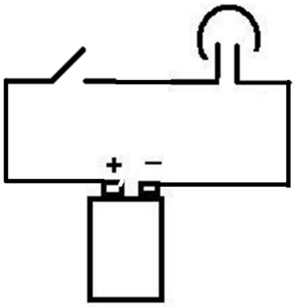
Chapter 3: A Brief Introduction to A Few Essential Electronics Concepts

This book is geared toward individuals who have some background in computer programming but little background in electronics beyond what they learned (and presumably forgot) from eighth grade science class. This chapter is not intended to provide anything other than a rudimentary understanding of electrical circuits to provide enough information to get the reader going building and programming projects that use microcontrollers. As more advanced technologies are used in later chapters additional topics will be covered.

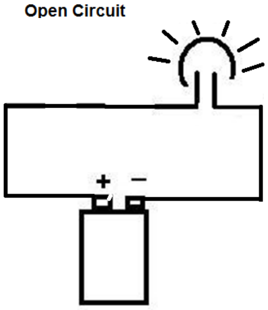
Ohm's Law

You probably recall from eighth grade that electricity is the flow of electrons. It occurs when two conditions exist 1) Some atoms have a deficiency of electrons and others have a relative surplus AND 2) there is a path between these two sets of electrons that facilitates the flow of electrons from the surplus atoms to the deficient atoms. A battery is a device that contains atoms that have both a surplus of electrons (the negative pole) and a deficiency of electrons (the positive pole). If we provide a conductor between those two poles to will provide a path so that the electrons can flow.



Open Circuit

Here I have constructed such a circuit with a battery, a switch and a light bulb. When the switch is open there is no path for the electrons to travel from the negative pole of the battery (where there is a surplus of electrons) to the positive pole of the battery where there is a deficit. When the switch is closed there is now a path for the electrons to travel and as they flow from the negative pole of the battery to the positive pole the travel through the light bulb causing it to light up.



Closed Circuit

The amount of electrons flowing through the circuit is called current and it is measured in amperes or, more commonly amps. Typically in the circuits that we will build the amount of current is quite small and so it will be measured in thousandths of an amp or **milliamps** (ma). The amount of current flowing depends on two things: 1. The voltage of the battery (think of this as the amount of pressure to get the electrons to move) and 2. the amount of electrons that the path is able to accommodate (generally expressed in terms of the opposition to the flow of electrons, or resistance. The voltage is measured in **volts** and the resistance is measured in **ohms.**

The higher the resistance, the less current will flow, the higher the voltage, the more current will flow. This relationship is expressed mathematically in a formula know as **Ohm's Law**:

$$\text{current (in amps)} = \frac{\text{Voltage (in volts)}}{\text{Resistance (in Ohms)}}$$

or, more commonly: $$\mathbf{I = \frac{E}{R}}$$

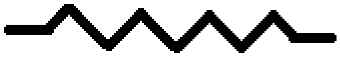
where I is current, E is voltage, and R is resistance.

The reason this is important is that most electronic components have rates for the maximum amount of current or voltage that they can withstand without being damaged. For example each of the pins on the PIC microcontroller (except for the pins that power it) can only withstand 25 ma of current without damage. The voltage that we will be dealing with in the projects in this book will generally be 5 volts. In order to insure that the current flowing in a circuit connect to a pin on the microcontroller does not exceed 25 ma, it will sometimes be necessary to add some resistance to the circuit because resistance and current have an inverse relationship.

Light Emitting Diodes

The early projects in this book all use Light Emitting Diodes (LED's). A diode is a device that only conducts electricity in one direction. Have you noticed that when you put batteries in a device (such as a TV remote control) and you accidentally put them in backwards it doesn't cause the device to break? (It won't work that way, but at least it doesn't break!) The reason is that there is a diode in the circuit to protect the device by not allowing current to flow the wrong direction. An LED is a special kind of diode that, in addition to only conducting electricity in one direction, glows when current is flowing through it in the correct direction. You've probably got these device in an awful lot of things that you use every day. They come in a range of colors and brightnesses. They are relatively inexpensive (in quantity about 1.5 cents each) and they interface very easily to microcontroller circuits. You'll notice that they have two leads that come out the bottom and one of the leads is longer than the other. The long lead should always be connect to the positive pole of a battery (or positive power bus on your circuitboard). This is because it will only conduct electricity (and light up) when it is connected in one direction.

