some information and can't remember where you put the data sheet.

Connect the meter leads to the solar cell leads as shown in Figure 3-4. Set the range switch to 0.6 V DC. Hold the solar cell about 6 to 8 inches away from a 100-watt light bulb and record the voltage: ____________ V. The normal maximum output voltage for this type of cell is around 0.4 to 0.5 volt. Now turn off the light and record the voltage: ____________ V. Place the cell in direct sunlight and record the voltage that you read on the meter: ____________ V. Again it should be around 0.4 to 0.5 volt. Carefully place the cell back in the package or some other safe place so that the surfaces of the cell do not become scratched. We will use this cell again in a later chapter.

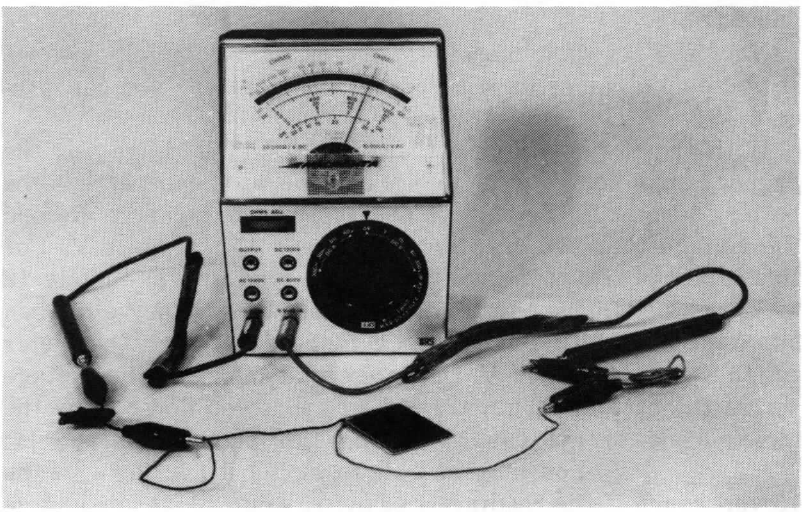


Figure 3-4. Measuring the output voltage of a solar cell.

The next thing that we are going to do is to see what happens when a battery is operated in a circuit. Put your 9-volt battery back in the radio and measure the voltage with the radio turned off. Here is where the thin pointed test probes are handy for getting at the battery terminals when the clip is attached. Yours should read about 9.0 volts. Voltage is: __________ V. Now turn the radio on and measure the voltage again. Voltage is: __________ V. Depending upon the condition of the battery and the load placed on the battery by the radio, the battery voltage may drop down to about 8 volts or so. If it drops much lower than this, it is an indication that the battery is getting very weak.

Now let's try connecting some batteries together and see what happens. Insert two $1\frac{1}{2}$-volt D cells in a battery holder as shown in Figure 3-5. Be sure that you get them in with the

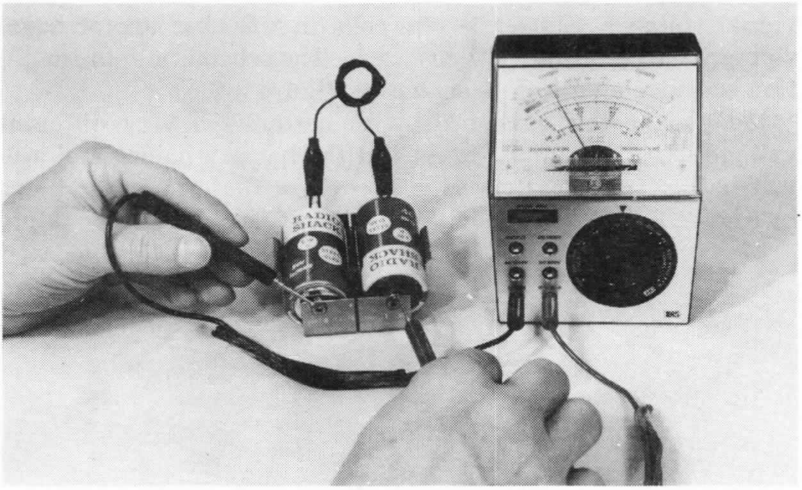


Figure 3-5. Measuring voltage across two 1.5-volt batteries connected series-aiding.

polarity shown. Connect the two end terminals together with a jumper lead as shown. Set the meter range switch to the 15 V DC range and connect the meter leads to the battery holder as shown. Record the voltage that you read on the meter: __________ V. You should read about 3 volts. It may be possible to make this reading on the 3-volt scale if the voltage is less than 3 volts. Cells connected in this way are said to be

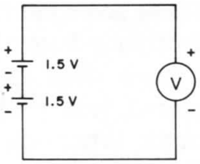


Figure 3-6. Schematic representation of measurement in Figure 3-5.

connected in *series-aiding* and the total voltage is equal to the sum of the two individual voltages. The schematic representation of the connection is shown in Figure 3-6.

Change the position of the jumper lead as shown in Figure 3-7. Connect the meter leads as shown and record the value of voltage read on the meter. You can switch to the lowest range of the meter for this reading: ___________ V. A reading of zero volts is normal for this hook up. Cells connected in this manner are said to be connected in *series-opposing* and the total voltage is equal to the difference between the two individual voltages. Since the two cells in this test are of equal voltage, the resulting voltage is zero. The schematic representation of this connection is shown in Figure 3-8.

Let's make the same tests with batteries having different voltages. Use one of the D cells in the battery holder and a 9-volt battery with battery clip to connect the circuit as shown in Figure 3-9. We are placing a 9-volt battery in series aiding

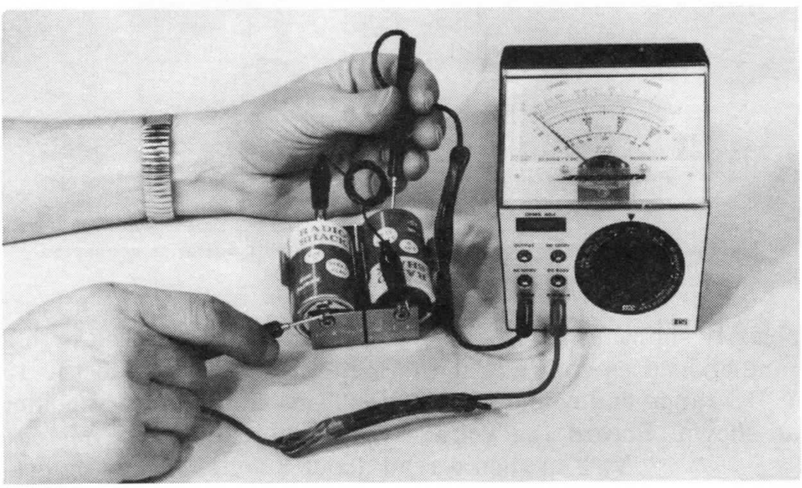


Figure 3-7. Measuring voltage across two 1.5-volt batteries connected series-opposing.

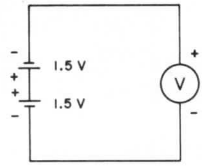


Figure 3-8. Schematic representation of measurement in Figure 3-7.

with the 1½-volt D cell. What is your estimate of voltage for this hookup? __________ V. Set the meter range switch to the proper range and measure the voltage: __________ V. You should read a voltage around 10.5 volts. The schematic representation of this connection is shown in Figure 3-10.

Next, let's try a series-opposing connection. Change the polarity of the D cell in the circuit. What is your estimate of the voltage? __________ V. Connect the meter leads across the circuit and record the voltage: __________ V. This should be around 7.5 volts. The schematic representation of the circuit is shown in Figure 3-11.

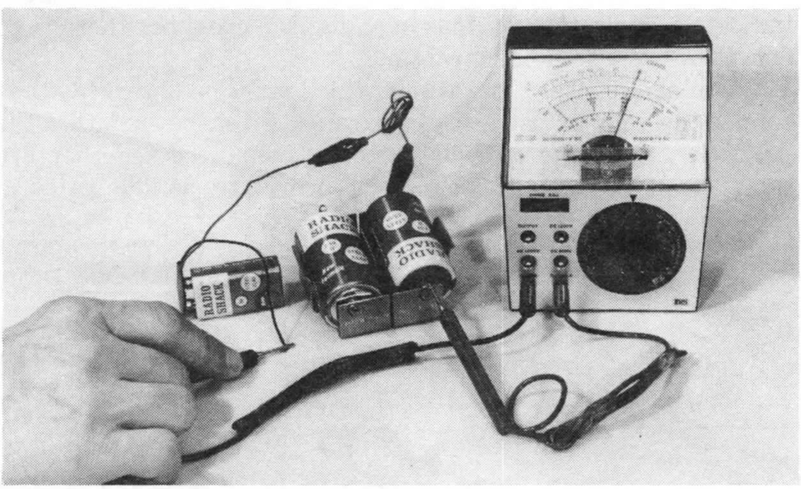


Figure 3-9. Measuring voltage across 1.5 and 9-volt batteries connected series-aiding.

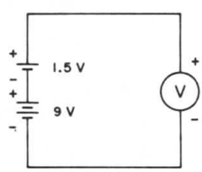


Figure 3-10. Schematic representation of the connection made in Figure 3-9.

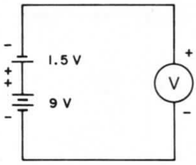


Figure 3-11. Schematic of a 9-volt and 1.5-volt battery connected series-opposing.

There is another way that we can connect batteries together. Place two 1½-volt D cells in the battery holder as shown in Figure 3-12. Use the polarity illustrated. Connect the holder terminals together with jumper leads as shown. Set the meter range switch to 3 V DC and connect the meter test leads to the holder terminals. Record the measured voltage: __________ V. You should read about 1.5 volts. Cells connected in this way are said to be connected in *parallel.* This type of connection does not increase the available voltage, but it does allow both cells to provide power for the circuit and this doubles the power available. The schematic representation of this connection is shown in Figure 3-13. The dots at the intersection of the lines indicate a connection. If lines in a diagram cross but there is no dot, then there is no connection.

There are several precautions which must be observed when connecting cells or batteries in parallel. First, be sure that the polarities of all the cells or batteries connected together are the same. If the cells are connected incorrectly as illustrated in

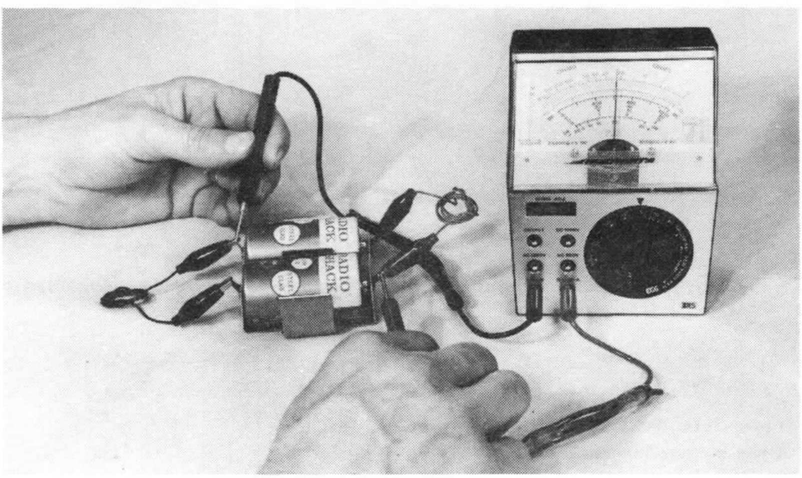


Figure 3-12. Two 1.5-volt batteries connected in parallel.

Figure 3-13. Schematic representation of the connection made in Figure 3-12.

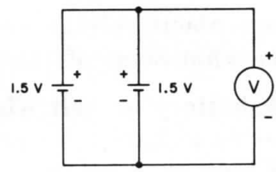
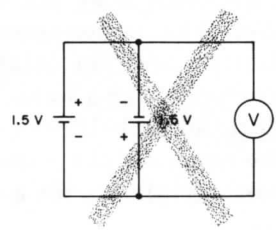


Figure 3-14 the cells will destroy themselves in very short order. In fact, high energy batteries such as automobile batteries may explode if connected in this manner.

Second, do not connect cells or batteries of different voltages in parallel. This type of connection, illustrated in Figure 3-15 may also result in the batteries or cells being destroyed.

That's all the measurements we are going to do in this chapter. Switch the meter range switch to either the highest DC

Figure 3-14. Two 1.5-volt batteries connected improperly.

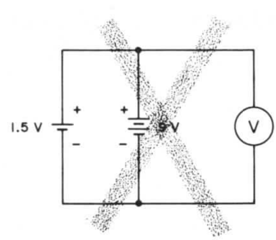


range or the OFF position before setting it aside. You should remember to do this each time you use your meter. This will minimize the possibility of damage to the meter if you forget to check the setting of the range switch before making some future measurement.

SUMMARY

In addition to getting some practice in making measurements with your VOM you should have learned a few

Figure 3-15. Never connect batteries of different voltages in parallel.



things about voltage sources in this chapter. Let's consider what some of these measurements have taught us.

1. **A battery or cell when supplying current to a load tends to have a lower voltage than under no-load conditions. As a battery ages and approaches the end of its useful life, the loaded voltage decreases.**
2. **A battery receiving a charge has a higher voltage across it than under no-load or loaded conditions.**
3. **Solar cells are relatively low voltage sources which are highly dependent on light intensity.**
4. **Series-connected batteries may be polarized to obtain a resultant voltage which is the sum of the individual voltages (series-aiding) or the difference of the two individual voltages (series-opposing). The series-aiding connection is by far the more commonly used connection. The series-opposing connection is generally a faulty condition obtained when batteries are inserted improperly in a holder.**
5. **Paralleling batteries or cells of equal voltage provides the same output voltage but increases the amount of power available for a circuit.**

QUESTIONS

1. *Draw a schematic diagram of a 6-volt and a 9-volt battery connected in series-aiding.*
2. *What is the voltage of the series circuit in question 1 above?*
3. *What should be the voltage of four D cells connected in series-aiding?*
4. *What would be the resulting voltage if one of the D cells in question 3 above is inserted with reverse polarity?*
5. *What two precautions must be observed when connecting batteries in parallel?*
6. *What precaution is recommended after using a VOM?*

CHAPTER 4

DC CURRENT

In this chapter we are going to learn about something that no one has ever seen—electrical current. Even though we can't see current, we are all familiar with the effects of electrical current, such as light and heat (Figure 4-1). When current passes through a light bulb it causes the bulb to glow. When current passes through a heating coil in an electric heater, heat is generated.

In Chapter 1 you learned that it was the source of voltage that provided the energy to run an electrical circuit. It is this source of voltage that causes the current to flow in the circuit. Without voltage we would have no current flow.

Current flow in an electrical circuit may be compared to the flow of water in a pipe (Figure 4-2). Water pressure in the system causes water to flow in the pipe. As long as the pressure exists and the pipe is not blocked, the water will flow. The amount of water which flows is dependent upon the amount of pressure and the opposition or resistance offered to the flow of water by the pipe. In an electrical circuit the source of voltage is like the water pressure and the current is like the flow of water in the pipe. The amount of current flow depends on the amount of voltage and the opposition or resistance offered to the flow of current by the electrical circuit. This opposition or resistance to the flow of current is discussed more fully in the next chapter.

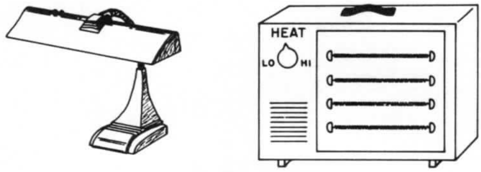


Figure 4-1. Two effects of electrical current are light and heat.

Over the years, since the phenomenon of electric current flow was first discovered, men have proposed several different explanations for it. Most scientists today agree that electric current is made up of the movement of extremely small particles called *electrons*. We are not going into a detailed explanation of atomic structure (we'll leave that to the physics books). However, a little background will help in understanding why current flows easily in some materials and with difficulty in others.

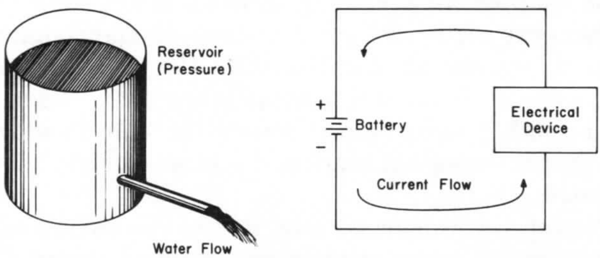


Figure 4-2. Current can be compared to a flow of water in a pipe.

All matter is composed of extremely small atoms. Very simply, an atom consists of a nucleus which is said to be positively charged (+) and a group of electrons which move around the nucleus. This is illustrated in Figure 4-3. The electrons have a negative charge (–). The positive charge of the nucleus is balanced by an equal negative charge of the electrons, so that there is a resulting neutral charge when the atom is considered as a whole.

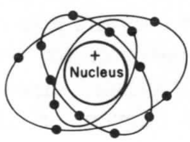


Figure 4-3. Representation of an atom.

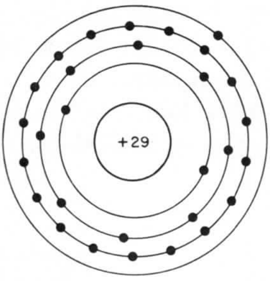


Figure 4-4. A copper atom.

The structure of atoms is different for different materials. Atoms differ in the size of the nucleus and the number of electrons around the nucleus. For example, an atom of copper consists of a nucleus surrounded by 29 electrons (Figure 4-4).

An atom of carbon consists of a smaller nucleus with only 6 electrons (Figure 4-5).

Another difference between atoms is the ease with which the electrons can be moved from one atom to another. In some materials such as copper, the electrons can be quite easily moved from one atom to another when subjected to some source of energy, such as a battery. In other materials, such as glass, the electrons are tightly bound to the nucleus and do not move freely when subjected to a source of energy.

Now, let's see what all this has to do with current flow. In order for current to flow we need two basic ingredients. First, as you have already seen, we need a source of voltage. Second, we need a complete *path* through which current can flow. Normally this path consists of some type of electrical device, such as a light bulb, which is connected to the source by conductors, such as wire. When we put all of these together we form a circuit. This circuit is illustrated in the schematic diagram of Figure 4-6.

With things connected as shown in the diagram we have a *complete path* or circuit. In order to have current flow, we must have a complete path from the negative terminal of the

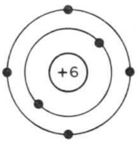


Figure 4-5. A carbon atom.

battery, through the electrical device, called the load, and back to the positive terminal of the battery. The copper wires are called conductors since they conduct the current from the battery to the load with little opposition to its flow. As we mentioned above, the electrons in copper are relatively free to

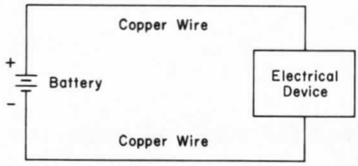


Figure 4-6. Schematic diagram of a complete circuit.

move when a voltage is applied. The EMF (electromotive force) of the battery forces electrons to move in the direction shown (Figure 4-7). The battery is not the source of electrons. The electrons are already available and the battery simply provides the energy to move these electrons around the circuit. The electrons flow away from the negative terminal of the battery, through the lower wire, through the load, through the upper

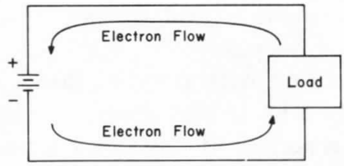


Figure 4-7. Direction of electron flow in a complete circuit.

wire, and then to the positive terminal of the battery. It is important to note that electrons *always* flow from negative to positive in the circuit connected to the battery.

If one of the wires should be disconnected or broken, there would no longer be a complete path for current flow and current flow would cease. This condition is referred to as an "open" circuit (Figure 4-8).

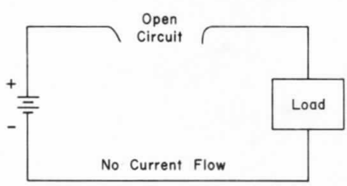
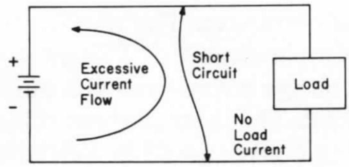


Figure 4-8. Current cannot flow in an open circuit.

Figure 4-9. Excessive current flows through a short circuit.



If a wire or some other conducting material should be connected across the load (either accidentally or deliberately), then the current drawn from the battery would be excessively high. With the load "shorted out" there is very little opposition or resistance to the flow of current and battery current will be excessive. No current will flow through the load. This is illustrated in Figure 4-9. This condition is harmful to the battery or other voltage source.

It is not necessary for an electron to travel all the way around the circuit in order to produce current flow. The situation can be illustrated by imagining a hollow tube completely filled with Ping-Pong balls (Fig. 4-10). If we insert an additional ball at the left end of the tube, a ball will be forced out of the right end of the tube. In the process, all of the balls moved to the right. There was a movement of balls without the necessity of the first ball traveling the full length of the tube. Of course, if we continue to insert balls, the first one will eventually make its way across the length of the tube (Figure 4-10).

In order to be specific about how much current is flowing in a circuit, we should establish definitions concerning quantity

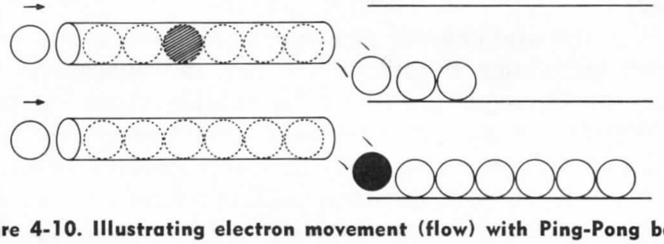


Figure 4-10. Illustrating electron movement (flow) with Ping-Pong balls.

of electrons. The number of electrons which will flow in our simple circuit of Figure 4-7 depends on the magnitude of the voltage source and the opposition or resistance offered by the load. The term *current* refers to the quantity of electrons passing a given point in a circuit during a time interval of 1 second. The quantity of electrons is measured in units called *coulombs* (pronounced cool-ohms). One coulomb is the quantity of 628×10^{16} electrons. That's 628 followed by 16 zeroes! The electron is so small that you could put all 628×10^{16} in the bottom of a gallon bucket and still have room for a gallon of water. The letter Q is used to represent the quantity of electrons (also called charge) in a circuit.

We said that current was the quantity of electrons that flow past a point in a circuit in 1 second. The letter I is used to represent current. We can express the relationship between current, charge, and time with the formula

$$I = Q \div t = \frac{Q}{t}$$

where,

I is the current,
Q is the charge,
t is the length of time in seconds that we measure the charge passing a given point.

The division sign in the formula can be read as "per" and thus current is coulombs per second.

The basic unit of measure for current is the ampere. 1 ampere of current is equal to 1 coulomb of electrons passing a given point in 1 second. If we sat by a point in a circuit with a stopwatch and counted electrons (a rather impossible task, of course) and counted 20 coulombs of electrons in a period of 5 seconds, the corresponding value of current flow would be $I = 20 \div 5 = 4$ amperes. The letter A is used as the abbreviation for amperes.

Back in the first chapter you learned how to express volts in different units such as millivolts (mV) and microvolts (μV). We can use the same prefixes when talking about current. In most electronic circuits it is more convenient to express current in terms of milliamperes (mA) or microamperes (μA).

Just to refresh your memory, milli is a prefix which means $\frac{1}{1000}$. One milliampere is equal to 0.001 ampere. To change amperes to milliamperes, multiply the number of amperes by 1000 (move the decimal point 3 places to the right). For example, 0.022 ampere × 1000 = 22 mA. To change milliamperes to amperes, divide the number of milliamperes by 1000 (move the decimal 3 places to the left). For example, 65 mA ÷ 1000 = 0.065 A.

If the current is very low we may express it in microamperes (μA). Micro is a prefix which means $1/_{1,000,000}$. One microampere is equal to 0.000001 ampere. To change amperes to microamperes multiply the number of amperes by 1,000,000 (move the decimal 6 places to the right). For example, 0.000156 A × 1,000,000 = 156 μA. To change microamperes to amperes divide the number of microamperes by 1,000,000 (move the decimal 6 places to the left). For example, 82 μA ÷ 1,000,000 = 0.000082 A.

An additional unit which is used occasionally is nanoamperes (nA). *Nano* is a prefix which means $1/_{1,000,000,000}$. One nanoampere is equal to 0.000000001 ampere. To change amperes to nanoamperes, multiply the number of amperes by 1,000,000,000 (move the decimal 9 places to the right). For example, 0.000000052 A × 1,000,000,000 = 52 nA. To change nanoamperes to amperes divide the number of nanoamperes by 1,000,000,000 (move the decimal 9 places to the left). For example, 12 nA ÷ 1,000,000,000 = 0.000000012 A.

A chart showing the relationship between these various units is given in Figure 4-11.

