Chapter 1
The Basics

The key to understanding electronics, even the most complicated circuits, lies in understanding the charges and forces of electrons. Electricity is, quite simply, electrons moving. So the question is, where to and why do they move? An electron is a negatively charged particle. The most basic tenant of electronics (and physics) is that like-charged particles repel and oppositely-charged particles attract. If for example you set 2 magnets on a table with the same poles facing each other, they will move apart; if you face the opposite poles, they will move together. Electrons are attracted by positive (opposite) charges and repelled by negative (like) charges. **Electrons will ALWAYS flow from a more negative charge to a more positive charge.**

1.1 CONDUCTORS AND INSULATORS

Elements in their normal state contain the same number of protons and electrons. In an introductory view of the atom, the electrons revolve around the nucleus in orbits. Orbits are given a letter designation, “K” being the innermost orbit, then “L”, etc. The currently accepted atomic structure is much more complicated, but the “orbit” concept will still work for the purposes of understanding electronics. For most elements the outer orbit does not contain the maximum number of electrons, but all of the more inner orbits do. The fewer electrons in the outer orbit, the more likely the atom is to have (and accept) free electrons, and conduct electricity. The free electrons normally move in a random way, but can be controlled.

A conductor is an element with less than half the maximum electrons in its outer orbit. An insulator is an element with more than half of the maximum electrons in its outer orbit. Stated simply, the better the conductor the easier it is to get the electrons to move. Lets take a conductor and place a more positive charge at one end and a more negative charge at the other. What will happen? The free electrons will be repelled by the more negative charge and attracted to the more positive charge. The electrons need to stay with an electron as much of the time as possible, however. This means that they “jump” from atom to atom. They can only move to the next atom when a spot opens up for it. Imagine a circle of chairs filled with people. If one person wants to move to another chair, everyone must move at the same time. Electrons behave in the same way. When you throw a switch in a circuit connected to a light bulb, electrons move from one atom to another. They “bump” other electrons to the next atom. The electrons from the switch don’t immediately move from the switch to the light bulb; they push the electrons closest to the light bulb there first, eventually getting to the bulb themselves. All of this can happen only if there is a closed circuit.

1.2 CURRENT AND VOLTAGE

There are two of the main ways to describe and measure electricity; Current and Voltage. Current is the flow of electrons in a particular direction. As stated above the electrons would have to flow from a more negative charge to a more positive charge. Throughout this book that will be referred to as Electron flow and will be represented in drawings as $\longleftarrow e$. Current flow, however, is the opposite of electron flow, going from a more positive charge to a more negative charge. Current is represented with the symbol **I** and in this book will be presented in drawings as

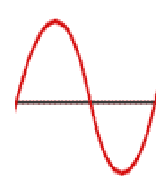
I $\longrightarrow$. The unit of current flow is called the ampere. The charge that causes this electron movement can be thought of as an electronic pressure and is called Voltage. Voltage is represented with the symbol **V**. Voltage is the difference in potential between two points. Most often we refer to a voltage with respect to Ground. Ground will be discussed in more detail later in this chapter, but for now all you need to understand is that Ground is 0 volts. Note that you can have Voltage without Current flow, but you can NOT have Current flow without Voltage. Another way of describing electricity is Power. Power is defined as the rate at which work is done. Power is measured in units called Watts and is represented by **P.** The formula for power is simply voltage multiplied by current. **P=VI**

1.3 NEGATIVE VOLTAGES

So far in the text you have read that electrons move from a more negative to a more positive charge. *Why not just say that they move from negative to positive?* First, there can be charges that are more negative than ground. Lets take a normal 9Volt battery. What if we connect the positive terminal of the battery to ground? That positive terminal is now at 0 volts (remember GND is always 0 volts). The negative terminal would now be at –9 volts. We will see many examples of negative voltages in this book. Whether we call the voltages negative or positive is just a measurement with ground as the "zero" or reference point. Electrons don't know what or where ground is. All that they care about is the relationship of voltages on either side of it. What if you have a conductor going from –20 volts to –9 volts? What direction would the electrons flow? They would flow from more negative (-20 volts) to more positive (-9 volts). If the conductor had 20 volts on one end and 50 on the other, the electrons would flow from 20 volts to 50 volts.