LEDs are devices that will be destroyed if two much current is sent through them. In order to limit the amount of current flowing through them we will add some resistance to the circuit as determined by Ohm's Law. A resistor is a device that add resistance to a circuit. It's value is, of course, measured in ohms and the symbol for a resistor in an electric circuit looks like this:



The real world device has a set of stripes on it (called a "color code") that allows you to determine it's value. Suppose we connect a 1000 ohm resistor between our microcontroller and the LED we are using (see the board set up in Chapter 4 for an example). We can use Ohm's law to calculate the maximum current that will flow through this circuit (assuming we are running the microcontroller at 5 volts):

$$\mathbf{I = \frac{E}{R}} \qquad I = 5/1000 \qquad I = .005 \text{ amp or 5 ma.}$$

This is substantially below the 25 ma that can be supplied by the PIC and it is also below the maximum current that can be tolerated by the LED.

Alternating Current and Bypass Capacitors

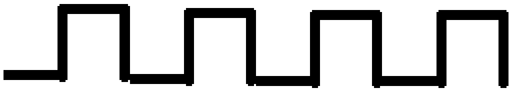
You probably also remember from eighth grade science class that electricity comes in two flavors: alternating current (AC) and direct current (DC). Alternating current is the type that comes out of a wall socket in your home, while direct current is most often supplied either by batteries, or devices that convert the AC in your house into DC (such as cell phone chargers). Most of what we will do in this course involves direct current and you might consider that a good thing because the mathematics involved with DC are much simpler than AC.[1]

However, alternating current is around us pretty much all the time in the form of electromagnet radiation. While you probably think of this radiation in the context of radio signals (such as those from cell phones) electromagnet radiation is also generated inadvertently by most electrical appliances. It's just about impossible to avoid. However, if this radiation gets picked up by our microcontroller circuit, it can have unpredictable and undesirable consequences. There are electrical devices called **capacitors** which, among other things, can keep this AC out of our circuits. They do this because they have the unique ability to conduct alternating current while blocking direct current. So, for example, we'll place these capacitors across the power supply leads for every chip that we use as close to the chip as possible, connecting the power lead in each case to ground through the capacitor. Any AC coming into the chip will thus be sent to ground and kept out of the chip. However, the capacitor does not short the power lead to ground because it will not conduct direct current. When capacitors are used in this way they are called **bypass capacitors**.

Keeping Time

Every computer requires a clock. By clock I don't mean a device that knows the day and time, but rather a device that can generate regular pulses that allows the processor to sequence its operations. Computer programs contain a list of instructions that must be executed in a precise order. For this to happen the processor must have some sense of time. The regular pulses that come from a computer clock allows the processor to execute the instructions at regular intervals. For microcontrollers there are a number of possible sources for this required clock.

You could use a device called an **oscillator.** This is a device that you power up just like you do the microcontroller and it then sends out a series of very regular pulses alternating between the input voltage and ground (zero volts). The would look something like this:



Another possibility is to connect a device called a crystal to the microcontroller to provide a clock. A crystal is a metal can that contains a piece of the a mineral called quartz lodged between two metal plates. When electricity is run though the device it vibrates a very precise frequency in such a way that it can be used as a clock. It generally requires bypass capacitors on both leads. A similar device is called a ceramic resonator. It is generally available with the capacitors already included. It is often

[1] It's been observed that Thomas Edison favored transmitting DC for use in homes rather than AC (favored by Nicola Tesla) because Edison had little formal education and wasn't capable of mastering the mathematics necessary to manage AC.

slightly cheaper than a crystal (especially when you take into account the lack of capacitors) but it is not quite as accurate and is more susceptible to change frequency with changes in temperature.