Current is measured with a current meter such as an ammeter, milliammeter, or microammeter. The function of a milliammeter is included in the VOM. Basically the current meter is placed *in series with* the load at the point where the current is being measured (Figure 4-12). The schematic symbol for an ammeter is a circle with the letter A. A milliammeter would be indicated by mA; a microammeter by μA. You will recall that voltage is measured by placing the voltmeter *across* the load. In Chapter 7 you will make some practical current measurements.

In the early days of electricity, before the electron was discovered, it was thought that current flowed from positive to negative in a circuit. This direction is opposite to that of actual electron current flow. This is illustrated in Figure 4-13. This concept of *current flow* has been replaced by the *electron*

To Change	To	Move Decimal
A	mA	3 places to left
A	μA	6 places to right
A	nA	9 places to right
mA	A	3 places to left
mA	μA	3 places to right
mA	nA	6 places to right
μA	A	6 places to left
μA	mA	3 places to left
μA	nA	3 places to right
nA	A	9 places to left
nA	mA	6 places to left
nA	μA	3 places to left

Figure 4-11. Relationship between various units of current.

flow theory by most authors. Unfortunately, however, you will occasionally run across a magazine article or other literature where this "conventional current" concept is erroneously used. The reader must use his own intelligence to determine whether *electron flow* or *"conventional current"* is being used. *Throughout this series of books we will use electron current flow.*

SUMMARY

Current flow is the result of a voltage being applied to a circuit. Without voltage there will be no current flow.

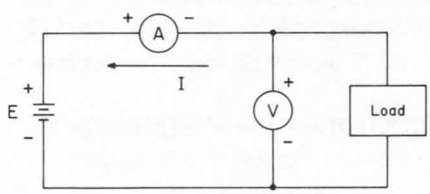


Figure 4-12. Current is measured in series with the load.

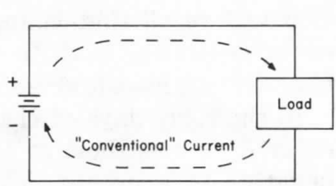


Figure 4-13. Illustration of "conventional current" flow.

Some of the effects of current flow are production of light and heat.

Current flow in an electrical circuit can be compared to the flow of water in a pipe.

Current flow consists of the movement of tiny particles called electrons. Electrons are negatively charged and form part of the atomic structure of materials.

Atoms of different materials differ in number of electrons, and in ease of moving electrons from one atom to another. The electrons in copper are quite easy to move by applying a source of energy such as a battery.

In order to have current flow, we need two essentials—a source of voltage and a complete path through which current can flow.

Electrons flow in the circuit from negative to positive. An "open" anywhere in the circuit will cause the current flow to cease. A "short" circuit causes excessive current to flow from the voltage source.

The unit of measure for quantity of electrons or charge is the coulomb. One coulomb is 628×10^{16} electrons.

The basic unit of measure for current flow is the ampere. One ampere represents one coulomb flowing past a point in a circuit in one second. $I = Q/t$. Other units of measure for currents are mA, μA and nA.

Current is measured by an ammeter, milliammeter or microammeter. The current meter is placed in series with the load at the point of current measurement.

"Conventional current" flow is opposite in direction to electron current flow.

QUESTIONS

1. *What is current?*
2. *What two things are necessary in order to have current flow?*
3. *What is the effect of an open circuit on current flow?*
4. *What is the effect of a short circuit on current flow?*
5. *What current is represented by the movement of 3 coulombs past a point in 6 seconds?*
6. *Convert 0.0026 A to milliamperes; to microamperes.*
7. *Convert 106 μA to milliamperes; to amperes.*
8. *Draw a circuit showing a battery connected to a load with a milliammeter to measure current and a voltmeter to measure voltage.*

CHAPTER 5

RESISTANCE

Resistance is the property of an electrical circuit which determines the amount of current which will flow for a given amount of applied voltage. For a constant source voltage, the higher the resistance, the lower will be the amount of current flow. For a given amount of voltage, if the resistance is doubled, the current will be cut in half. We will deal with the exact mathematical relationship between voltage, current, and resistance in Chapter 7.

A sufficiently low resistance allows current to flow with negligible opposition or resistance. This is the desirable property of a *conductor*. Recall that in Chapter 4 you learned that a conductor is made of materials which have many free electrons which can enter into conduction as a flow of current. A conductor is considered anything which can conduct current with negligible opposition to the flow. Examples are copper wire, copper strips on a printed circuit board, metals, carbon such as in lead pencils, and impure water, such as salty water. Some of these examples are illustrated in Figure 5-1.

A sufficiently high resistance tends to limit current to such an extent that no significant current can flow in the circuit. This is the desirable property of an *insulator*. Recall that an insulator is made of materials whose electrons are tightly bound to the nucleus and are not free to enter into conduction. An insulator is considered anything which can limit the flow

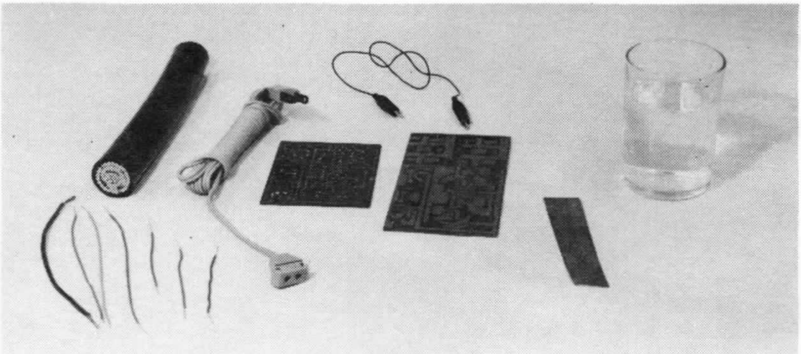


Figure 5-1. Examples of conductors.

of current to an insignificantly low level. Examples are paper, glass, pure water, ceramic, plastic, mica, bakelite and dry wood. A *resistor* is a device which has a resistance value between that of a conductor and that of an insulator. Resistors are made with specific values of resistance to control circuit current. This control of circuit current allows us to design specific circuits. Resistors are available with various materials used in their construction. Some of these materials are special alloy wire, carbon and oxides of metals. Various shapes and sizes of resistors are available for different applications. Some resistors are fixed in value, while others are variable. Some of the more common types of fixed resistors are illustrated in Figure 5-2. Generally speaking, the larger the resistor, the greater its power handling capability. We will deal with power in detail in Chapter 11.

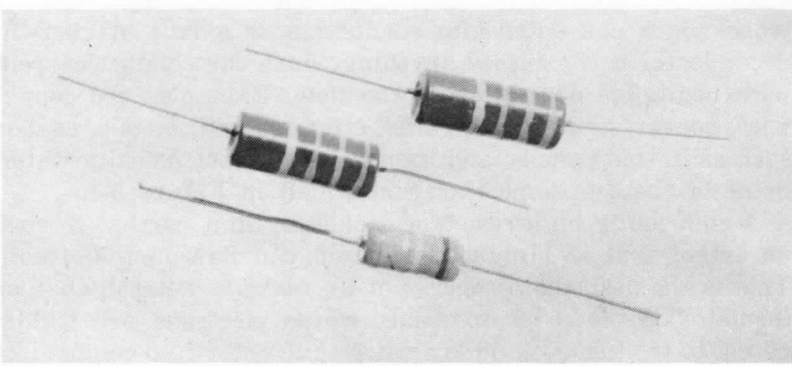


Figure 5-2. Some fixed resistors.

The amount of resistance is measured in units called *ohms*. The Greek capital letter omega (Ω) is the universal standard symbol for ohms. Resistance is measured using an ohmmeter or the ohmmeter function of a VOM. An ohm is defined as the resistance which allows a current flow of 1 ampere when a voltage of 1 volt is applied.

The basic unit of resistance is too small for most practical applications. Resistance is expressed in larger units by use of prefixes. *Kilohm* and *megohm* are the most widely used units for resistance in electronic circuits. One kilohm is equal to 1000 ohms and is abbreviated K ohms or KΩ. (Note: Many years ago the letter M was used to indicate kilohms and is still on some old schematics diagrams and parts labels.) The procedure for converting from one unit to another is similar to that discussed for voltage and current and is summarized in the chart of Figure 5-3.

To Change	To	Move Decimal
Ohms	Kilohms	3 places to left
Ohms	Megohms	6 places to left
Kilohms	Ohms	3 places to right
Kilohms	Megohms	3 places to left
Megohms	Ohms	6 places to right
Megohms	Kilohms	3 places to right

Figure 5-3. Relationship among units of resistance.

One of the most economical and widely used types of resistors is the *carbon composition* resistor. This type is available in ratings from about 1 ohm to 22 megohms. They are available in power ratings from ⅛ watt to 2 watts.

Resistance values are generally indicated by means of color bands or stripes on the resistor body. There are usually four bands or stripes on each resistor. The first three bands give the resistance value and the fourth band gives the tolerance of the resistance. The chart of Figure 5-4 shows the system that is used.

The first band gives the first digit of the resistance, the second band gives the second digit and the third band gives the decimal multiplier. Let's try some examples to see how the

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

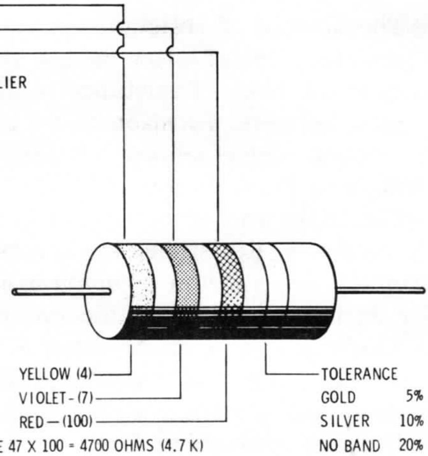


Figure 5-4. Resistor color code.

system works. We will assume that the first three bands on the resistor are *brown, red* and *orange* in that order. The first digit is 1, the second digit is 2 and the decimal multiplier is 1000 (three zeros). The value of the resistor is 12,000 ohms or 12K ohms.

Let's try another one with bands of *yellow, violet* and *black.* The first digit is 4, the second is 7 and the decimal multiplier is 1 (no zeros). The resistance is 47 ohms. Another resistor has bands of *orange, orange* and *green.* The first two digits are 33 and the multiplier is 100,000 (5 zeros). The value is 3,300,000 ohms or 3.3 megohms.

The tolerance of a resistor expresses how much the actual value of the resistor may differ from the rated value as indicated by the color code. This tolerance is a percentage of the rated value. Standard tolerances are 5, 10 and 20% for carbon composition resistors. The fourth color band is used to indicate the tolerance. The colors used are also given in the chart of Figure 5-4.

A few examples may help you to understand tolerance better. If the rated value of a resistor is 1000 ohms (color bands of brown, black, red) and the tolerance is 10% (silver band) the actual value may be anywhere between 10% below 1000 to 10% above 1000. To find the possible range of values, multiply the resistance value by the percentage (expressed as a decimal). In our example the difference is $1000 \times 0.10 = 100$

ohms. The lowest possible value for this resistor is 1000 − 100 = 900 ohms. The highest possible value is 1000 + 100 = 1100 ohms.

Let's try another one. The four bands on the resistor are red, red, yellow, and gold. The rated value is 220,000 ohms or 220K ohms. The tolerance is 5%. The possible difference is 220 × .05 = 11K ohms. The range of possible values is 220 − 11 = 209K ohms to 220 + 11 = 231K ohms.

These same color-digit relationships are used for color coding other electronic components. If you have trouble learning or remembering the color code you may want to purchase a color-code guide such as the one illustrated in Figure 5-5. This guide is available at your Radio Shack store.

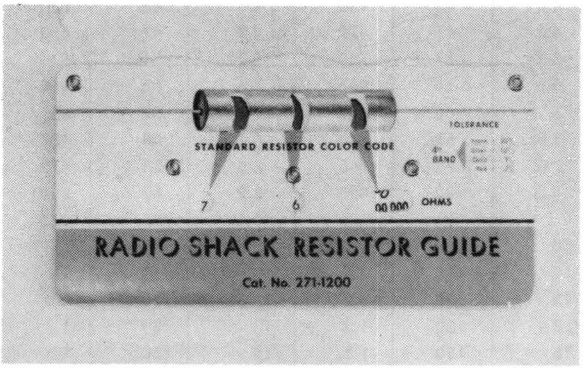


Figure 5-5. Resistor color-code guide.

Carbon composition resistors are available in certain standard values of resistance. The standard values have been established by the EIA (Electronics Industries Association). A chart giving the standard values available with 5% and 10% tolerance is shown in Figure 5-6.

You will notice in the chart that the sequence of significant digits for the 10% resistors is repeated with an additional 0 added each time. Notice the sequence 10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68, 82 is repeated *10*0, *12*0, *15*0, *18*0, *22*0, *27*0, *33*0, etc., and again *10*00, *12*00, *15*00, etc. This choice of values is based on the possible range of values due to the tolerance. For example, the possible range of values of a 27 ohm resistor having 10% tolerance is from 27 − 2.7 = 24.3Ω to 27 + 2.7 =

29.7Ω. The range of values of a 33 ohm resistor is 33 − 3.3 = 29.7Ω to 33 + 3.3 = 33.3Ω. For a 22 ohm resistor the range is 22 − 2.2 = 19.8Ω to 22 + 2.2 = 24.2Ω. This information is shown in the graph of Figure 5-7. You can see that the possible values cover the complete range from 19.8 to 33.3Ω. It is not necessary to have any other values between those given. This same relationship could be shown for any other group of values.

0.24 Ω	2.4 Ω	24 Ω	240 Ω	2.4 KΩ	24 KΩ	240 KΩ	2.4MΩ
0.27	**2.7**	**27**	**270**	**2.7**	**27**	**270**	**2.7**
0.30	3.0	30	300	3.0	30	300	3.0
0.33	**3.3**	**33**	**330**	**3.3**	**33**	**330**	**3.3**
0.36	3.6	36	360	3.6	36	360	3.6
0.39	**3.9**	**39**	**390**	**3.9**	**39**	**390**	**3.9**
0.43	4.3	43	430	4.3	43	430	4.3
0.47	**4.7**	**47**	**470**	**4.7**	**47**	**470**	**4.7**
0.51	5.1	51	510	5.1	51	510	5.1
0.56	**5.6**	**56**	**560**	**5.6**	**56**	**560**	**5.6**
0.62	6.2	62	620	6.2	62	620	6.2
0.68	**6.8**	**68**	**680**	**6.8**	**68**	**680**	**6.8**
0.75	7.5	75	750	7.5	75	750	7.5
0.82	**8.2**	**82**	**820**	**8.2**	**82**	**820**	**8.2**
0.91	9.1	91	910	9.1	91	910	9.1
1.0 Ω	**10 Ω**	**100 Ω**	1.0 KΩ	10 KΩ	100 KΩ	1.0 MΩ	1.0MΩ
1.1	11	110	1.1	11	110	1.1	11
1.2	**12**	**120**	**1.2**	**12**	**120**	**1.2**	**12**
1.3	13	130	1.3	13	130	1.3	13
1.5	**15**	**150**	**1.5**	**15**	**150**	**1.5**	**15**
1.6	16	160	1.6	16	160	1.6	16
1.8	**18**	**180**	**1.8**	**18**	**180**	**1.8**	**18**
2.0	20	200	2.0	20	200	2.0	20
2.2	**22**	**220**	**2.2**	**22**	**220**	**2.2**	**22**

Values in boldface type are 10% tolerances; all sizes are 5% tolerances normally available.

Figure 5-6. Typical standard composition resistor sizes.

Notice in the chart of Figure 5-6 that the values available with a 5% tolerance include all the 10% values, plus one additional value between each of the 10% values. Since the range of each value is less with only 5% tolerance, it is necessary to have additional values to cover the complete range of possible resistance.

This type resistor is also available with 20% tolerance. Since the range of each value is greater with 20% tolerance, it is

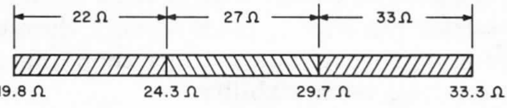


Figure 5-7. Possible resistances ranges of 10% tolerance resistor values.

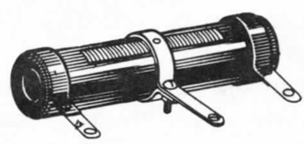
not necessary to have as many values to cover the complete range of possible resistance. The 20% resistor values follow the sequence of digits, 10, 15, 22, 33, 47, and 68.

Carbon composition resistors have limitations which prevent their use in some applications. These limitations are overcome to a large extent by other types of resistors, such as wirewound and deposited film. The wirewound resistor is generally used for higher power applications. They are available with power ratings from one to several hundred watts. The ceramic form and wire characteristics allow them to withstand high operating temperatures without damage. These resistors are noted for their long term stability. Some typical wirewound resistors are illustrated in Figure 5-2.

Occasionally it is necessary to use an adjustable resistor in a circuit. If it is necessary to set the circuit current to a specific value, an adjustable resistor can be used to accomplish this. An adjustable wirewound resistor is shown in Figure 5-8. The metal strap (adjustable lug) around the body of the resistor can be clamped anywhere along the exposed wire element until the exact value of resistance is obtained. Extra adjustable lugs are sometimes used to obtain additional tapped values of resistance.

Another common type is the deposited-film resistor. In this type resistor a film of carbon, or the oxide of some metal, is deposited around the outside of a cylindrical insulating body. Wire leads are connected to the ends of the deposited film and

Figure 5-8. An adjustable wirewound resistor.



the entire structure is coated with a hard insulating coating. This type resistor can also be made to very close tolerances, is available with higher voltage ratings than the carbon type, and has better long term stability.

There are occasions where it is necessary to have a resistor whose values can be varied continuously from one value to another (usually from zero up to a certain value). An example of this is the volume control on your radio. In this case the variable resistor allows you to adjust the volume from zero

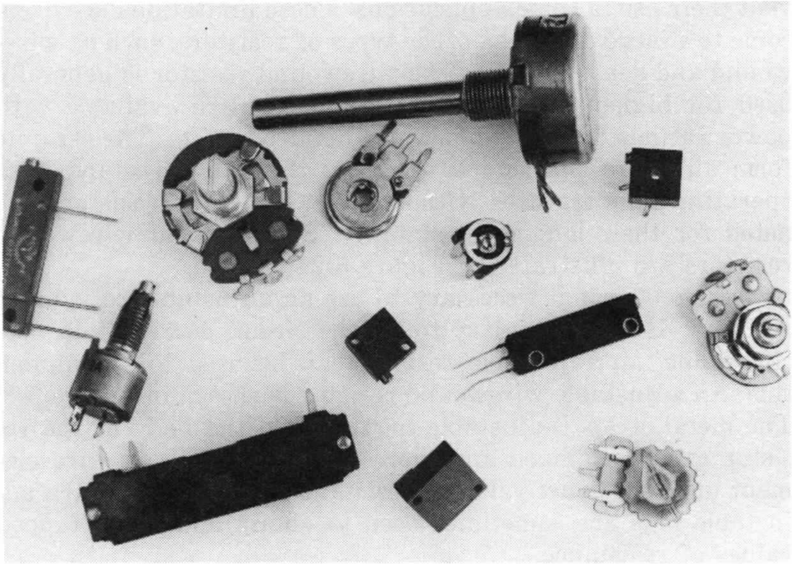


Figure 5-9. Various types of variable resistors.

up to a very loud level. This type of resistor is constructed in a circular shape with a resistive element of either carbon or some type of alloy wire and a movable contact which can be rotated to any position on the resistance element. This construction is illustrated in Figure 5-9 along with some typical variable resistors. This type resistor is often referred to as a *potentiometer*. Generally, the moving contact, called the arm, is capable of rotating about 270° around the resistive element.

Potentiometers are made in various power ratings from 1/8 watt to about 500 watts. Resistance values for potentiometers, sometimes called *pots*, range from about 0.5 ohm to 10 meg-

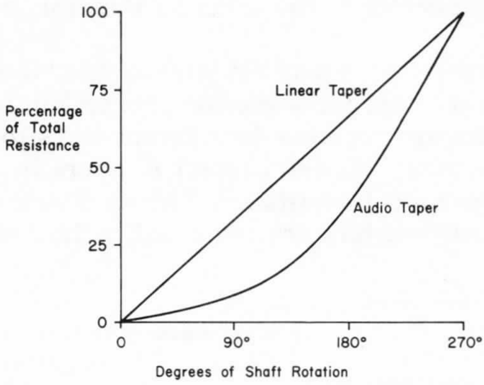


Figure 5-10. Shaft rotation versus resistance.

ohms. Pots are also available with different tapers. By taper we mean the manner in which the resistance varies as the arm (movable contact) is rotated around the resistive element. A common taper is the linear taper. In this type the resistance changes at a constant rate with the rotation of the arm. This is illustrated by the graph of Figure 5-10. This graph shows the percentage of resistance for the degree of rotation of the arm.

Another common taper is the audio taper, also shown in the graph of Figure 5-10. In this type of pot the amount of resistance change is low near the low end of the rotation and becomes greater as rotation gets near the end. Other tapers are available for special applications.

When buying a potentiometer you usually have to specify the power rating, resistance value and the taper, as well as the particular case and mounting style desired.

Occasionally variable resistors are made with only two terminals, one end terminal and a terminal for the moving contact. This type of variable resistor is called a *rheostat*.

The schematic symbols used for resistors are shown in Figure 5-11. The symbol for a fixed resistor is used regardless of the type of resistor (carbon, wirewound, etc.). The symbol

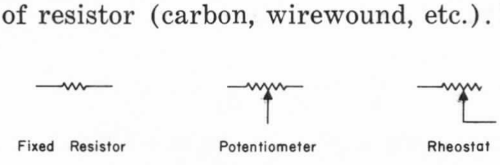


Figure 5-11. Schematic symbols for resistors.

for the potentiometer is the same as that for an adjustable resistor.

In some situations we may not have on hand the exact value of resistance we need for a specific application. It is possible to connect resistors together in different ways to get exactly the values we want. We can connect resistors in series to increase the amount of resistance. This is illustrated in Figure 5-12. When resistors are connected in this way the total

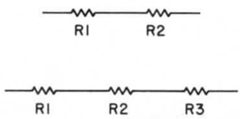


Figure 5-12. Connecting resistors in series.

resistance is equal to the sum of the individual resistances. We can express this in a formula as

$$R_T = R_1 + R_2 + R_3 + \ldots..$$

where R_T is the total resistance as measured across the entire series circuit. For example, if we connect a 1200 ohm and a 470 ohm resistor in series, the total resistance is 1200 + 470 = 1670 ohms. If we connect a 100K ohm, 220K ohm and 560K ohm resistor in series, R_T = 100 + 220 + 560 = 880K ohms.

We can also connect resistors in parallel as shown in Figure 5-13. When we connect resistors in parallel the total resistance as measured across the entire parallel circuit is always less than the smallest resistor in the parallel combination. The mathematical relationship for resistors in parallel is

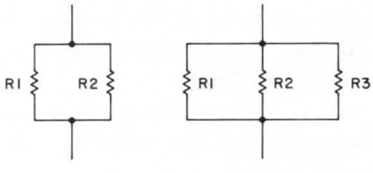


Figure 5-13. Connecting resistors in parallel.

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots\ldots}$$

This relationship is easily remembered by the phrase, "the reciprocal of the sum of the reciprocals."

When only two resistors are connected in parallel this formula simplifies to

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

This relationship is sometimes stated as, "the product over the sum." For example, if 12K and 22K resistors are connected in parallel, the total resistance of the combination is

$$R_T = \frac{12 \times 22}{12 + 22} = 7.8\text{K ohms}$$

One interesting fact about resistors in parallel is that when like values are connected in parallel the total resistance is simply the resistor value divided by the number of resistors. For example, two 10K ohms resistors in parallel result in a total resistance of $10 \div 2 = 5$K ohms. Four 10 megohm resistors in parallel have a total resistance of $10 \div 4 = 2.5$ megohms.

There are some special types of resistors which we will simply mention at this time. A VDR (voltage dependent resistor) is one whose resistance varies with the amount of voltage across it. An LDR (light dependent resistor) has a resistance value that varies with light intensity. Other resistors have resistance values dependent upon temperature (thermistor).

Figure 5-14. A resistance-capacitance substitution box.

Resistors are common components in electronic equipment. When designing or troubleshooting equipment, it is handy to have a source of resistors available. A resistor substitution box makes this quite convenient. A group of common value resistors are mounted in a box and the value can be selected by means of a switch. The Radio Shack resistor substitution box is shown in Figure 5-14.

In previous sections you learned that conductors have a very small amount of opposition or resistance to the flow of current. Even though the resistance is small it does have a definite value. The actual resistance of a wire depends on three factors: length, size (or thickness) and the natural resistance of the type of metal used. For a given wire size (diameter) the longer the wire, the higher the resistance.

The resistance is directly proportional to the length. This is expressed mathematically as $R \propto l$. R is the letter used to represent resistance in formulas, l is the length, and $\propto$ is a symbol used to indicate that one thing is proportional to another.