1.4 DC and AC

There are two basic types of current, direct (DC) or alternating (AC). Direct current (the kind that batteries produce) has electrons that move in the same direction all the time. Alternating current has electrons moving in one direction, then the other in some frequency. *But don't electrons always move from more negative to more positive?* Yes, but with alternating current, the charges that cause the movement of electrons change. For instance, let's hook one end of a conductor to ground and the other end to a charge of +10 volts. Electrons are going to move from ground to the +10 volts. Now let's switch the +10 volts for –10 volts. Now the electrons will move the opposite direction. If we keep switching the + and – voltages we will have an Alternating Current. Alternating current is constantly changing. The pattern of the signal is called the Waveform. The most common waveform is the Sine Wave. To the right you will see a display of a sine wave going through one cycle. The up/down axis represents voltage, while the left/right axis represents time. The sine wave is the simplest of all AC signals and is also referred to as a "pure" tone, because it contains no harmonics.



Direct current signals tend to stay the same voltage over time; therefore we can describe them with a simple voltage. Alternating current voltages often change in a cyclical way. A sine wave, for example, starts at 0 volts then goes up to its maximum positive voltage, back to 0, down to its maximum negative voltage, then back to 0. The time it takes to do all of this, or go through one cycle, is called its period. Since the voltage is constantly changing it must be defined in one of three ways. Peak voltage (V_{pk}) is the maximum (peak) voltage that the AC signal attains. Peak to Peak (V_{pk-pk}) is the voltage measured from the maximum (peak) positive voltage to the maximum (peak) negative voltage. With most AC signals the numeric value of the positive and negative peaks are the same, only the polarity is different, so the V_{pk-pk} is typically twice the $V_{pk.}$ The most useful way to describe the potential of an AC signal is to use V_{rms}. V_{rms} measures AC signals in a way that gives a voltage value that is equal to what the voltage would be if it were converted to a DC signal. Most VOMs (volt-ohm meters) will read AC signals in V_{rms}. To convert to V_{rms} multiply V_{pk} by 0.707. To convert back toV_{pk} multiply V_{rms} by 1.414.

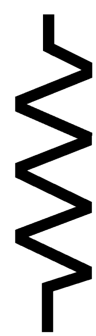
AC Voltages

$$\mathbf{V_{rms}=0.707(V_{pk})}$$

$$\mathbf{V_{pk}=1.414(V_{rms})}$$

1.5 RESISTANCE and RESISTORS

Earlier we talked about conductors, with the best conductors it is very easy for electrons to move. It is very difficult for electrons to move through an insulator. Not all conductors are the same; some allow electron movement more easily or resist the flow of electrons less. We call this property Resistance and it is measured in units called Ohms and represented with the letter **R**. The symbol for ohms is **Ω** (omega). Different conductors have different amount of resistance. If a conductor has 1Ω of resistance per inch for a specific size wire, then we could use 100 inches of it and make a 100Ω resistor. Resistors are the first and most common type of passive electronic component. They make up the majority of most electronic circuit. You don't have to make your own resistors, you can simply buy them. Most resistors are labeled with colored bands to indicate the resistance value. Historically there have been four bands, though it is now common to see five bands. The first two or three bands are the digit indicators and follow the color code below.



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

The next (second to last) band is the multiplier and follows the color code below.

Black=1	Brown=10	Red=10^2	Orange=10^3	Yellow=10^4	Green=10^5	Blue=10^6

The last band is for tolerance. It is difficult (and often unnecessary) to make a resistor at the exact value, so they come in different tolerances. The tighter the tolerance, the more the resistor will cost. Tolerance is indicated by the color code below.

Brown=1%	Red=2%	Orange=3%	Yellow=4%	Gold=5%	Silver=10%	none=20%

All conductors have some resistance to them. Most of the time in this text and in electronics in general we will connect components in our theoretical designs with "perfect" conductors. These have no resistance but don't exist in the real world. For the most part the addition of "real" conductors when the designs are built does not affect the way the circuit functions.

1.6 OHMS LAW

The most important formula in electronics is OHMS LAW.

V=IR

This shows the relationship between the three main measurements used in a circuit. It also shows how the units used to measure these relate. 1volt will cause 1amp of current to flow through 1Ω. Let's plug some numbers into the equation and see what happens. Let's start with our earlier example.

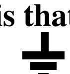
1V=1A*1Ω

Keep the resistance the same and double the voltage.