More recently designed microcontrollers contain their own oscillator which can be used as the processor clock. In years past these clocks were not very precise and also would run rather slowly compared with the speeds that could be obtained by a resonator or a crystal. But in recent years they have improved dramatically. Not only are they more accurate and faster than they used to be, they are now programmable so that you can often run them at a wide range of speeds. The internal oscillator in the 16F1459 processor that will be used in this book, for example can be programmed to run at any of the following speeds:

31 KHz
31.25 KHz
62.5 KHz
125 KHz
250 KHz
500 KHz
1 MHz
2 MHz
4 MHz
8 MHz
16 MHz
24 MHz
32 MHz
48 MHz

This book will use the internal oscillator in the chip, most of time set for 4 MHz. You might wonder, particularly if you are a gamer who is used to overclocking his PC, why you would ever run this processor at anything less than the maximum speed possible. There are at least two very good reasons for this. First, the faster you run the chip, the more electricity it will consume and the warmer it will get. If your final project is going to run from a battery, the rate of electricity consumption might matter to you. Second, sometimes writing the software can be more difficult at higher speeds. For example, our first program will cause an LED to blink on and off. The program will work by flipping the state of the LED (from on to off or from off to on) and then waiting a little less than 2/10s of a second to flip it again. The processor has to keep track of how much time has passed and, because it is an 8 bit processor, it can only count up to 255 before it starts over again. The faster the chip runs, the higher it has to count to allow 2/10s of a second to pass. This is easier to do at lower speeds.

Powering Your Project

If your project is small and does not draw very much current, you can use the PicKit programmer to provide power to it during the design phase. However, when you get to the point where you want your project to run independently of the programmer, or if the current demands of your project exceed about 30 ma., you'll need to provide an independent source of power for it. There are several options available. Perhaps the easiest (and most portable) is to use a battery. The PIC16F1459 that will be used for the project in this book is capable of operating on any voltage in the range 2.3v to 5.5 volts. You might think that 3 volts would be a good choice because you could simply power the project from a pair of AA or AAA batteries. And it might be. But be careful to consider the power requirements of the other parts of your circuit. If, for example, you are also using another chip that requires 5 volts, it would be easier to use that voltage for everything, rather than provide two different voltages for the two different parts.

If you decide to use 5 volts there are a couple of battery combinations that will work. When batteries are connected in series (end to end) you get the total voltage by adding the individual voltages. If you get a battery holder that can contain 3 AA or AAA cells (such as Radio Shack's 270-412) it will provide 4.5 volts, which is close enough. Another possibility would be to use 4 rechargeable nickel cadmium batterys ("ni-cad's"). While these batteries are called AA batteries and look very similar to alkaline AA batteries, they actually produce 1.2 volts, not 1.5 volts. As a result, 4 of them will nicely produce 4.8 volts.

Another option would be to use a 5 volt voltage regulator. A voltage regulator is a device that accepts a wide range of DC input voltages, but produces a specified voltage output. So, for example, you could use a 78L05 regulator that would accept voltages between 8 and 30 volts and produce a 5 volt output. The 78L05 will generally work with currents up to 100 ma. If you need more power, you could select a 7805 instead, which will produce a full 1 amp output, but may require a heat sink to keep it cool. The 7805 is available in most local Radio Shack stores.[2] You will need a capacitor on the input and output of the device, 10 uf should do it.[3] You can use either electrolytic or tantalum capacitors, but be careful, these capacitors or polarized (the longer lead is positive) and if hooked up backwards they will explode.

Voltage regulators generally have 3 pins on them, one for input, one for output and one to connect to both the input and output ground. The only thing you need to add to use one
You may wonder how long your project will run on battery power. The capacity of batteries is rated in milli-amp-hours (mAh) or amp-hours (Ah). A mAh is what you get when a project that draws, say, one milli-amp runs for one hour. You can get an estimate of the amount of time that your project will run using the following formula:

$$\text{Time in Hours} = \frac{\text{Battery Capacity in mAh}}{\text{Current Drawn in mA}}$$

If you use AAA alkaline batteries the capacity will be about 1200 mAh. If you use AA alkaline batteries you will get about 2700 mAh. These figures are approximate because the capacity of the battery depends on how quickly you discharge it. The more current you draw, the lower its total capacity will be.