For a given length of wire, the greater the cross-sectional area (A) of a wire, the lower the resistance. The resistance is inversely proportional to the area. Expressed mathematically, this is $R \propto 1/A$.

The third factor is a property of the metal used for the wire. This property is called the *resistivity* of the material. Resistivity is the amount of resistance in a unit cube of the material and is designated by the greek letter rho (ρ). The resistance is directly proportional to the resistivity, $R \propto \rho$. Materials like gold, silver, and copper have low values of resistivity. Materials like carbon, tin, and metal alloys have a higher value of resistivity. If we combine all three of these factors into a formula we have this expression.

$$R = \frac{\rho l}{A}$$

There are standard wire sizes which are used in electrical and electronic circuits. The wire size is designated by a number. Standard sizes for house wiring are No. 10, 12, or 14. A copper wire table provides some interesting information about wire. A partial wire table is shown in Figure 5-15. A complete copper wire table provides information about wires ranging in size from 0.46-inch diameter (No. 0000) to 0.0015-inch diameter (No. 46). A complete copper wire table is included in the Radio Shack *Electronics Data Book*. Our purpose here is just to point out a few basic facts about the resistance of wire.

Notice in the chart that for each wire number, you can find the diameter of the wire, the resistance of 1000 feet of the

Number	Diameter in Mils	Resistance per 1000 Ohms	Normal Current Handling Capacity Amperes
10	101.9	1.018	14.8
12	80.8	1.619	9.33
14	64.1	2.575	5.87
16	50.8	4.094	3.69
18	40.3	6.510	2.32
20	32.0	10.35	1.46
22	25.4	16.46	.918

Figure 5-15. Copper-wire table.

wire and the maximum amount of current which should normally be allowed to flow through the wire. The diameter is given in mils. A mil is $\frac{1}{1000}$ of an inch. No. 10 wire has a diameter of 100 mils or 0.1 inch. The diameter of the wire is of importance when winding coils or transformers where space is a consideration. The resistance is considered when dealing with long lengths of wire such as installation of speakers and running long power cables. The current handling capability is considered for all applications. In some cases the choice of wire to use is dependent upon mechanical considerations. For example, a No. 40 wire may have adequate current handling capability but it is so small (about like a human hair) that it is not practical. Most "hookup" wire for use in electronic circuits is No. 20 or 22, covered with plastic insulation.

SUMMARY

Resistance is the property of an electrical circuit which determines the amount of current which will flow for a given amount of applied voltage.

A conductor allows current to flow with negligible opposition or resistance.

An insulator limits current flow to an insignificantly low value because of its extremely high resistance.

A resistor has a resistance value between that of a conductor and an insulator.

Resistance is measured in units called ohms. The symbol for ohm is Ω. An ohm is the resistance which allows a

current flow of 1 ampere when a voltage of 1 volt is applied.

Other resistance units are widely used, such as the kilohm (1000 ohms) and the megohm (1,000,000 ohms).

Common types of resistors used in electronics are carbon composition, wirewound and metal film.

Resistance values and tolerance for carbon resistors are indicated by means of a standard color code. Carbon resistors are available with standard resistance values from about 1 ohm to 22 megohms.

Wirewound and metal film resistors are used for applications where carbon resistors are not suitable.

Adjustable resistors are used when the resistance must be set to some specific value.

Variable resistors, such as potentiometers and rheostats are used in many applications. Potentiometers are available with either a linear or special taper.

When resistors are connected in series the total resistance is equal to the sum of the individual resistances.

$$R_T = R1 + R2 + R3 + \ldots\ldots\ldots$$

When resistors are connected in parallel the total resistance is the "reciprocal of the sum of the reciprocals."

$$R_T = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \ldots\ldots\ldots}$$

When there are only two resistors in parallel the relationship simplifies to the "product over the sum."

$$R_T = \frac{R1 \times R2}{R1 + R2}$$

A resistor substitution box is a very handy piece of equipment for electronic design and troubleshooting.

Information about wire such as diameter, resistance and current handling capability are given in a copper wire table.

The resistance of a wire or device is given by the relationship

$$R = \frac{\rho l}{A}$$

QUESTIONS

1. *Define the term conductor.*

2. *Define the term insulator.*

3. *What is the basic unit of resistance and how is it related to current and voltage?*

4. *Convert 470,000 ohms to kilohms; to megohms.*

5. *Convert 390KΩ to ohms; to megohms.*

6. *A resistor has color bands of red, violet, yellow, silver. What is the nominal value, tolerance and possible range of values for the resistor?*

7. *Refer to the copper wire table of Figure 5-15. How much resistance is there in 10 feet of No. 22 wire?*

8. *What is the total resistance of the following combinations of series resistances?*
   a. *100Ω, 220Ω.*
   b. *1500Ω, 2.7KΩ, 4.7KΩ.*
   c. *470Ω, 1.2KΩ, 6.8KΩ.*

9. *What is the total resistance of the following combinations of parallel resistances?*
   a. *330Ω, 820Ω.*
   b. *1000Ω, 1000Ω, 500Ω.*
   c. *2.7KΩ, 4.7KΩ.*

CHAPTER 6

RESISTANCE MEASUREMENTS

In the last chapter we discussed the concept of resistance and some of the factors which determine resistance. In this chapter you will be making some resistance measurements with your VOM. Before starting through this chapter be sure you have the necessary additional items listed below. If you do not have all of these you can obtain them at your nearby Radio Shack store. The catalog numbers of these items are given in the material list.

1. Resistor kit of 100 ½-watt resistors
2. Panel lamp indicators, 12 volt

Resistance measurements are made using the ohmmeter function of the VOM. Before we start making measurements let's get familiar with this function on our VOM. The resistance scale is the top scale of the meter. The scale of the typical VOM we have been discussing is shown in Figure 6-1. Notice that on this scale "0" is at the right end of the scale and resistance values increase to the left. The actual value indicated by the scale is dependent upon the setting of the range switch. The range switch is shown in Figure 6-2. There are four positions on the ohmmeter portion of the switch. These are labeled R × 1, R × 10, R × 100, and R × 1K. These designations refer to the multiplier which must be applied to the scale values for each switch position. The test leads are placed in the same

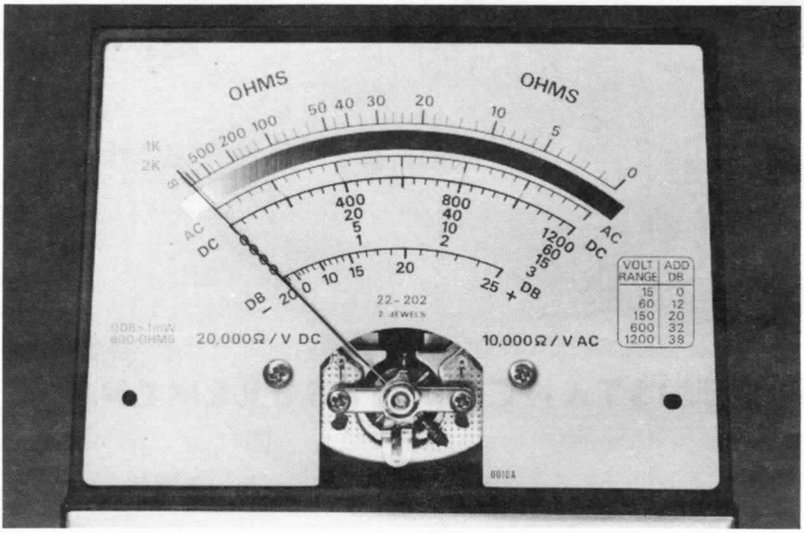


Figure 6-1. The scale of a typical VOM.

jacks that are used for voltage measurement—COM and V-Ω-A. Another part of the ohmmeter function is the ohms adjust (OHMS ADJ) control located to the left of the range switch and illustrated in Figure 6-2. This control is used to set the pointer to "0" ohms before you start measuring.

Figure 6-2. The range switch.

When the test leads are connected to the resistance being measured, an internal battery in the VOM causes a current to flow through the resistance. The meter deflection caused by this current is calibrated in resistance. This current which flows through the test leads can be excessive under some conditions and may cause damage to some very sensitive types of components. Current through the meter is always highest on the lowest resistance range.

The basic procedure to be used for measuring resistance is quite simple. The four steps used are as follows:

1. Select the proper range. If the approximate value of resistance is not known, start with the highest range. The range can be reduced as necessary to obtain an accurate reading.
2. Touch the two test leads together and adjust the OHMS ADJUST control until the meter reads 0.
3. Place the test leads across the resistance being measured.
4. Read the value of the resistance on the meter scale. Care must be used in interpreting the scale markings since the scale is nonlinear.

The values on the scale are dependent upon the position of the range switch. On the R × 1 range the scale values are read directly from the scale. On the R × 10 range we mentally multiply the scale by 10 (add a zero at the end of each scale value). For example, in this position a reading of 60 means a resistance of 600 ohms is being measured. On the R × 100 range we mentally multiply the scale by 100 (add two zeros to the scale reading). On the R × 1K range we mentally multiply the scale by 1000 (add three zeros to the scale reading).

Listed below are a few basic rules which you should keep in mind as you make resistance measurements.

1. Power must be removed from the circuit under measurement or the meter may be damaged.
2. The device or component under measurement must not be paralleled by other resistances. That is, the device must be isolated from other conductive paths or resistances.
3. Use the resistance range which yields a near center-scale reading for best accuracy.

4. Adjust OHMS ADJUST for 0 for each resistance range before making measurements on that range.
5. If zero cannot be obtained in the lowest range of the ohmmeter the battery in the VOM is weak and must be replaced. An old, weak battery left in the meter will give inaccurate readings, but worse still, it may leak acid which will damage the meter.

Now let's make some measurements. Use the kit of 100 resistors and separate the resistors into groups by resistance value. This is a good time to practice the color code that you learned in the last chapter. You will notice that there are three to six resistors of each value listed in the chart of Figure 6-3. After you have separated the resistors, start with the

Marked Value	Measured Value	Marked Value	Measured Value
15		10K	
22		15K	
100		22K	
180		56K	
270		100K	
330		120K	
390		220K	
470		330K	
680		470K	
1K		1 Meg	
4.7K			

Figure 6-3. Measured resistances of resistors from package.

lowest ones, 15 ohms, and measure the value of each resistor and place the value in the blank provided.

Notice that measured values of resistance generally do not exactly equal the color code values. This is normal due to the tolerance of the resistors themselves and the accuracy of the meter.

Next, we'll get some practice with series circuits. In the last chapter you learned that the total resistance of resistors in series is equal to the sum of the individual resistances. You can conveniently connect resistors in series, using some of your test lead jumper cables as shown in Figure 6-4. Use the

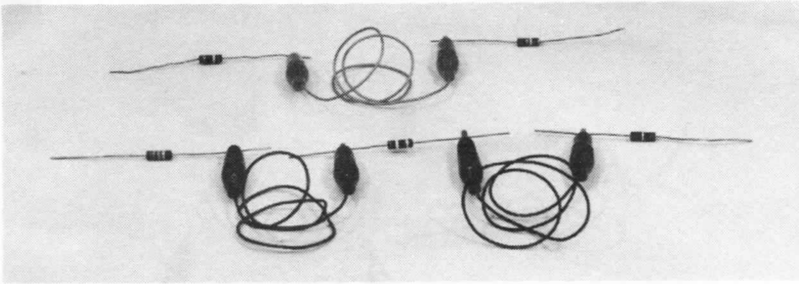


Figure 6-4. Use jumper leads to series resistors.

various resistor combinations listed in the chart of Figure 6-5 and calculate or estimate and then measure the resistance of the series connection. Enter your calculated (or estimated) values and the measured values in the blanks in the chart of Figure 6-5. The calculated and measured values for each com-

Resistors to Be Series-Connected (Ohms)	Calculated or Estimated Total (Ohms)	Measured Value (Ohms)
100, 100		
100, 1K		
100, 10K		
100, 100K		
22K, 56K		
270, 330, 1K		
4.7K, 10K, 22K, 56K		

Figure 6-5. Calculated and measured values of series resistors.

bination should be reasonably close, taking into account the accuracy of the meter and tolerance of the resistors.

We can do a similar experiment with parallel resistors. Recall that the total resistance for two resistors in parallel is the "product over the sum." When two or more resistors of the same value are in parallel, the total resistance is equal to the resistor value divided by the number of resistors. Resistors can be connected together using jumper cables as shown in Figure 6-6. Use the various resistor combinations

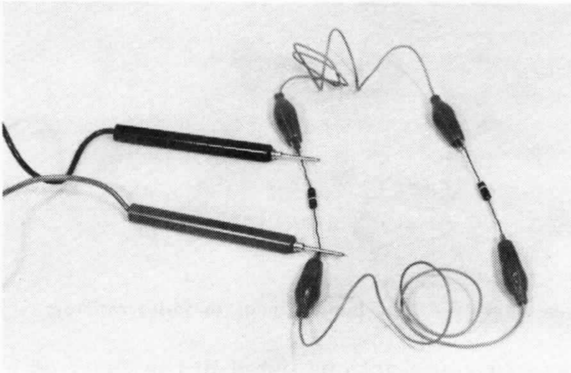


Figure 6-6. Use jumper leads to parallel resistors.

listed in the chart of Figure 6-7 and calculate and then measure the resistance of the parallel connections. Place your calculated (or estimated) values and measured values in the chart of Figure 6-7.

Resistors to Be Parallel-Connected (Ohms)	Calculated or Estimated Total (Ohms)	Measured Value (Ohms)
100, 100		
100, 1K		
100, 10K		
100, 100K		
390, 680		
56K, 220K		
15K, 15K, 15K		
120K, 120K, 120K, 120K		

Figure 6-7. Calculated and measured values of parallel resistors.

With the ohmmeter set on the highest range, hold the tip of a test lead in each hand. Record the resistance: ____ ohms. The reading that you get will depend on the resistance of your skin. If you happen to be sweating or are nervous, your skin resistance will be lower than when you are calm. This is one of the principles of the "lie detector." The fact that your body has a measurable amount of resistance is important to keep in mind when measuring high values of resistance. If your hands happen to be touching the test leads while you are making the measurement, you may get an inaccurate reading. Measure a 1 megohm resistor without touching the leads, and then touching the leads. You will notice a difference in the two readings. Repeat this with a 100 ohm resistor and notice that body resistance has no effect because it is very much higher than the 100 ohm value.

We can illustrate a very interesting property of light bulbs with the ohmmeter. Use the R $\times$ 1 range and measure the resistance of one of the 12-volt pilot lamps: __________ ohms. Repeat measurement on the R $\times$ 10 range: __________ ohms. Notice that the resistance on the R $\times$ 1 range is significantly higher. This is due to the characteristic of the tungsten filament in the bulb—the resistance depends on the amount of current flowing through it.

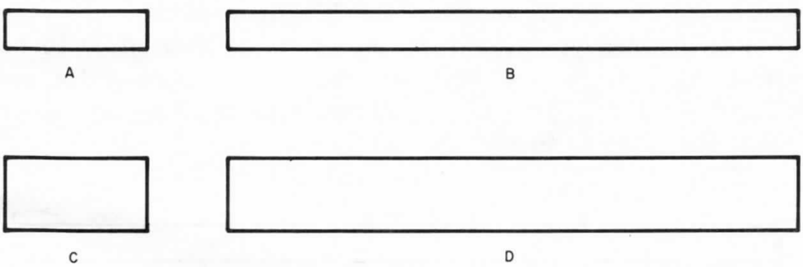


Figure 6-8. Measuring resistances of different areas.

To prove to yourself that there is actually current flow in the test leads, touch the leads to the terminals of a transistor radio speaker or earphones and notice that a click or scratch is heard.

One of the relationships that we discussed in the last chapter was that the resistance of a wire or conductor is proportional to the length of the conductor and inversely proportional to the cross-sectional area of the conductor. We can illustrate this with a few simple experiments. In Figure 6-8 you will notice four rectangles of different sizes. Carefully darken these rectangles with a No. 1 or No. 2 *lead* pencil (not an indellible type or "plastic lead" type). Try to make the layer of lead as heavy and uniform as possible and stay within the lines as much as possible.

Set your ohmmeter on the R × 1K range. Notice that rectangle B is four times as long as A but has the same width (cross-sectional area). Since the resistance is directly proportional to length, the resistance of B should be about four times the resistance of A. Measure the resistance of A by placing the test leads close to the ends of the darkened rectangle: ____________ ohms. Measure the resistance of B: __________ ohms. The last reading should be about four times the first. It may not be exact because of differences in the thickness of the layer of lead in each case. Notice that rectangle C is the same length as A but is twice as wide. Since the resistance is inversely proportional to the cross-sectional area (represented by the width in this example), the resistance of C should be about ____________ that of A. Measure the resistance of C: ____________ ohms. This reading should be about one half that of A. Rectangle D is twice as long as A and twice as wide also. Since the length is doubled and the area is doubled you would expect the resistance of D to be about ____________ to the resistance of A. Measure the resistance of D: ____________ ohms. This reading should be about the same as that of A.

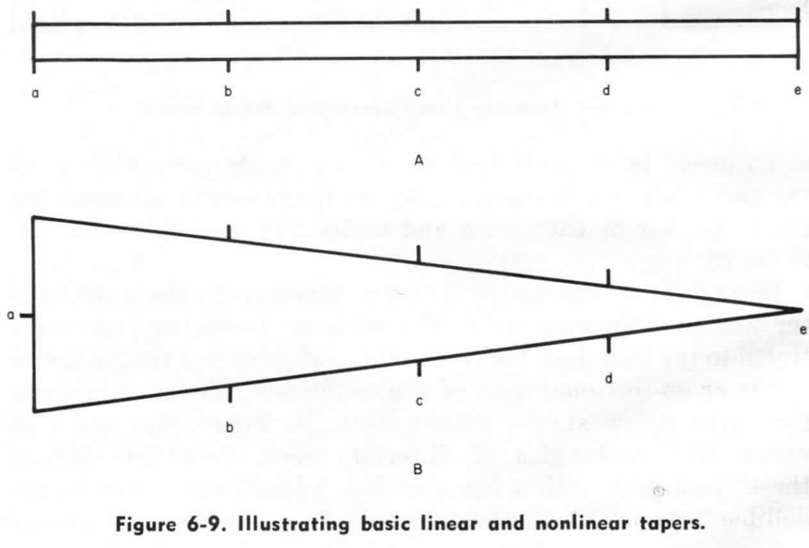


Figure 6-9. Illustrating basic linear and nonlinear tapers.

Another item that was brought out in the last chapter was the taper of variable resistors. We can illustrate basic tapers, linear and nonlinear with the help of Figure 6-9. Fill in the rectangle A, and the long triangle B with a soft pencil just as you did in the previous figure.

Set your ohmmeter on the R $\times$ 1K range. Place one test lead at the left end of rectangle A. Place the other test lead right along side of the first and then gradually slide the second test lead along the length of the rectangle. Notice that the resistance gradually changes as the lead moves across the conductor. Measure the value of resistance between adjacent points on the rectangle and record the values. a-b: ____________, b-c: ____________, c-d: ______________, d-e: ____________. Notice that the resistance between adjacent segments is about the same. This illustrates a linear taper. Now move down to triangle B. Place one test lead at the left end of the triangle. Place the other test lead right along side of the first lead and then gradually slide the second test lead along the length of the triangle. Notice that the resistance gradually changes as the lead moves across the conductor but at a different rate than for the rectangle above. Measure the value of resistance between adjacent points on the triangle and record the values. a-b: _____________, b-c: _____________, d-e: _____________, Notice that the resistance between adjacent segments gradually increases. This illustrates a nonlinear taper. The most common nonlinear taper is the "audio taper" which is used in audio amplifier volume controls.

We can illustrate the principle of insulators with a similar experiment. Darken in the squares shown in Figure 6-10.

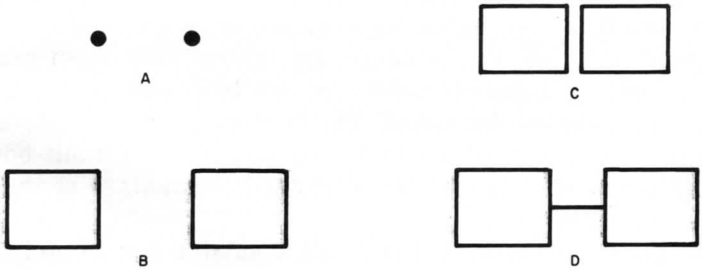


Figure 6-10. Illustrating the principles of an insulator.

Don't forget to pencil in the single line between the squares at D. With the ohmmeter set on the highest range place one test lead on each of the two dots at A in the figure. The resistance should read infinite (∞) because paper is an insulator. Move the test leads to the two squares at B. The reading should still be infinite. Even when the distance between the squares is quite small, as at C, the reading will still be infinite. Occasionally insulators develop faults and a slight conductive path exists across the insulator. This is illustrated by the line between the squares at D. Measure the resistance between the two squares: ____________ ohms. Even though the reading is still quite high it is no longer infinite. When this condition exists in an insulator, it is said to have "leakage." The conductive path is referred to as the "leakage path" and the resistance measured is called the "leakage resistance."

Another common use of the ohmmeter in electronic servicing is checking *continuity* of conductors. By continuity of a conductor we mean a continuous conductive (low resistance) path between two points in a circuit. To check continuity the ohmmeter is used to measure the resistance between the two points in question. The R×1 range is used to insure that the reading is as near to zero ohms as possible. You can practice checking continuity by measuring the resistance between the clips at each end of your set of jumper cables. The resistance of each jumper lead should be 0 ohms. A reading which is significantly higher indicates either a broken lead or a bad connection.

The ohmmeter is quite often used to locate *intermittents*. An intermittent is a fault condition which shows up during certain mechanical, electrical or thermal conditions. The resistance of an intermittent conductor increases momentarily from zero to a high value. This condition is referred to as an intermittent open. For example, an intermittent open caused by a cracked printed circuit board can be found by using the R×1 range of the ohmmeter. The continuity of the suspected conductor is measured while flexing the printed circuit board. The intermittent open is indicated by a momentary change in the meter reading.

The resistance of an intermittent insulator momentarily decreases from infinity to some low value. This condition is referred to as an intermittent short. For example, an intermittent short caused by broken insulation between some wires in a cable can be found by using the highest ohmmeter range. The resistance between suspected wires is measured while flexing the cable. The intermittent short is indicated by a momentary change in the meter reading.

SUMMARY

Resistance measurements are made using the ohmmeter function of the VOM. The major parts of the ohmmeter are the scale, range switch and ohms adjust control. The resistance value indicated by the scale is dependent upon the setting of the range switch.

An internal battery causes current to flow through the circuit when resistance is measured.

There are four steps used when resistance is measured.

1. Select proper range.
2. Touch test leads together and zero the meter.
3. Place leads across resistance being measured.
4. Read the value of resistance on the meter scale.

There are 5 basic rules to keep in mind when making resistance measurements.

1. Remove power from circuit being measured.
2. Isolate component to be measured.
3. Use the resistance range which yields a near-center scale reading for best accuracy.
4. Check meter zero on each range used.
5. If zero cannot be obtained in lowest range, replace ohmmeter battery.

The total resistance of resistors in series is equal to the sum of the individual resistances.

The total resistance of two resistors in parallel is the "product over the sum." When two or more resistors of like value are connected in parallel, the total resistance is equal to the resistor value, divided by the number of resistors.

When measuring high values of resistance, be sure that your hands are not touching the test leads.

The resistance of light bulbs is dependent upon the amount of current through them.

The resistance between the terminals of an insulator is usually extremely high. If a slight conductive path develops across the insulator it is said to have "leakage."

An ohmmeter can be used to check the continuity of a conductor. Continuity of a conductor means a continuous conductive (low resistance) path between two points in a circuit.

An ohmmeter can be used to locate intermittents. An intermittent is a fault condition which shows up during certan mechanical, electrical, or thermal conditions. A circuit may have an intermittent open (high resistance) or an intermittent short (low resistance).

QUESTIONS

1. *What is the purpose of the ohms adjust control on an ohmmeter?*
2. *What is the probable cause of not being able to zero the ohmmeter on the $R \times 1$ range?*
3. *Give the four-step procedure for measuring resistance.*
4. *On the meter we discussed, what range switch positions would be used for measuring the following resistances?*
   - *a. 2KΩ*
   - *b. 10Ω*
   - *c. 10KΩ*
   - *d. 0Ω*
5. *Why must the power be removed from a circuit before resistance measurements are made?*
6. *What is the range of possible resistance values for a 15KΩ, 10% resistor? Do all of your 15KΩ resistors fall within this range?*
7. *What is meant by an intermittent short? What range on the ohmmeter is used to detect an intermittent short?*
8. *What is meant by an intermittent open? What range on the ohmmeter is used to detect an intermittent open?*

CHAPTER 7

OHM'S LAW

In the previous chapter we mentioned the general relationships between voltage, current and resistance in an electrical circuit. Now we are ready to deal with the exact relationships. Before starting through this chapter be sure that you have a variable-voltage DC power supply capable of delivering up to 24 volts. A recommended supply is given in the parts list.

