

LESSON 1 - CIRCUITS AND CIRCUIT ELEMENTS

Objectives:

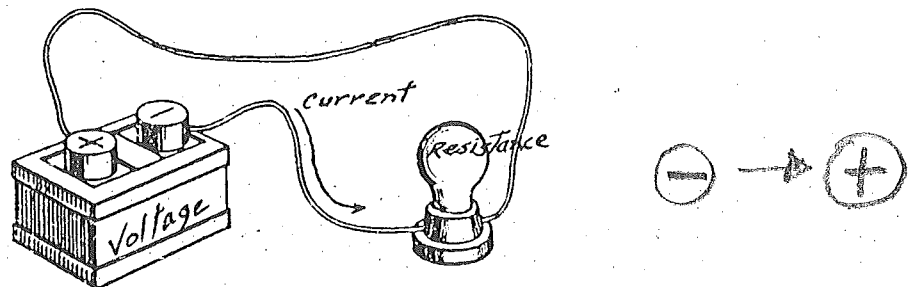
In this lesson you will:

- (a) Learn what an electronic circuit is.
- (b) Learn the meaning of current, voltage and resistance in a circuit.
- (c) Consider the electronic circuit and how it is used in energy conversion.
- (d) Learn how to draw and interpret a schematic diagram.

WHAT IS A CIRCUIT?

In future sections of this unit we will spend most of our time with electronic components. We will explore what they look like, their schematic symbols, how they are rated, and how they function. We will examine how they are selected and manufactured. Before we do this, though, we should devote a bit of time to examining the context in which we will be using the devices, that is, the electronic circuit.

All electronic circuits, no matter how simple or complex, have three factors associated with them. They have current, voltage, and resistance. Current "flows" through conductors, voltage makes the current flow, and resistance opposes or controls the current. The circuit is simply a complete path for current to flow.



Let us look more closely at such a circuit, with emphasis on the "big three", current, voltage, and resistance.

The Electron in Electronics

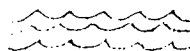
In order to find out about current it is necessary to investigate the electron for it is the movement of free electrons in one direction that constitutes current flow.

Electrons, from which the word electronics is derived, are among the smallest particles known to us. They fit into the scheme of things something like this:

Matter

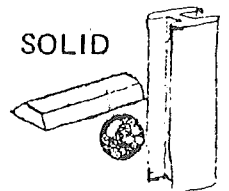
All the universe is made up of matter, something that has mass and occupies space. It is found in gaseous, liquid, or solid state.

LIQUID



GAS

SOLID

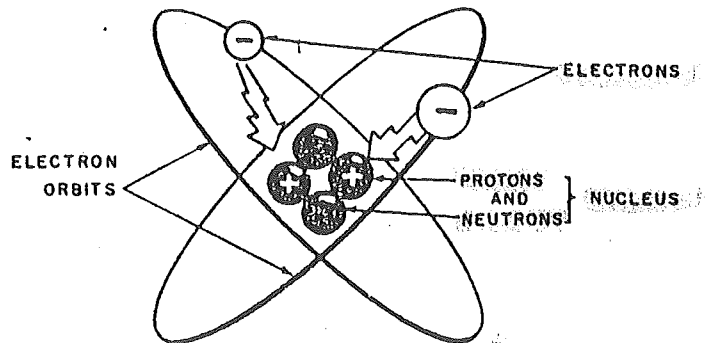


Elements and Atoms

Matter in turn is made up of elements, substances found naturally in the universe, such as carbon, oxygen, copper, etc.

Each element is made up of atoms which are composed of a central core (the nucleus) filled with positively charged particles known as protons, and uncharged particles called neutrons. Surrounding the nucleus, in various orbits, are negatively charged particles called electrons.

All atoms are so constructed, regardless of whether they form hydrogen or gold. The only important difference is in the number of protons and electrons each will have. Hydrogen has one proton and one electron, while gold has seventy-nine of each.

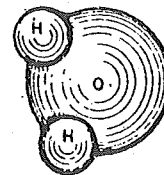


Atomic Structure

Molecules

Different elements often combine to form other substances, such as as water - a combination of two elements, hydrogen and oxygen.

WATER MOLECULE

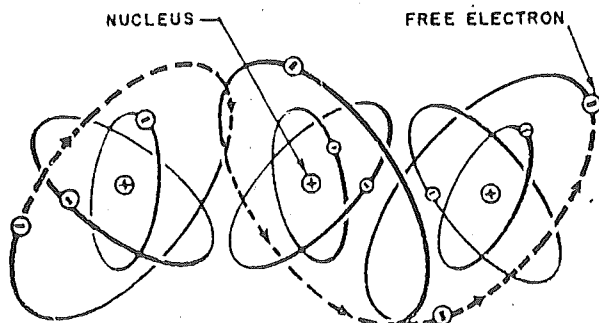


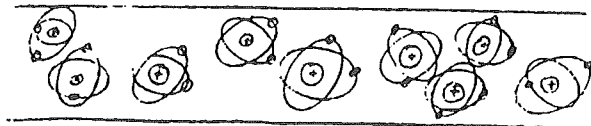
TWO HYDROGEN ATOMS COMBINED WITH ONE OXYGEN ATOM

CURRENT

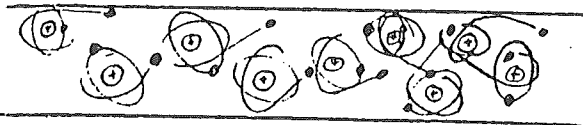
Free Electrons

Not all electrons are the same distance from the nucleus of an atom. Those electrons which are furthest away from the nucleus are held to the atom least tightly. Due to normal thermal agitation (heat) some of these outermost electrons will break away, or become free. They remain free for only a fraction of a second, when they are pulled into other nuclei, yet at any given time there are millions, indeed trillions of free electrons in a particular substance. If we can get these free electrons to move in one direction we have what is known as current.





Rubber - few free electrons



Copper - many free electrons

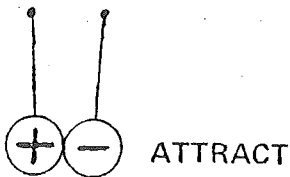
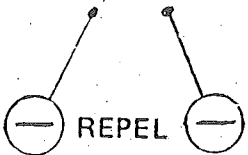
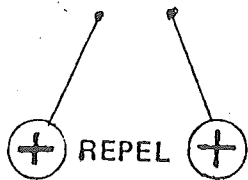
Good Conductors

Some materials have many more free electrons than others. Rubber, for example, has almost none at any temperature, while copper is just loaded with them. Rubber is considered a good insulator to current flow (it has so few free electrons to move.) Yet copper is an excellent conductor.

To get free electrons to move in one direction (current flow) an outside force of some type is needed. The outside force we use is known as voltage.

Voltage

As we have said, at any given time there are trillions of free electrons in a particular material such as copper. (Actually any metal will have countless free electrons.) However these free electrons are "dancing around" in all directions and do not constitute current flow. They must move in one direction before current can be said to exist.



Basic Scientific Law

One way to get them to move in the same direction is to take advantage of a basic scientific law:

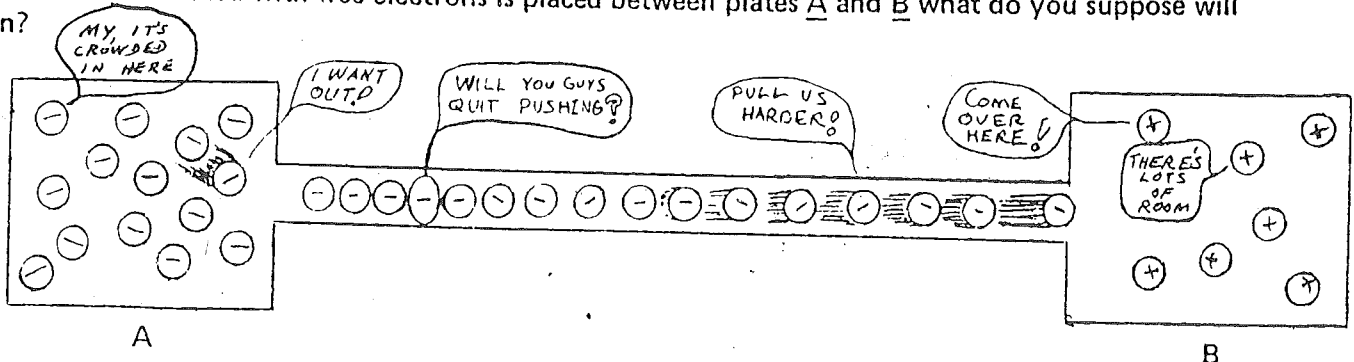
Like charges repel and unlike charges attract.

This means that protons with positive (+) charges will repel each other and electrons with negative (-) charges will repel each other. But when protons are brought near electrons they will attract.

Using this principle we can set up a difference in charge known as voltage, or electro-motive force (EMF). Here's how it works:

If we fill plate A with an excess of electrons, and take an equal number away from plate B we have a difference in charge between the two plates.

If a conductor filled with free electrons is placed between plates A and B what do you suppose will happen?



Well, the electrons on plate A now have a place to go and they start pushing the free electrons in the conductor along—in one direction, (like charges repel.) The protons are eager to aid in the process and pull the free electrons over, (unlike charges attract.)

But It Will Not Last Long

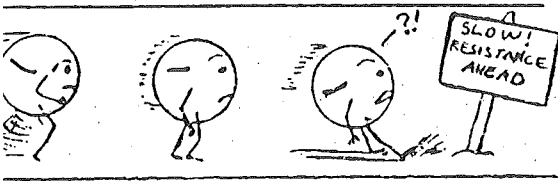
In the above illustration current flow will take place for a very short period of time because there is no way to replenish plate A with a negative charge and plate B with a positive charge. To have a continuous source of voltage this would have to be done. There are currently six popular methods of developing a sustained voltage. They are:

- | | |
|-------------|--------------|
| 1. Friction | 4. Pressure |
| 2. Light | 5. Chemical |
| 3. Heat | 6. Magnetism |

In future lessons we will look into these methods in some detail.

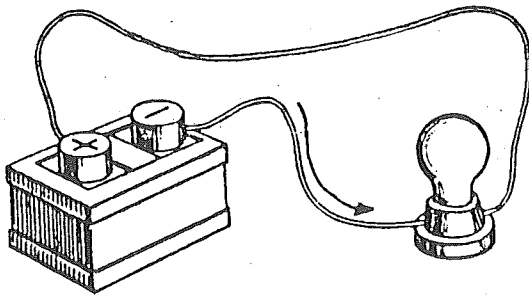
Resistance

We have seen how the movement of free electrons in one direction constitutes current flow, and how a difference in charge, or voltage makes it happen. There will be however, in every circuit, a certain "opposition" to current flow. You can think of it as a "friction" existing in the system. This friction is known as resistance, and is present to some extent even in the best of conductors.



The Complete Circuit

The simple circuit shown here has a source of voltage (the battery), current flowing through the conductors, and resistance in the wires and light bulb. It, along with more complex circuits contains the "big three" in electronics:



Current— Voltage— Resistance.

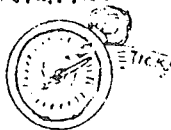
Ampere — The Unit of Measurement

The unit of measurement for current is the ampere. It is related to two factors:

ELECTRONS.

The quantity of free electrons.

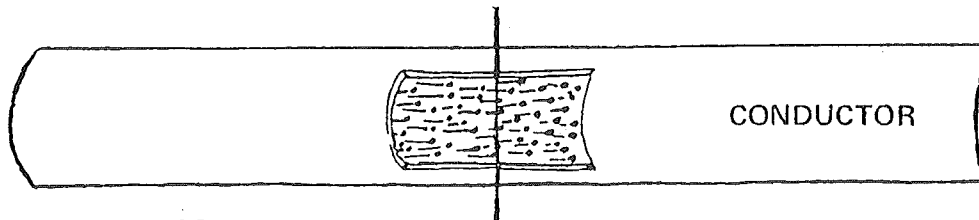
The time in seconds.



An ampere (or amp. for short) is a measurement of a certain number of free electrons (quantity) passing a given point in a conductor in one second (time).

The quantity of free electrons that we are dealing with is very large — 6,280,000,000,000,000,000. (6.28×10^{18}) electrons. Such a large quantity is referred to as a coulomb. A coulomb is 6.28×10^{18} electrons.

If one coulomb passes a given point in one second, we have one ampere of current flow.



6.28×10^{18} Electrons passing in one second is one Ampere

What if there were two coulombs passing in one second? We would have two amperes.

Three coulombs in one second — Three amperes

Two coulombs in two seconds — One ampere

Two coulombs in one half second — Four amperes

THE VOLT

In the bottom picture on page 3, the electrons which have been moved to Plate A have a great deal of what we call potential energy, and the electrons left on plate B have very much less potential energy. Potential energy really relates to the effort required to attach an electron to the surface. Since plate A (negatively charged) repels electrons, a fair bit of effort is required to attach an electron, hence the high potential energy of these electrons. Of course, since plate B is positively charged, we really don't have to expend any effort at all to attach an electron. In fact, a lot of effort is required to remove an electron. Hence we say that there is a potential energy difference between plates A and B.

The metric unit of energy is the joule. It's not a lot of energy.

If you wanted to bring to a boil enough water for a pot of tea, you would require about a quarter of a million joules of electrical energy! Now, if we observe one coulomb of charge moving between



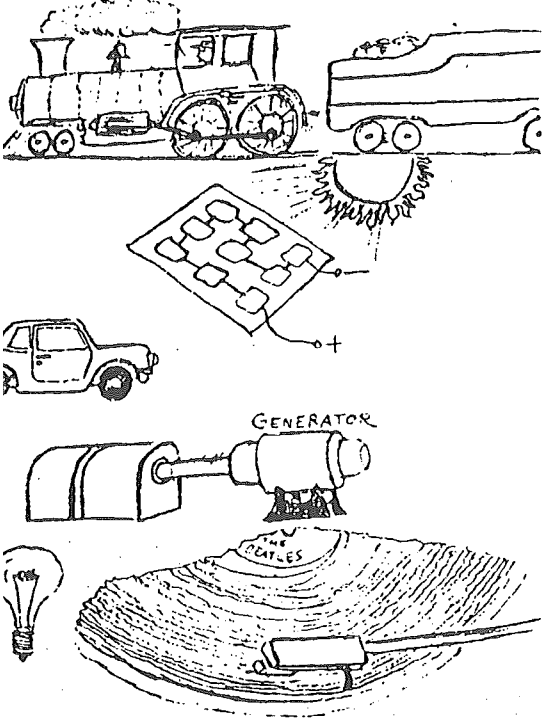
$\frac{1}{4}$ million joules!

two points in a circuit, and we measure a potential energy difference of one joule for that quantity of charge, we say that there is a potential difference of one volt. In other words, one volt of potential difference is equal to an energy change of one joule for each coulomb of charge moved. The term voltage was brought in as an alternative to the term potential difference, and now the two terms are often used interchangeably.

ENERGY TRANSFORMATION

Technological societies can be distinguished from others in their ability to harness and convert various forms of energy.

Below we see illustrated a half dozen forms of energy. Conversion of one form to the other takes place to accomplish things society deems valuable.



- | | | |
|-------------|---|---|
| Heat | — | Warm water creates steam and turns a wheel. |
| Light | — | Photovoltaic cells convert light directly into electricity. |
| Chemical | — | Oil is burned (exploded) to create mechanical motion. |
| Mechanical | — | Rotating turbine produces electricity. |
| Electricity | — | Light bulb converts electricity into light. |
| Magnetism | — | Cartridge converts magnetic energy into electricity. |

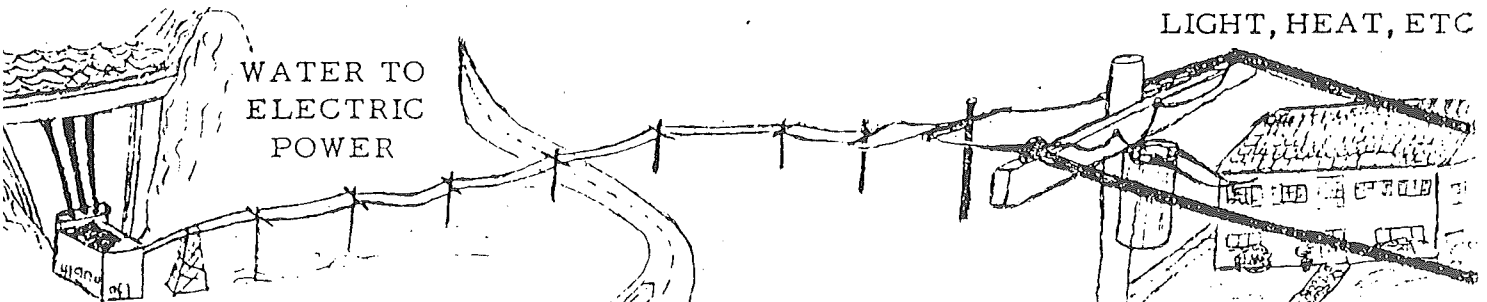
As you can see from the list above, electrical energy (current flow) is mentioned right along with heat, light, mechanical, magnetism, and chemical energy. Yet there is a strange thing about electrical energy: *

* Electrical Energy by itself is practically useless.