2V=2A*1Ω

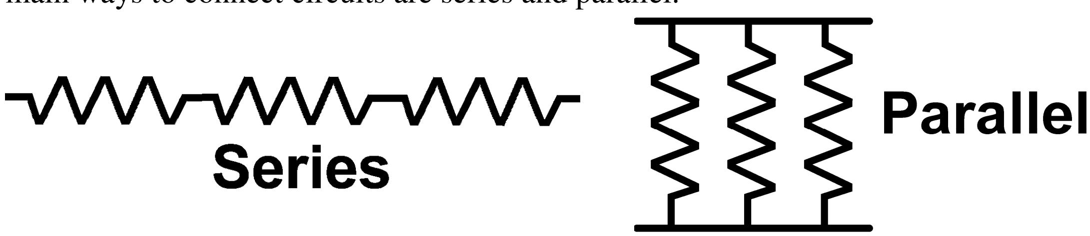
More voltage means more current, and more current means more voltage.

1.7 GROUND

Ground or earth is actually that, the dirt. It is considered to be at 0 volts. **The most important part of the idea of ground is that it NEVER changes from 0 volts.** Ground is represented with the symbols GND, , or . There are differences between these symbols that will be discussed later in the text.

1.8 SERIES and PARALLEL CIRCUITS

When you connect electronic components together you have a circuit. The two main ways to connect circuits are series and parallel.

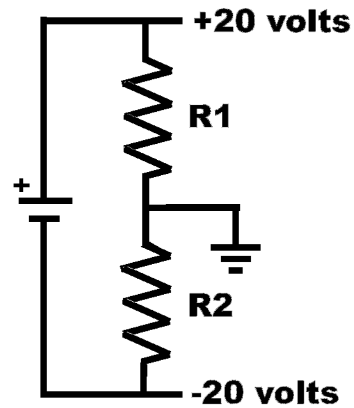


A series connection occurs when the current follows a single path through all of the components. Components that are in series will all have the same amount of current flow in each component. When the equivalent leads of two or more components are connected together they are said to be in parallel. Parallel components have equal voltage drops. Most circuits will have both series and parallel sections.

When resistors are connected in series, their values add to make the total resistance of the circuit. When they are in parallel, however, they actually reduce the circuit resistance.

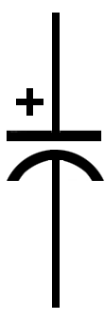
Use this formula to add resistors in parallel. $\mathbf{1/R_{total}=1/R_1 + 1/R_2 + 1/R_3 + \ldots}$

Any part of a circuit can be connected to ground. If you have a 40 volt battery, you can connect the negative lead of the battery to ground, you would then have +40 volts and 0 volts. You could also connect the positive lead of the battery to ground, you would then have 0 volts and –40 volts. A third option is shown in the schematic to the right. Using two resistors of equal value connected in series between the + and – terminals of the battery, connect the point between the resistors to ground. This leaves you with +20 volts and –20 volts. This is called a **Bi-Polar** power supply.



1.9 CAPACITORS

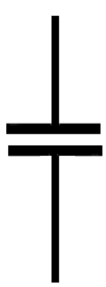
AC signals have a repetitive cycle. How often this cycle repeats is called its frequency. Sound is a type of AC signal, and the higher the pitch of the sound, the higher the frequency of the signal. **Capacitors** are another type of passive electronic component (we already learned about another passive component, resistors). A capacitor is made up of two conductive plates with a space in between them. The space is filled with an insulator. This insulator is called the **dielectric**.



polarized

The conductive plates can be made from a number of materials; most capacitors are named after the dielectric material (electrolytic, ceramic, mica). Electrolytic capacitors are very common, especially for higher values of capacitance. Most electrolytic capacitors are polarized; one end needs to be connected to the more positive part of the circuit. Most other types of capacitors and some electrolytics are non-polar. This means that the two ends of the capacitor are interchangeable.

Three things determine the value of the capacitor; surface area of the plates, spacing of the plates, and the dielectric material. This capacitance is measured in units called Farads and is represented by the symbol F. Capacitance is defined as the property of a capacitor which opposes any change in voltage across it. Reactance is the equivalent of resistance for a capacitor. It is represented by the letter Z and is measured in Ohms.

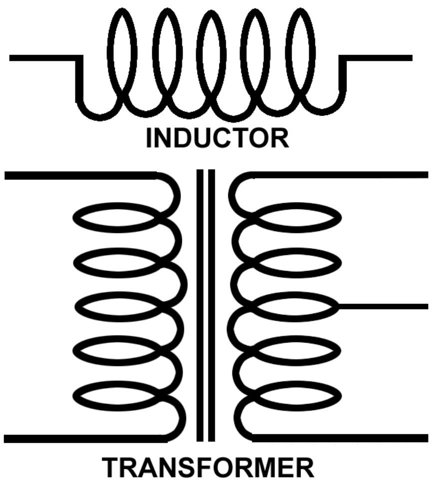

non-polar

Reactance of capacitors in series and parallel circuits adds the opposite of resistors. Series capacitors are added using the inverse formula. $\mathbf{1/C_{total}=1/C_1 + 1/C_2 + 1/C_3 + \ldots}$

The reactance of a capacitor decreases with frequency. Think about what that means. Imagine an AC signal going through a capacitor (the capacitor is in series with the source and load). The higher the frequency of the signal, the lower the reactance and the easier it is for the signal to pass through it. The lower the frequency, the more difficult it is for the signal to pass. The formula for reactance in a capacitor is $X_c=1/2\prod FC$.