The most basic mathematical relationship between voltage, current and resistance is known as Ohm's Law. This law was first discovered in 1827 by Georg Simon Ohm, an early pioneer in the study of electricity. He discovered that the current in a circuit is directly proportional to the voltage and inversely proportional to the resistance. Stated in a formula this is expressed as

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

The current is equal to the voltage divided by the resistance. This formula can be used to find the current in a circuit when the voltage and resistance are known.

If the voltage and current are known, and the amount of resistance is to be found, the formula can be rearranged to

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

The resistance is equal to the voltage divided by the current.

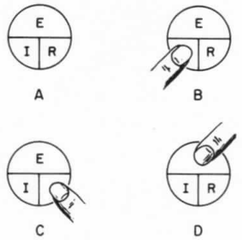


Figure 7-1. Illustrating Ohm's law.

If the current and resistance are known, and you want to know the voltage, the formula can be rearranged to

$$E = IR$$

The voltage is equal to the current multiplied by the resistance.

As we go through this chapter, you will learn when and how to use each of these formulas. Some people have found the sketch in part A of Figure 7-1 to be helpful in remembering these three relationships. If you want to know the formula for finding the current, place your finger over the I as in part B. $\frac{E}{R}$ is visible and thus $I = \frac{E}{R}$. If you want to know the formula for finding resistance, cover the R with your finger as in Part C. $\frac{E}{I}$ is visible and thus $R = \frac{E}{I}$. The formula for voltage is found by placing your finger over the E, part D. IR is visible and thus $E = IR$. It is vitally important to your success in electronics that you understand and remember these three relationships and understand when and how they can be applied to circuit problems.

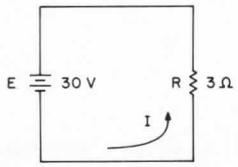


Figure 7-2. Calculating current in a simple series circuit.

Let's try a few sample calculations to demonstrate the use of Ohm's law. If a 30-volt source of voltage is connected across a resistance of 3 ohms (Figure 7-2), how much current will flow through the resistor? Using the formula $I = E/R$ and inserting the values for E and R we have $I = 30/3 = 10$ A.

If a 9-volt source is connected across a resistance of 4.5K ohms, how much current will flow through the resistor? $I =$

$\frac{9}{4.5 \times 10^3} = 2 \times 10^{-3}$ A = 2 mA. You can save time in calculations of this type by noticing that when you divide volts by K ohms, the resulting current flow is given in mA. In the above example 9/4.5K = 2 mA. A similar relationship exists between volts, megohms and μA. For example, if a 6-volt source is connected across a resistance of 2 megohms, the current flow will be:

$$I = \frac{6}{2 \times 10^6} = 3 \times 10^{-6}\ A = 3\ \mu A.$$

Or simply I = 6/2 M = 3 μA. When using the simplified procedure, the symbols K, mA, M and μA should be included in the formula. This helps us to remember to use the proper units of measure in the answer.

Suppose you wanted to know how much resistance was necessary to limit the current flow to 25 mA in a circuit which had a voltage of 250 volts. We can use the formula R = E/I and insert the values for E and I.

$$R = \frac{250}{25\ mA} = 10K\ ohms.$$

This same relationship can be used to determine the value of resistance already in a circuit. If the voltage across a resistor is measured as 76 volts, and the current through the resistor is measured as 4.2 mA, the value of resistance is R = 76/4.2 mA = 18K ohms.

If the value of resistance is known and the current is known or can be measured, the value of voltage across the resistor can be determined. For example, the current flow through a 6.8K resistor is measured as 15 mA. The voltage across the resistor can be found by using the formula E = IR and inserting the values for I and R. E = 15 mA × 6.8K = 102 volts.

In Chapter 4 you learned that current is measured by using an instrument called an ammeter, milliammeter, or microammeter. The function of DC current measurement is provided by the VOM. The scales used for DC current measurement on our typical VOM are the same ones used for DC voltage measurement. The particular scale used and the value of current indicated by the scale is dependent upon the position of the range switch. The scale is shown in Figure 7-3 and the

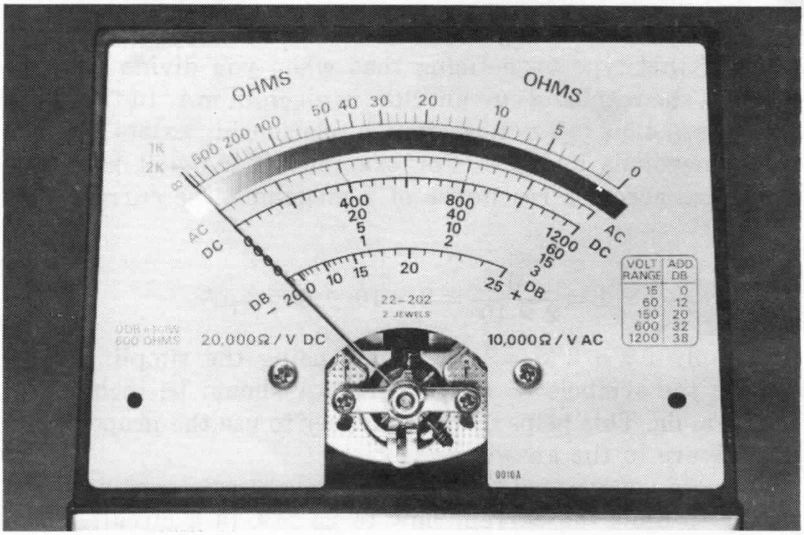


Figure 7-3. The scale of a typical VOM.

range switch is shown in Figure 7-4. There are four switch positions for the current function. These are labeled 60μ, 3m, 30m, and 300m. In the 60μ position the third range of calibrations (0 to 60) is used and the full-scale value is 60 μA. The current values are read directly from the scale. In the 3m

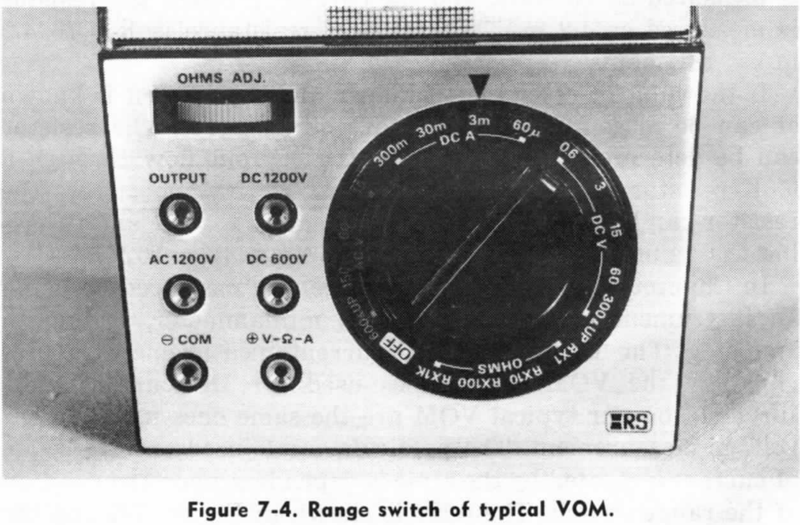


Figure 7-4. Range switch of typical VOM.

position the first range (0 to 3) is used and the full-scale value is 3 mA. The values are read directly from the scale. In the 30m position the same scale is used, but we mentally multiply each scale value by 10 (add one zero). The full scale value is 30 mA. In the 300m position the same scale is used, but we mentally multiply each scale value by 100 (add two zeros). The full scale value is 300 mA.

The black test lead is placed in the COM jack and the red test lead in the V-Ω-A jack.

When measuring current, the meter is placed in *series* with the load at the point where the current is being measured (Figure 7-5).

There are a few simple rules to keep in mind when making current measurements.

1. Disconnect the power before inserting the current meter.
2. Polarize the meter so that the electron current enters the COM (−) terminal and leaves the V-Ω-A (+) terminal as shown in Figure 7-5. If the meter is placed in the circuit with the wrong polarity the meter pointer will deflect down-scale.
3. Use the proper meter current range. If the approximate value of current is known, use the lowest range which includes the expected current. If the value of current is unknown, always start with the range switch in the highest position and switch downward until the proper range is reached. For best accuracy, always use the lowest meter range which includes the current under measurement.

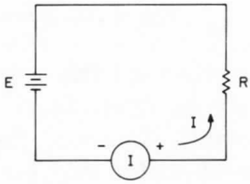


Figure 7-5. Place meter in series with load to measure current.

4. Energize the circuit, notice the position of the pointer on the meter scale, and read the value of current. Keep in mind the previous experience you have had in interpreting the meter scales.
5. *CAUTION:* Never place a current meter across (in par-

allel with) a voltage source as excessive current flow may burn out the meter.

6. After current measurements are finished, restore the meter range switch to the highest voltage range (or the OFF position if provided). This helps protect the meter against accidentally connecting the meter across a voltage source later on when you forget to set the range switch properly.

Let's set up a simple circuit so we can get some experience with current measurements. If a 1K resistor is connected across a 15-volt source, the current flow will be $I = E/R = 15/1K = 15$ mA. Set up the circuit with the variable voltage power supply as shown in Figure 7-6. Before using the power supply,

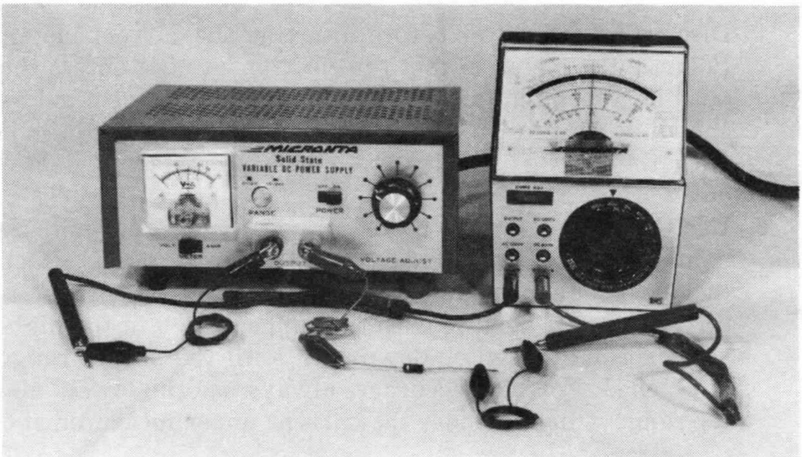


Figure 7-6. Hookup of circuit to variable power supply.

carefully read the operating instructions. Set the VOM range switch to 30m. Start with power supply output at 0 volts. Gradually increase the output voltage while observing the current meter and power supply voltmeter readings. Adjust for a voltage of 15 volts. You should read approximately 15 mA on the VOM. Don't expect the reading to be *exactly* the same as the calculated value. This is due to the tolerance of the resistor and the accuracy of the current and voltage meters. For example, the tolerance of a 10% resistor could give us a current reading anywhere between 13.5 and 16.5 mA!

If your reading is not close to the 15 mA value, double check the resistor color code and your interpretation of the meter scales. Reduce power supply output to 0 V after making the measurement.

If the resistance is changed to 10K ohms, what will be the value of current flow? $I = E/R = 15/10K = 1.5$ mA. Change the resistor in the circuit of Figure 7-6 to 10K and switch the VOM range to 3m. Gradually increase the voltage to 15 volts (watch the meters). Current value: ____________ mA. This should be close to 1.5 mA. Reduce supply to 0 volts.

Now we'll change the resistor value to 330K. 330K is equivalent to 0.33 megohm. The current flow will be $I = E/R = 15/0.33\ M = 45\ \mu A$.

Replace the 10K resistor with a 330K resistor and switch the VOM range switch to 60μ. Gradually increase the voltage to 15 volts. Current value: ____________ μA. This should be close to 45 μA. Reduce supply to 0 volts.

Make the calculation on the next one yourself and check your results by measurement. What current will flow if 10 volts is applied to a 220K resistor? Remember to check current range and increase voltage slowly. Calculated current: ____________. Measured current: ____________.

Calculate the resistor value necessary to limit the current to approximately 4.2 mA with a 20-volt source. R = ____________. Select one of your resistors which is closest to this value and insert in the circuit. Measured current: ____________.

What value of resistor will limit the current to about 40 μA with a 9-volt source? R = ____________. Select the resistor closest to this value and insert in the circuit. Measured current: ____________.

If a current of 1 mA flows through a 10K resistor, what is the voltage across the resistor? $E = IR = 1\ mA \times 10K = 10$ volts. Set up the circuit of Figure 7-6 with a 10K resistor and adjust the power supply until 1 mA of current is flowing. What is the voltage indicated by the power supply meter? ____________. This should be close to 10 volts.

If a current of 43 μA flows through a 470K resistor, what is the voltage across the resistor? Calculated voltage: ____________. Connect a 470K resistor in the circuit and adjust the power supply until 43 μA of current is flowing. What voltage is indicated by the power supply meter? ____________.

In the foregoing calculations and measurements you have practiced using all three forms of Ohm's Law. In the next few chapters we'll apply this law to some more complicated circuits.

Due to the complexity of many relationships in electronics it is more convenient to visualize these relationships in a graphical form than to use a long data chart. A graph is a visual presentation of the relationship between two or more electrical quantities. For example, in the relationship $I = E/R$ we might be interested in the manner in which the current changes if we change the voltage across a resistance. Let's take a 1K resistor and see how the current changes as the voltage is changed. We can calculate the current flow for certain values of voltage. The chart of Figure 7-7 gives these values of

1	2	3	4	5
	Calculated	Current	Measured	Current
Voltage Volts	R = K1 mA	R = 2K mA	R = 1K mA	R = 2K mA
0	0			
5	5			
10	10			
15	15			
20	20			

Figure 7-7. Data chart for circuit measurements.

current and voltage. Assumed voltage values are listed in column 1 and calculated current values for the 1K resistor are listed in column 2. This information can be presented on a graph by following certain standard procedures. The basic parts of a graph are shown in Figure 7-8. The values of the quantities involved are placed along the two coordinates. The horizontal line at the bottom is called the X axis or abscissa. We place the values of the independent variable along this line. The independent variable is the one which we control, voltage in this example. The vertical line at the left is called the Y axis or ordinate. We place the values of the dependent variable along this line. The dependent variable is the variable whose value is dependent upon the value of the independent variable.

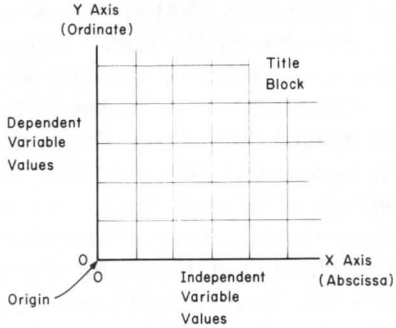


Figure 7-8. Basic parts of a graph.

The current is the dependent variable in our example. The intersection of the X and Y axes is called the origin and is the 0 value point for both the independent and dependent variables. A title block is always included which describes the purpose of the graph and presents any special conditions under which the information or data was obtained. The graph is constructed by transferring the information in the data chart to the graph. A point or small circle is placed at the intersection of corresponding values of the two variables.

Figure 7-9 is a graph of the data presented in the chart of Figure 7-7. The X axis is calibrated with the values of voltage. The Y axis is calibrated with values of current. When plotting values which do not fall directly on one of the lines on the graph, you may estimate the location of the value in the same manner as you interpret meter readings that fall between the lines on the meter scale. The first pair of values from the chart, E = 0 V, I = 0 mA is plotted by a point at the origin. The next pair of values, E = 5 V, I = 5 mA is plotted at the intersection of the 5 volt and 5 mA lines. The other pairs

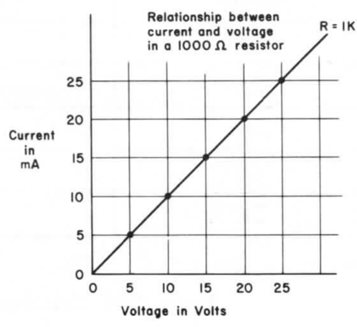


Figure 7-9. Graph of the data presented in Figure 7-7.

of values are plotted in a similar manner and then a smooth line is drawn through all the points. In this case a straight line can be drawn through all of the points.

You will notice in the chart of Figure 7-7 that column 4 is labeled "Measured Current, R = 1K, mA." Set up a circuit to measure the current through a 1K resistor for the different values of voltage. Refer to Figure 7-6 if you need help in setting up the circuit. Place the values of measured current in the chart and then plot these values on the graph on Figure 7-9. Draw a line through the points. This line should fall close to the previous line, taking into account all of the factors affecting the accuracy of the readings.

Let's repeat the same series of calculations and measurements with a resistance of 2K ohms. Connect two 1K resistors in series to provide the 2K ohms of resistance. Measure the current at each value of voltage indicated in the chart and place the value of current in the fifth column of Figure 7-7, labeled "Measured Current, R = 2K, mA." Plot these values on the graph of Figure 7-9.

By observing the lines in the graph of Figure 7-9, we can draw the following conclusions about the relationship between current and voltage.

1. For any value of resistance, as voltage increases, current also increases. For example, when the voltage is doubled the current is doubled. Since the voltage and current are

1	2	3
Resistance Ohms	**Calculated Current mA**	**Measured Current mA**
1K		
2K		
3K		
4K		
5K		

E constant at 20 V DC

Figure 7-10. Calculated and measured currents.

increased by the same factor, we can say that the current is directly proportional to the voltage.

2. Since the graph of the relationship is a straight line, the relationship is said to be *linear*.
3. The lower the resistance, the higher the current and the steeper will be the graph of current versus voltage. The slope of the line gives us an indication of the value of resistance. The steeper the slope, the lower the value of resistance. For very low values of resistance (approaching a short circuit) the slope becomes quite steep (almost vertical) and the current value will be excessively high even for low values of voltage.
4. The measured values may not be exactly the same as the theoretical (calculated) values.

Let's examine the relationship between current and resistance if the voltage is held constant. Using the relationship I = E/R, with a fixed value of voltage of 20 volts, calculate the current flow for the values of resistance listed in column 1 of the chart of Figure 7-10. Place the values of current in column 2 of the chart. After all the calculations have been made, set up a circuit with the supply set at 20 volts and measure the current for the different values of resistance. You may have to connect resistors in series to obtain the chart values. Use your clip leads to do this. Place the values of measured current in column 3 of the chart. Next plot the corresponding values on the graph of Figure 7-11. Use one colored pencil for the calculated values and another color for the measured values. Draw a smooth line through each set of points. The two

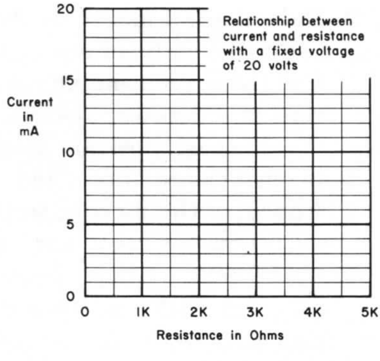


Figure 7-11. Graph for data presented in Figure 7-10.

curves should be fairly close to each other. Notice several things about the curves.

1. As the resistance increases in value, the current decreases. Thus we can say that the current is inversely proportional to resistance. For example, as resistance is doubled, the current is halved.
2. Notice from the curves that as resistance is decreased the current increases at an ever increasing rate. For this reason we must have enough resistance in a circuit to limit the current to a safe value.

SUMMARY

The most basic relationship between voltage, current and resistance is Ohm's Law. The three forms of this law are:

$$I = E/R \qquad R = E/I \qquad E = IR$$

Usng these relationships any of the three quantities can be found if the other two are known.

Current is measured using an ammeter, milliammeter or microammeter. The function of DC current measurement is provided by the VOM.

When measuring current, the meter is placed in series with the load at the point where the current is being measured. The following rules should be followed when making current measurements.

1. **Disconnect the power before inserting the current meter.**
2. **Polarize the meter so that the electron current enters the COM (−) terminal and leaves the V-Ω-A (+) terminal.**
3. **Use the proper meter current range. If the value of current is unknown, always start with the range switch in the highest position and switch downward until the proper range is reached.**
4. **Energize the circuit, notice the position of the pointer on the meter scale and read the value of current.**
5. ***CAUTION:* Never place a current meter across (in parallel with) a voltage source as excessive current flow may burn out the meter.**

6. After current measurements are finished, restore the meter range switch to the highest voltage range (or the OFF position if provided).

You have gained some experience in calculating values using Ohm's law and verifying your calculations by actual measurements.

A graph is a visual presentation of the relationship between two or more electrical quantities. Values of quantities can be presented in a data chart and a graph can be constructed from these values. The graph is plotted on two coordinates with the independent variable on the X axis and the dependent variable on the Y axis.

When the relationship between current and voltage with a fixed value of resistance was plotted, we observed that the current is directly proportional to the voltage and that the relationship is linear.

The slope of the line gives us an indication of the value of resistance. The steeper the slope, the lower the value of resistance.

When the relationship between current and resistance with a fixed voltage was plotted on a graph, we observed that current is inversely proportional to the resistance.

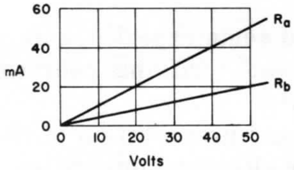
QUESTIONS

1. *Give the three mathematical forms of Ohm's law from memory.*
2. *What current will flow when 47K ohms is placed across a 9-volt source?*
3. *What current will flow when 325 volts is applied across a 5K ohm load?*
4. *What resistance is indicated by a current flow of 300 μA when 60 volts is applied?*
5. *How much resistance is required to limit current flow to 5 mA when 120 volts is applied?*
6. *What is the voltage across a 1 megohm resistor which has 0.5 mA of current flow through it?*
7. *How much voltage is applied to a circuit in which 25 mA flows through a 3K ohm resistor?*

8. *What values of resistance are indicated by the graph below?*

$R_a =$ ________________

$R_b =$ ________________



9. *The current in a circuit with fixed resistance is measured as 30 mA. To double the current value, the voltage must be* ________________.

10. *The current in a circuit with fixed voltage is measured as 30 mA. To double the current value, the resistance must be* ________________.

CHAPTER 8

SERIES CIRCUITS

In the previous chapter you learned the relationship between voltage, current and resistance in a simple circuit consisting of a voltage source and a resistor. Most of the actual circuits you will encounter in your study and work in electronics are more complicated than this. There are many combinations of resistors and other circuit elements which are used in actual circuits. One of the common circuit configurations is the series circuit. The schematic diagram of a series circuit consisting of three resistors in series across a voltage source is shown in Figure 8-1.

In this type of circuit the current flows out of the battery negative terminal, through each of the resistors and then into the positive terminal of the battery. There are three important relationships in the series circuit which will hold true regardless of the number of resistors in the circuit. We will state these relationships first and then consider each in more detail.

1. The total resistance in the circuit is equal to the sum of the individual resistances.
2. The same value of current flows in all parts of the circuit and is equal to the applied voltage divided by the total resistance.
3. The sum of the individual resistor voltages is equal to the applied voltage.

In Chapter 5 you learned that the total resistance in a series circuit is equal to the sum of the individual resistances.

$$R_T = R1 + R2 + R3 + \ldots$$

In the circuit of Figure 8-1 the total resistance is

$$R_T = 1K + 2K + 10K = 13K \text{ ohms}$$

The current flow is found using Ohm's law.

$$I = \frac{E_a}{R_T} = \frac{26}{13K} = 2 \text{ mA}$$

The path for electron flow in this type circuit is directly through each resistor from the source negative terminal to the source positive terminal. Since the current flows from one resistor to the next, the same value of current flows in all parts of the circuit.

The voltage across each resistor can be found using one of the forms of Ohm's law, E = IR.

The voltage across R1: $E_{R1} = 2 \text{ mA} \times 1K = 2$ volts.
The voltage across R2: $E_{R2} = 2 \text{ mA} \times 2K = 4$ volts.
The voltage across R3: $E_{R3} = 2 \text{ mA} \times 10K = 20$ volts.

The sum of these voltages equals the applied voltage.

$$E_a = E_{R1} + E_{R2} + E_{R3} = 2 + 4 + 20 = 26 \text{ volts}$$

The voltage across each resistor, caused by the flow of current through it, is referred to as the *IR drop*. The expression, IR drop, is used because the resistor voltage (calculated bv I×R) reduces, or drops, the supply voltage available for the remainder of the resistors in the circuit. For example, the voltage across R2 and R3 can only be the applied voltage of 26 volts minus the 2-volt drop in voltage across R1. The third

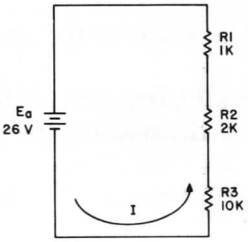


Figure 8-1. A simple series circuit.