That may seem quite surprising at first. But what did electricity ever do for you? Heat can warm you, light will show you the way, mechanical energy will ease your burden— but electricity, what?

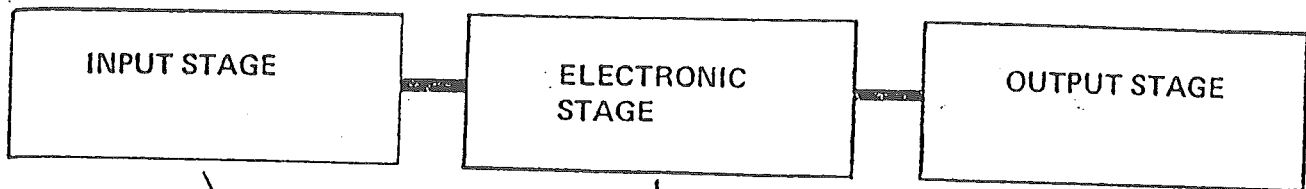
Electrical energy must be converted to another form of energy in order to be useful.

Let us explore this concept a bit further.



The Complete Electronic System

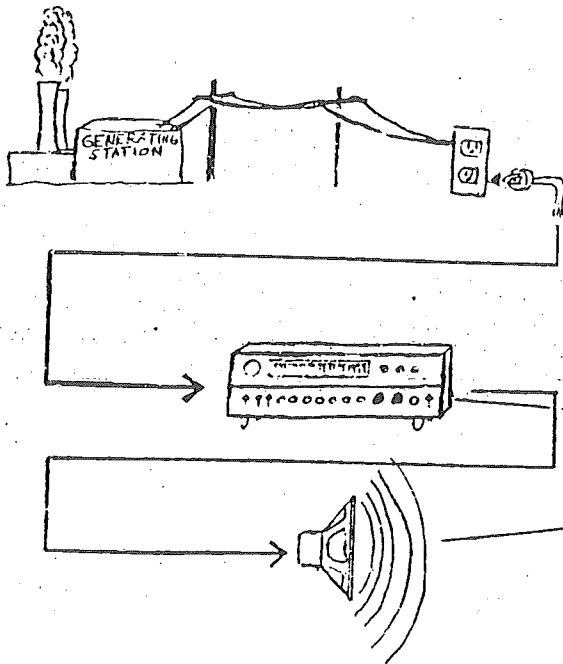
All electronic systems, whether your home stereo system or one of the many projects available, can be broken down into three stages as shown here:



The electronic stage is all electrical. Its input is electrical and its output is electrical.

The input and output stages are both transducers. A transducer is a device that changes one form of energy into another.

Here is an example.



* The input stage consists of a transducer that converts the mechanical energy into electrical energy.

* The electronic stage amplifies or enlarges the electrical energy.

* The output stage, again a transducer, (speaker) converts this large electrical energy back into mechanical energy to produce sound.

SUMMING UP

In this lesson we have sought to understand the electronic circuit and how it fits into the overall electronic system. We have looked at current, voltage, and resistance, that are part of every circuit. In addition we have seen how every electronic system can be subdivided into three stages.

Viewing electronic devices within this framework should help to improve your understanding of the electronic equipment you encounter. Later on we will see how every electronic circuit can be divided into two types; those that regulate and those that switch.

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UNIT 1 LESSON 1 QUESTIONS

1. Define the following:
 - (a) circuit
 - (b) electric current
 - (c) voltage
 - (d) resistance
2. Where do the free electrons in a conductor come from?
3. In a complete circuit, what is required before current will flow?
4. What current flows in a wire if two coulombs of electrons pass a given point in four seconds?
5. If one coulomb of electrons loses five joules of energy in passing through a resistor, what is the potential difference across the resistor?
6. What current flows in a wire if 15 coulombs of electrons pass a given point in 3 seconds?
7. If 3 coulombs of electrons lose 5 joules of energy in passing through a resistor, what is the potential difference across the resistor?
8. If it takes 250,000 joules to heat enough water for a cup of tea, how much charge must move through a 120 V kettle's heating element to heat this much water? Answer in both coulombs and electrons.
9. List the three basic stages of any electronic system.
10. What is a transducer?
11. List three transducers not discussed in this chapter, and explain what they do.

LESSON 2 - RESISTORS

Objectives:

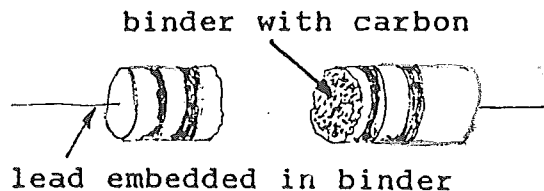
In this lesson you will:

- (a) Learn how common resistors are made
- (b) Learn how resistance is measured
- (c) Learn to use the colour code for resistor values
- (d) Learn the meaning of the terms "preferred values" and "tolerance".

CONSTRUCTION

The Carbon Composition Resistor

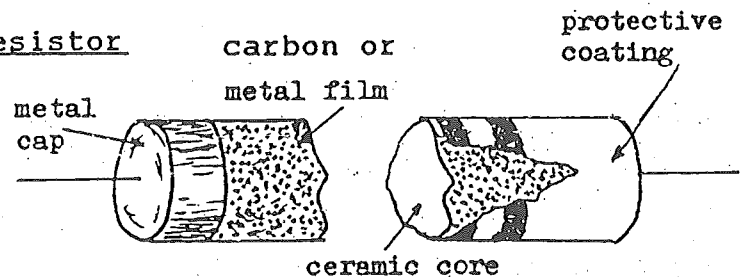
If you were to break open a common carbon composition resistor it would look like this inside:



Carbon is the main element, and, by itself, has very little resistance. When a non-conductive "binder" material is added, the resistance goes up. The greater percentage of binder to carbon, the higher the resistance.

The carbon Film or Metal Film Resistor

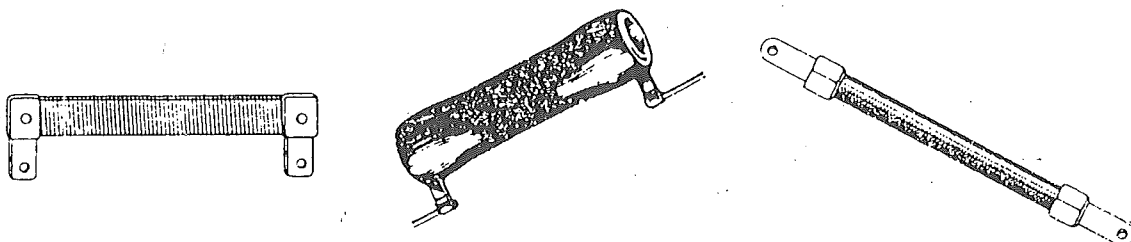
This resistor consists of a non-conducting ceramic core with a very thin film of metal or carbon covering the outside of the core. The thinner the film, the higher the resistance. Spiral grooves are often scored in the film to increase resistance.



Metal film resistors are generally preferred to carbon film resistors for applications such as high quality audio systems, as they introduce less "noise" (which appears as hiss in the system). They are, however, more expensive, and carbon film resistors usually are quite acceptable.

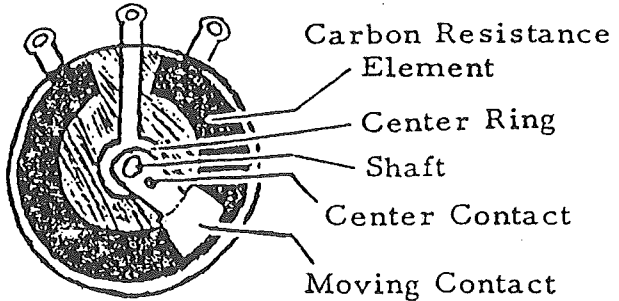
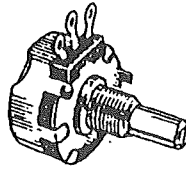
The Wire-Wound Resistor

The wire-wound resistor consists of a length of high-resistance wire (such as an alloy of nickel and chromium, called nichrome) wrapped around an insulating core. High-power resistors are constructed around a ceramic core, then enclosed in enamel, a porcelain solution, or ceramic material, then baked.



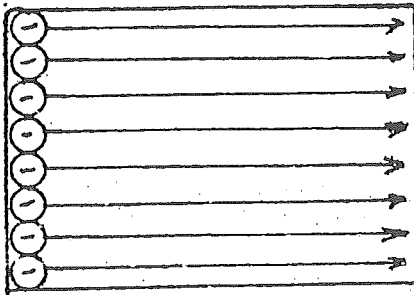
The Potentiometer, or Rheostat

This is a variable resistor. It can be of the carbon or the wire-wound type. The resistance between the two outer terminals is fixed. A rotating shaft is connected to the center terminal, and the shaft is connected to a moving contact (wiper) which makes contact with the resistance element. As the shaft is rotated, the resistance between the center terminal and either end terminal varies according to the quantity of carbon between them.



UNITS OF RESISTANCE

Each resistor contains a certain amount of resistance - and that resistance is measured in ohms. A resistor with 100,000 ohms would provide four times the opposition to current flow as a 25,000 ohm resistor.



25,000
ohms

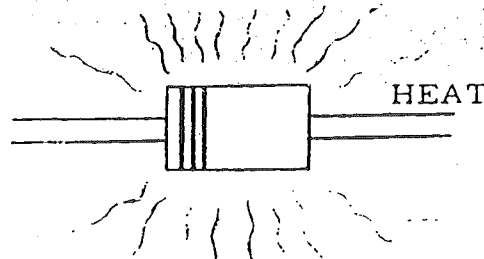


100,000
ohms

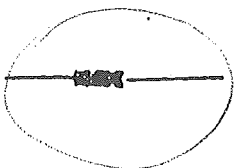
When specifying resistor values, we often use the symbol Ω instead of the word ohm. For example, 150 ohms could be written as 150 Ω .

POWER

Just as rubbing your hand on a rough surface warms it up, so do electrons moving through a conductor produce heat.



How much heat a resistor can handle is known as its power rating, and is primarily a function of its size. Common resistor sizes and relative power ratings (measured in watts - this will be discussed in more detail later) are shown below.



1/4 watt



1/2 watt



1 watt



2 watt

THE RESISTOR COLOR CODE

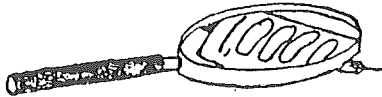
Secret Code?

The resistor color code is a method of indicating the resistance value in ohms and the tolerance range. It is not a secret code designed by sinister cryptographers to confuse and frustrate us. On the contrary, it was made as easy as possible to facilitate its wide usage. Anyone can learn it in just a few minutes, including you.



Why The Color Code

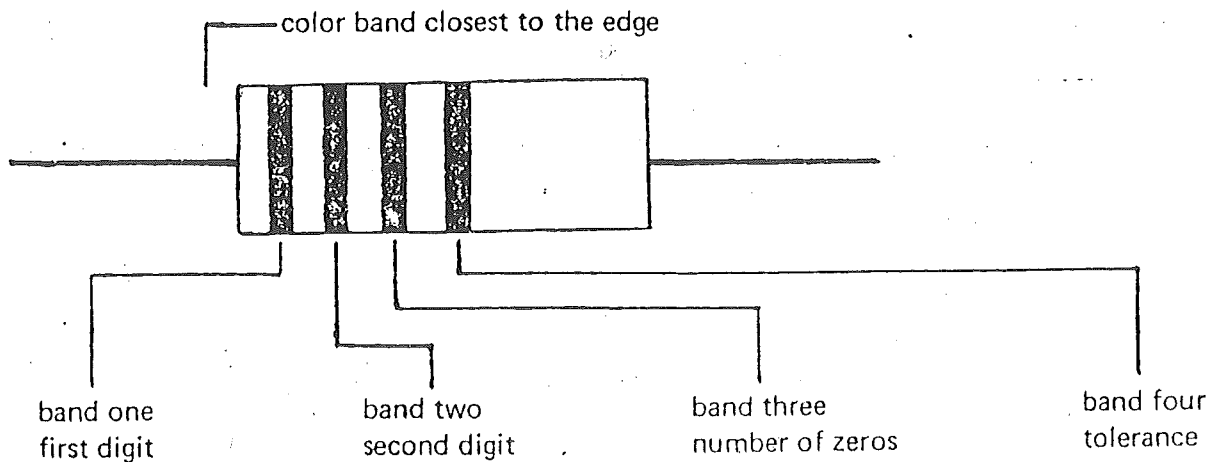
With the color code we use colored bands in order to overcome two basic problems:



- One — It would be very difficult to see large numbers on a small resistor. 1,000,000 ohms printed on a $\frac{1}{4}$ watt resistor can look pretty tiny.
- Two — Even if we could see the number, placement of the resistor in the project might entirely obscure it.

The color coded bands that go entirely around the resistor seem to solve these two problems.

When reading the color code the resistor should be held as shown here. The color band closest to the edge is number one.



Each colour is assigned a numerical value, as shown in the chart on the following page.

This is the colour code chart:

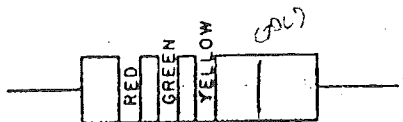
Color	Numerical Meaning 1st and 2nd Figures	Multiplying Value	Percent Tolerance
Black	0	1	
Brown	1	10	
Red	2	100	
Orange	3	1,000	
Yellow	4	10,000	
Green	5	100,000	
Blue	6	1,000,000	
Violet	7	10,000,000	
Gray	8	100,000,000	
White	9	1,000,000,000	
Gold	0.1		5%
Silver	0.01		10%
If tolerance is not indicated by color:			20%

Remember, each colour stands for a particular number. For example, red stands for two.

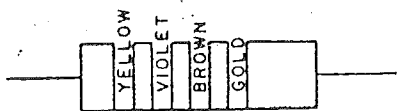
Remember as well:

- The first band always represents a numeral.
- The second band always represents a numeral.
- The third band always represents the multiplier (for all colours except gold and silver, the colour tells the number of zeros added to the numerals).

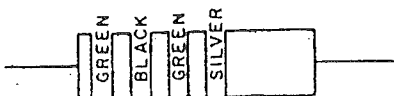
Examples:



First number, red: 2
 Second number, green: 5
 Third band, yellow (4) means times 10,000. In other words, put 4 zeros after the first two figures: 2 5 0000
 Resistance is 250,000 ohms.
 Lack of a fourth color means that the actual ohms may be as much as 20% more or less than the rated value 250,000.



First number, yellow: 4
 Second number, violet: 7
 Third color, brown: 1. This '1' tells how many zeros to place after the 4 and 7.
 Resistance is 470 ohms.
 The gold band means that the resistor's actual ohms is within 5% of the 470.



First number, green: 5
 Second number, black: 0
 Third, green: tells how many zeros to put after the 5 and 0.
 5 0 00000 = 5,000,000 ohms
 Silver: 10% tolerance: Resistor may measure anywhere between 4,500,000 and 5,500,000 ohms.

Too Many Zeros

00 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0
0 0 0 0 0 0

There is one more thing. We often find it bothersome to use all the zeros that can sometimes appear in a number. Writing out 220,000 ohms or 1,000,000 ohms can get quite tedious, to say nothing of space consuming.

To solve this problem, an abbreviation system has been devised using letters to stand for thousand and million.

k = kilo. which means thousand, or three zeros (000).