Another way to power your project would be to use a plug in power supply (like the one that recharges your cellular phone). There are several specifications to look for when selecting one of these. Obviously it must have the voltage output that matches the power requirements of your project. In addition, you need to make sure that this voltage is **regulated**. A regulated power supply will produce approximately the same voltage regardless of how much current is drawn (as long as you don't exceed the current specification of the power supply). Many plug in power supplies (including most of those that recharge laptop computer batteries) are **unregulated**. Many power supplies indicate on them whether they are regulated or unregulated. If they don't, use a voltmeter to measure their output and see if it matches the voltage listed on the supply. If it does, it is probably regulated. If it is unregulated, you will probably get a reading that is higher than that indicated.

Another thing to look for in selecting a power supply is that, of course, it must be DC rather than AC. Both types of plug in supplies exist, so look carefully. It may say "AC" or "DC". Alternatively, a flat line generally indicates DC while a sine curve indicates AC. Finally, somewhere on the power supply it should indicate which conductor is + and which is -. If you have any doubt, use a digital voltmeter to determine this. If you get a negative voltage reading, it means you have hooked it up backwards.

[2] Radio Shack part number 276-1770.
[3] Radio Shack Part number 272-1436 or 272-1013.

If you have a voltage source that is too high for your circuit (say, you want to run it on a 9v battery) or you want to use an unregulated power supply you can do that by building a voltage regulator circuit on the project itself. This will convert a fairly wide range of voltages (generally at least 8-15 volts) into the voltage specified by the regulator. Voltage regulators are fairly simple devices. Typically they have a pin to connect the positive voltage input, a pin that provides the positive (regulated) voltage output and a common ground that is used for both input and output. Generally you will need a device called a capacitor connected between input and ground to prevent a voltage spike when the device is powered on. The value of the required capacitor will vary depending on the voltage regulator that you select, but generally it will be large enough that it will require an electrolytic or tantalum capacitor. When using these capacitors, be careful. If you hook them up backwards, they will explode after a couple of seconds.

Sometimes you may find a power supply rated in watts rather than amps. A watt is a measurement of power, which is a combination of voltage and current. You'll note that household appliances are often rated in watts rather than amps. The formula for calculating watts is as follows:

Power in Watts = Voltage in Volts x Current in Amps

So if you see a power supply rated in watts, you might think that you can simply divide that by the voltage to get the amount of current it can supply. However a wattage rating on these devices is usually the amount of power consumed by the device, not the amount of power it can deliver. Power supplies are not 100% efficient. Typically, assume the device is only 50% efficient, so divide the current result of your calculation by two to get a realistic estimate of the current that the device can deliver.

A Digression on Object Oriented Hardware

The hottest thing in computer programming for the past few decades has been object-oriented programming. The reason that it is so important to software development is because it causes programmers to think of software as collections of components which can be mixed and matched in various combinations to achieve a range of functionality. Want to add a word processor to your program? No problem, just grab a word processor object and drop it in. You don’t have to understand the internal programming or workings of the word processor; all you have to understand is the user interface.

The same thing has become true of hardware, but we don’t call it “object-oriented hardware”. Perhaps we should. So much functionality is encapsulated in slabs of silicon these days that the people who use these parts in circuits can't possibly understand how all the bits inside actually work. Instead they rely on documentation to teach them the "user interface" for these parts so that they can be dropped into electronic designs and just work.

The manufacturers of these parts want to make it as easy as possible for developers to use their parts so they not only publish the details of the user interfaces, they also generally publish some circuits or reference designs that can be used to create new products. All of this information is contained in a document called a "datasheet". Not only is it not considered "plagiarism" to steal the design directly from a datasheet, but the manufacturers want you to do that because their goal is to sell parts, not to sell designs.

This creates a bonanza for both professional designers and hobbyists alike. Want to add USB to your project. No problem. Just go get the FTDI datasheet for there FT232R part, take their, download their driver and you've got USB! The same goes for a world of other parts. Want an accelerometer? No problem! There's a part and a data sheet for that. Want to add Wifi? Bluetooth? A touchscreen. It's all available and you don't have to understand how USB, Wifi, Bluetooth or touchscreens do what they do; you just have to master the datasheet.

This chapter has not been intended to be a tutorial in electronics theory. Rather it is designed to give you a brief background that will allow you to get started. Additional essential issues will be covered in later chapters as they come up.