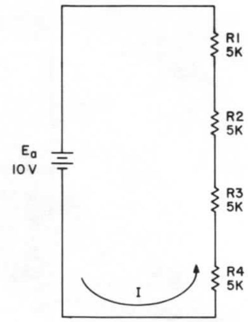


Figure 8-2. Series circuit with four equal resistors.

rule of series circuits mentioned above is sometimes stated: the applied voltage is equal to the sum of the "IR drops" around the circuit.

Let's look at another series circuit and make some calculations on it. The series circuit shown in Figure 8-2 contains four equal resistors in series, across a source of voltage. The total resistance is $4 \times 5K = 20K$ ohms. The current flow is $I = E/R = 10/20K = 0.5$ mA. The voltage drop or IR drop across each resistor is $E = IR = 0.5 \text{ mA} \times 5K = 2.5$ volts. The sum of the IR drops across each resistor equals the applied voltage of 10 volts.

Let's verify the three basic relationships of the series circuit by making some measurement on an actual circuit. Take three of your 1K resistors and carefully measure the exact value of each resistor with your ohmmeter. Record the values. R1 = ______________ ohms, R2 = ______________ ohms, R3 = ______________ ohms. Calculate the total of these three values. R_T = ______________ ohms. Connect the three resistors in series using your test lead jumper cables as shown in Figure 8-3. Measure the total resistance with your ohmmeter. R_T = ____________ ohms. This measured value should agree very closely with the calculated value above. This verifies the first relationship that the total resistance in the circuit is equal to the sum of the individual resistances. Assume that 18 volts will be applied across the series combination. Calculate the current flow. $I = E/R_T$ = ______________ mA. Switch your VOM to the 30 mA range and connect the VOM and series resistor combination across the output of the power supply as shown in Figure 8-4. Gradually increase the power supply output to 18 volts. The value of current indicated on the VOM is _________ mA.

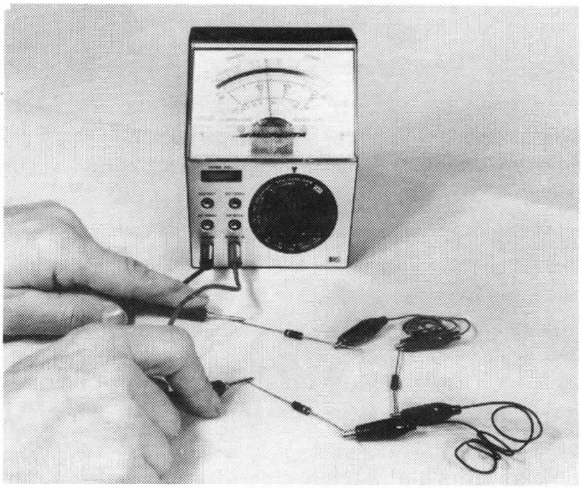


Figure 8-3. Measure total resistance.

This should agree very closely with the calculated value above. Turn off the power supply and insert the meter between R2 and R3 in place of the jumper cable. Use the jumper cable to connect R1 to the power supply negative terminal as shown in Figure 8-5. Set the power supply voltage to 18 volts again and measure the current: ____________ mA. Repeat the above

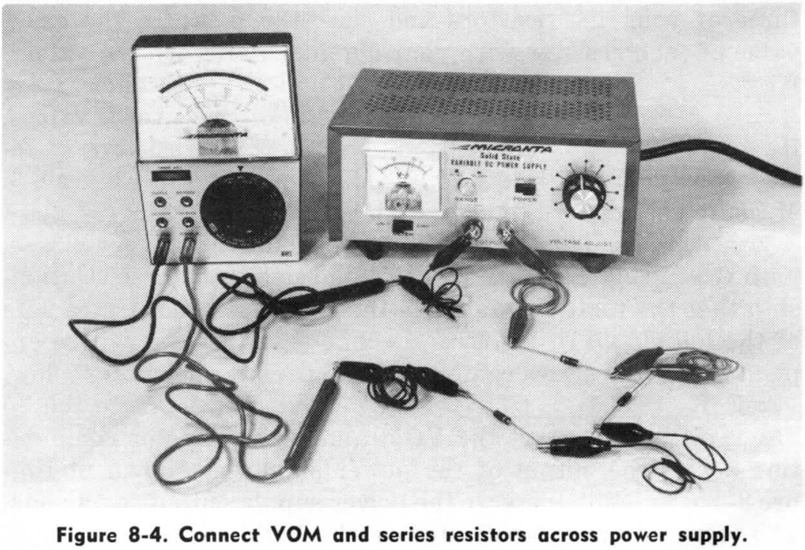


Figure 8-4. Connect VOM and series resistors across power supply.

procedure with the meter between R1 and R2: ________ mA and between R1 and the power supply positive terminal: ________ mA. The four readings should be the same, assuming that you have set the power supply to exactly 18 volts for each reading. We have verified that the same value of current flows in all parts of the series circuit and is equal to the applied voltage divided by the total resistance.

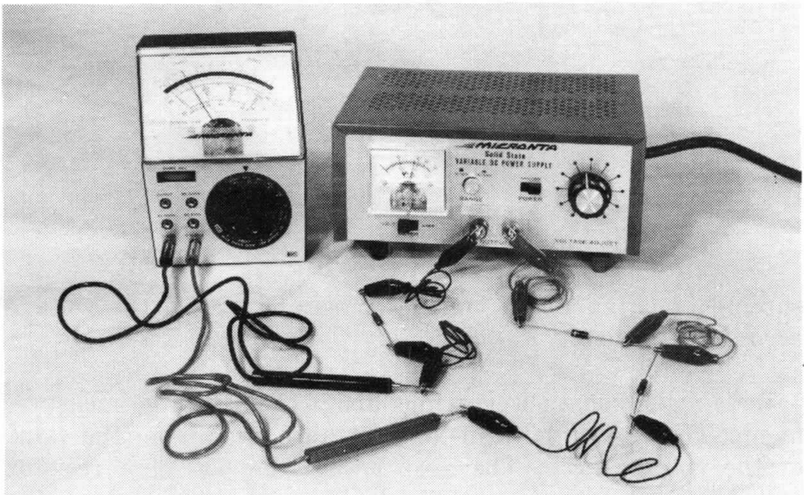


Figure 8-5. Connect VOM between two resistors.

To verify the third relationship connect the series combination across the power supply as shown in Figure 8-6. Switch the VOM to the 60-volt range and connect across R3 as shown. E_{R3} = ____________ volts. Place the meter across each of the two remaining resistors and record the voltage. E_{R2} = ____________ volts, E_{R1} = ____________ volts. Add these three voltages to find the total, E_T = __________ volts. Place the VOM across the entire series combination and read the total voltage, E_T = ____________ volts. The calculated and measured values should agree quite closely, taking into account the accuracy of the voltmeter readings. This verifies that the sum of the individual resistor voltages is equal to the applied voltage.

Now hook up the series circuit as shown in Figure 8-7. Use your clip leads as before. Set the output of the power supply to 12 volts. Use the same procedure as in the previous mea-

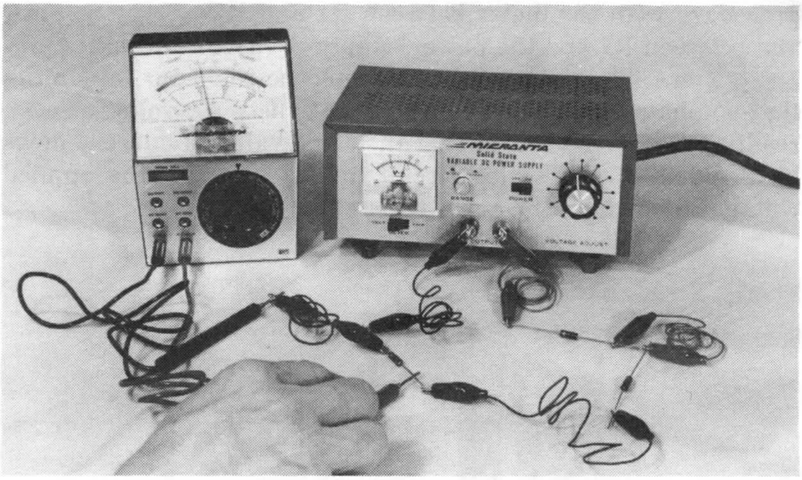


Figure 8-6. Connect resistors only across power supply.

surements (Figure 8-6) and measure and record the voltage across each resistor. E_{R1} = ____________ volts, E_{R2} = ____________ volts, E_{R3} = ____________ volts.

Let's make some observations about these voltage measurements. The higher the value of resistance, the higher the value of the voltage drop. The drop across the 680 ohm resistor (about 4 volts) is approximately twice the drop across the 330 ohm resistor (about 2 volts). The drop across the 1K resistor (about 6 volts) is approximately three times the drop across the 330 ohm resistor. This can also be seen from the formula E = IR. Since the same value of current flows in all parts of the circuit, the amount of the voltage drop will be directly proportional to the resistance value of the resistor. If one resistance is three times the value of another, the voltage drop across the larger resistance will be three times the

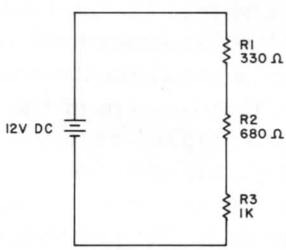


Figure 8-7. Series circuit of three different resistors.

drop across the smaller. From these observations we can make the following statement. The voltage drop across a resistor in a series circuit is directly proportional to the resistance of the resistor.

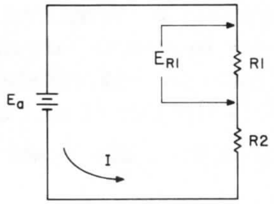


Figure 8-8. Potentiometer rule can be applied to this simple series circuit.

This leads us to a very important relationship for series circuits known as the *potentiometer rule.* Use of the potentiometer rule allows us to calculate or estimate the amount of voltage across a resistor in a series circuit without the necessity of calculating or measuring the current. Consider the simple series circuit shown in Figure 8-8. From our previous study we can express the following relationships.

$$I = \frac{E_a}{R_T} \text{ and } I = \frac{E_{R1}}{R1}$$

Since the current I is the same for both of these equations we can equate the two expressions and obtain the relationship

$$\frac{E_{R1}}{R1} = \frac{E_a}{R_T}$$

This relationship is called the potentiometer rule. This is called the potentiometer rule because this is the principle of operation for an actual potentiometer. Recall that a potentiometer is one of the types of variable resistors (Figure 8-9). The voltage at the arm of the potentiometer is proportional to the position of the arm on the resistive element. The closer the arm is to the top of the resistive element, the higher will be

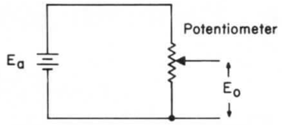


Figure 8-9. Potentiometer is a variable resistor.

the output voltage, E_o. By rearranging the above relationship we obtain

$$E_{R1} = E_a \frac{R1}{R_T}$$

Expressed in words, we could say that the voltage across a resistor in a series circuit is equal to the applied voltage times the ratio of that resistance to the total resistance. Let's go back to the circuit of Figure 8-7 to verify this. The total resistance, $R_T = 330 + 680 + 1000 = 2010$ ohms. The ratio, $\frac{R1}{R_T} = \frac{330}{2010} \cong \frac{1}{6}$. The voltage across R1 should be about $1/6\ E_o \cong 1/6 \times 12 \cong 2$ volts. The ratio, $\frac{R3}{R_T} = \frac{1000}{2010} \cong \frac{1}{2}$. The voltage across R3 should be about $1/2\ E_a \cong 1/2 \times 12 \cong 6$ volts. These values agree with the values obtained from measurements on this circuit.

One last idea before we leave series circuits. It may have occurred to you already that it is not always necessary to use a current meter to determine the value of current flowing in a series circuit. If you know the value of resistance and can measure the value of voltage across the resistor, you can calculate the current using Ohm's law, $I = E/R$. This method is quite practical to use in cases where it is difficult to break into a circuit to insert a current meter. Such is the case when working with printed-circuit boards. Let's try an example. In the circuit of Figure 8-7 the voltage measured across the 330-ohm resistor is approximately 2 volts. The circuit current flow should be $I = E/R = 2/330 \cong 6$ mA. You can verify this by inserting a current meter in the actual circuit. The measured current should be approximately 6 mA. This method is generally called the voltage-drop method of current measurement.

SUMMARY

There are three important relationships in the series circuit which will hold true regardless of the number of resistors in the circuit.

1. **The total resistance in the circuit is equal to the sum of the individual resistances.**

$$R_T = R1 + R2 + R3 + \ldots$$

2. The same value of current flows in all parts of the circuit and is equal to the applied voltage divided by the total resistance.

$$I = \frac{E_a}{R_T}$$

3. The sum of the individual resistor voltages is equal to the applied voltage.

$$E_a = E_{R1} + E_{R2} + E_{R3} + \ldots$$

The voltage across a resistor, caused by the flow of current through it is referred to as the *IR drop.*

You have verified each of the three basic relationships by performing actual measurements.

The voltage drop across a resistor in a series circuit is proportional to the resistance of the resistor.

The potentiometer rule is useful in calculating or estimating the amount of voltage across a resistor in a series circuit without the necessity of calculating or measuring the current.

$$\frac{E_{R1}}{R_1} = \frac{E_a}{R_T}$$

The voltage across a resistor in a series circuit is equal to the applied voltage times the ratio of that resistance to the total resistance.

$$E_{R1} = E_a \frac{R1}{R_T}$$

The value of current flowing in a circuit can be found by the voltage drop method. I = E/R.

QUESTIONS

1. *What is the total resistance of a circuit with resistors of 10K, 33K, and 270K in series?*

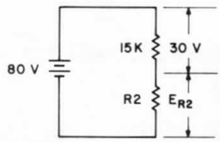
2. *Draw the schematic diagram of this circuit when connected to a 100-volt DC source.*

3. *Calculate the value of current which will flow in this circuit.*

4. *What is the voltage drop across each of the three resistors in this circuit?*

5. *Name a rule which can be used to solve for IR drops without the necessity of finding the circuit current. Give a formula associated with this rule.*

6. *A series circuit is shown below.*



   a. *What is the voltage drop, E_{R2}?*
   b. *What is the resistance of R2?*

7. *If two series resistors have a resistance ratio of 5 (R1/R2 = 5), what will be the ratio of voltage across these two resistors? Will this voltage ratio be the same for any value of applied voltage?*

CHAPTER 9

PARALLEL CIRCUITS

In the previous chapter you learned some basic characteristics of series circuits. In this chapter we are going to study another common circuit configuration, the parallel circuit. Before you start through this chapter, be sure you have the necessary additional items listed below. The Radio Shack catalog numbers of these items are given in the material list.

1. Experimenter's P-box.
2. Solderless spring terminals.

The schematic diagram of a simple parallel circuit is shown in Figure 9-1.

In this type of circuit the current flows out of the battery negative terminal to the junction of the two resistors. The current then divides between the two resistances in accordance with relationships which we will explain later. At the top junction the currents recombine and return to the battery positive terminal. Figure 9-2 shows another way of drawing the schematic diagram of the same circuit. You will see both methods used for indicating the connections in a parallel circuit. We will use the method of Figure 9-2 in our study.

Each of the paths for current flow is called a *branch*. The circuits of Figures 9-1 and 9-2 each have two branches. The current in each branch is called the branch current.

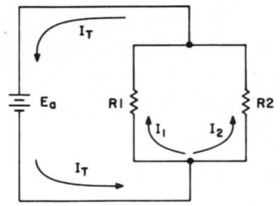


Figure 9-1. Schematic diagram of a simple parallel circuit.

The term *shunt* is also used to describe a parallel connection, but we will use the more popular term, parallel.

There are three important relationships in the parallel circuit which will hold true regardless of the number of resistors in the circuit. We will state these relationships first and then consider each in more detail.

1. The same value of voltage is applied to each of the branches in the circuit.
2. The total current flow is equal to the sum of the individual branch currents. The total current is equal to the applied voltage divided by the equivalent resistance.
3. The equivalent resistance is equal to the reciprocal of the sum of the reciprocals.

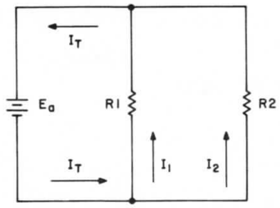


Figure 9-2. Alternate way of drawing circuit of Figure 9-1.

By observing the schematic of Figure 9-3 we can see that there is no voltage drop between the battery terminals and the resistors. Therefore, we can say that the same value of applied voltage appears across each resistor—10 volts in the example of Figure 9-3.

Also, from observation of Figures 9-1, 9-2, and 9-3, we can see that the current from the battery divides into two branch

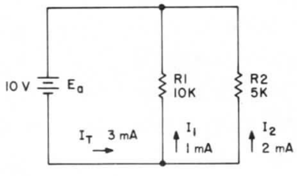


Figure 9-3. No voltage drop between battery and the resistors.

currents and then recombines at the top junction. Since there is no other path for the current we may conclude that the total current must be equal to the sum of the individual branch currents. The amount of current flowing in each branch can be determined from Ohm's law. For the circuit of Figure 9-3,

$$I_1 = \frac{E_a}{R1} = \frac{10\text{ V}}{10\text{K}} = 1\text{ mA}$$

$$I_2 = \frac{E_a}{R2} = \frac{10\text{ V}}{5\text{K}} = 2\text{ mA}$$

The total current is the sum of these two branch currents.

$$I_T = I_1 + I_2 = 1 + 2 = 3\text{ mA}$$

Ohm's law can also be used to express the relationship between the applied voltage, total current, and the effective total resistance of the circuit.

$$R_T = \frac{E_a}{I_T} = \frac{10\text{ V}}{3\text{ mA}} = 3.33\text{K ohms}$$

The total resistance in a parallel circuit can also be calculated using "the reciprocal of the sum of the reciprocals" as you learned in Chapter 5.

$$R_T = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \ldots}$$

Recall that when there are only two resistances in parallel this relationship simplifies to the product over the sum.

$$R_T = \frac{R1 \times R2}{R1 + R2}$$

For the circuit of Figure 9-3

$$R_T = \frac{10 \times 5}{10 + 5} = \frac{50}{15} = 3.33\text{K ohms}$$

It is not necessary to know how the above formulas are obtained, but for those who are interested we have included a derivation in the Appendix.

Let's look at another parallel circuit and make some calculations. A three-branch parallel circuit is shown in Figure 9-4.

The same value of applied voltage, 12 volts, appears across each branch. The branch currents can be calculated as follows.

$$I_1 = \frac{E_a}{R1} = \frac{12\ V}{4K} = 3\ mA$$

$$I_2 = \frac{E_a}{R2} = \frac{12\ V}{3K} = 4\ mA$$

$$I_3 = \frac{E_a}{R3} = \frac{12\ V}{6K} = 2\ mA$$

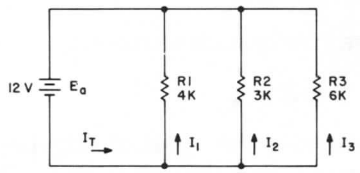


Figure 9-4. A three-branch parallel circuit.

The total current is

$$I_T = I_1 + I_2 + I_3 = 3 + 4 + 2 = 9\ mA$$

The total resistance is

$$R_T = \frac{E_a}{I_T} = \frac{12\ V}{9\ mA} = 1.33K\ ohms$$

Let's verify the three basic relationships of the parallel circuit by making some measurements on an actual circuit. Use your ohmmeter and carefully measure the resistance of one of your 10K and 22K resistors. R1 (10K) = ____________ ohms, R2 (22K) = ____________ ohms. Calculate the total resistance of these two resistors in parallel.

$$R_T = \frac{R1 \times R2}{R1 + R2} =$$

Use your Experimenters P-Box and solderless spring terminals and set up the circuit as shown in Figure 9-5. The terminals are located in holes A1, G1, M1, A6, G6, and M6. You may use your test lead jumper cables or short pieces of hookup wire for the connections between terminals. If you use hookup wire, carefully remove ¼ inch of insulation from each end of the wire before inserting it in the terminals.

Set the power supply output for 18 volts output as indicated on your VOM. Verify that the 18 volts also appears across each

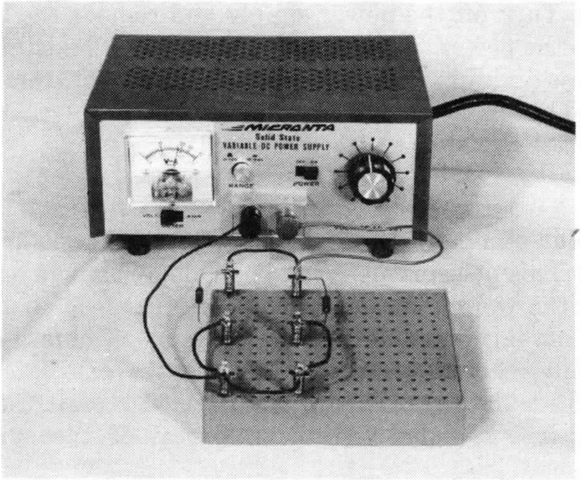


Figure 9-5. Hookup of parallel circuit and power supply.

resistor. E_{R1} = ______________ volts, E_{R2} = ____________ volts. This verifies the first rule of the parallel circuit that the same value of voltage is applied to each of the branches in the circuit.

Calculate the branch currents and total current for the circuit.

$$I_1 = \frac{E_a}{R1} = \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_ mA}$$

$$I_2 = \frac{E_a}{R2} = \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_ mA}$$

$$I_T = I_1 + I_2 = \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_ mA}$$

Use your VOM as a milliammeter and measure the current through the 10K resistor. This can be done by removing the lead between terminals G1 and M1 and connecting the VOM leads in its place. I_1 = ______________ mA. Put the lead back in place and connect the VOM in place of the lead between terminals G6 and M6 to measure the current through the 22K resistor. I_2 = ______________ mA. Put the lead back in place and connect the VOM in place of the lead between terminal M1 and the power supply to measure the total current. I_T = ______________ mA. The total current should be equal to the sum of the two branch currents taking into account the meter accuracy. We have just verified the second law of the parallel circuit that the total current flow is equal to the sum of the individual branch currents. Turn off the power supply and remove the leads connected to the power supply. Calculate the total resistance of the circuit by dividing the applied voltage by the total current measured above.

$$R_T = \frac{E_a}{I_T} = \_\_\_\_\_\_\_\_\_\_ \text{ mA}$$

Use your ohmmeter and measure the total resistance of the network. This measurement can be made by placing one lead on either of the two top terminals and the other lead on any of the four bottom terminals. R_T = __________ K ohms. This measured value should agree closely with the calculated values. This verifies the third rule of the parallel circuit that the total resistance is equal to the reciprocal of the sum of the reciprocals.

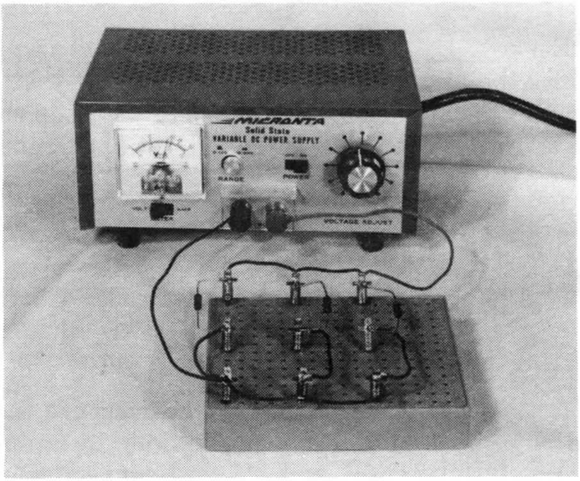


Figure 9-6. Adding another resistor in parallel.

Add three more terminals and connect a 4.7K resistor in parallel with the other two resistors as shown in Figure 9-6. The terminals are located in holes A11, G11, and M11. Set the power supply to 18 volts and measure the current through the 4.7K branch by connecting the VOM in place of the lead between terminals G11 and M11. I_3 (4.7K) = __________ mA. From the previous test I_1 (10K) = __________ mA, I_2 (22K) = __________ mA.

Let's make some observations about these current readings. The current through the 4.7K branch is the largest of the three. The current through the 22K branch is the smallest of the three. Thus we can conclude that the higher the resistance in a parallel branch, the lower will be the current. The current through the 4.7K branch is approximately twice the current through the 10K branch. Notice that 4.7K is approximately ½ the resistance of 10K. The current through the 4.7K branch is approximately 5 times the current through the 22K branch. 4.7K is approximately ⅕ the resistance of 22K. Thus we can conclude that the currents in the branches of a parallel circuit are inversely proportional to the resistances of the branches.