M = meg. which means million, or six zeros (000,000).

Here is how it works:

Instead of writing 22,000 we write 22k

Instead of writing 11,000,000 we write 11M

47k would be 47,000.

10M would be 10,000,000.

What would you do with a 4.7k resistor?

It is simple, just move the decimal point three places to the right. (k tells us it is thousand, or three places.) You would have:

4,700.

A 3.3M resistor would be:

3,300,000

Many publications and manufacturers now specify resistance values by replacing the decimal point with a letter; R meaning ohms, k meaning kilohms, and M meaning megohms. For example, 270 ohms would be written as 270R, 3900 ohms would be written as 3k9, and 4.7 megohms (4,700,000 ohms) would be written as 4M7.

PREFERRED VALUES

Why these strange values (like 560 ohms) for resistors? Well, just as our coinage comes in different denominations (pennies, nickles, etc.) convenient for making change, so are resistors sold in what are called "preferred values". The manufacture of resistors is not an exact process, and resistors produced will most likely not be exactly the desired value. So the manufacturer chooses tolerances (acceptable variation) and preferred values so that there will be no rejects. For example, if he wishes to manufacture a 1 kilohm resistor with 10% tolerance, he can include in this group any resistor between 900 ohms (-10%) and 1100 ohms (+10%). He will also sell 1200 ohm resistors, so that any resistors between 1080 ohms and 1320 ohms can be included in this group. He will sell other groups so that the maximum value of one group overlaps with the minimum value of the next group.

Table Showing Preferred Values:

Examples of 10% series values:

220R, 1k0, 3k9, 820k

Examples of 20% series values:

220R, 1k0, 3k3, 680k

20%	10%
1.0	1.0
	1.2
1.5	1.5
	1.8
2.2	2.2
	2.7
3.3	3.3
	3.9
4.7	4.7
	5.6
6.8	6.8
	8.2

Summing Up:

There are probably more resistors found in electronic devices than any other components. In order to choose the right resistor for the job, you must be familiar with the variety of types and values available. We have looked at the most common types in this lesson. The colour code will allow you to choose the right value of resistance, and knowledge of the power rating of resistors will ensure that your circuit operates safely and reliably.

UNIT 1 LESSON 2 QUESTIONS

1. List four different types of resistors.
2. Why is the power rating of a resistor important?
3. Suppose a circuit calls for a 1/4 watt resistor, but you have only a 1/2 watt resistor. Can you use it in the circuit? Why?
4. Why do we use a colour code to specify resistor values, instead of just stamping a number on the resistor?
5. Write the following resistor values in ohms.
(a) 68R (b) 2k2 (c) 56k (d) 33M
6. Write the following resistor values as numbers with the appropriate letter in place of the decimal point.
(a) 3900 ohms (b) 220 ohms (c) 470,000 ohms
(d) 8200 ohms (e) 1,500,000 ohms
7. List preferred values for 5% resistors from 1 ohm to 10 ohms.

LESSON 3 - THE SCHEMATIC DIAGRAM

OBJECTIVES:

In this lesson you will:

- (a) Study schematic diagrams and their use.
- (b) Compare schematic diagrams to pictorial drawings.
- (c) Learn how to translate pictorial drawings into schematic diagrams.

WHAT IS A SCHEMATIC DIAGRAM?

The schematic diagram is a construction drawing and in that sense it is similar to architectural plans or machine shop drawings. The purpose is to show how to "build" an electronic device. Accordingly, the schematic diagram must contain complete information about all the components used, and how the components are connected electrically.

THE KEY ELEMENTS

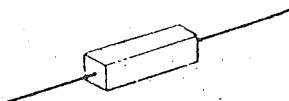
Any schematic diagram must follow these simple rules:

- (a) All components are represented by standard symbols. Several will be given here as examples. You will encounter many others as you progress through the course.

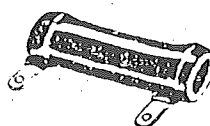
RESISTOR - There are 4 basic types.



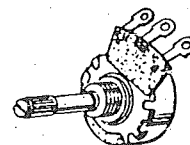
CARBON
OR METAL
FILM



SAND BLOCK



WIRE WOUND

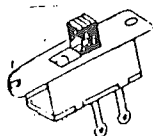


POTENTIOMETER
(variable resistor)



SWITCH

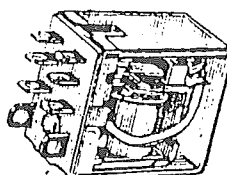
Five types



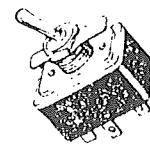
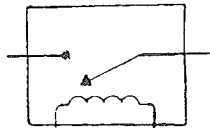
SLIDE



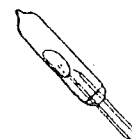
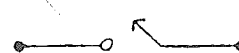
MOMENTARY



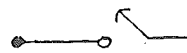
RELAY



TOGGLE



MERCURY



Switches may have any number of terminals. They have to have at least two. A relay is a electro-magnetic switch.

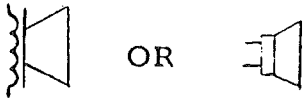
SPEAKER

There are 1000's of types. Here are a few.



SPEAKER

EARPHONE



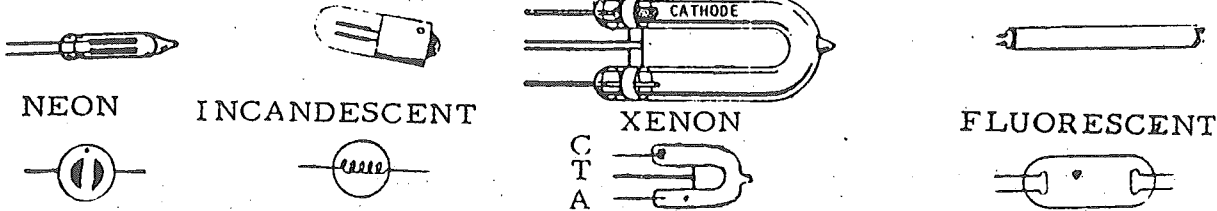
OR



Speakers come in many sizes and shapes. An earphone may be thought of as a special type of speaker although the principle of operation is slightly different.

LAMP

We show 4 types.



NEON

INCANDESCENT

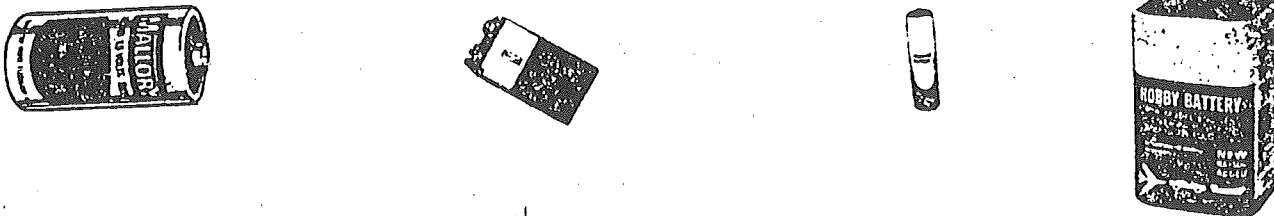
XENON

FLUORESCENT

Lamps come in many sizes, shapes and voltages. Some use a vacuum, some are filled with gas and some are coated with a phosphorus material.

BATTERY

There are several types.



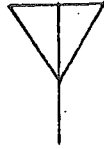
On the schematic symbol for a battery, the short line indicates the negative terminal.

NOTE ON KINDS OF DRY CELL BATTERIES (Standard, Alkaline, NiCad, Mercury)

1. Standard — The typical dry cell comes in several sizes including AA, A, C and D.
2. Alkaline — These come in the same sizes but have longer life than the standard.
3. NiCad — These are RECHARGEABLE up to 1000 times.
They come in the same sizes as standard.
4. Mercury — These are very tiny and are used in digital watches, etc.

ANTENNA

There are many types of antenna, ranging from a simple straight wire to the very complex TV antenna or the microwave dish antenna.

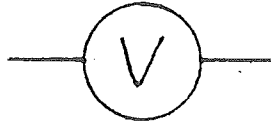


GROUND

This is the point from which all voltage measurements are made. It may or may not be connected to earth via a three-prong plug.



VOLTMETER



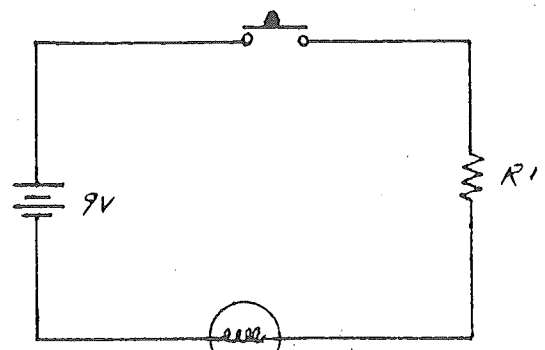
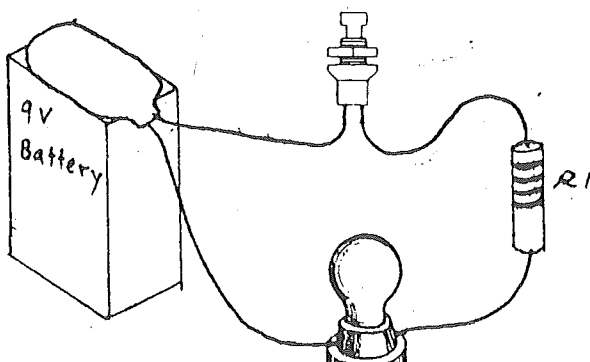
AMMETER

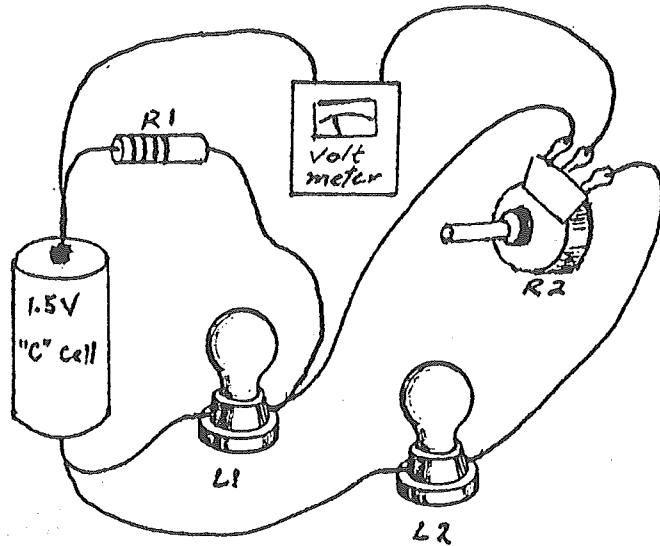


- (b) Component symbols are often given a letter and number designation for parts identification.
 - (c) Electrical connections (wires or traces on a circuit board) are shown as straight line segments joining component symbols.
 - (d) The junction of any conductors is shown by a dot at the junction.
 - (e) Conductors which cross but do not touch are shown like this
- or like this

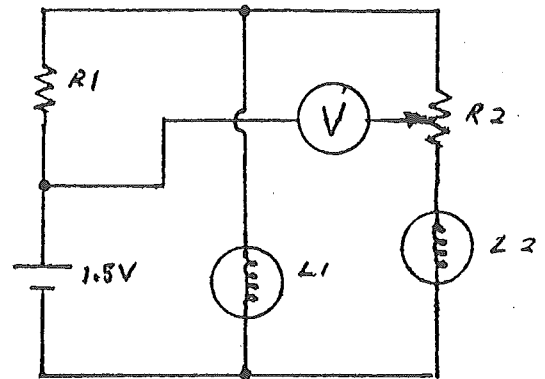


Following are two examples of schematic diagrams, along with pictorial drawings of their corresponding actual circuits.





Pictorial



Schematic

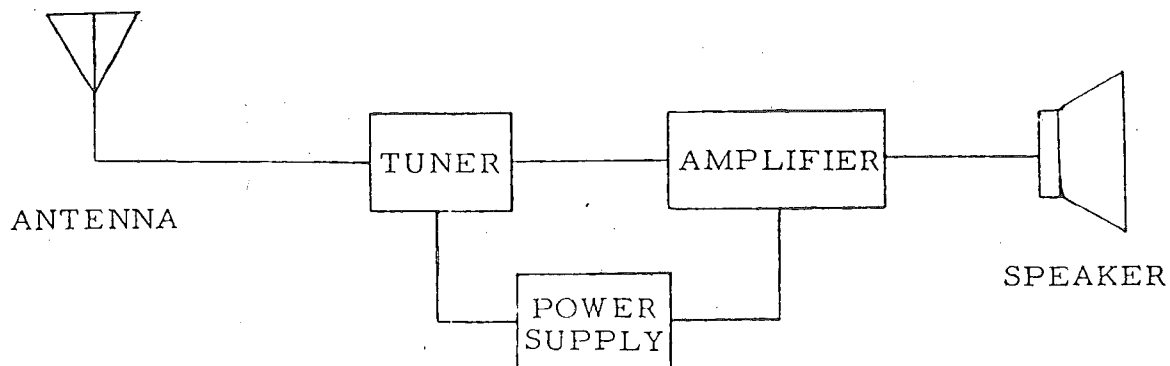
Other Types Of Electronic Drawings

In addition to schematic and pictorial drawings there are block and wiring diagrams.

Block Diagram

A typical block diagram is shown below. Its purpose is to indicate the relationship between various stages in an electronic system. It has the following characteristics:

- * Each block represents a circuit or stage.
- * The blocks are joined by lines which indicate the path of signal flow.
- * Each stage is labeled as to its function.
- * The diagram does not give any information as to the components used within each stage.



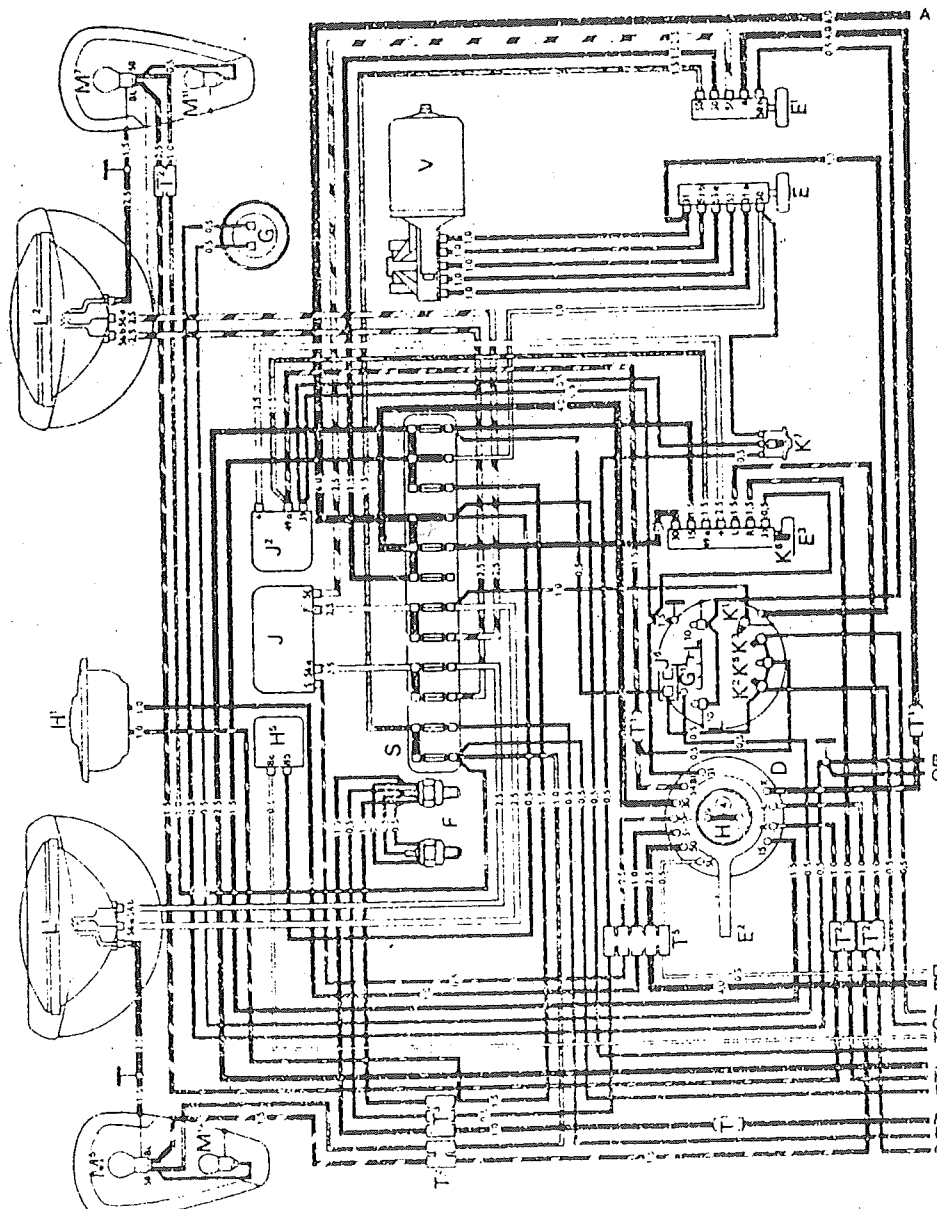
BLOCK DIAGRAM OF A RADIO

Wiring Diagram

The wiring diagram shows wiring connections in a simplified manner. Wires are often identified by different colours. Such diagrams find extensive use in automotive and aircraft wiring schemes. Below is shown a typical wiring diagram.