1.10 TRANSFORMERS and INDUCTORS

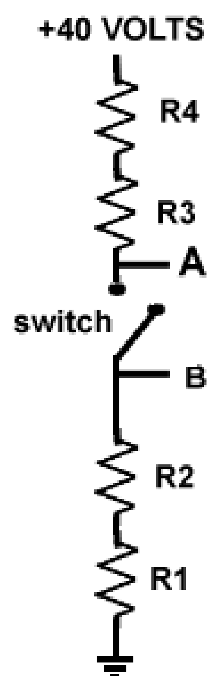
An inductor is electrically the opposite if a capacitor. An inductor works against changes in voltage. The higher the frequency going into an inductor, the harder it is to get through. An inductor is a coil of wire, and if you ever made a simple electro-magnet you have made an inductor. Current flowing through the coil induces a magnetic field.



This magnetic field lags slightly behind the current. You can also create an electrical current in a coil of wire by adding a magnetic field to it. Since the magnetic field created by an electrical current lags behind the current, it will stay the same if the current changes. That magnetic field created by the current flow then works against any change in that flow. If you wind two inductors together and put a current through one, it will induce a magnetic field in the other. This magnetic field then induces an electrical current in the other. Does that seem like a lot of work to go from current to current? Well it turns out that if we change the number of coils of wire on one of the inductors (the secondary), we can get a different amount of current than we put into the first inductor (the primary). The relationship of the two inductors is called the Turns Ratio. We have now created a transformer. Since we can't simply create more current, we have to convert it from something else. That something else is voltage. The power of the secondary (**VI**) must equal the power of the primary (**VI**). We will discuss a number of uses for transformers in the coming chapters.

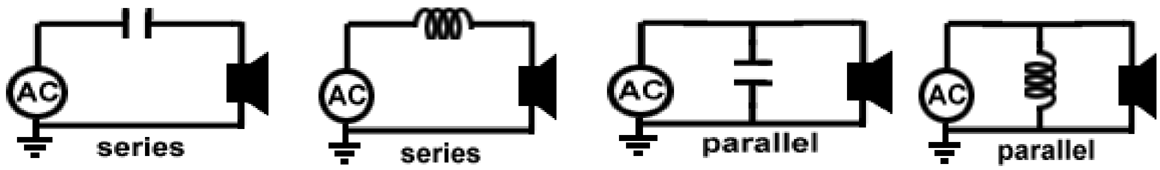
1.11 VOLTAGE DIVIDERS

Any components in a circuit between a voltage source and ground must dissipate or "drop" the entire voltage of the source. Lets look at a example circuit. If each of the resistors is equal, then they would each drop 10 volts. What would the voltage be at point B? It would be 20 volts. Now what would the voltage at B be if the switch were open? Think about it this way, how much current is now flowing through R1 and R2? Since there is no connection between the +40 volts and ground, there is no current flowing. No current means no voltage drop, so the voltage at B with the switch open is 0 volts or the same as ground. With the switch open the voltage at B will not change no matter what the values of R1 and R2. What about the voltage at A when the switch is open? Again, no current is flowing so there is no voltage drop across the resistors. A would be at +40 volts.



1.12 PASSIVE FILTERS

Now lets look at some practical circuits using some of the passive components we have talked about so far. Filters are used everywhere in electronics, getting rid of unwanted frequencies. The simplest filter is made with either a capacitor by itself or an inductor by itself. The much lower cost of capacitors makes them the more common choice for filters. There are two ways to make a filter; you can send the frequencies you don't want to ground (taking them away from the load), or you can block the unwanted frequencies from the load.



The capacitor in series forms a **High Pass Filter** while the inductor in series forms a **Low Pass Filter**. In the Parallel circuits the capacitor forms a Low Pass Filter and the inductor forms the high pass filter. A high pass filter allows higher frequencies to pass more easily, while a low pass filter allows lower frequencies to pass more easily.