In a two-branch parallel circuit the ratio of branch currents is inversely proportional to the ratio of branch resistances. This can be expressed mathematically as

$$\frac{I_1}{I_2} = \frac{R2}{R1}$$

This relationship is more convenient than Ohm's law for calculating the value of an unknown quantity when the other three circuit values are known. For example, consider the circuit of Figure 9-7. If $R1 = 10K$, $R2 = 20K$, and $I_2 = 5$ mA, then

$$\frac{R2}{R1} = \frac{2}{1} \qquad \text{therefore} \qquad \frac{I_1}{I_2} = \frac{2}{1}$$

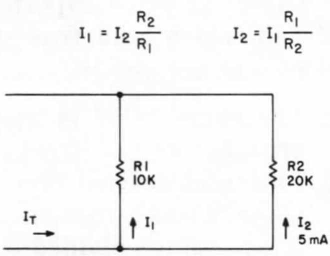


Figure 9-7. Current through resistor R1 is unknown.

Since $I_2 = 5$ mA, $I_1 = 10$ mA

In a two-branch circuit if the resistance of each branch and the total current are known, the current through a branch can be calculated using the relationship

$$I_1 = I_T \frac{R2}{R1 + R2}$$

In the circuit of Figure 9-8 if R1 = 2K, R2 = 8K, and $I_T = 20$ mA, then

$$I_1 = 20 \text{ mA}\frac{8K}{2K + 8K} = 16 \text{ mA}$$

The current through the other branch is

$$I_2 = I_T - I_1 = 20 - 16 = 4 \text{ mA}$$

This relationship is called the "parallel-resistor current rule." Both this rule and the relationship of the ratio of branch

$$I_1 = I_T \frac{R_2}{R_1 + R_2} \qquad I_2 = I_T \frac{R_1}{R_1 + R_2}$$

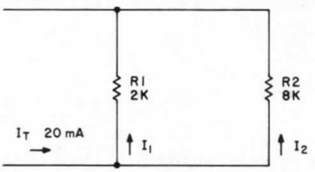


Figure 9-8. Calculate current through each branch.

currents in a two-branch parallel circuit are useful in estimating currents in parallel circuits.

SUMMARY

There are three important relationships in the parallel circuit which hold true regardless of the number of resistors in the circuit.

1. **The same value of voltage is applied to each of the branches in the circuit.**
2. **The total current flow is equal to the sum of the individual branch currents. The current is equal to the applied voltage divided by the total resistance.**
3. **The total resistance is equal to the reciprocal of the sum of the reciprocals.**

Each of the paths for current flow is called a branch. The current through each path is called the branch current.

You have verified each of the three basic relationships by performing actual measurements.

The higher the resistance in a parallel branch, the lower will be the current. The currents in the branches of a parallel circuit are inversely proportional to the resistances of the branches.

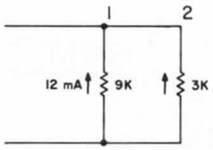
$$\frac{I_1}{I_2} = \frac{R_2}{R_1}$$

The parallel-resistor current rule can be used to calculate or estimate the branch currents in a parallel circuit.

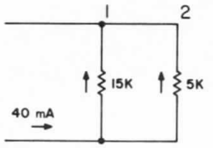
$$I_1 = I_T \frac{R2}{R1 + R2}$$

QUESTIONS

1. *What is the total resistance of a circuit with resistors of 20K, 20K, and 10K in parallel?*
2. *Draw the schematic diagram of the above circuit with a 40-volt DC source.*
3. *Calculate the values of the branch currents and total current in the above circuit.*
4. *In the circuit shown below calculate the current through branch 2. What is the total current flow?*



5. *In the circuit shown below calculate the current through branch 2 using the parallel-resistor current rule. What is the current in branch 1?*



CHAPTER 10

SERIES-PARALLEL CIRCUITS

In the previous two chapters you learned about simple series and parallel circuits. Many of the circuits used in electronics are made up of combinations of series and parallel circuits. These combinations are referred to as series-parallel circuits.

An example of a series-parallel circuit is shown in Figure 10-1. In this circuit there are two resistors in series between points A and B and two resistors in parallel between points B and C. In analyzing circuits of this type we are usually concerned with the total current drawn from the supply and the amount of voltage across various parts of the circuit. The analysis of this type of circuit consists of proceeding in an orderly manner to reduce each section of the circuit to a single equivalent resistance, and then combining these into one equivalent resistance for the entire circuit.

Recall that resistors in series can be represented by a single equivalent resistance equal to the sum of the resistances. This is illustrated in Figure 10-2. This sum for the two series resistances in our example is $R_{AB} = R1 + R2 = 8K + 6K = 14K$ ohms.

Resistors in parallel can also be represented by a single equivalent resistance equal to the reciprocal of the sum of the reciprocals or the product over the sum. This is illustrated in

Figure 10-3. This equivalent resistance for the two parallel resistances in our example is

$$R_{BC} = \frac{R3 \times R4}{R3 + R4} = \frac{9K \times 18K}{9K + 18K} = 6K \text{ ohms.}$$

These equivalent resistances are then effectively connected as shown in Figure 10-4. Notice that we have reduced the

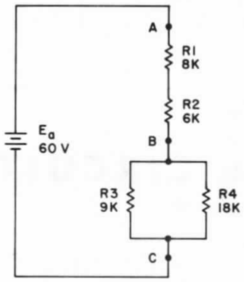


Figure 10-1. An example of a series-parallel circuit.

circuit to two resistances in series. We can combine these two into a single equivalent resistance, $R_{AC} = R_{AB} + R_{BC} = 14K + 6K = 20K$ ohms (Figure 10-5).

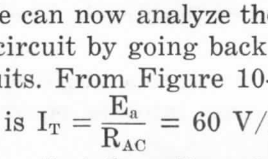


Figure 10-2. Resistances in series can be represented by an equivalent resistance.

We can now analyze the current and voltage distribution in our circuit by going back step by step through our equivalent circuits. From Figure 10-5 we can see that the total current flow is $I_T = \frac{E_a}{R_{AC}} = 60\ V/20K = 3$ mA. From Figure 10-4 we can see that the voltage drop between points A and B is $E_{AB} = I_T R_{AB} = 3\ mA \times 14K = 42$ V. The voltage drop between points

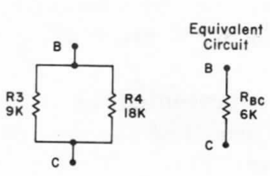


Figure 10-3. Resistors in parallel can also be represented by an equivalent resistance.

B and C is $E_{BC} = E_a - E_{AB} = 60 - 42 = 18$ V. These voltage drops are indicated in Figure 10-6.

The total current of 3 mA divides between R3 and R4.

$$I_3 = \frac{E_{BC}}{R3} = 18\ V/9K = 2\ mA.$$

$$I_4 = I_T - I_3 = 3\ mA - 2\ mA = 1\ mA$$

The voltage drop across R2 is $E_{R2} = I_TR2 = 3\ mA \times 6K = 18$ V. The drop across R1 is $E_{R1} = I_TR1 = 3\ mA \times 8K = 24$ V.

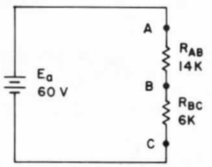


Figure 10-4. Equivalent circuit of Figure 10-1.

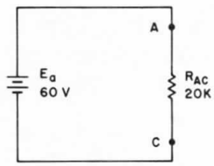
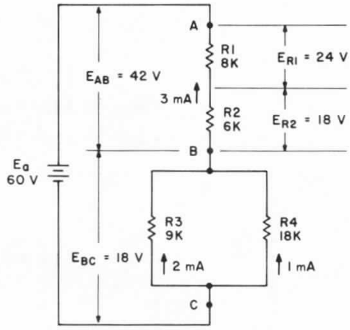


Figure 10-5. Equivalent circuit of Figure 10-4.

By following an orderly step-by-step procedure we have been able to determine the current and voltage for each resistor in the circuit.

Let's try another possible series-parallel combination. Figure 10-7 shows a circuit with two parallel branches, each con-

Figure 10-6. Various voltage drops in the circuit.



sisting of several series resistors. Each branch can be reduced to a single equivalent resistance. For branch 1, $R_{B1} = R1 + R2 + R3 = 22K + 10K + 15K = 47K$ ohms. For branch 2, $R_{B2} = R4 + R5 = 47K + 47K = 94K$ ohms. This reduces our original circuit to that shown in Figure 10-8. The two equivalent resist-

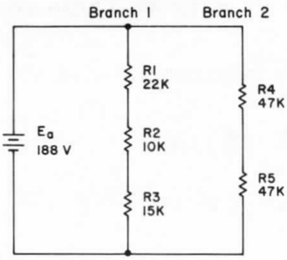


Figure 10-7. Circuit with two parallel branches.

ances can be combined into one. $R_{eq} = \frac{R_{B1} \times R_{B2}}{R_{B1} + R_{B2}} = \frac{47K \times 94K}{47K + 94K}$ = 31.3K ohms. This is shown in Figure 10-9.

Now let's figure out the currents and voltages in each part of the circuit. The total current is

$$I_T = \frac{E_a}{R_{eq}} = 88\ V/31.3K = 6\ mA.$$

From the circuit of Figure 10-8 we can see that the current in branch 1 is,

$$I_1 = \frac{E_a}{R_{B1}} = 188\ V/47K = 4\ mA.$$

The current in branch 2 is, $I_2 = I_T - I_1 = 6 - 4 = 2$ mA. The voltage across each resistor in the original circuit can be calculated as follows (Figure 10-10).

$$E_{R1} = I_1R1 = 4\ mA \times 22K = 88\ V$$
$$E_{R2} = I_1R2 = 4\ mA \times 10K = 40\ V$$
$$E_{R3} = I_1R3 = 4\ mA \times 15K = 60\ V$$
$$E_{R4} = I_2R4 = 2\ mA \times 47K = 94\ V$$
$$E_{R5} = I_2R5 = 2\ mA \times 47K = 94\ V$$

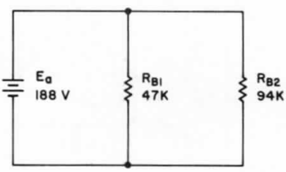


Figure 10-8. Equivalent circuit of Figure 10-7.

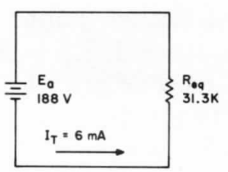


Figure 10-9. Equivalent resistance of two resistances in Figure 10-8.

We are going to look at one more example of a series-parallel circuit and analyze it entirely by means of measurements. The circuit of Figure 10-11 consists of two groups of parallel resistors connected in series. Use your Experimenters P-box and connect the circuit together as shown in Figure 10-12. You can use the same terminal locations as in the last chapter. Use your ohmmeter and measure the resistance between points A and B

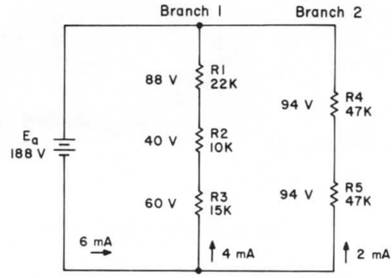


Figure 10-10. Calculating voltage drop across each resistor.

(Figure 10-11), R_{AB} = ____________ ohms. This is the equivalent resistance of R1 and R2 in parallel. Measure the resistance between points B and C, R_{BC} = ____________ ohms. This is the equivalent resistance of R3, R4, and R5 in parallel. Now measure the resistance between points A and C, R_{AC} = ____________ ohms. This is the equivalent resistance of the entire circuit.

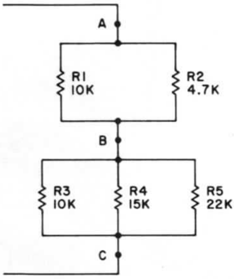


Figure 10-11. Two groups of parallel resistors connected in series.

Connect the circuit to the power supply with the VOM included to measure the total current. Adjust the power supply for 18 V output and measure the current flow, I_T = ____________ mA. Replace the VOM connection to the power supply with a test lead jumper cable or a piece of hookup wire. Use

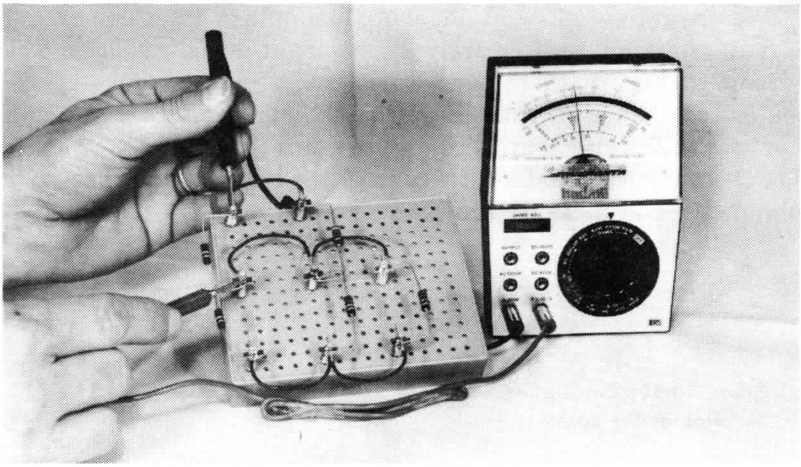


Figure 10-12. Hookup of circuit shown in Figure 10-11.

the VOM and measure the voltage between points A and B, E_{AB} = ________________ volts, and between points B and C, E_{BC} = ________________ volts.

Measure the current through each resistor by lifting one end of each resistor (only one at a time, of course) and connect the VOM as shown in Figure 10-13. Record the values below.

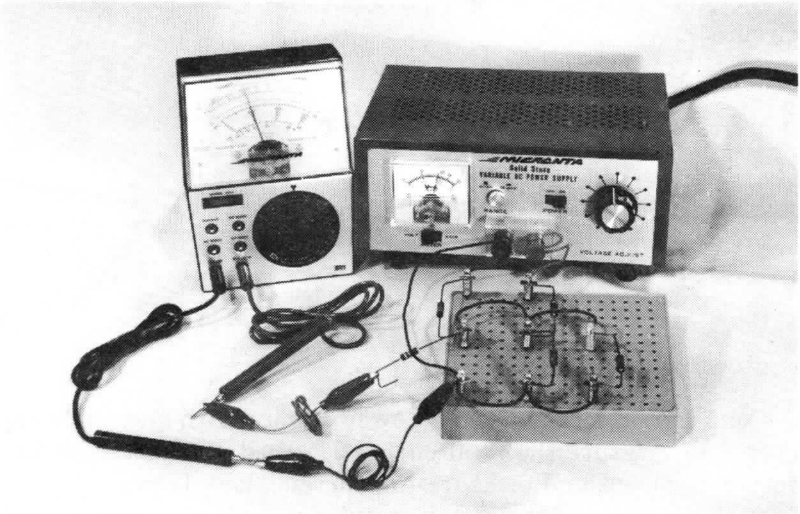


Figure 10-13. Measuring current through individual resistors.

I_{R1} = ______________ mA
I_{R2} = ______________ mA
I_{R3} = ______________ mA
I_{R4} = ______________ mA
I_{R5} = ______________ mA

A repairman or technician will probably use the measurement method more than the calculation method to find values of resistance, voltage and current. After all, if it can be easily measured, why bother calculating it? For example, one ohmmeter measurement of a dozen parallel resistors takes a lot less time than calculating the reciprocal of the sum of the reciprocals.

SUMMARY

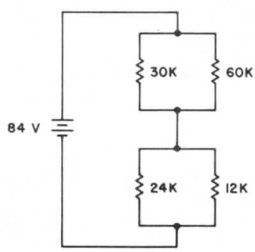
Series-parallel circuits are made up of various combinations of series and parallel resistors. These circuits are analyzed by proceeding in an orderly manner to reduce each section of the circuit to a single equivalent resistance and then combine these into one equivalent resistance for the entire circuit.

Series-parallel circuits can consist of parallel branches containing resistors in series or series-connected groups of parallel resistors or any combination of the two.

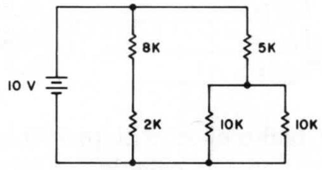
It is possible to analyze this kind of circuit by making calculations on the equivalent circuits or by makng measurements on an actual circuit.

QUESTIONS

1. *For the circuit shown below, find the current through each resistor and the voltage across each resistor. What is the total current flow?*



2. *For the circuit below, calculate the current through each resistor and the voltage across each resistor. What is the total current flow?*

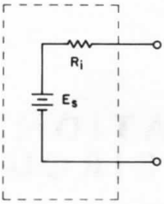


CHAPTER 11

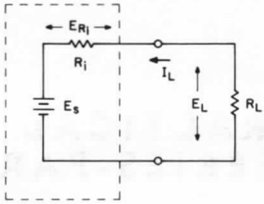
PRACTICAL APPLICATIONS OF SERIES-PARALLEL CIRCUITS

There are some very practical applications of series-parallel circuits which will help you to understand certain circuit peculiarities. You may make a measurement of some circuit voltage or current which seems to be different than what you have calculated or estimated. Assuming that you haven't made a mistake in your calculations, there may be a perfectly logical explanation for the difference. Let's look at some of these possible causes.

So far in our discussions we have considered that all of our voltage sources are constant-voltage devices. That is, we have assumed that regardless of how much current we draw from the source the output voltage will remain the same. In actual practice this is generally not the case. Most DC voltage sources have an internal resistance which causes the actual output voltage of the source to become lower as more current is drawn from the source. The diagram of Figure 11-1A shows the schematic symbol for a DC source in series with its internal resistance, R_i. With no load applied to the source, the output voltage (at the source terminals) is the source voltage, E_S. Since there is no current flow through R_i, there will be no voltage drop across R_i and the terminal voltage will equal the source voltage. However, when we place a load on the source as shown in Figure 11-1B the terminal voltage will be less than the source voltage. The current flowing through R_i produces a voltage drop, $E_i = I_L R_i$. This voltage drop subtracts from E_S so that the load voltage, E_L, will be less than E_S. $E_L = E_S - E_{R_i} = E_S - I_L R_i$. From this relationship we can see that as we draw more current from the source the output voltage will decrease. Let's try an experiment to demonstrate this characteristic. Use the battery holder and two 1½-volt D cells and connect the batteries in series-aiding to provide an output voltage of 3 volts. Refer to



(A) No load applied, no voltage drop.



(B) With load applied, terminal voltage is less than source.

Figure 11-1. Internal voltage drop of power supply.

Figure 3-5 if you want to refresh your memory on connecting the batteries together. Measure the no-load output voltage of the series battery combination, E_S = ______________ volts. Use your Experimenters P-box and connect three 15 ohm resistors in parallel and then connect the 3-volt battery source to the resistors as shown in Figure 11-2. Measure the loaded output voltage of the batteries, E_L = ______________ volts. Disconnect the load as soon as the measurement is made as this is a heavy load on the batteries. Three 15 ohm resistors in parallel have an equivalent resistance of 5 ohms. Calculate the current flow,

$$I_L = \frac{E_L}{R_{eq}} = \frac{\quad}{5} = \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_ A}$$

The voltage drop across the internal resistance of the batteries is equal to the difference between the no-load and loaded output

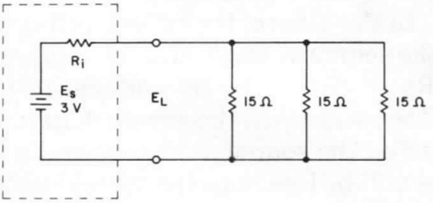


Figure 11-2. Three equal parallel resistors hooked across power supply.

batteries, $E_{R_i} = E_S - E_L =$ ____________ $-$ ____________ $=$ ____________ volts. The internal resistance is,

$$R_i = \frac{E_{R_i}}{I_L} = \_\_\_\_\_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\_\_\_\_\_ \text{ ohms.}$$

Depending on the condition of the batteries, this value of resistance may range from almost zero up to several ohms. As batteries become older the internal resistance keeps increasing until the loaded output voltage is no longer sufficient for proper operation. This is why a battery must be checked under loaded conditions to determine how good it is. Even a very poor flashlight cell will have close to 1½ volts output with no load.

The selenium solar cell which you used in Chapter 3 also has a significant value of internal resistance. Let's see how much. Connect the meter leads to the solar cell leads, red to red and black to black. Hold the solar cell about 6 to 8 inches from a 100-watt light bulb and measure the no-load source voltage. $E_s =$ ____________ volt. Use two of your jumper leads and connect a 100 ohm resistor across the solar cell. Hold the cell about 6 to 8 inches from the 100 watt light bulb and measure the loaded voltage across the resistor. $E_L =$ ____________ volt. This will usually be around 0.1 to 0.2 volt. Calculate the current flow.

$$IL = \frac{E_L}{R_L} = \frac{\quad}{100} = \_\_\_\_\_\_\_\_\_\_\_\_ \text{ mA}$$

Calculate the voltage across the internal resistance of the cell.

$E_{R_i} = E_s - E_L =$ __________ $-$ __________ $=$ __________ volt

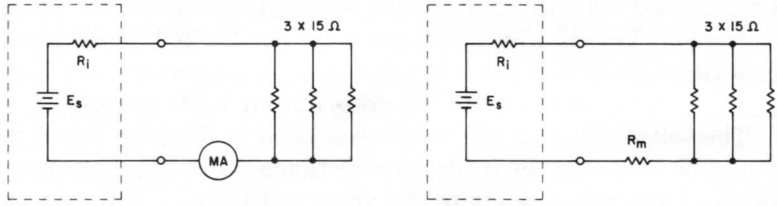
The internal resistance is

$$R_i = \frac{E}{I_L} = \text{---} = \_\_\_\_\_\_\_\_\_\_ \text{ ohms}$$

This value will usually be around 100 to 200 ohms.

Some power supplies also have a significant value of internal resistance which causes the same effect on load voltage. There is a type of power supply, called a voltage regulated power supply, which has a negligible amount of internal resistance. With this type of supply the output voltage remains constant regardless of the amount of current drawn from the supply, as long as the value of current does not exceed the ratings of the supply.

There is another component in the circuit which can cause the circuit conditions to differ from our calculated values. That component is the ammeter or milliammeter which we place in series with the circuit to measure the current. In all our previous diagrams involving an ammeter, we have shown the meter in series with the load and have neglected any affect of this series component on circuit operation (Figure 11-3). In the experiments you have done so far we have selected component



(*A*) *Disregarding meter resistance.* (*B*) *Including meter resistance.*

Figure 11-3. Circuit with current meter inserted.

values and voltage values which have minimized the effect of the meter. However, in actual practice this will not always be the case. The meter has a definite value of resistance usually designated R_m and produces a voltage drop whenever current flows through it. This is illustrated in Figure 11-3B. The drop in the meter resistance, E_{R_m}, also subtracts from the supply voltage leaving less voltage across the load than we thought we had. If we assume that R_i and R_m are each 1/2 ohm, the circuit of Figure 11-3B has an equivalent circuit shown in Figure 11-4. The equivalent load resistance is 5 ohms. The total resistance in the circuit is $R_T = R_i + R_L + R_m = 1/2 + 5 + 1/2 = 6$ ohms. The total current flow is

$$I_L = \frac{E_S}{R_T} = 3\ V/6 = 0.5 \text{ ampere.}$$

The actual load voltage, $E_L = I_L R_L = 0.5 \times 5 = 2.5$ volts. If we

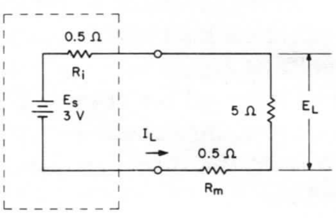
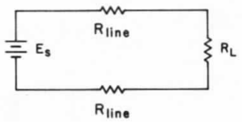


Figure 11-4. Equivalent circuit of Figure 11-3B.

had not taken R_i and R_m into account we would expect the full 3 volts to appear across the load and the current to be 3 V/5 = 0.6 ampere. There is almost a 20% difference between the calculated and the actual values.

Use the 3-volt source and parallel resistor combination from the previous test and insert the VOM in series to read the current. The measured current flow is ____________ A. Notice that this value is less than that calculated previously. The difference is due to the presence of the meter resistance in the circuit.

Figure 11-5. Illustrating resistance of wire in a circuit.



Another cause for reduced voltage across the load is the resistance of the wire connecting the source to the load. This is illustrated in Figure 11-5. If there is a significant amount of line resistance, R_{line}, then a voltage drop will result when current flows. Fortunately in most circuits you will work on, this problem can be neglected. If, however, a long line is necessary, then the resistance of the line must be kept quite low. This is done by using a sufficiently large wire size to conduct the current with a negligible voltage drop.

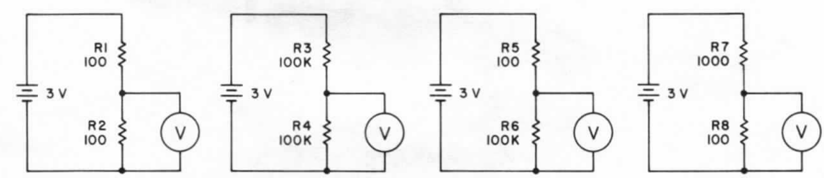


Figure 11-6. Illustrating effect of voltmeter on a circuit.