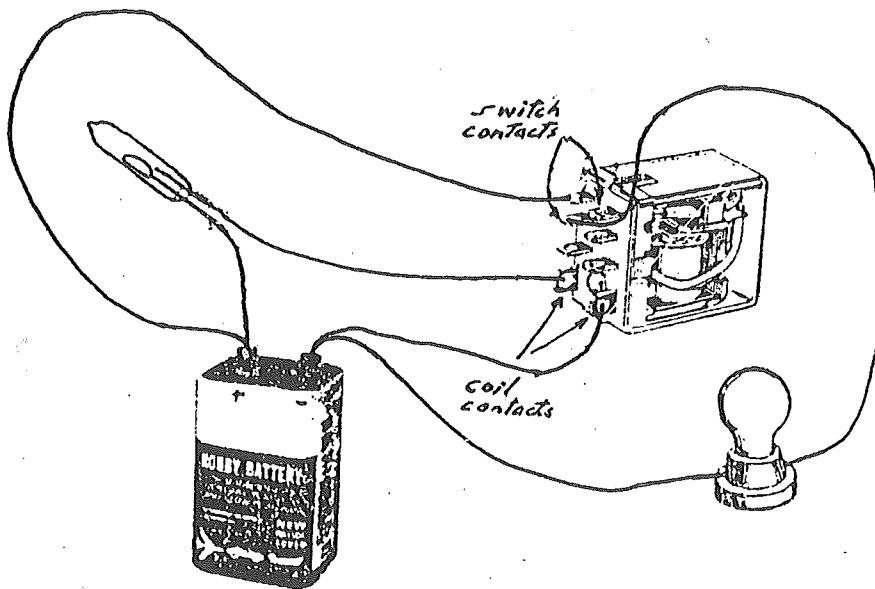
WIRING DIAGRAM — 1971 SUPER BEETLE

- | | | |
|---|---------------------------------------|---|
| A - Battery | F4 - Back-up light switch | K6 - Emergency flasher warning light |
| B - Starter | G - Fuel gauge sending unit | K7 - Dual circuit brake system warning light |
| C - Generator | G1 - Fuel gauge | L1 - Sealed beam unit, left headlight |
| C1 - Regulator | H - Horn button | L2 - Sealed beam unit, right headlight |
| D - Ignition/starter switch | H1 - Horn | L10 - Instrument panel light |
| E - Windshield wiper switch | H5 - Ignition key warning buzzer | M1 - Parking light, left |
| E1 - Light switch | J - Dimmer relay | M2 - Tail/brake light, right |
| E2 - Turn signal and headlight dimmer switch | J2 - Emergency flasher relay | M4 - Tail/brake light, left |
| E3 - Emergency flasher switch | J6 - Fuel gauge vibrator | M5 - Turn signal and parking light, left front |
| F - Brake light switch | K1 - High beam warning light | M6 - Turn signal, left rear |
| F1 - Oil pressure switch | K2 - Generator charging warning light | M7 - Turn signal and parking light, right front |
| F2 - Door contact and buzzer alarm switch, left | K3 - Oil pressure warning light | M8 - Turn signal, right rear |
| F3 - Door contact switch, right | K5 - Turn signal warning light | M11 - Side marker light, front |



LESSON 3 REVIEW PROBLEMS

1. Draw the schematic diagram for the circuit shown in pictorial form below.



2. What is the purpose of a block diagram?
3. What is the purpose of a wiring diagram?
4. Give an example of where a wiring diagram might be used, in addition to automotive and aircraft wiring schemes.
5. A scientist wants to pick up a weak radio signal with an antenna, amplify it and feed it into a detector. If a certain frequency is present, the detector will turn on an oscillator (tone generator) which will drive a speaker, producing an audible alarm. Draw a block diagram showing this system.

LESSON 4 - OHM'S LAW

Objectives:

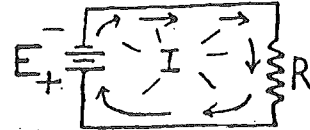
In this lesson you will:

- (a) Learn the meaning of Ohm's Law, and how to apply it to typical electrical situations

OHM'S LAW

As has been mentioned before, a circuit, no matter how simple or how complex, consists of three factors: voltage, current and resistance. Voltage, produced by a difference in charge, supplies the pressure to push (and pull) current through the circuit. Furthermore, there is always a certain opposition to that current known as resistance.

In the circuit shown here, a battery supplies voltage to move electrons through the circuit wiring and resistor R, or load. It is important to understand that R does not necessarily represent a resistor per se, but rather the resistance of the load, or device using electricity. It could be the resistance in a lamp, motor, radio, etc. (There is also a very small amount of resistance in the wire itself, but in most cases this can be ignored.)



Voltage, current and resistance, sometimes referred to as the "Big Three" in electronics, are measured in specific units and designated with particular letter symbols.

<u>"Big Three"</u>	<u>Unit</u>	<u>Letter Symbol</u>
Current	Amperes	I
Difference in charge (EMF)	Volts	E
Resistance	Ohms	R

Many years ago a German physicist named Georg Simon Ohm (1787-1854) discovered that there is a simple and straightforward relationship between voltage, current and resistance. This became known as Ohm's Law. It states that "current multiplied by resistance equals voltage." Or put mathematically to keep it simple:

$$E = I \times R$$

First let us see how this law can aid us in finding the unknown voltage, current, or resistance in a circuit. Then we will explore the relationship itself.

Finding Voltage

If you know the resistance and current in a circuit you can find the voltage. The formula is:

$$E = I \times R$$

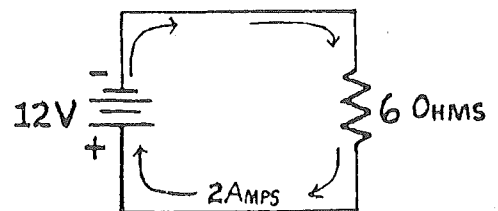
Example: If a circuit has 2 amperes of current flowing through 6 ohms resistance there are 12 volts of pressure being applied.

$$E = I \times R$$

$$E = 2 \times 6$$

$$12 = 2 \times 6$$

By a simple rearrangement of the basic formula we can solve for current (I) or resistance (R).



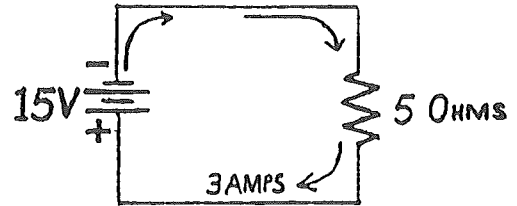
Finding Current

If you know the voltage and the resistance in a circuit you can find the current. The formula is:

$$I = E/R$$

Example: If a circuit has 15 volts of pressure with 3 ohms resistance, there is 5 amperes of current flowing.

$$I = E/R \quad I = 15/3 \quad 5 = 15/3$$



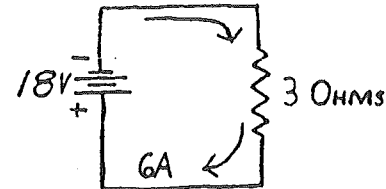
Finding Resistance

If you know the voltage and the current in a circuit you can find the resistance. The formula is:

$$R = E/I$$

Example: If a circuit has 18 volts of pressure pushing 6 amperes of current there would be 3 ohms of resistance in the circuit.

$$R = E/I \quad R = 18/6 \quad 3 = 18/6$$



It should be apparent that if you know two out of three factors, by applying the appropriate formula it is always possible to find the third factor.

To find voltage when current and resistance is known:

$$E = I \times R$$

To find current when voltage and resistance is known:

$$I = E/R$$

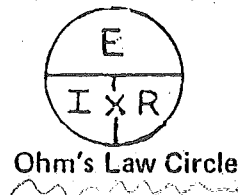
To find resistance when voltage and current is known:

$$R = E/I$$

If you have trouble remembering the three forms of the equation, try using the symbolic diagram shown to the right.

Simply cover the unknown factor and the position of the other two factors tells you what to do.

For example: If the unknown factor is resistance, cover the R the R and the answer is E/I, so divide the amount of voltage by the amount of current.



The relationship between the "Big Three" can be stated as follows:

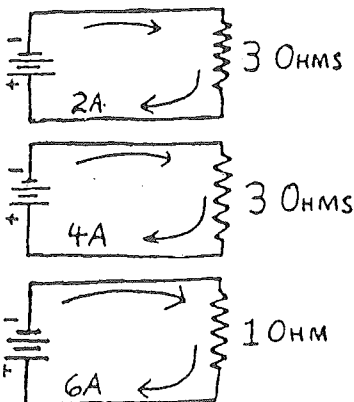
1. Current in a circuit will increase providing the voltage is increased and the resistance remains the same.

$$I = E/R$$

2. Current in a circuit will decrease if resistance increases and voltage remains the same.

$$I = E/R$$

Here is an illustration:



In this circuit we have 6 volts pushing 2 amperes of current through 3 ohms of resistance. There are two ways to increase the current. One, increase voltage, or two, decrease resistance.

— If the voltage were to double (12V) but the resistance remains the same what would happen to the current?

$$I = E/R \quad I = 12/3 \quad I = 4 \text{ amperes.}$$

With twice the electrical pressure (voltage) we would expect an increase in current flow.

— If we now decreased the resistance to one ohm, (but kept the voltage the same) we will have reduced the opposition to current. Thus more current will flow.

SUMMING UP

Ohm's Law ($E = I \times R$), though very simple, is a very powerful tool in circuit analysis. As long as you know two of the three circuit quantities, you can always find the third.

UNIT I LESSON 4 QUESTIONS

1. Using Ohm's Law, find the missing quantity for each of the following devices:

DEVICE	VOLTAGE (volts)	CURRENT (amperes)	RESISTANCE (ohms)
a) 60-watt lamp bulb	120	0.5	
(b) Automobile headlamp	12	2.1	
(c) Toaster	120		15
(d) Electric flatiron	120		12
(e) Soldering iron		2.0	57.5
(f) 100-watt lamp	120		144
(g) Radio-tube filament		0.15	233
(h) 2-cell flashlight bulb		0.28	10.7
(i) Electric frying pan	115	10	

LESSON 5 - RESISTORS IN SERIES AND PARALLEL

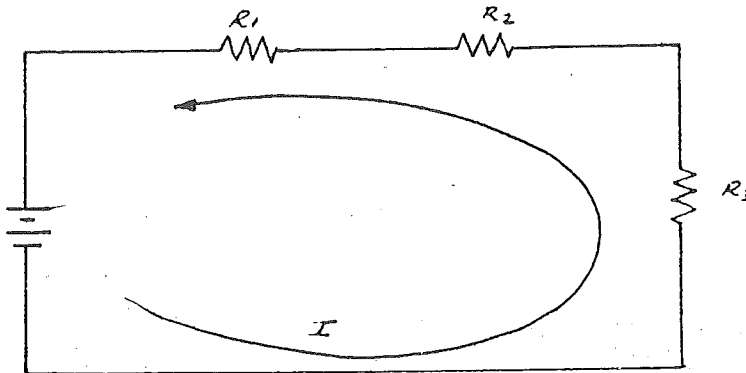
Objectives:

In this lesson you will:

- (a) Learn the meaning of the terms "series" and "parallel".
- (b) Learn how to find the net resistance of a set of resistors in series.
- (c) Learn how to find the net resistance of a set of resistors in parallel.
- (d) Explore the idea of voltage drop.

SERIES

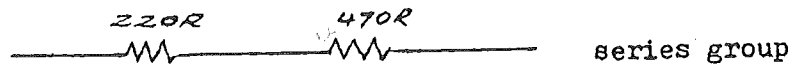
Devices are said to be in series when they are connected so that there is only one path for current flow.



A Series Circuit

Total Series Resistance

The total resistance of a set of resistors in series is the sum of the individual resistors. For example, the total resistance of the series group shown below is $220 \text{ ohms} + 470 \text{ ohms} = 690 \text{ ohms}$.



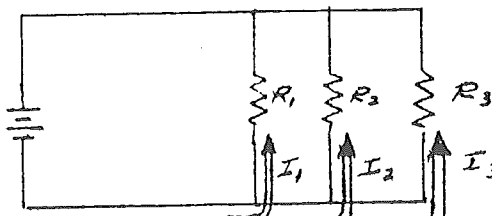
This means that the net effect on the circuit is the same as that of a single 690 ohm resistor.



PARALLEL

When devices are connected so that current can take different paths, they are said to be connected in parallel.

A Parallel Circuit



For any number of resistors in parallel, the net resistance can be found by applying the formula

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \dots$$

where R is the net resistance of the group and r_1 , r_2 , etc., stand for each of the individual resistors.

For example, to find the net resistance of the parallel combination of 100, 200 and 400 ohms, we proceed as follows:

$$\frac{1}{R} = \frac{1}{100} + \frac{1}{200} + \frac{1}{400} = .01 + .005 + .0025 = .0175$$

$$\frac{1}{R} = .0175 ; \frac{R}{1} = \frac{1}{.0175} ; R = 57 \text{ ohms, to the nearest ohm.}$$

If the resistors in the parallel group all have the same resistance, the rule can be greatly simplified: Just divide the resistance of a single resistor by the number in the group. For example, the net resistance of three 150 ohm resistors in parallel is $150 \div 3 = 50$ ohms. This makes sense. After all it is three times easier for electrons to go through the group than to go through only one.

If there are only two resistors, you can do this:

$$R = \frac{r_1 \times r_2}{r_1 + r_2}$$

So the net resistance of a 50 ohm resistor and a 20 ohm resistor in parallel would be

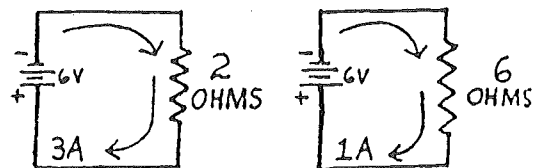
$$R = \frac{50 \times 20}{50 + 20} = 14.3 \text{ ohms.}$$

Knowing these rules is very helpful. If your supply of resistors is somewhat limited, and you need a resistor value you don't have, you might be able to combine values you have to make up the required value. For example, a 470 ohm resistor could be combined with a 330 ohm resistor in parallel to make a 200 ohm resistor (actually, 194 ohms, but that's within 5%, close enough for most purposes).

Voltage Drop

A circuit will always "use up" all of the voltage it is supplied with. If a 6 volt battery is used to power a circuit, regardless of what type or how complex, the entire 6 volts will be used to push electrons through the circuit.

In these two circuits we have a 6 volt battery and a given amount of resistance. (That resistance represents the total resistance in the circuit and is shown as one resistor for convenience.)



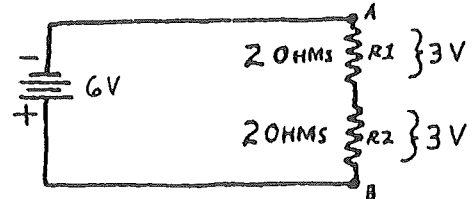
In circuits A and B 6 volts of pressure is being used to push current through the circuit. In both circuits the entire 6 volts is being used. This is a very important point. Because of different resistances, differing amounts of current will flow; but both circuits use the entire 6 volts provided.

In circuit A, 6 volts of pressure is pushing 3 amperes of current through 2 ohms resistance.

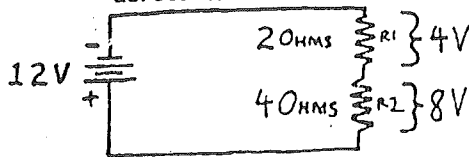
In circuit B, 6 volts of pressure is pushing one ampere of current through 6 ohms resistance.

In both circuits the voltage drop across the resistance is 6 volts. We say that 6 volts was dropped or used up in pushing current through the circuit.

If we were to place two resistors in a circuit as shown here, there would still be a 6 volt drop, but across the total resistance, or from points A to B. Each resistor in turn would drop or use up a portion of that 6 volts, depending on its value. In this example, since both resistors are of the same rating they will each drop half the voltage, or 3 volts.

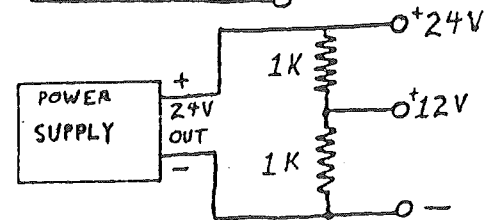
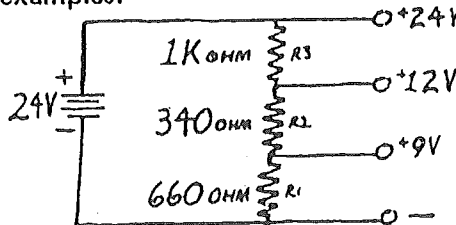
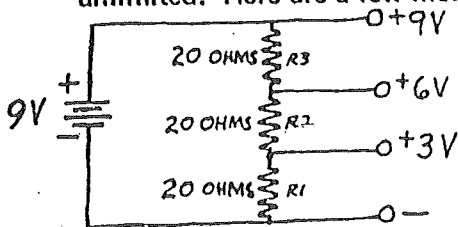
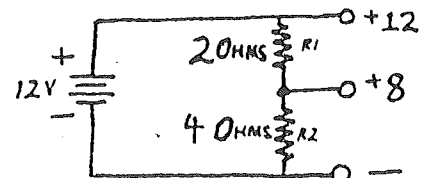


In this circuit the voltage drop across each resistor is indicated. The total voltage drop across the circuit is 12 volts. Yet, each resistor uses only a portion of that 12 volts in order to

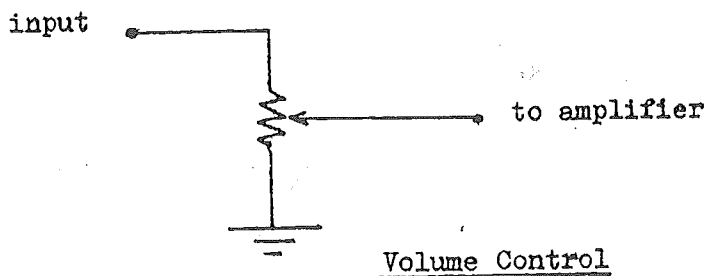


push 2 amperes of current through it. R1 takes 4 volts while R2 takes 8 volts. (The resistance of R2 is twice that of R1 and it would thus take more voltage to push 2 amperes through it.)

If R1 and R2 were indeed resistors a simple voltage divider network could be formed as shown here. Such divider networks are used extensively in the output stage of many power supplies and we will study them more closely later. In this circuit, by using two resistors we can "tap off" 8 volts and 12 volts for whatever use we desire. The possibilities for this kind of thing are almost unlimited. Here are a few more examples:



If we want a variable voltage, all we have to do is replace the fixed series resistors with a potentiometer. Rotating the shaft will then give us any desired voltage from zero volts right up to the supply voltage. This is how a volume control works. The audio signal is impressed across the outer terminals of the potentiometer, and the center terminal provides a variable signal level to the amplifier.



Volume Control

SUMMING UP

In this lesson we have looked at series and parallel circuits, and have discovered how to find the net resistance of series and parallel resistors. We have also explored the concept of voltage drop and how it is used with voltage dividers.

LESSON 5 QUESTIONS

1. Why are automobile headlights not connected in series?
2. A 100 ohm resistor and a 200 ohm resistor are connected in series with a 20 volt supply.

- (a) Draw a schematic diagram showing this circuit.
- (b) Find the total resistance of the series resistors.
- (c) Apply Ohm's Law to the entire circuit as a whole to find the current through the resistors.
- (d) Apply Ohm's Law to each individual resistor to find the voltage drop across each resistor.

300 Ω
.067 A
V₁₀₀ = 6.7V
V₂₀₀ = 13.3V

3. Describe two features that distinguish a parallel circuit from a series circuit.

4. A 1000 ohm resistor and a 500 ohm resistor are connected in parallel. *20V across both*

- (a) Draw a schematic diagram showing this circuit.
- (b) What is the voltage across each resistor?
- (c) Apply Ohm's Law to each resistor to find the current through each resistor.
- (d) Calculate the total current drawn by the resistors.

20V
1000 Ω : 20mA
500 Ω : 40mA
60mA

5. Find the net resistance of the following combinations of resistors:

- (a) 6.8 kilohms and 4.7 kilohms in parallel *2.78K*
- (b) 250 ohms and 360 ohms in series *610 ohms*
- (c) 50 ohms and 70 ohms in parallel *29.1 ohms*
- (d) 100, 200 and 300 ohms all in parallel *54.5 Ω*
- (e) 3000, 2200 and 560 ohms all in series *5760 ohms*

6. Given only the following resistor values (all in ohms): 100, 150, 220, 330, 470, 560, 680, 1000; find series or parallel combinations of two resistors which would produce a net resistance of:

- (a) 50 ohms *100 P 100*
- (b) 340 ohms *680 P 680*
- (c) 690 ohms *220 S 470*
- (d) 660 ohms *330 S 330*
- (e) 158 ohms *220 P 560*

7. A circuit in a house is connected to 120 volts. The wires leading to an electrical outlet have a total resistance of 2.0 ohms. An electric motor and a lamp are plugged into the same electrical outlet (in parallel).

- (a) Draw a schematic diagram showing this circuit. (The 120V supply can be drawn as a 120V battery for now, even though this is not really the case.)

(b) An electric motor usually draws a large amount of current just when it starts. In this case, it draws 15 amperes. Use Ohm's Law to calculate the voltage drop across the wiring at this time. *30V*

(c) For the voltage drop calculated in (b), find the remaining voltage across the motor and the lamp. *90V*

(d) Use the information from (c) above to explain why a lamp on the same circuit as a motor may dim noticeably just when the motor starts.

LESSON 6 - CAPACITORS

Objectives:

In this lesson you will:

- * Learn what a capacitor is and what it is used for.
- * Learn how a capacitor is constructed.
- * Learn the basic characteristics of various types of capacitors.



WHAT IS A CAPACITOR

A capacitor is an electrical component that stores electrical energy. In that sense it is similar to a battery.

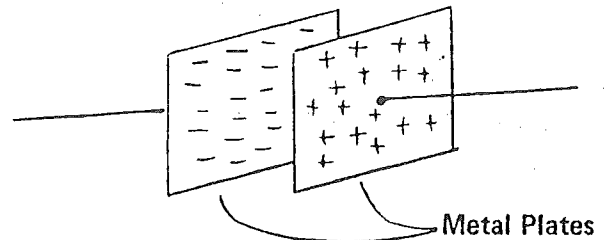
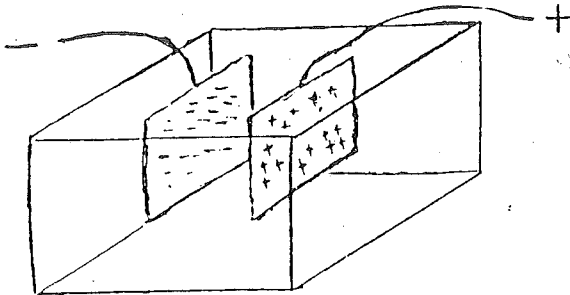
Capacitor



Battery

A battery generates electrical energy as a result of chemical action. It converts chemical energy into electrical energy which is available in the form of negative and positive charges.

A capacitor, consisting of two metal plates separated by an insulator, does not generate or produce anything. It stores, for release at a later time, electrical energy on its plates. That electrical energy, in the form of negative and positive charges, must first come from a battery, generator, oscillator, or other source of electricity.



BATTERY

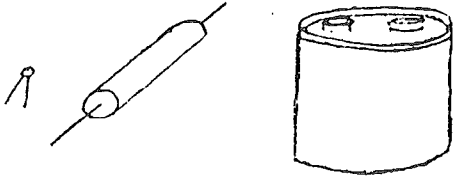
A Battery Produces Electrical Energy From Chemical Energy.

CAPACITOR

A Capacitor Stores Electrical Energy (Derived from other sources) For Release Later On.

Storing Electrical Energy

A device that will store and then release (charge and discharge) electrical energy can be very useful. This is particularly true when such a device, because of its physical characteristics, can determine how much electrical energy is stored and how long it takes to store and release that energy. A capacitor has the ability to do these two things; store a certain quantity of electrical energy, and take a certain amount of time to store and release electrical energy. It is this that gives the capacitor its wide use in many types of circuits.



Depending on their size, some Capacitors can store more electrical energy than others.



It takes a certain amount of time to charge and discharge a Capacitor.

Capacitors Have Many Applications

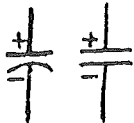
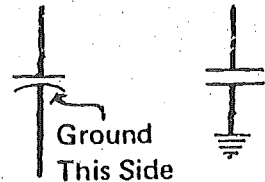
A capacitor is almost as common a component as a resistor. It is found in:

- Tuning circuits of radios, tv's, etc.
- Timing circuits to control burglar alarm delays, flash rates, and so forth.
- Photoflash units.
- AC motor controls.
- Filtering circuits of power supplies.

We will look at some of these applications shortly.

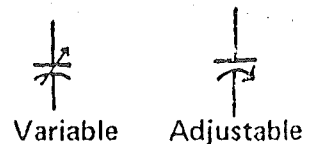
Schematic Symbols

The schematic symbol for a capacitor is shown here. The curved line of the first symbol indicates the side of the capacitor which should be connected to ground, if a ground connection is needed.



Some capacitors have a positive and negative terminal and are labeled as shown.

Variable and adjustable capacitors are shown with an arrow; like this:



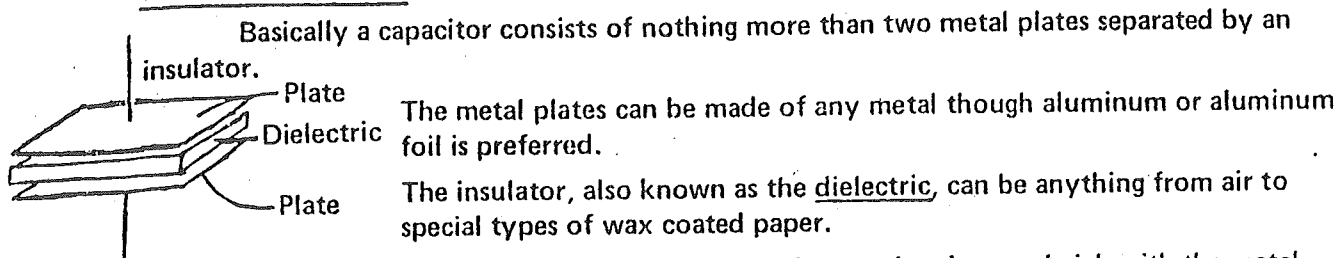
Capacitor Safety

Before we take a look at how capacitors function and how they are used, let us dwell for a moment on the potential danger involved in handling them.

Capacitors can be deadly! Even small capacitors can store hundreds of watts of power. A quick discharge across you can cause severe harm. Be sure all capacitors are safely discharged before handling. Do not be foolish — treat capacitors with respect, and avoid unnecessary injury. To discharge a capacitor, connect both sides together with an insulated wire.

HOW A CAPACITOR FUNCTIONS

Parts Of A Capacitor



As you can see from the illustration; the basic capacitor is a sandwich with the metal plates being the "bread" and the dielectric the "bologna," "tuna fish," or what have you.

How A Capacitor Stores Electrical Energy

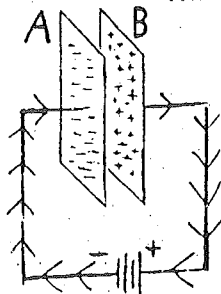
As we said earlier, a capacitor stores electrical energy on its plates. One plate fills up with electrons \ominus the other plate, losing electrons, winds up with an excess of protons \oplus . The result is a temporary battery.

To see how this occurs let us look at what happens when a capacitor is connected across a direct source of voltage such as a battery.



Before the capacitor is placed across the battery both plates are neutral; that is neither one has an excess of electrons or protons.

When the battery is connected, this is what takes place.



Electrons from the negative terminal of the battery (finally having a place to go) rush to fill up plate A of the capacitor.

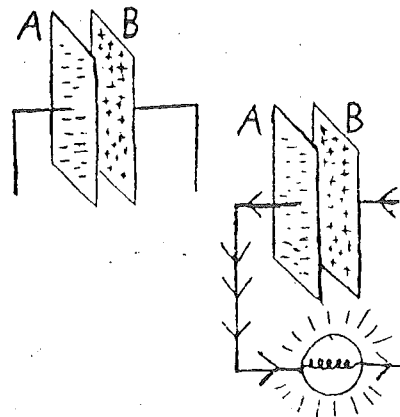
At the same time the positive terminal of the battery pulls (free) electrons off plate B of the capacitor.

In addition, the electrons filling up plate A push electrons off of plate B (remember like charges repel) and on toward the positive terminal of the battery.

In this manner the capacitor becomes charged. While this charging takes place current is flowing in all parts of the circuit. True, current will not flow for very long since the charging time is quite short. In a matter of moments the capacitor is "full," that is it can accept no more electrons on plate A or lose any more from plate B. It is fully charged and storing electrical energy.

— If the battery is completely removed from the circuit, the capacitor will continue to hold a charge (store electrical energy) until it leaks off, or is discharged through another circuit.

— If we now place a circuit, consisting of a light bulb, for example, across the capacitor, the capacitor will discharge through the bulb causing it to light. This discharging of the capacitor, like the charging, will occur for only a short period of time.



How long it takes the capacitor to charge and discharge and how much of a charge it can hold, is a function of factors that we will discuss shortly. For now it is enough to see how a capacitor acts as a temporary storage device for electrical energy.

Enter The Farad

The amount of charge a capacitor will hold at a given voltage is known as its capacitance, and is measured in farads (abbreviated F). A one farad capacitor would hold one coulomb of charge at a voltage of one volt, two coulombs at two volts, ten coulombs at ten volts, etc. As it turns out, the farad is a large value of capacitance, not the sort of thing to build into a transistor radio unless you also happen to own a wheelbarrow to carry it in, so for convenience, we use fractional units, as follows:

one microfarad (abb. μF) = one millionth of a farad (10^{-6} F)

one nanofarad (abb. nF) = one thousandth of a microfarad (10^{-9} F)

one picofarad (abb. pF) = one millionth of a microfarad (10^{-12} F)

Practical values of capacitors range from about one picofarad in high-frequency radio circuits to tens of thousands of microfarads (still a small fraction of a farad) in large power supply circuits.

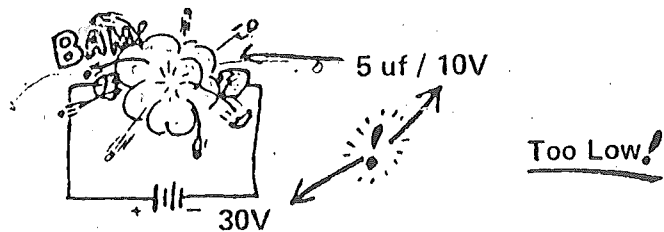
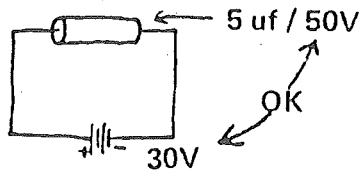
Just like we do for resistors, we often state capacitor values with the multiplier symbol in place of the decimal point. So a 4.7 nF capacitor might be listed as 4n7, and a .22 μF capacitor might be listed as $\mu 22$.