We have seen how certain series resistances can cause a change in circuit conditions. It is also possible for a parallel resistance to alter the expected conditions in a circuit. One parallel component, whose effect has been neglected so far, is the voltmeter. In all the circuits involving a voltmeter we have simply shown the voltmeter in parallel with a resistance and have not considered any effect which the voltmeter may have on the circuit. This is illustrated in Figure 11-6. For each circuit we could calculate the expected voltage reading using the potentiometer rule.

Circuit a

$$E_{R2} = E_a \frac{R2}{R1 + R2} = 3 \frac{100}{200} = 1.5\ V$$

Circuit b

$$E_{R4} = E_a \frac{R4}{R3 + R4} = 3 \frac{100K}{200K} = 1.5\ V$$

Circuit c

$$E_{R6} = E_a \frac{R6}{R5 + R6} = 3 \frac{100K}{100.1K} \approx 3\ V$$

Circuit d

$$E_{R8} = E_a \frac{R8}{R7 + R8} = 3 \frac{100}{1100} \approx 0.27\ V$$

Let's see if these values can be verified with the voltmeter. Use your Experimenter's P-box again to set up the four series-

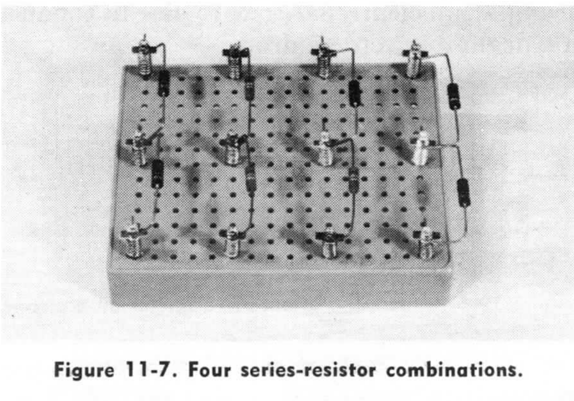


Figure 11-7. Four series-resistor combinations.

resistor combinations as shown in Figure 11-7. You may locate the terminals in A1, 6, 11, 16; G 1, 6, 11, 16; M 1, 6, 11, 16. Use two 1½-volt D cells in the battery holder to provide a 3-volt source. Connect the 3-volt source to each pair of resistors in turn and measure the voltage across the bottom resistor of each pair with the 3-volt range of your VOM

Measured Value	Calculated Value
E_{R2} = ____________ V	1.5 V
E_{R4} = ____________ V	1.5 V
E_{R6} = ____________ V	3.0 V
E_{R8} = ____________ V	0.27 V

By comparing the measured and calculated values we can see that it is possible for the voltmeter to have an effect on the reading. This effect is commonly called *voltmeter loading* or just simply *loading*. This loading effect can be explained quite logically.

In order for the voltmeter needle to move up-scale a small amount of current must be drawn from the circuit. Since current is drawn from the circuit, the voltmeter can be represented as a resistance. The amount of current taken by the voltmeter and its effective resistance are dependent upon the construction of the meter. The amount of resistance in the voltmeter is generally expressed in terms of its *ohms-per-volt sensitivity*. This simply means that for each volt of full-scale calibration, the meter will have a certain amount of resistance. Note: This meter resistance is not dependent on the meter reading but the full-scale calibration only. Therefore, to find the resistance of any voltmeter range simply multiply the full-scale calibration times the ohms-per-volt sensitivity rating of the meter. The Radio Shack meter which we have been describing has an ohms-per-volt sensitivity rating of 20,000 ohms-per-volt. On the 3-volt range of this meter the meter resistance of the voltmeter is $3 \times 20{,}000 = 60{,}000$ ohms. On the 100-volt range the resistance is $100 \times 20{,}000 = 2$ megohms.

Recall that when two resistances are connected in parallel, the total resistance is less than either of the two resistances. Anytime we connect the voltmeter across a resistance the effective resistance of the combination is lowered. The effect which this will have on the voltage distribution in a circuit depends on the value of the resistance across which the meter is connected and the value of any other series resistance in the same circuit. Refer to the comparison of measured and calculated values that you recorded earlier. Notice that the measured voltage across R4 is considerably less than the calculated value. The values of measured voltage on the other three resistors agree closely with the calculated values. Let's see why the

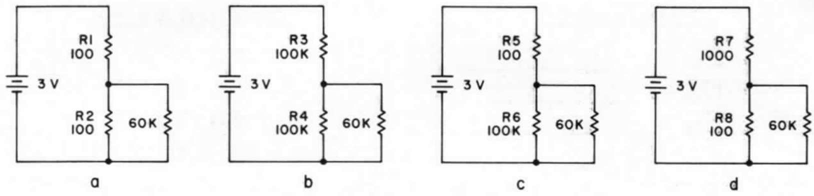


Figure 11-8. Circuit of Figure 11-6 redrawn.

readings are accurate in some cases and not in others. We can redraw the circuits of Figure 11-6 showing the 60,000-ohm voltmeter resistance across each circuit (Figure 11-8). If we calculate the equivalent resistance of each parallel combination the circuits can be reduced to those shown in Figure 11-9.

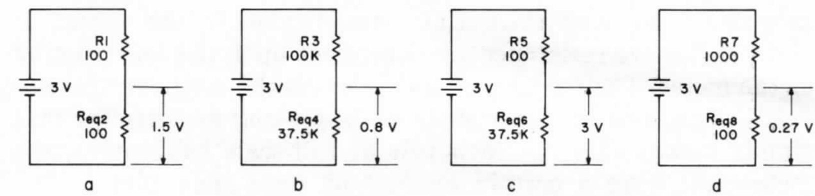


Figure 11-9. Circuit of Figure 11-8 redrawn.

If we apply the potentiometer rule to the circuits of Figure 11-9 we can calculate the expected voltage across the resistors.

Circuit a

$$E'_{R2} = E_a \frac{R_{eq2}}{R_{eq2} + R1} = 3\frac{100}{200} = 1.5 \text{ V}$$

Circuit b

$$E'_{R4} = E_a \frac{R_{eq4}}{R_{qe4} + R3} = 3\frac{37.5K}{137.5K} = 0.82 \text{ V}$$

Circuit c

$$E'_{R6} = E_a \frac{R_{eq6}}{R_{eq6} + R5} = 3\frac{37.5K}{37.6K} \approx 3 \text{ V}$$

Circuit d

$$E'_{R8} = E_a \frac{R_{eq8}}{R_{eq8} + R7} = 3\frac{100}{1100} = 0.27 \text{ V}$$

These values should agree closely with the measured values recorded earlier.

The question may have come to your mind, "How can I tell when the meter loading effect is negligible, and when it is significant?" There is a simple way to tell. Find the parallel equivalent resistance of the two original resistors and compare this value to the meter resistance. If the meter resistance is at least 100 times greater than the equivalent parallel resistance the loading effect can be neglected. The lower the ratio of meter resistance to equivalent parallel resistance, the more pronounced will be the loading effect and the greater will be the error in the meter reading. Let's apply this test to our circuits. In circuit a, the parallel equivalent of R1 and R2 is

$$R_{eq} = \frac{R1 \times R2}{R1 + R2} = \frac{100 \times 100}{100 + 100} = 50 \text{ ohms.}$$

The ratio of meter resistance to equivalent resistance is $\frac{60000}{50} = 1200$. In this circuit the loading is negligible. In circuit b the parallel equivalent of R3 and R4 is 50K ohms. The ratio is $\frac{60000}{50000} = 1.2$. In this circuit the loading effect is quite noticeable as you have already discovered. In circuit c the parallel equivalent resistance is 100 ohms and the ratio is 6000. Again the loading effect is negligible. In circuit d the parallel equivalent resistance is 91 ohms and the ratio is approximately 660. The loading effect is negligible. The explanation of this relationship involves some concepts that are a bit more complicated than you have studied so far. For now it is sufficient that you know how to tell if the loading effect can be neglected.

SUMMARY

Series-parallel circuits are made up of various combinations of series and parallel resistors. These circuits are analyzed by proceeding in an orderly manner to reduce each section of the circuit to a single equivalent resistance and then combine these into one equivalent resistance for the entire circuit. Series-parallel circuits can consist of parallel branches containing resistors in series or series-connected groups of parallel resistors or any combination of the two. It is possible to analyze this kind of circuit by making calculations on the equvalent circuits or by making measurements on an actual circuit.

There are several circuit conditions which can make the operation of an actual circuit differ from what we expect. One of these is the internal resistance of the source. This resistance causes the output voltage of the source to become lower as more current is drawn from the source. A regulated power supply has a negligible amount of internal resistance and the output voltage remains constant as varying amounts of current are drawn from the supply.

Another reason for unexpected circuit operation is the resistance of the current meter. This resistance increases the total circuit resistance and causes the current to be less than in the unmetered circuit.

Any resistance in the wire connecting the source to the circuit causes the same effect on circuit operation as the source internal resistance or ammeter resistance.

The voltmeter can also cause a meter loading effect which causes the voltage read on the meter to be less than the unmetered voltage value. If the ratio of meter resistance to the equivalent parallel resistance of the circuit is at least 100 the meter loading is negligible.

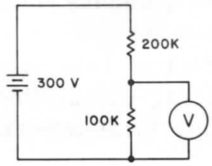
The resistance of a voltmeter is found by multiplying its ohms-per-volt sensitivity rating times the full-scale voltage calibration.

QUESTIONS

1. *The no-load voltage of a voltage source is 12 volts. When a 100-ohm load is placed across this source the load voltage is 10 volts. What is the internal resistance of the source?*

2. *A milliammeter is placed in series with a 450-ohm load across a 6-volt battery with negligible internal resistance. The meter indicates a current of 10 mA. What is the internal resistance of the meter? What value of current would flow if the meter were not in the circuit?*

3. *A 10,000-ohms-per-volt meter with a full-scale calibration of 10 volts is placed across a circuit as shown below. What voltage will be indicated on the meter? What is the unmetered voltage across the 100K resistor?*



CHAPTER 12

POWER AND ENERGY

In our previous considerations of DC circuits we have been dealing with the relationships between voltage, current, and resistance. There are two more circuit parameters which are also important to your understanding of circuits. These are *energy* and *power*. Energy is defined as the ability to do work. Work is defined as the useful transformation of energy from one form to another. One of the fundamental laws of physics is the law of conservation of energy which states that energy can neither be created nor destroyed. It can only be changed from one form to another. You are probably familiar with the more common forms of energy. These are electrical, mechanical, light, heat, chemical, and atomic. Work is done when electrical energy is transformed into mechanical energy in an electric motor. Work is done when electrical energy is converted into light energy in a light bulb. Work is done when the chemical energy stored in your body is converted to mechanical energy when you pick up a box and move it from one place to another.

Energy and work are usually designated by the same unit of measure. In a mechanical system the energy required to move an object is the product of the weight of the object times the distance it is moved. If a 10-pound box is moved a distance of 4 feet the work done and the energy required to perform this work is equal to $10 \times 4 = 40$ foot pounds.

Power may be defined as either the rate at which work is done or the rate at which energy is converted from one form to another. In considering mechanical energy and power, the most familiar unit of power is the horsepower. Many years ago it was determined that the average work horse was capable of doing work at the rate of about 550 foot-pounds per second. This power, or rate of work, was designated as one horsepower, 1 HP. Many mechanical devices are rated in terms of horsepower. Gasoline engines are rated as having a certain horsepower. A lawn mower engine, for example, is rated around 2 to 3 horsepower.

In an electrical circuit, work is done whenever electrons are forced to flow through a resistance. The work performed is the conversion of electrical energy into heat. The amount of work done, and thus the energy required, is dependent upon the amount or quantity of electrons moved and the potential required to move them through the resistance. In Chapter 4 you learned about the relationship between current and quantity of electrons. The quantity or charge of electrons is the amount of electrons passing a point in a certain time and is given by the relationship

$$Q = It.$$

The energy or work in an electrical circuit is equal to the product of the voltage and the quantity of electrons moved. The letter W is used to stand for both work and energy.

$$W = EQ = EIt$$

Work is equal to the product of voltage in volts, current in amperes, and time in seconds. The unit for both work and energy is called a *joule*. One joule of energy is required for a voltage of 1 volt to cause 1 ampere of current to flow for 1 second. We said that power is the rate at which work is performed or the rate of energy conversion. If we divide the amount of energy used by the length of time involved we can determine the power. The letter P is used to designate power.

$$P = \frac{W}{t} = \frac{EIt}{t} = EI$$

The unit of power in electrical circuits is called a *watt*. A power of 1 watt is indicated when 1 volt causes 1 ampere to flow through a circuit. In the circuit of Figure 12-1 a voltage of 20 volts causes a current of 2 amperes to flow through the 10 ohm resistor. The circuit power is

$$P = EI = 20 \times 2 = 40 \text{ watts.}$$

We can say that energy is being converted from electrical to heat energy at a rate of 40 watts per second. The term dissipation is generally used to describe the conversion of electrical energy to heat. In this example the resistor is dissipating 40 watts of power.

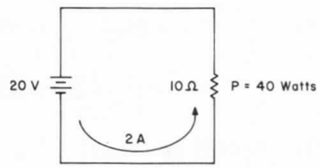


Figure 12-1. The power expended in this circuit is 40 watts.

The basic unit of power is the watt. As with other units there are times when the basic unit is not convenient and smaller or larger units can be used. For small amounts of power it is sometimes easier to use the milliwatt (mW) or the microwatt (μW). A milliwatt is equal to $\frac{1}{1000}$ of a watt. A microwatt is equal to $\frac{1}{1,000,000}$ of a watt. For large amounts of power the kilowatt (kW) is used. A kilowatt is equal to 1000 watts. The chart of Figure 12-2 shows the relationships for converting from one unit to another. For example, a power

To Convert	Multiply	Move Decimal Point
W to mW	W $\times$ 10^3	3 places to right
W to μW	W $\times$ 10^6	6 places to right
W to kW	W $\times$ 10^{-3}	3 places to left
mW to W	mW $\times$ 10^{-3}	3 places to left
mW to μW	mW $\times$ 10^3	3 places to right
μW to W	μW $\times$ 10^{-6}	6 places to left
μW to mW	μW $\times$ 10^{-3}	3 places to left
kW to W	kW $\times$ 10^3	3 places to right

Figure 12-2. Relationship between units of power.

of 0.023 watt is equal to 23 mW. A power of 3500 watts is equal to 3.5 kW.

There are two other ways of calculating the power dissipated in a resistance. Since E = IR we can substitute the expression IR for E in the power formula and obtain

$$P = EI = IRI = I^2R$$

In the circuit of Figure 12-1,

$$P = I^2R = 2^2 \times 10 = 40 \text{ watts.}$$

Since I = E/R we can substitute the expression E/R for I in the power formula and obtain

$$P = EI = E\frac{E}{R} = \frac{E^2}{R}$$

In the circuit of Figure 12-1,

$$P = -\frac{E^2}{R} = \frac{20^2}{10} = 40 \text{ watts.}$$

Any of the three forms of the power equation can be used to calculate the power.

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

The choice of formula is usually one of convenience. Use whichever one is the easiest. Let's try a few examples to see how to determine the power in a circuit. In the series circuit of Figure 12-3, the power dissipated in each resistor can be calculated as follows.
The total resistance is

$$R_T = R1 + R2 + R3 = 1 + 2 + 4 = 7K \text{ ohms}$$

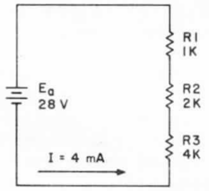


Figure 12-3. Calculate power dissipated in each resistor.

The total current flow is

$$I = \frac{E_a}{R_T} = \frac{28}{7K} = 4 \text{ mA}$$

The power dissipated in each resistor is

$$P_{R1} = I^2R1 = (4 \times 10^{-3})^2\, 1 \times 10^3 = 0.016 \text{ watt} = 16 \text{ mW}$$
$$P_{R2} = I^2R2 = (4 \times 10^{-3})^2\, 2 \times 10^3 = 0.032 \text{ watt} = 32 \text{ mW}$$
$$P_{R3} = I^2R3 = (4 \times 10^{-3})^2\, 4 \times 10^3 = 0.064 \text{ watt} = 64 \text{ mW}$$

The total circuit power is

$$P_T = E_aI = 28 \times 4 \times 10^{-3} = 0.112 \text{ watt} = 112 \text{ mW}$$

Notice that if we add the values of power dissipated in each resistor we obtain this same total circuit power.

$$P_T = P_{R1} + P_{R2} + P_{R3} = 16 + 32 + 64 = 112 \text{ mW}$$

In a series circuit such as this the power dissipated among the resistors, with the highest power dissipated in the highest value of resistance. The power dissipated in the 4K resistor is 4 times the power dissipated in the 1K resistor.

Consider the parallel circuit shown in Figure 12-4. In a parallel circuit it is usually easiest to use the E^2/R form of the power formula because the voltage is the same for all the resistances. The power dissipated in each resistor can be calculated as follows.

$$P_{R1} = \frac{E_a^2}{R1} = \frac{40^2}{1K} = \frac{1600}{1000} = 1.6 \text{ watts}$$
$$P_{R2} = \frac{E_a^2}{R2} = \frac{40^2}{2K} = \frac{1600}{2000} = 0.8 \text{ watt}$$
$$P_{R3} = \frac{E_a^2}{R3} = \frac{40^2}{4K} = \frac{1600}{4000} = 0.4 \text{ watt}$$

The total power in the circuit is

$$P_T = E_aI_T = 40 \text{ V} \times 0.07 \text{ A} = 2.8 \text{ watts}$$

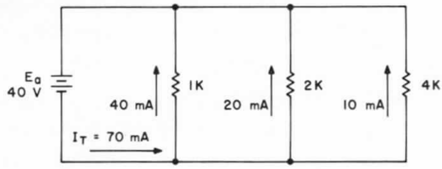


Figure 12-4. Calculate power dissipated in each resistor in this parallel circuit.

Notice that if we add the values of power dissipated in each resistor we obtain this same total circuit power.

$$P_T = P_{R1} + P_{R2} + P_{R3} = 1.6 + 0.8 + 0.4 = 2.8 \text{ watts}$$

In a parallel circuit the power is distributed among the resistances with the highest power dissipated in the smallest value of resistance. The power dissipated in the 1K resistor is 4 times the power dissipated in the 4K resistor.

If we wanted to calculate the amount of energy dissipated in either of the above circuits we could do so by multiplying the power by the amount of time that power is dissipated. This is expressed in the relationship

$$W = Pt$$

In the parallel circuit of Figure 12-4 the power dissipated is 2.8 watts. If the circuit was turned on for a total of 10 seconds the energy converted to heat would be

$$W = Pt = 2.8 \times 10 = 28 \text{ watt seconds (joules)}$$

The unit of energy used here is the *watt second*. One watt second is equivalent to one joule.

The electric power companies charge their customers for the total amount of energy that is used each month. The unit of energy which they use is the *kilowatt hour*. Suppose that in your house the power dissipated by all the lights is 1200 watts or 1.2 kilowatts (kW). If all these lights are left on for a period of 3 hours, the total amount of energy used is,

$$W = Pt = 1.2 \times 3 = 3.6 \text{ kilowatt hours (kWh)}.$$

The energy used is indicated by a watt-hour meter similar to the one shown in Figure 12-5. The amount of energy is indicated by the dials on the face of the meter. A reading of the numbers indicated on the dial is taken each month. The difference between the readings at the beginning and end of the month is the actual amount of energy used for that month. This is illustrated by the two sets of dials shown in Figure 12-6. Notice that alternate dials rotate in opposite directions. When reading the dials you must be careful to observe the direction of rotation. The reading for the start of the month is indicated on the top set of dials, 43468 kWh. The reading for the end of the month is indicated on the bottom

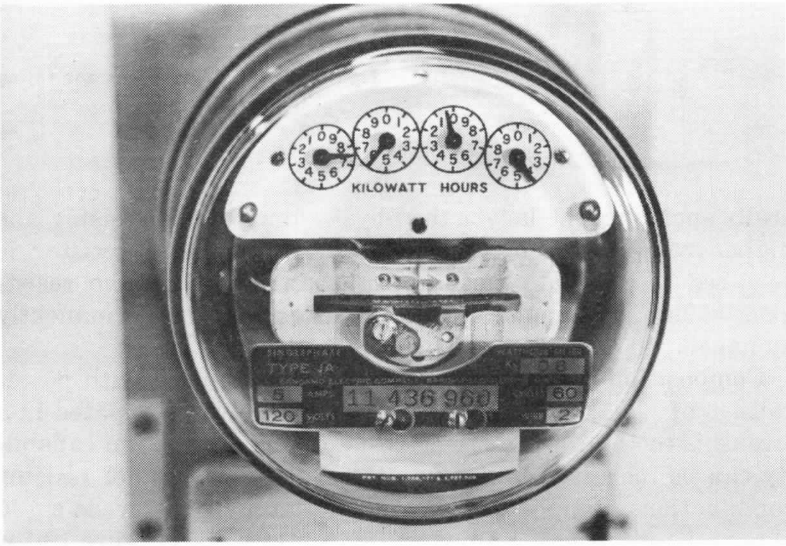


Figure 12-5. A watt-hour meter.

set of dials, 44093 kWh. The difference between the two readings is

$$44093 - 43468 = 624 \text{ kWh}.$$

If the rate is 3¢ for each kWh, then the bill for the month is

$$625 \times 0.03 = \$18.75.$$

Another important consideration of power is the power rating of resistors. When selecting a resistor to be used in a circuit we must not only use the correct value of resistance but the resistor must be able to dissipate the heat developed. Gen-

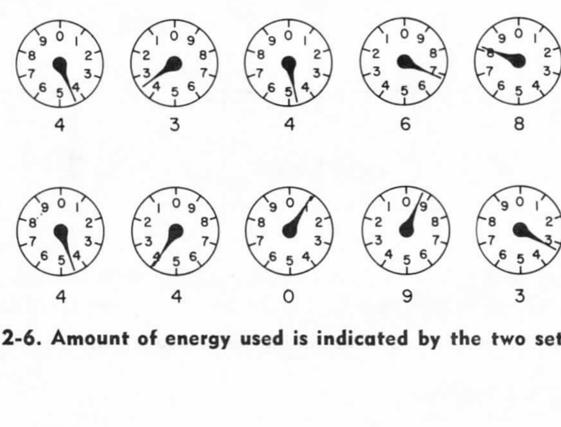


Figure 12-6. Amount of energy used is indicated by the two sets of dials.

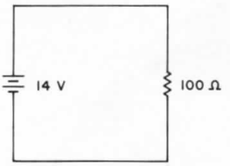


Figure 12-7. Calculate wattage rating for the resistor.

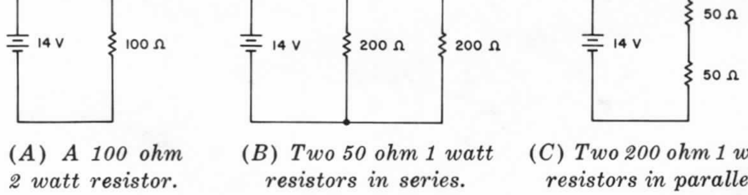
erally speaking, the larger the physical size of the resistor, the higher will be its power-dissipation rating. If a resistor is required to dissipate more power than its rating the resistance value may change and the resistor may be permanently damaged.

Composition carbon resistors are manufactured with power ratings of $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, 1, and 2 watts. If the power dissipated in a circuit is too high for a single resistor, the dissipation capability can be increased by using either series or parallel resistor combinations. Suppose, for example, that a circuit needs a 100 ohm resistor with an applied voltage of 14 volts (Figure 12-7). The power dissipated in the resistor is,

$$P = \frac{E^2}{R} = \frac{14^2}{100} = \frac{196}{100} \approx 2 \text{ watts}$$

If only 1 watt resistors are available, obviously a 100 ohm 1 watt resistor will not be able to dissipate this power without damage to the resistor. If we use two 50 ohm resistors in series, as shown in Figure 12-8B, the total circuit resistance will be the same but each resistor will dissipate only half of the power. This is calculated as follows. Since the resistances are equal, 7 volts will appear across each one. The power in each resistor is

$$P \approx \frac{E^2}{R} = \frac{7^2}{50} = \frac{49}{50} \approx 1 \text{ watt}$$



(A) A 100 ohm 2 watt resistor. *(B) Two 50 ohm 1 watt resistors in series.* *(C) Two 200 ohm 1 watt resistors in parallel.*

Figure 12-8. Different ways of obtaining necessary wattage for the resistor.

We could also use two 200 ohm resistors in parallel as shown in Figure 12-8C. The total resistance is still 100 ohms. The power dissipated in each resistor is within its rating.

$$P = \frac{E^2}{R} = \frac{14^2}{200} = \frac{196}{200} \approx 1 \text{ watt}$$

It isn't very economical to use too many resistors to obtain a high dissipation capability.

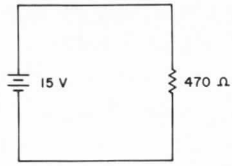


Figure 12-9. Simple series circuit.