Well, Blow Me Up!

In addition to being rated in terms of the amount of charge it can hold, a capacitor has a maximum voltage rating. Thus a particular capacitor might be rated as:

47 μF / 200 V

Now, if this capacitor is used in a circuit that calls for a 22 μF capacitor, don't worry too much. The circuit may not work quite as expected, but you won't have to call the ambulance. However, if it is placed in a circuit which supplies more than 200 volts to the capacitor, the capacitor may blow up. Now you can call the ambulance! In actual practice, a capacitor with a voltage rating of at least twice that expected to be encountered in circuit operation should be used.



Remember - when choosing a capacitor you need to know:

- Capacitance in microfarads, nanofarads, or picofarads.
- Voltage rating (sometimes referred to as working volts)

FACTORS DETERMINING CAPACITANCE

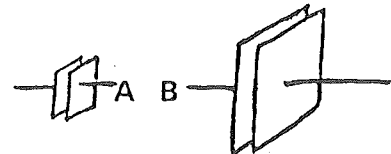
There are essentially three factors that determine the amount of charge a capacitor will hold. They are:

- The size of the plates.
- The distance between the plates.
- The type of insulator or dielectric used.

Let us look at each one briefly.

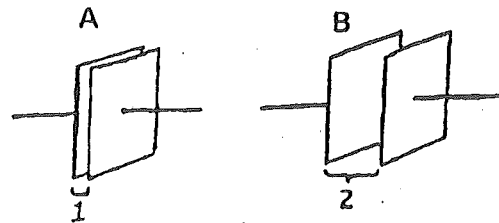
Size of plates

You should easily see that the larger the plates of a capacitor, the more electrons and protons they are able to hold, and the more capacitance there is. Capacitor A having smaller plates, holds less of a charge than capacitor B.



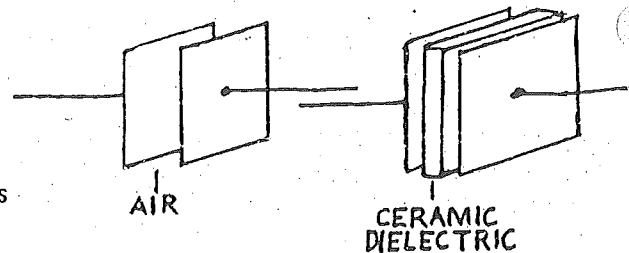
Distance between the plates

The closer the plates are together, the greater charge or capacitance. Since the plates of capacitor A are closer together, each plate has more effect upon the other. All things being equal, capacitor A will have twice the capacitance of capacitor B.



Type of insulator (dielectric)

The type of dielectric used determines the insulating ability of the capacitor and thus the amount of charge it can hold on its plates without leaking across. Better dielectrics allow for thinner dielectrics, which in turn allow the plates to be positioned closer together. That, we have seen, increases capacitance.



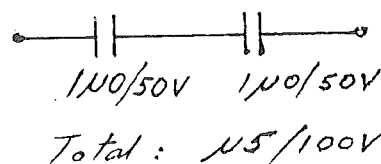
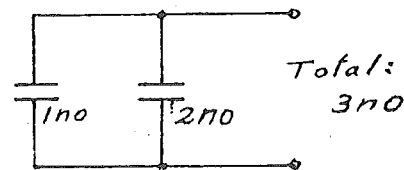
Connecting Capacitors In Series And Parallel

Connecting capacitors in parallel is just like increasing the area of their plates, so

$$C_{\text{total}} = C_1 + C_2 + C_3 + \dots$$

Placing capacitors in series decreases the total capacitance. This is because doing so is equivalent to increasing the distance between the plates. (as a bonus: since the plate distance has in effect been increased, so in the voltage handling ability). The formula for series capacitors is just like that for parallel resistors, so

$$\frac{1}{C_{\text{total}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots$$

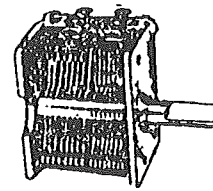


Let us review the characteristics of the more widely used capacitors.

Air Capacitors

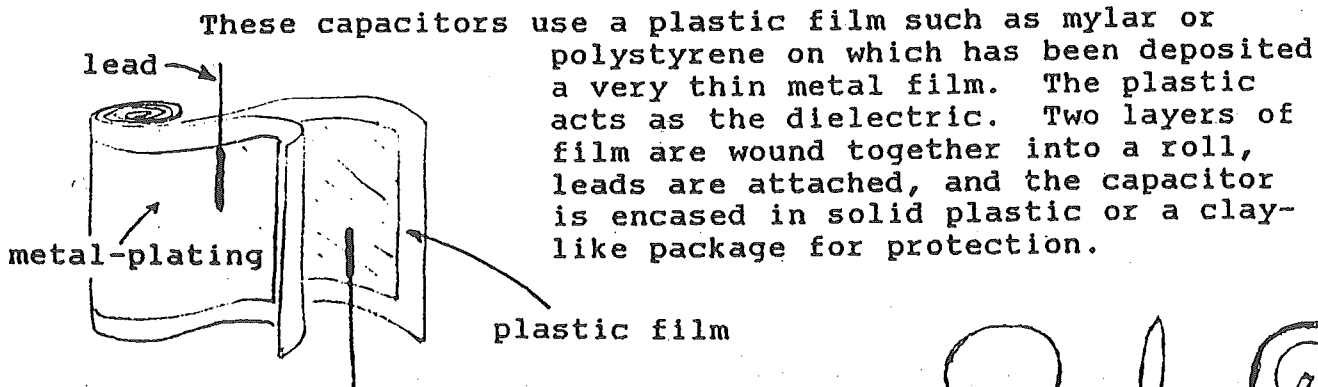
Air capacitors are those that use air as the dielectric. They come in fixed and variable versions and range in capacitance from 3 pf to 365 pf. They are quite large compared to the capacitance they provide. Such capacitors find use primarily in tuners for radio receivers.

Air capacitors have the advantage of being very stable, having a long life, and a dielectric that does not cost anything. Air capacitors are, however, susceptible to changes in humidity which can cause arcing between the plates.



A tuning cap

Metallized Plastic Film Capacitors

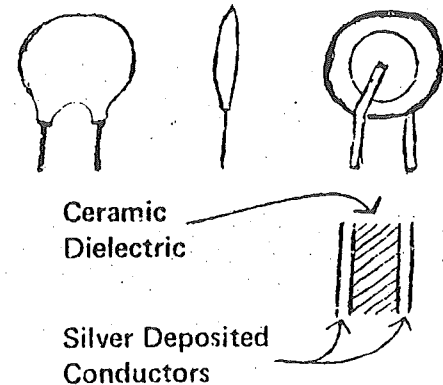


These capacitors use a plastic film such as mylar or polystyrene on which has been deposited a very thin metal film. The plastic acts as the dielectric. Two layers of film are wound together into a roll, leads are attached, and the capacitor is encased in solid plastic or a clay-like package for protection.

Ceramic Disc Capacitors

Ceramic disc capacitors (those made with ceramic dielectrics) range in value from 0.5pf to 3mfd. Operating voltages vary from 3 VDC to 30,000 VDC. In construction, a layer of silver is deposited onto both sides of a ceramic disc. Thus the "plates" are in very close contact with the dielectric.

Ceramic disc capacitors have a good size-to-capacitance ratio. They are none the less rather fragile and must be handled with care so as not to damage or crack the protective outer coating.

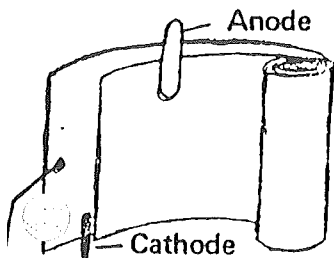


Electrolytic Capacitors

Electrolytic capacitors provide more capacitance for their size than any other type.

As such they are used extensively as filter capacitors for power supplies.

Their construction is somewhat unusual. There is an anode plate of aluminum. It is coated with a film of aluminum oxide which becomes the dielectric. A liquid electrolyte acts as the cathode or second plate and connection is made to it with a metallic conductor. In actual practice a porous paper is wrapped around the anode and saturated with the electrolyte to eliminate spillage.



is Paper Impregnated Cathode Electrolyte

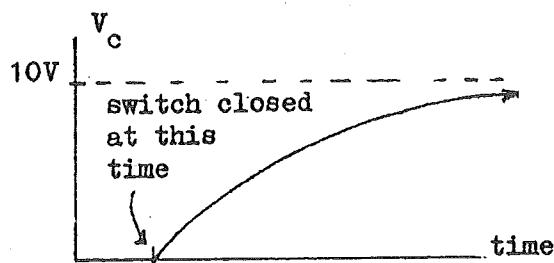
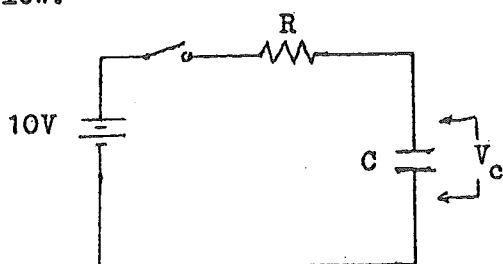
Because of this unusual type of construction, electrolytic capacitors are polarized, that is, they have a positive and negative terminal. Extreme care must be taken to insure that they are connected with regard to such polarity.

CHARGE AND DISCHARGE

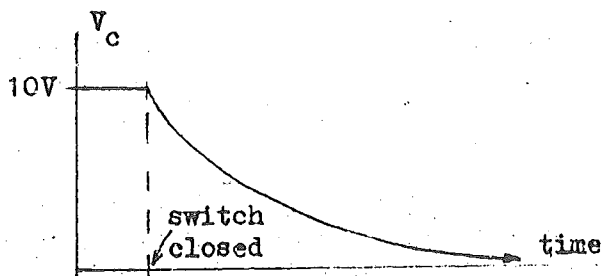
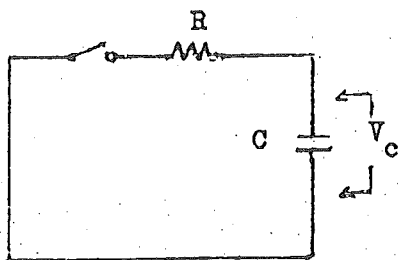
Recall that the purpose of a capacitor is to store electrical energy, and to release it again. This is done by the movement of charge through conductors (and, whether we want it or not, through a certain resistance). This movement of charge will take time. The less the resistance in the circuit, the shorter the charging or discharging time, but the capacitor can never be charged or discharged instantaneously.

Time Constant

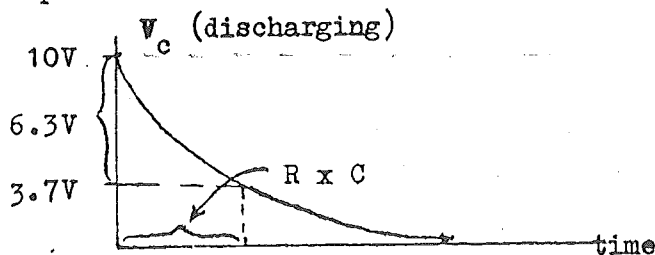
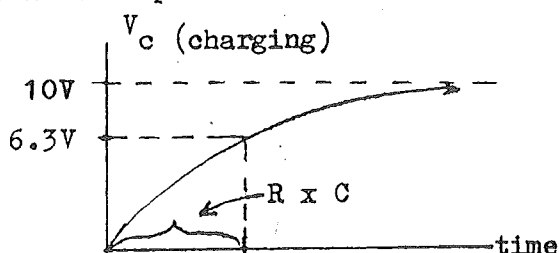
When a completely discharged capacitor is connected to a battery, current flow is greatest and the rate at which the voltage across the capacitor rises is greatest just after the battery is connected. This is shown in the graph below.



A capacitor discharging through a resistor produces a similar graph, as shown below.



A really surprising result comes out of the study of these sorts of graphs. When we are charging a capacitor, regardless of the supply voltage, and regardless of the capacitance and resistance values used, the time (in seconds) it takes for the capacitor to charge up to 63% of the supply voltage is equal to R (in ohms) \times C (in farads), or, because it is sometimes simpler, we use R in megohms and C in microfarads. As well, the time (again in seconds) taken for a capacitor to discharge 63% through a resistor is equal to $R \times C$. It is this phenomenon that makes the capacitor so useful in timing circuits.



The product $R \times C$ we call the time constant. It tells us how long we must wait for the capacitor to charge or discharge. For practical purposes, we usually consider this time to be equal to four times the time constant.

$$\text{Charge or discharge time} = 4 \times R \times C$$

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UNIT 1 LESSON 6 QUESTIONS

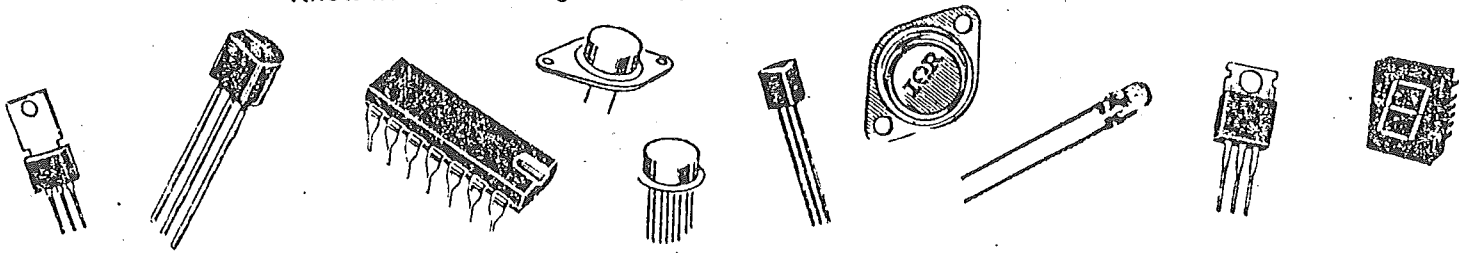
1. What is the primary function of a capacitor?
2. What is the main difference between a battery and a capacitor?
3. Describe the simplest form of capacitor.
4. Describe briefly the process by which a capacitor stores electrical energy.
5. Convert:
 - (a) 56000 pF to nF [REDACTED]
 - (b) .001 uF to nF [REDACTED]
 - (c) 220 nF to uF [REDACTED]
 - (d) .015 nF to pF [REDACTED]
 - (e) .0033 uF to pF [REDACTED]
 - (f) 6800 pF to uF [REDACTED]
6. List three factors which determine the capacitance of a capacitor.
7. Two 470 uF/25V capacitors are connected in series.
 - (a) Find the voltage rating of this combination.
 - (b) Find the net capacitance of this combination.
8. Two 1000 uF/16 V capacitors are connected in parallel.
 - (a) Find the net capacitance of this combination.
 - (b) Find the voltage rating of this combination.
9. What is the time constant of a 100 uF capacitor in series with a 1000 ohm resistor? [REDACTED]
10. How long would it take to charge a 5000 uF capacitor through a 500,000 ohm resistor? [REDACTED]
11. List four different types of capacitor, and briefly describe how each is constructed.
12. Name two important uses for capacitors.

Lesson 7- SOLID STATE COMPONENTS – DIODES, SCRS, ICS, TRANSISTORS, & LEDS

OBJECTIVES;

In this lesson you will;

- * Study diodes and SCRs and how they are used.
- * Learn how transistors and integrated circuits are used.
- * Understand the difference between TTL and CMOS ICs.
- * Know how a seven segment display works.



SOLID STATE COMPONENTS

In this lesson we will explore some important solid state components. Components which are referred to as "SOLID STATE" components are those which are made of materials such as silicon or germanium.

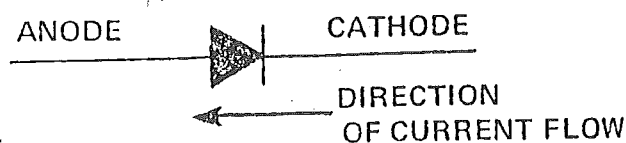
DIODES

One Way Gate

Diodes, sometimes known as rectifiers, are one-way gates. They allow current to flow through them in one direction only. As such diodes find application in converting AC (alternating current) to DC (direct current). We will see how this takes place in future lessons.

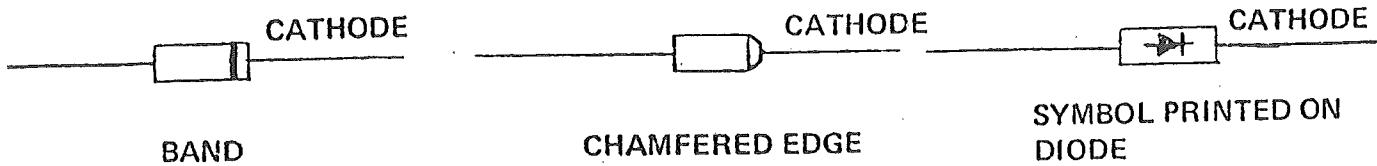
Symbol

The diode symbol is shown below. The direction of current flow is always opposite the direction the arrow is pointing.



Which End Is Which?

Since current moves from a negative to a more positive source, the pointed end on the symbol indicates the negative terminal or cathode. On the diode itself this is shown as a band, chamfered edge, or other atypical marking. The diode must be installed in the right direction, for like an electrolytic capacitor, it has a polarity.



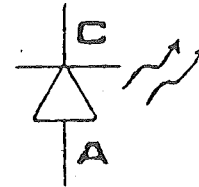
LED (Light Emitting Diode)

An LED is a special type of diode that emits light when current travels through it. They come in red, orange, green, and yellow colors, with red being the most popular. It is important to remember that the LED like any other diode has a polarity. The cathode end is usually indicated by a flat edge or short lead as shown here.

**FLAT EDGE OR SHORT LEAD
IS CATHODE**

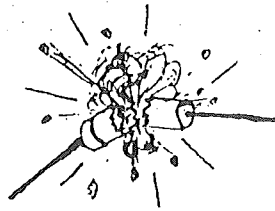


LONG LEAD IS ANODE



Current And Voltage Rating

Diodes are rated in their ability to handle current and voltage. A 1 ampere, 200 volt diode can handle up to 1 ampere of current and up to 200 volts of electrical pressure. If either one or both of these factors are exceeded the diode could be destroyed along with your project.

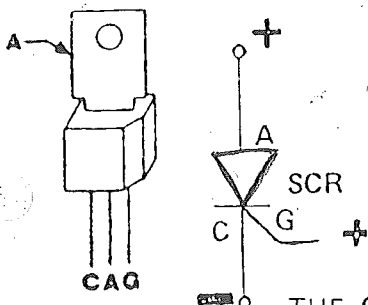


SCR (SILICON CONTROLLED RECTIFIER)

How An SCR Functions

An SCR is a "diode with a difference." Like a diode it has a cathode and anode, and allows current to flow through it in one direction only. Yet, unlike an ordinary diode it has a gate electrode as well. The gate is used to "trigger" the SCR into conduction..

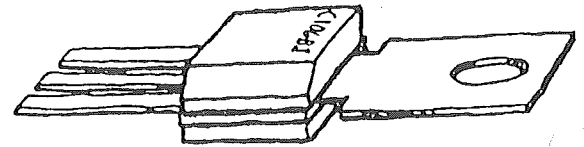
Only when the gate receives a positive voltage will the SCR conduct. Even if the positive voltage is then removed from the gate the SCR will continue to conduct. The only way to "turn off" the SCR is to remove or reverse the positive voltage which is on the anode. The SCR in effect becomes an "electronic switch" that is closed by briefly applying a positive voltage to the gate.



THE GATE NEEDS A POSITIVE VOLTAGE FOR SCR TO CONDUCT

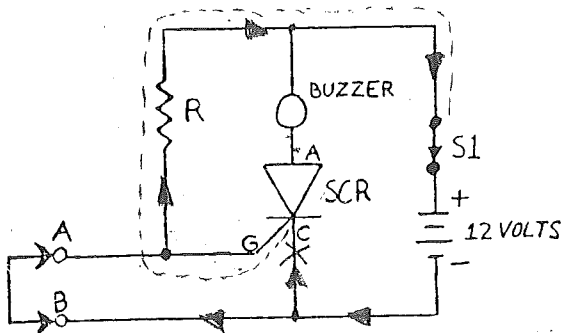
Current And Voltage Ratings

Like diodes, SCRs are rated in terms of their current and voltage handling ability. The GE106B1, a typical SCR used in numerous PPG projects, is rated at 2 amperes and 200 volts. This means that the GE106B1 can handle up to 2 amperes and 200 volts.



How SCRs Are Used

SCRs are used in countless circuits, from latching burglar alarms to color organs. Below is a circuit that employs an SCR along with a brief explanation as to how it works.

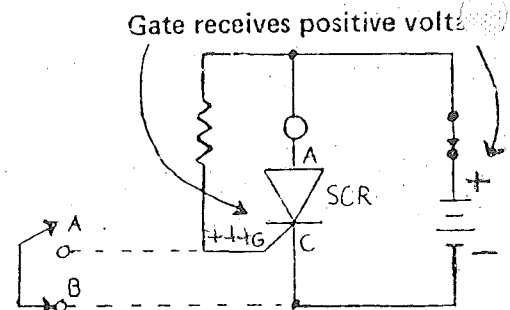


In this circuit the cathode (C) and anode (A) of the SCR are connected through a buzzer and switch to the 12-volt battery. However, there is no current traveling through the buzzer because the SCR is not conducting. It is not conducting because the gate is "held down" to the negative terminal of the battery by the jumper between points A and B.

Remember, the SCR can only conduct if the gate goes positive with respect to the cathode.

If the wire jumper is broken, the gate is released from the negative terminal and placed at a positive voltage through resistor R. The SCR will conduct and the buzzer sounds.

Now (and this is very important) even if the jumper between A and B is reconnected, it will have no effect on the SCR. Once the gate triggers the SCR "on" it loses control of its operation. The only way to turn the circuit off is to open S1, removing voltage from the SCR. Closing S1 again resets the alarm.

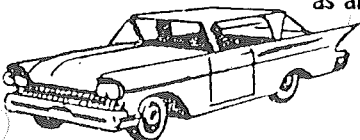


TRANSISTORS

Revolutionary Development

As we mentioned in lesson 3, the transistor, invented in 1948, is one of the most significant technological developments of our time. It has completely revolutionized the electronics industry in the last quarter century. We will study its application as an amplifier and oscillator in Unit III.

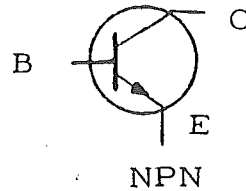
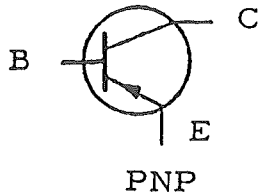
1948 A.D.



Types of Transistors

Transistors are made from semiconductive materials such as silicon or germanium. Depending on how these materials are "sandwiched" together, the transistor becomes a PNP or an NPN type.

Schematically, the two transistor types are represented like this:



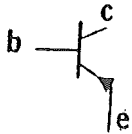
EMITTER - E

BASE - B

COLLECTOR - C

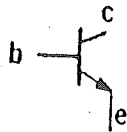
A lead is attached to each section of the transistor. These sections are known as the emitter, base, and collector and are designated by the letter symbols E, B, and C respectively.

The direction the arrow points indicates whether the transistor is a PNP or NPN.



On a PNP transistor the arrow points in.

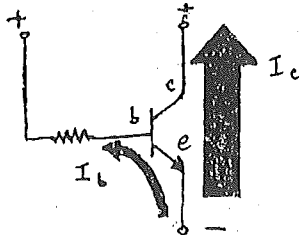
The arrow is always on the emitter.



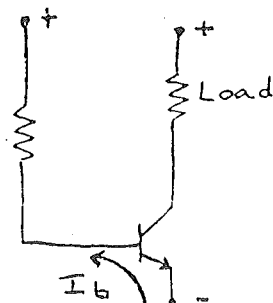
On a NPN transistor the arrow points out.

Transistor Action

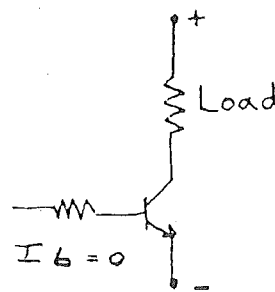
The transistor is designed to act as an amplifier of current. If a voltage is applied between the collector and the emitter, then a very small amount of current flowing between the base and the emitter causes a much greater current to flow between the collector and the emitter.



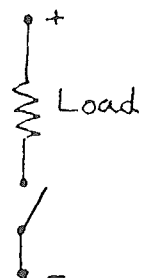
So the transistor is a control device, just as is the SCR, but in quite a different sense. If sufficient base current is provided, the transistor conducts very well between the collector and the emitter, and the transistor can also be used as an electronic switch. However, if base current is removed, the transistor immediately stops conducting.



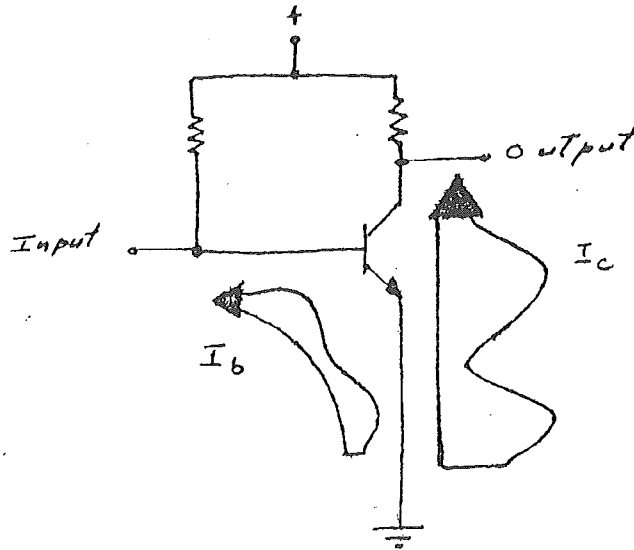
closed switch



open switch

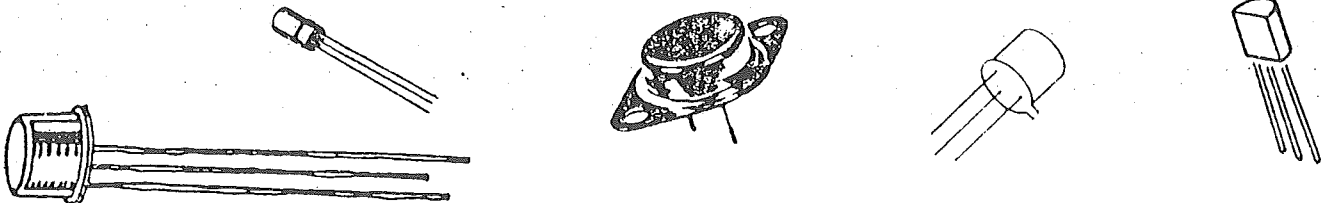


By keeping a small current flowing in the base, and by causing variations in the base current, we can cause very large variations in the collector current. When we do this, we are using the transistor as an amplifier. A small signal at the input (base) causes a much larger signal at the output (collector).



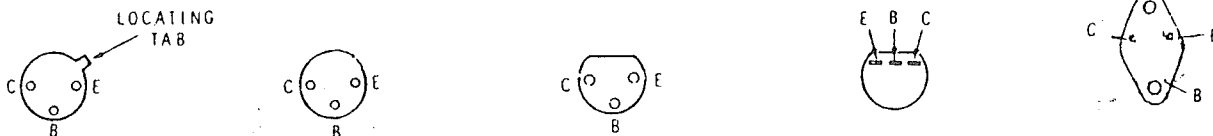
General Purpose And Power Transistors

In addition to describing transistors as PNP or NPN, they are classified as general purpose and power transistors. Size usually determines the type, with the power transistor being the larger (to dissipate more heat or wattage.) Some typical examples along with their lead configuration are shown below.



Lead Identification

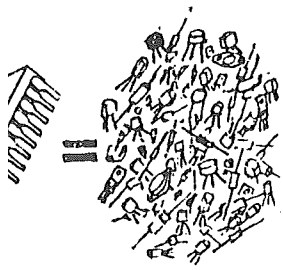
Identifying the transistor leads correctly is extremely important. Always view the transistor with the leads pointing toward you. Typical lead configurations are shown here.



Numbering System

All solid-state devices are identified by combinations of letters and numbers, the most common for transistors and SCR's using a 2N prefix. Any device can be identified by its code. For example, 2N3904 and 2N3055 are transistors; 2N5061 is an SCR. Manufacturers use many different systems, though, and it's a good idea to have numerous manufacturers' data books handy.

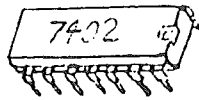
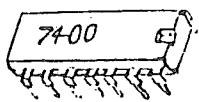
INTEGRATED CIRCUITS (ICs)



Integrated circuits or ICs, by increasing density and at the same time reducing the size, represent a major advance in circuit design. While using transistor technology, they are able to incorporate the equivalent of hundreds of components in a single package that is less than the size of an average capacitor. We will explore how this is accomplished in a future lesson. For now let us see how ICs are classified and numbered.

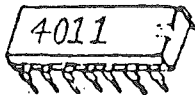
IC Families

ICs are classified according to their "family" designation. The most popular types are;



TTL--

Transistor-Transistor Logic. They are usually identified with a 7400 number. For example 7400, 7402, 7403.

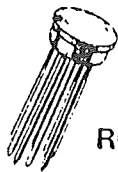


CMOS--

Complimentary -Metal Oxide-Semiconductor. They are usually identified with a 4000 number. For example 4001, 4011.

IC Packages

ICs are also classified according to package style. The most popular types are round and DIP (Dual-In-Line Package.)



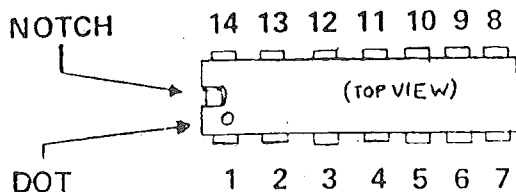
ROUND



DIP

IC Pin Numbers

Each IC has a certain number of pins. It is most important that you know which pins are numbered 1, 2, 3, etc. The top view of a 7404 IC is shown here.



Note the following points;

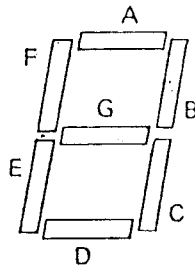
- * The notch or dot is your key to locating pin number one.
- * Pin number one is to the left of the notch or dot.
- * Pins are numbered counter-clockwise around the IC. Remember pin 8 is across from pin 7, not pin 1.

SEVEN SEGMENT DISPLAY

Seven segment displays are seen everywhere-- in calculators, watches, clocks, cash registers, test gear, gas pumps, and computers just to name a few devices. These displays may be liquid-crystal, flourescent, or LED types. Your component kit includes an FND 510 common anode one-half inch LED display .

Seven Segments

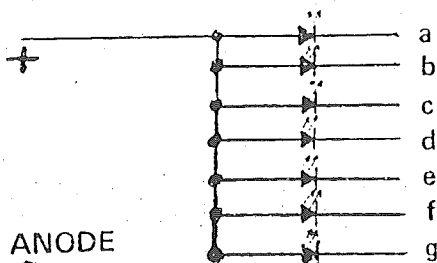
The digital display we have been refering to consists of seven segments as shown below. With seven segments it is possible to indicate the numbers 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, and a few upper and lower case letters.



Each segment has a "letter designation" a through g. This pattern holds true for all seven segment displays regardless of what they are made of.

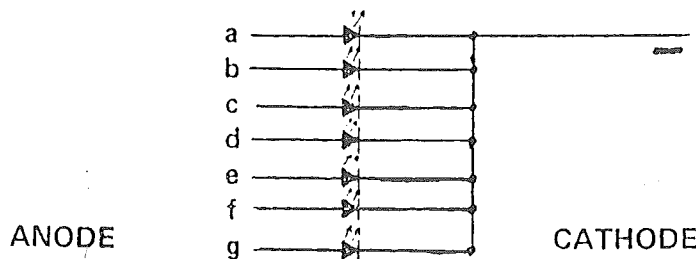
Separate LEDs

Each segment (in an LED display) is actually a tiny LED. This is shown schematically below.



Notice that all anodes are connected together, or in common. They will all go to a positive voltage when connected in a circuit. This is known as a common anode display.