If more dissipation is required, wirewound resistors may be used. This type of resistor is manufactured with power ratings from about 1 watt to several hundred watts. These various types and sizes of resistors are illustrated for you in Figure 5-2 in Chapter 5.

Perhaps a little experiment here will give you a better feeling for power dissipation. The resistor kit which you purchased contains ½ watt resistors. Connect a 470 ohm resistor in the simple circuit illustrated in Figure 12-9. The power dissipated in the resistor is

$$P = \frac{E^2}{R} = \frac{15^2}{470} = \frac{225}{470} = 0.48 \text{ watt}$$

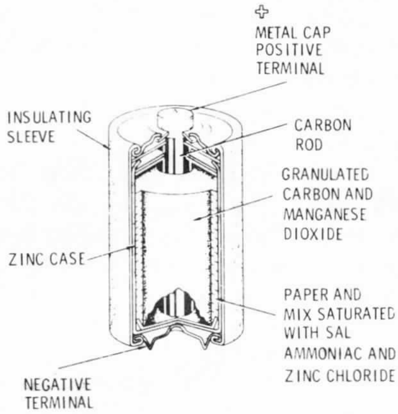


Figure 12-10. Cutaway view of a typical flashlight cell.

This power is very close to the rating of ½ watt. Leave the circuit connected and lightly touch the resistor with your finger to sense the heat dissipated. Now increase the power supply voltage to 21 volts. The power dissipated now is

$$P = \frac{E^2}{R} = \frac{21^2}{470} = \frac{441}{470} = 0.94 \text{ watt}$$

This is approximately twice the rating of the resistor. *Very carefully* touch the resistor with your finger. (Someone has described the finger as a digital wattmeter.) Notice that the resistor is considerably warmer than in the previous test. Disconnect the circuit and allow the resistor to cool off. Measure the resistance with your ohmmeter. If the resistance value has changed significantly from 470 ohms (more than 10%) then perhaps you had better discard it before it gets mixed with the good resistors.

Another circuit component which is affected by dissipation of energy is the battery. A battery provides electrical energy by the reaction of the chemicals and the dissimilar metal electrodes inside the battery. A cutaway view of a typical flashlight cell is shown in Figure 12-10. For a given type of battery the amount of chemical energy available for conversion to electrical energy is dependent upon the size of the battery. The bigger the battery, the more energy it can supply. Batteries are generally rated in terms of the length of time for which they can deliver a crtain amount of current without the output voltage dropping below a specified voltage. The voltage at which the battery is considered to be discharged is called the *endpoint* voltage. For a standard 1½-volt flashlight cell the endpoint voltage is typically between 0.85 V and 1.2 V depending upon the application. Typical ratings for several different sizes and styles of 1½-volt flashlight cells are given in Figure 12-11.

Some batteries are rated in terms of the load resistance which can be placed across the battery for a specified length of time. This rating can be converted to a current rating by using Ohm's law. If a 1½-volt cell is rated for a 5 ohm load for 3 hours with an endpoint voltage of 1 volt, the initial current rating is

$$I = \frac{E}{R} = \frac{1.5}{5} = 0.3 \text{ A} = 300 \text{ mA}$$

Type cell	Size	End point voltage in volts	Number of hours at specified current continuous operation				
			10 mA	20 mA	50 mA	100 mA	300 mA
Standard	AA	0.9	80	30	8.5	–	–
Standard	C	0.9	270	115	3.3	11	–
Standard	D	0.9	745	260	70	24	4.5
Long Life	D	0.9	1800	540	160	84	24

Figure 12-11. Typical ratings for several different sizes and styles of 1.5-volt batteries.

The cell will supply this load for 3 hours before the output voltage drops below 1 volt.

Automotive batteries are rated in terms of ampere hours (Ah). This rating is based on a discharge time of 10 hours. A battery with a rating of 180 Ah is capable of delivering $180/10 = 18$ amperes for a period of 10 hours before it has to be recharged.

Recall from the last chapter that as a battery is delivering energy to a load, the internal resistance of the battery increases and the output voltage will decrease. If the internal resistance becomes too high, the output voltage of the battery will fall below a certain allowable minimum value. Some batteries can be recharged by forcing current to flow through the battery in a reverse direction. This process reduces the internal resistance, restores the internal chemicals to their original condition and the battery is once again capable of supplying energy to a load. As you learned in the previous chapter, the condition of a battery must be checked under loaded conditions.

SUMMARY

Two additional circuit parameters are important to your understanding of circuit operation—energy and power. Energy is defined as the ability to do work. Work is defined as the useful transformation of energy from one form to another. The common forms of energy are electrical, mechanical, light, heat, chemical, and atomic.

Energy and work are designated by the same unit of measure. In mechanical systems they are measured in foot-pounds or some similar unit. In electrical circuits energy is measured in joules or watt-seconds. One joule

(watt-second) of energy is converted when 1 volt causes a current flow of 1 ampere for 1 second. Energy is calculated using the relationship

$$W = EIt$$

Power may be defined as either the rate at which work is done or the rate at which energy is converted from one form to another. In mechanical systems one of the common units of power is the horsepower. One horsepower is equal to a rate of energy conversion of 550 foot-pounds per second. In electrical systems power is measured in watts and is calculated using one of three equations.

$$P = EI$$

$$P = I^2R$$

$$P = \frac{E^2}{R}$$

Other units such as the milliwatt (mW), microwatt (μW), and kilowatt (kW) are used to express power if the basic unit is inconvenient.

Depending upon the application, the energy in an electrical circuit is converted into one or more of the other forms of energy such as mechanical, chemical, light or heat. When current flows through a resistance the energy is converted to heat which must be dissipated by the resistance.

In a series circuit the heat dissipated is distributed among the resistors in dlirect proportion to the values of resistance. The largest resistance dissipates the most heat.

In a parallel circuit the heat dissipated is inversely proportional to the resistance. The smallest resistance dissipates the most heat.

In both series and parallel circuits the total circuit power may be found by adding the values of power dissipated in each individual resistor.

Energy can be calculated using the relationship

$$W = Pt = \text{watt-seconds}$$

Power companies charge their customers for the total amount of energy that is used each month. This is measured in units called kilowatt hours, kWh. A watt-hour meter is used to measure the energy consumed.

The power dissipation rating of a resistor must be considered when selecting a resistor for a particular circuit function. Carbon composition resistors are available with ratings of 1/8, 1/4, 1/2, 1, and 2 watts.

Series and parallel resistor combinations can be used to increase the dissipation capabilities of a circuit. Wirewound resistors provide increased dissipation capabilities wth ratings up to several hundred watts.

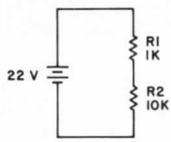
In a brief experiment you determined that a resistor which dissipates more power than its rating becomes quite hot and may even change resistance value.

A battery provides electrical energy by the reaction of the chemicals and the dissimilar metal electrodes in the battery. Cells and batteries are generally rated in terms of the length of time for which they can deliver a certain amount of current without the output voltage dropping below a specified voltage known as the endpoint voltage. Some cells and batteries are rated in terms of the load resistance which can be placed across the battery for a specified length of time. Automobile batteries are rated in terms of the ampere hours.

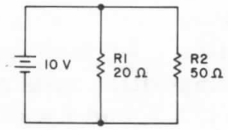
Some cells and batteries can be recharged to restore the internal chemicals and electrodes to their original condition.

QUESTIONS

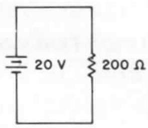
1. *In your own words define energy, work, and power.*
2. *How much energy is supplied by a 9-volt battery which delivers 50 mA to a load for 10 minutes. Express the answer in watt seconds.*
3. *In the circuit below calculate the power in each resistor and the total circuit power.*



4. *In the circuit below calculate the power in each resistor and the total circuit power.*



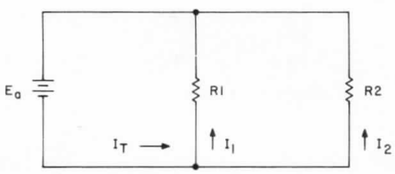
5. *The power dissipated in the resistor in the circuit below is 2 watts. If only 1/2 watt resistors are available, show how either a series or parallel combination of resistors could be used so that dissipation ratings are not exceeded.*



APPENDIX A

DERIVATIONS

1. Equivalent resistance of parallel resistors.



a. The total current is equal to the sum of the branch currents.

$$I_T = I_1 + I_2 + I_3 + \ldots$$

b. The total current is equal to the applied voltage divided by the total resistance. Each branch current is equal to the applied voltage divided by the resistance of the branch. The above equation for total current could be expressed then as,

$$\frac{E_a}{R_T} = \frac{E_a}{R1} + \frac{E_a}{R2} + \frac{E_a}{R3} + \ldots$$

c. Since the voltage, E_a, appears in each term in the expression it can be cancelled out leaving us with

$$\frac{1}{R_T} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \ldots$$

d. By rearranging this expression we get

$$R_T = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \dots}$$

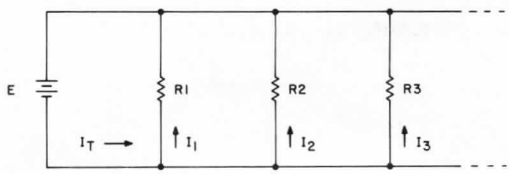
e. When there are only two resistors the basic relationship may be simplified as follows.

$$\frac{1}{R_T} = \frac{1}{R1} + \frac{1}{R2}$$

$$\frac{1}{R_T} = \frac{R1 + R2}{R1 \times R2}$$

$$R_T = \frac{R1 \times R2}{R1 + R2}$$

2. Current relationship in a two-branch parallel circuit.



a. In a parallel circuit the voltage across each branch is the same

$$E_1 = E_2 = E_a$$

$$E_1 = I_1\,R1 \qquad \text{and} \qquad E_2 = I_2\,R2$$

b. Since the voltages are equal we can equate the IR products

$$I_1\,R1 = I_2\,R2$$

c. Rearranging

$$\frac{I_1}{I_2} = \frac{R2}{R1}$$

3. Parallel resistor current rule.

a. The branch voltage is equal to the applied voltage

$$E_a = E_1$$

$$E_a = I_T\,R_T = I_T\,\frac{R1 \times R2}{R1 + R2}$$

$$E_1 = I_1 R1$$

b. The IR products can be equated since the voltages are equal

$$I_1 \, R1 = I_T \frac{R1 \times R2}{R1 + R2}$$

c. Divide both sides of the equation by R1

$$I_1 = I_T \frac{R2}{R1 + R2}$$

APPENDIX B

GLOSSARY

Abscissa—The horizontal axis of a graph. It is called the X axis.

Alternating current (AC)—Current which is continually changing in value and polarity.

Ammeter—An instrument used to measure current. The function of a DC ammeter is included in the VOM.

Ampere—The unit of measure for electric current. One ampere is equal to one coulomb of electrons flowing past a point in one second. One ampere of current will flow when one volt is applied to a one ohm resistance.

Atom—The smallest particle of an element which exhibits all properties of the element. Atoms consist of a nucleus and rings of orbiting electrons.

Battery—A source of DC voltage which is produced by the chemical reaction between the electrodes and the various chemicals within the battery.

Branch—One of the paths for current flow in a parallel circuit.

Calibrations—The numbers and graduation marks printed on a meter scale to indicate the values of the scale readings.

Carbon resistor—A resistor utilizing carbon as the resistance material.

Charge—Another name applied to the quantity of electrons. The letter Q is used for both charge and quantity. The unit of measure is the coulomb.

Circuit—A complete path for the flow of current. A circuit consists of a voltage source and a path through which current can flow. Sometimes this term is used to indicate a specific portion of a complete circuit.

Common—The designation used for the (−) jack on the VOM.

Composition carbon resistor—A resistor using a bulk of carbon as the resistance material.

Conductor—A material which offers a very low resistance path for the flow of current. A conductor is usually in the form of a copper wire or copper strip on a printed circuit board.

Continuity—The continuous conductive path between two points in a circuit.

Conventional current—An antiquated concept of electric current flow. "Conventional current" flows in a direction opposite to that of electron current.

Coulomb—The unit of measure for a quantity of electrons. One coulomb equals 6.28×10^{18} electrons.

Current—The movement of electrons. Current is measured in amperes, milliamperes, or microamperes. The letter I is used to symbolize current.

Direct current (DC)—Current which has a value that is always of the same polarity.

E—The letter E is a symbol used for voltage.

Electron—An extremely small particle with a negative charge. Electron motion around a circuit is called current flow.

Electromotive force (EMF)—The force which causes current to flow in a circuit. Also a term used for a source of voltage. The letters E or V are used to symbolize voltage.

Endpoint voltage—The voltage under load at which a battery is considered to be discharged.

Energy—The ability to do work. The letter W is the symbol used for energy. The joule or watt-second is the basic unit of measure.

Equivalent circuit—A simple circuit used to represent a more complicated circuit for purposes of analysis or calculation.

Equivalent resistance—The single value of resistance which is equal to the resulting resistance of parallel-connected resistors.

Film resistor—A resistor which uses film of carbon or metal oxide as the resistance material.

Graph—A visual presentation of the relationship between two or more measurable quantities.

Hookup wire—Copper wire, covered with plastic insulation, used for connecting components together in an electrical circuit.

I—The letter I is the symbol used for current.

Insulator—Anything which will limit the flow of current to an insignificantly low value.

Intermittent—An erratic condition which occurs during certain mechanical, electrical, or thermal conditions.

Jack—The hole on a VOM into which the test lead is inserted.

Joule—The unit of measure for energy or work.

Kilo—A prefix meaning 1000. Used with various units of measure, such as kilovolts and kilohms. The letter K is used to indicate kilo.

Kilohm ($K\Omega$)—A kilohm is equal to 1000 ohms.

Kilovolt (kV)—A kilovolt is equal to 1000 volts.

Kilowatt hour (kWh)—A unit of energy used in measuring electrical energy.

Leakage—Undesirable current flow in an insulator or insulation.

Leakage path—The undesirable path for current flow in an insulator or insulation.

Leakage resistance—The value of resistance in a leakage path.

Light dependent resistor (LDR)—A resistor having a resistance dependent upon light intensity.

Linear graph—A straight line relationship between two measurable quantities as drawn on a graph.

Loading—The effect of placing a voltmeter or ammeter in a circuit. Loading causes the meter reading to be less than the actual value of voltage or current without the meter in the circuit.

Micro (μ)—A prefix meaning $1/_{1,000,000}$. Used with various units of measure, such as microampere and microvolts. The Greek letter μ (mu) is used to indicate micro.

Microampere (μA)—A microampere is equal to one millionth of an ampere.

Microvolt (μV)—A microvolt is equal to one millionth of a volt.

Milli—A prefix meaning $1/_{1000}$. Used with various units of measure, such as milliampere and millivolt. The letter m is used to indicate milli.

Milliampere (mA)—A milliampere is equal to one thousandth of an ampere.

Millivolt (mV)—A millivolt is equal to one thousandth of a volt.

Milliwatt (mW)—A milliwatt is equal to one thousandth of a watt.

Nano—A prefix meaning $1/_{1,000,000,000}$. Used with various units of measure, such as nanoampere.

Ohm—The unit of measure for resistance. The symbol for ohm is the Greek letter Ω (omega).

Ohmmeter—An instrument used to measure resistance. The ohmmeter function is incorporated in the VOM.

Open circuit—A condition where the path for normal current flow is broken and current can no longer flow.

Ordinate—The vertical axis of a graph. It is also called the Y axis.

P—The letter P is the symbol used for power.

Parallax error—The error introduced by not observing a meter pointer from the proper angle.

Polarity—An electrical condition determining the direction of electron current flow in a circuit.

Potentiometer—A three-terminal variable resistor.

Power (P)—The rate at which energy is converted from one form to another. The symbol for power is P.

Power supply (DC)—A source of DC voltage which converts the 120-volt AC power line voltage to the desired value of DC output voltage.

Printed circuit—A circuit consisting of strips and areas of conductive material, such as copper, bonded to an insulating board, such as phenolic or fiber glass.

Q—The symbol used to indicate the quantity (charge) of electrons.

R—The letter R is the symbol used for resistance.

Range switch—The rotary switch on a VOM which selects the function and full-scale range of the meter.

Resistance—The property of an electrical circuit which determines the amount of current which will flow for a given amount of applied voltage. One volt across one ohm causes one ampere of current flow. The symbol for resistance is R.

Resistivity—The resistance of a unit cube of a material. Resistivity is indicated by the Greek letter ρ (rho).

Resistor—A device which has a resistance value between that of a conductor and that of an insulator.

Rheostat—A two-terminal, variable resistor.

Schematic—A diagram showing the way in which components are connected together to form an electrical circuit.

Short circuit—An abnormal, relatively low resistance connection between two points in a circuit. Excessive current may flow with this condition. Also called a short.

Solar cell—A device having a DC output dependent upon light intensity.

Taper—The manner in which the resistance of a variable resistor varies as the moving contact is rotated on the resistive element.

Thermistor—A resistor whose resistance value is dependent upon the temperature of the resistor.

Thermocouple—A device consisting of two different types of metals which produces a voltage across its terminals when the junction of the two metals is heated.

Tolerance—The amount by which the actual value of a resistor may differ from the rated value. Tolerance is usually expressed as a percentage of the rated value.

V—The letter V is a symbol used for voltage.

Volt—The unit of measure of voltage. One volt across one ohm causes one ampere of current flow. The letters E and V are both used as symbols for voltage.

Voltage dependent resistor (VDR)—A device having a resistance which depends upon the voltage applied to the device. Resistance usually decreases as voltage is increased.

Voltage source—A source of EMF.

Voltmeter—An instrument used to measure voltage. The function of a voltmeter is included in the VOM.

Volt-Ohm-Milliammeter (VOM)—A measuring instrument which contains the function of a voltmeter, an ohmmeter, and a DC milliammeter.

W—The letter W is the symbol used for energy or work

Watt—The unit of measure for electric power. The letter P is used to symbolize power.

Watt-hour meter—An instrument used to measure electrical energy.

Watt-second—A unit of energy equal to a joule.

Wirewound resistor—A resistor constructed of resistance wire which is wound on an insulating bobbin.

Y axis—The vertical axis of a graph. It is also called the ordinate.

X axis—The horizontal axis of a graph. It is also called the abscissa.

APPENDIX C

ANSWERS TO QUESTIONS

CHAPTER 1

1. It causes the current to flow in the circuit.
2. The volt.
3. 1.5 kV, 13.5 kV.
4. 2300 volts, 250,000 volts.
5. 6.7 mV, 324 mV.
6. 0.013 volt, 0.225 volt.
7. 456 μV, 7.8 μV.
8. 0.000027 volt, 0.000532 volt.
9. See Figure 1-3.
10. The values of a pulsating DC voltage are all of the same polarity, whereas the values of an AC voltage change polarity each half cycle to provide both positive and negative polarities.

CHAPTER 2

1. A voltmeter.
2. A volt-ohm-milliammeter. It is an instrument which is capable of measuring voltage, resistance, and current.
3. Jacks, range switch, meter.
4. 125 volts.

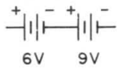
5. a. Insert the test leads in the proper jacks.
   b. Select the proper function and range.
   c. Place the test probe tips across the voltage to be measured.
   d. Notice the position of the pointer on the meter scale and read the value of voltage.

6. a. Start with the range switch in the highest position.
   b. Use the "flick test" to determine if the polarity is correct and the magnitude is within the range of the voltmeter.

7. The "flick" test is used to determine the polarity of a voltage and the relative magnitude without damaging the meter. The tip of the black test probe is placed on one terminal of the voltage being measured. The tip of the red test probe is momentarily tapped on the other terminal. If the pointer flicks slightly up-scale the polarity is correct and the magnitude is safe for that range. If the pointer flicks down-scale the test leads will have to be reversed.

8. This allows the pointer to be lined up properly over the meter scale to avoid the possibility of parallax error.

CHAPTER 3

1. 

2. 15 volts.

3. 6 volts.

4. 3 volts.

5. a. All the batteries must have the same voltage.
   b. All the batteries must have the same polarity.

6. Set the meter range switch in either the OFF position or on the highest DC voltage range.

CHAPTER 4

1. The flow of electrons in a circuit.

2. A voltage source and a complete path for electrons.

3. Current flow will stop.

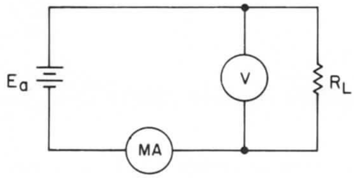
4. There will be a heavy current drain on the voltage source.

5. ½ ampere.

6. 2.6 mA, 2600 μA.

7. 0.106 mA, 0.000106 A.

8.



CHAPTER 5

1. A conductor is anything which can conduct current with a negligible loss of voltage across it.

2. An insulator is anything which can limit the flow of current to an insignificant amount.

3. The basic unit of resistance is the ohm. The resistance in a circuit will determine how much current will flow for a given voltage. For a given voltage the higher the resistance, the lower the current.

4. 470 kilohms, 0.47 megohm.

5. 390,000 ohms, 0.39 megohm.

6. 270KΩ, 10%, 243KΩ to 297KΩ.

7. 0.13 ohm.

8. a. 320 Ω.
   b. 8.9K Ω.
   c. 8.47KΩ.

9. a. 235 Ω.
   b. 250 Ω.
   c. 1.7KΩ.

CHAPTER 6

1. To allow the meter to be set to zero before making a resistance measurement. This calibrates the meter so that readings are accurate.

2. Ohmmeter battery is probably weak and needs to be replaced.

3. a. Select the proper range if known.
   b. Touch the two leads together and adjust the OHMS ADJUST control until the meter reads 0.
   c. Place the test leads across the resistance being measured.
   d. Read the value of resistance on the meter scale.

4. a. R × 100.
   b. R × 1.
   c. R × 1K.
   d. R × 1.

5. So the ohmmeter will not be damaged and to obtain correct ohmmeter readings.

6. 13.5KΩ to 16.5KΩ.

7. A momentary decrease in resistance to zero ohms. R × 1K or highest range.

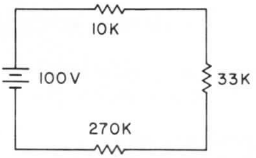
8. A momentary increase in resistance of a conductor to infinity ohms. R × 1.

CHAPTER 7

1. I = E/R, E = IR, R = E/I.
2. 0.19 mA.
3. 65 mA.
4. 200KΩ.
5. 24KΩ.
6. 500 V.
7. 75 V.
8. $R_a = 1K\Omega$, $R_b = 2.5K\Omega$.
9. Doubled.
10. Halved.

CHAPTER 8

1. 313KΩ.
2.



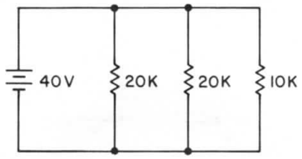
3. 0.32 mA.
4. $E_{10K} = 3.2$ V, $E_{33K} = 10.5$ V, $E_{22K} = 86.3$ V.
5. Potentiometer rule.

$$E_{R1} = \frac{R1}{R_T} E_a.$$

6. 50 V, 25KΩ.
7. 5, yes.

CHAPTER 9

1. $5K\Omega$.
2.



3. Current in each 20K branch is 2 mA, current in the 10K branch is 4 mA, and the total current is 8 mA.
4. 36 mA, 48 mA.
5. 30 mA, 10 mA.

CHAPTER 10

1. $I_{30K} = 2$ mA $E_{30K} = 60$ V $I_T = 3$ mA
   $I_{60K} = 1$ mA $E_{60K} = 60$ V
   $I_{24K} = 1$ mA $E_{24K} = 24$ V
   $I_{12K} = 2$ mA $E_{12K} = 24$ V
2. $I_{8K} = 1$ mA $E_{8K} = 8$ V $I_T = 2$ mA
   $I_{5K} = 1$ mA $E_{5K} = 5$ V
   $I_{2K} = 1$ mA $E_{2K} = 2$ V
   $I_{10K} = 0.5$ mA $E_{10K} = 5$ V

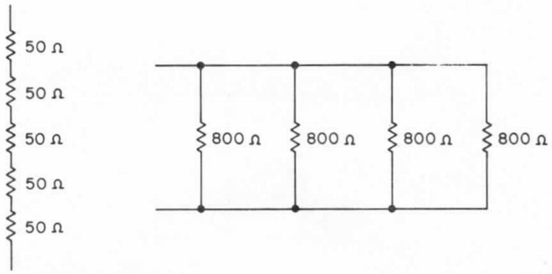
CHAPTER 11

1. 20 Ω.
2. 150 Ω, 13.3 mA.
3. 60 V, 100 V.

CHAPTER 12

1. Energy is the ability to do work.
   Work is the useful transformation of energy from one form to another. Power is the rate at which energy is converted from one form to another.
2. 270 watt seconds.
3. $P_1 = 4$ mW, $P_2 = 40$ mW, $P_T = 44$ mW.
4. $P_1 = 5$ W, $P_2 = 2$ W, $P_T = 7$ W.

5.



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