Common cathode displays are just the reverse, that is all cathodes are connected in common to a negative terminal.



SUMMING UP

You have studied the important characteristics of five solid state devices. There is much more to know about each one of course. That knowledge will come as we actually place these components in electronic circuits.

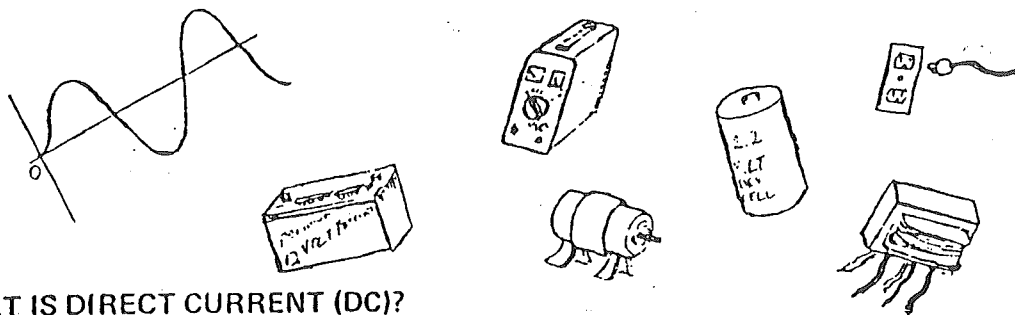
UNIT 1 LESSON 7 QUESTIONS

1. Draw the schematic symbol for a diode, indicating the cathode and anode ends.
2. What is the purpose of a diode?
3. Draw the schematic symbol for a light emitting diode.
4. Draw the schematic symbol for an SCR, indicating the cathode, anode, and gate electrodes.
5. What must you do to make an SCR conduct?
6. What must you do to turn off an SCR?
7. Draw the schematic symbol for an NPN transistor, and label the leads.
8. Draw the schematic symbol for a PNP transistor, and label the leads.
9. If you had a transistor and an SCR, both in the same type package, how would you tell them apart?
10. What two semiconductive materials are commonly used in the construction of transistors?
11. State two uses to which a transistor might be put.
12. State two major IC families.
13. Neatly sketch a 16-pin DIP IC, and number the pins.
14. Neatly sketch a seven segment display, and label the segments.
15. Explain the meaning of the terms "common cathode" and "common anode".

Objectives:

In this lesson you will:

- Learn what DC is and why it is used.
- Learn what AC is and how to understand graphs and AC wave forms.
- Learn about the role of generators and oscillators in producing AC.

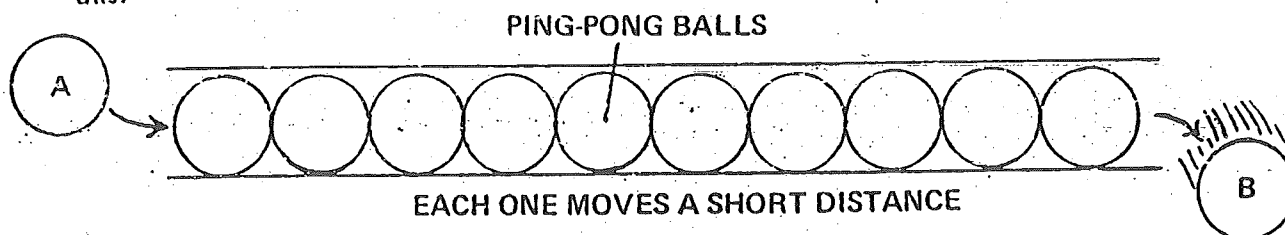


WHAT IS DIRECT CURRENT (DC)?

In Lesson 8, Unit 1, we defined current as the movement of free electrons in one direction. Those free electrons come from the conductor (copper wire for example) itself. Some materials just naturally have more free electrons than others. Those with lots of free electrons are known as good conductors. Here are listed a few good conductors.

- | | | |
|-----------|---------|----------|
| 1. Copper | 3. Gold | 5. Brass |
| 2. Silver | 4. Tin | 6. Zinc |

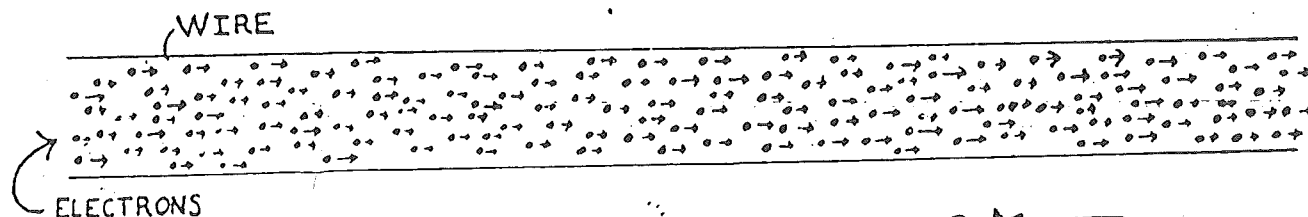
As free electrons (those that have broken away from their atom) move in one direction, they travel only a short distance. That is, each electron moves only a fraction of a centimeter – but the total effect is as if one electron moved all the way down the conductor. It works something like this:



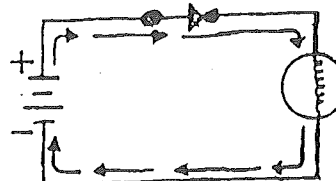
Assume a tube is filled with ping-pong balls.

If you push a ping-ball in the tube (A), one will fall out of the tube, (B). Each ping-pong ball in the tube only moved a short distance – but the effect was felt throughout the tube and at the output.

This is what happens in an electrical circuit. The ping-pong balls are the “electrons,” each one pushing on the other, though each electron moves only a slight distance. It is important to understand this because it explains why current flows everywhere in a circuit at the same time.



In the circuit shown here (and in every electrical circuit) when the switch is closed, electrons move in the direction indicated, everywhere in the circuit at the same time.

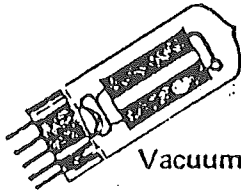


For every electron that leaves the negative terminal of the battery, one immediately returns to the positive terminal. The current is, for all practical purposes, instantaneous

THE NEED FOR DIRECT CURRENT (DC)

Direct current is current that flows in one direction over an extended period of time. It is produced by a source of voltage (with a negative and positive terminal) such as a battery or power supply. Shortly we will talk about alternating current (AC) which moves back-and-forth over a given period of time.

The need for DC is extensive. Here are just three components that require the use of DC:



Vacuum tubes

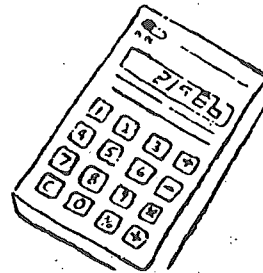
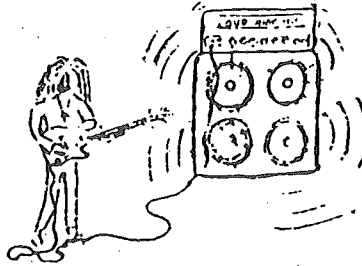
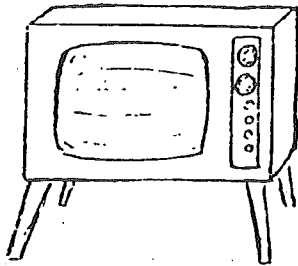


Transistors



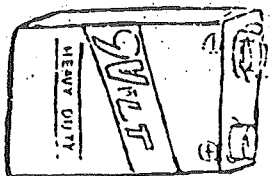
Integrated circuits

If you will think of the electronic equipment in use today — around your home or in industry, you will find that the vast majority of it contains at least some of the components listed above. If it has just one vacuum tube, transistor, or IC, it needs a source of DC.



As we just mentioned, there are primarily two sources of direct current, batteries and power supplies.

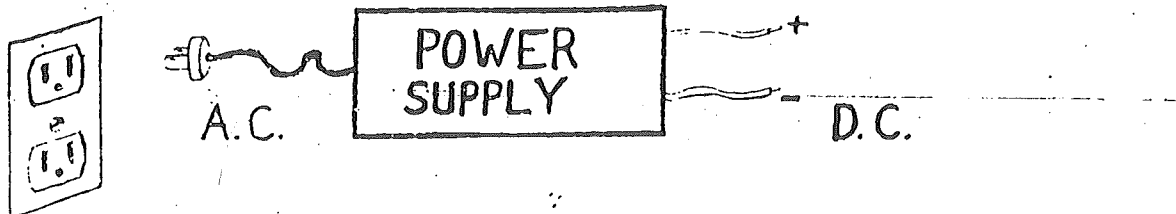
Batteries



Because of the low voltage and current requirements of today's solid state devices (transistors and ICs), batteries can provide a convenient source of DC for many pieces of electronic equipment. We will look at batteries more closely in Lesson 2.

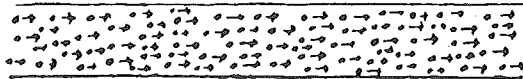
Power Supplies

Power supplies are electronic devices that change the AC coming out of your wall socket to a source of DC. Where portability is not essential, power supplies are extensively used. Much of Unit II, Lessons 4 through 9, is devoted to a discussion and analysis of this very important electronic circuit.

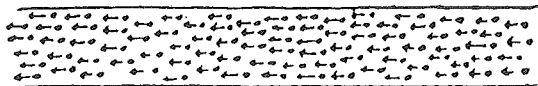


WHAT IS ALTERNATING CURRENT (AC)?

Alternating current, AC, is current that moves back and forth in a specified period of time. It moves first in one direction, then in the opposite direction.

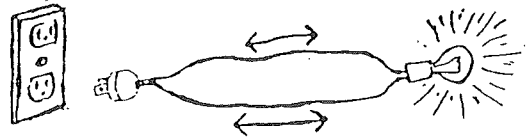


FIRST IN ONE DIRECTION--

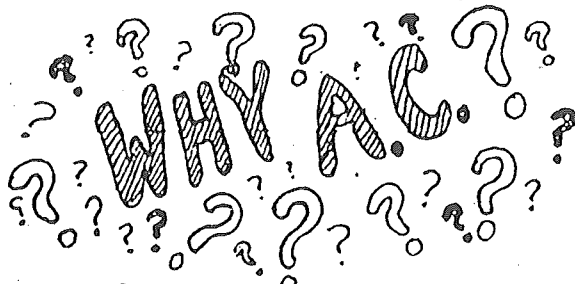


--THEN THE OTHER

Your wall socket at home provides you with electrical power (current and voltage) at 60 cycles per second. That means the current available, alternates, or moves back and forth, 60 times a second.



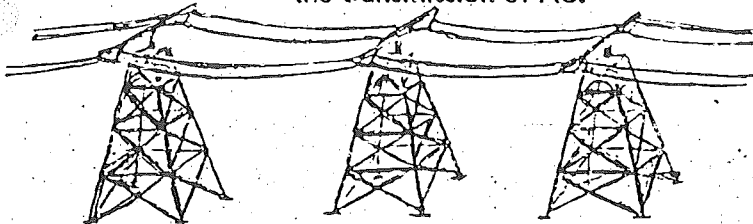
Why Do We Have AC?



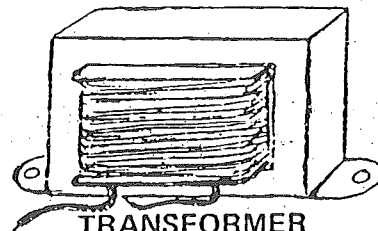
(one) The low power losses in the transmission of AC.

In the previous section we pointed out the need for DC. If the need is so extensive why then does the power company supply our homes, offices and factories with AC? AC is provided because of two important factors:

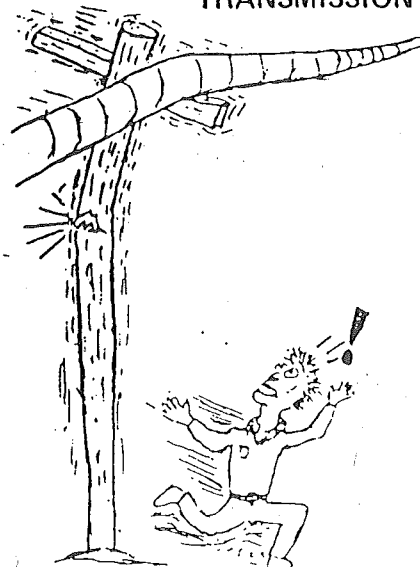
(two) The ease at which alternating current and voltage can be stepped up or down.



TRANSMISSION LINES



TRANSFORMER



Power Losses

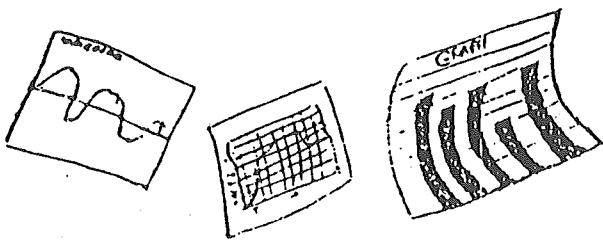
If DC were transmitted over long distances it would have to be at relatively low voltage and high current. To do so would require transmission lines as thick as telephone poles! The expense and power losses involved in such a system makes it impractical for today's power transmission needs.

Stepping Current And Voltage Up Or Down

To transmit power over great distances it needs to be sent in the form of high voltage and low current. In that way, power losses would be kept to a minimum. From the power plant voltage is stepped up (to 32,000 volts) and sent over the transmission lines. Only when it reaches the area of your home is it reduced, to 240 and 120 volts. Only AC with the use of transformers can make this possible.

GRAPHS AND AC WAVE FORMS

A graph is a method of pictorially comparing two or more quantities.

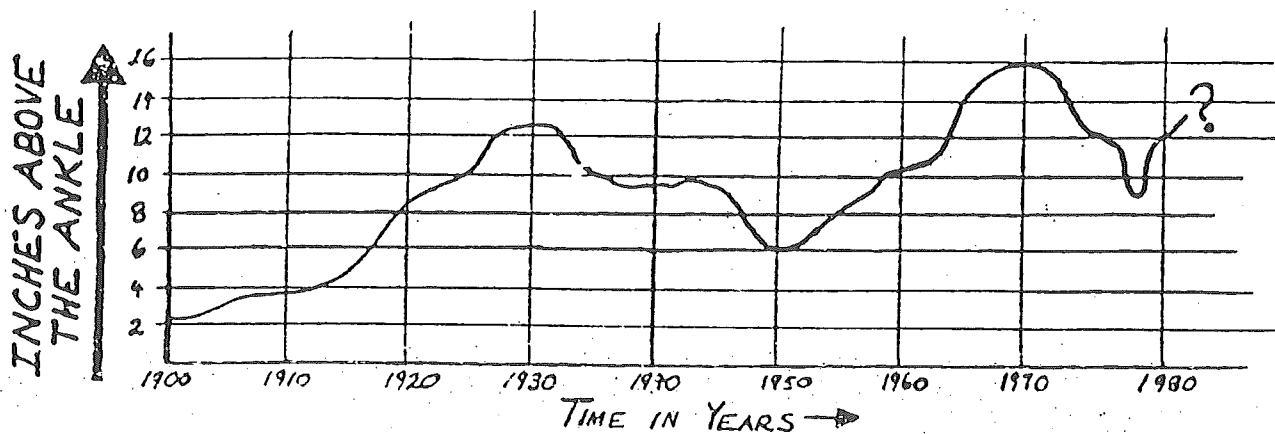


Graphs are used extensively in electronics to compare a wide variety of factors such as voltage, current, resistance, capacitance, inductance and so forth. Such graphs usually depict these factors over a given length of time.

Graphs are a quick and easy way to explain factors that would be difficult if not impossible to describe with words. Do not be intimidated or scared by them — their purpose is to make things easier to understand, not more complex.

A Typical Graph

Most graphs will depict one quantity on a vertical axis and the other on the horizontal axis. Here is an interesting example:



LENGTH OF WOMEN'S SKIRTS ABOVE THE ANKLE FROM 1900 to 1980.

Note: The vertical axis indicates inches above the ankle — the farther away from the horizontal line — the higher the skirt.

The horizontal axis indicates years, marked off in decades, with movement away from the vertical line showing an advance in years.

A Graph Depicting Electronic Data

This graph compares a DC voltage against time in seconds. Note the following points:

