

Practical Electronics

Part 1. Basic Components.

14 April 2009, 14 May 2009

Introduction

This document is an attempt to introduce the technology and practice of ordinary everyday electronics in a structured manner. This structure will hopefully promote quick assimilation by those who need a grounding of the subject in a short amount of time. It should be noted that this is not how I learned electronics. And I probably speak for the vast majority of people working in the field.

How to keep progressing quickly though this course: Never pass a word you do not completely understand without looking it up in a good dictionary and using it in sentences until you do understand it. All of us, particularly the “bright” ones, tend to skimp on this basic study rule. Well, maybe the “bright” ones can get away with it, but if you want to get bright and stay that way, follow this rule. And if you find yourself slowing down, go back and find the word you have stuck attention on, and clear it up. This is not all of Study Technology (developed by LRH) but is the most important element. In addition, studying a “mass-less” subject such as this without “mass” to balance the significance will tend to cave you in. The purpose of the demos and “practicals” is to prevent that, but they may not go far enough. There is nothing that can replace the extroverting effects of leaving study for a while and going for a walk, chopping some wood (to be prosaic), or getting hold of a kit of parts and actually building something for yourself. Having an oscilloscope to see waveforms is also a great help in this field. If such equipment were dirt cheap and available (as it really should be by now) I would not hesitate to demand that you acquire it if you are serious about learning this subject. However, since I currently don’t own a real oscilloscope myself, we will see how far we can go without one. However, don’t underestimate the power of tools that bring this data out of the realm of nebulous theory and give you a result you can see in front of you with your own eyes, or hear, or feel.

Basics, and source materials:

I did not discover electronics. So what gives me the right to write a course about it?

Countless writers in countless subjects could be challenged on this point.

In theory, you would get the fullest and most faithful understanding of a subject by starting with the seminal writings in the field, in the words of the original researchers, and following the subject forward in a chronological fashion.

The practical limitations faced by most writers, along with, perhaps, ignorance of the above datum, lead to the multitude of second-hand material that passes as legitimate instruction in this age.

From a whole track viewpoint, the real original material for most technologies is lost, and all we have left are the writings of modern scientists, engineers, inventors, and similar bright people who simply managed to figure some of it out and fashion some sort of technology around what they “discovered.”

I might mention, however, that I started my formal study of the subject with some rather old books. At least one text that I found (at my local library) was issued by the U.S. Navy for use in training its personnel. And I must say it was one of the clearest books I ever read on the subject. The majority of the references in my personal library are there to supply circuit design ideas and basic data on available parts. I still have a few books on basic theory, but most were lost somewhere along the way, and I cannot say that I miss them. One working prototype is worth a million books on how to design one or on how it “really” works. But you will have to be your own judge of how much theory you should know and to what extent your mental abilities allow you to encompass a broader understanding of the field. This course leans to the practical side, at least regarding the technology of electronics.

So: what do you really need to know to operate with some success in the field of electronics? I will keep this material, as best I can, to the subject of electronics technology only. To be successful in any field there are many other aspects and technologies that you must appreciate or be aware of. This course will not teach you all that other stuff.

Let’s start, then, with the word *electronics*.

It sounds like it has something to do with *electrons*. And so it does. My dictionary defines it as a science. I think of it more as a technology, which is to say an *applied* science. But I won’t be picky. It’s a study of the behavior and control of electrons. Let’s start with that.

Electron: An atomic particle. Word invented by Irishman George J. Stoney in 1891.

Assuming you have a grasp of *particle*, let’s move back to *atom*: the basic component of all matter. That’s the old philosophic definition. Nowadays we have to add: The smallest particle of matter that retains all the properties of the element made from it.

And *element*: One of a couple hundred substances that are the simplest forms of matter from which all other matter is created. An element has measurable, consistent, and

predictable physical and chemical properties and cannot be further simplified or broken down without losing those properties.

Here we have traced the seemingly harmless word “electron” back to a concept that seems vaguely connected with the original creation and various philosophies of existence. And so it is.

Has anyone ever seen an electron? Today, this particle is, by definition, impossible to actually hold down and look at with the eye or with any optical microscope. It is in constant motion, and if it were not, it would no longer be an electron. It is the most essential component, along with its “vector” the photon, of what most of us know as “energy.”

All of the above, then, is, basically, just *theory*. Electronics deals with a “particle” that is so close to being “nothing” that it only really exists as a particle in the theories of the physical sciences. Because its effects can be *felt* and *measured*, most of us assume, and we are entirely justified in doing so, that electrons are *real*.

Experiencing the basic particle of electronics:

I’m sorry if this seems trivial but I had to put it in. Have you ever gotten an electrostatic shock? Or some other electrical shock? Felt the heat of an incandescent light? Or been burned by one? Turned a switch on and had some device come to life? That’s all electrons.

Basic electronic components.

The battery.

Batteries are sources of electrons. They consist of two terminals held apart physically but connected by some sort of chemical medium. The chemical action produces an excess of electrons at one of the terminals. This action continues until the battery “wears out.” At that point it must either be replaced or recharged.

The circuit.

Circuit: the action of going around, or a path or route for doing such. In electronics, it is a path through which electrons may flow.

Drawing circuits is a key action of someone involved in electronics. So let’s get started:

Take a flashlight as an example. In a flashlight, electrons “flow” through the bulb, which makes it light up. Without getting over-involved in all the whys and wherefores, we can draw this circuit using standard symbols. (These symbols have never become *totally* standard, but are very close to universal.) We have below the symbols for a battery, a wire, a switch, and a lamp, and then they are shown connected together to make a circuit. Once you learn the basic rules of electricity and electronics, you will do most of your “thinking” in the subject with the help of either real or mental pictures of circuits such as the one below.

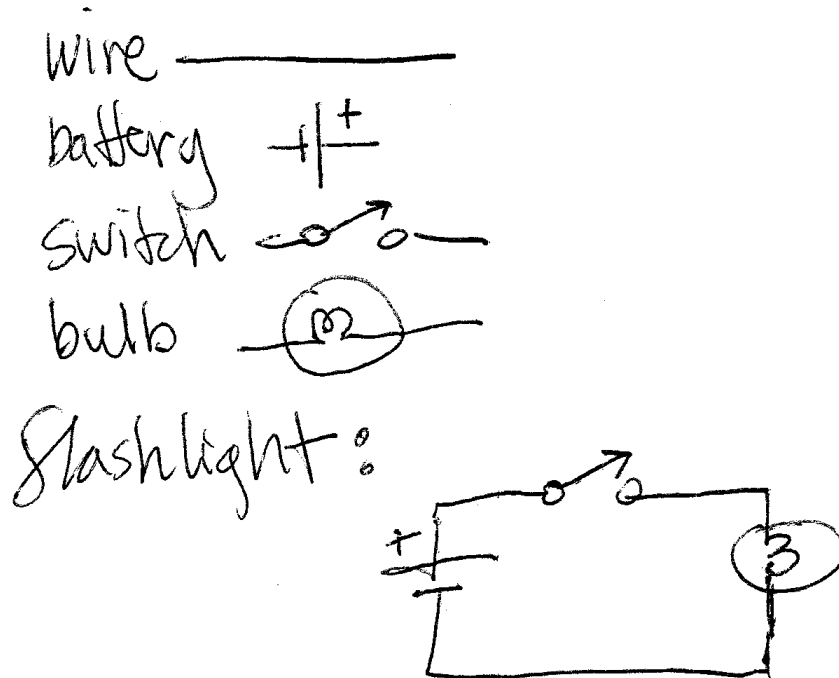


Figure 1.1 A circuit drawing - flashlight.

Nowadays (not so much when I was getting started) they have computer programs that allow you to draw circuits and test them “soft” without ever building them. This course will not use such programs, but they are definitely a learning tool. And as a design tool they are widely used. Sooner or later you will need to learn to use these programs. Whether this will ever totally replace the proverbial “drawing on a napkin” remains to be seen!

Practical:

Using the basic elements in Figure 1.1, make some drawings that arrange those elements in other ways. Think of some arrangements that might work, and some that might not work. Did the drawings help you “figure out” which arrangements might or might not work?

Plus and minus, and more symbols.

The electronics symbols developed over the years are definitely symbolic, but the simplest ones are also quite realistic in their own way. The battery, for example, indeed shows a separation between the two battery terminals. The plus side is the one labeled, in accordance with long-standing convention. Electrons are “negative” in physics, so some say we should trace their flow from negative to positive in circuits. But the real world didn’t exactly work out that way. Most circuit symbols that include arrows indicating direction of flow show a flow from positive to negative. This started, I would guess, with how vacuum tubes worked, and it has stuck quite thoroughly on down from there. So you might as well deal with that confusion right off the bat. You will normally trace circuit flow opposite to that of electron flow. Don’t worry; it works out ok.

Voltage, current, insulators, conductors and resistors.

Voltage: A measurable force arising from the accumulation of charge. (Technically this is *electromotive force*. But everyone calls it “voltage.”)

Current: A measurable flow occurring in the presence of a voltage. Though current is measured in *amperes*, it is seldom called “amperage.”

Insulator: A substance in which the current is miniscule in the presence of a voltage.

Conductor: A substance in which the current is substantial in the presence of a voltage.

Resistor: A substance in which the current is somewhere between miniscule and substantial in the presence of a voltage.

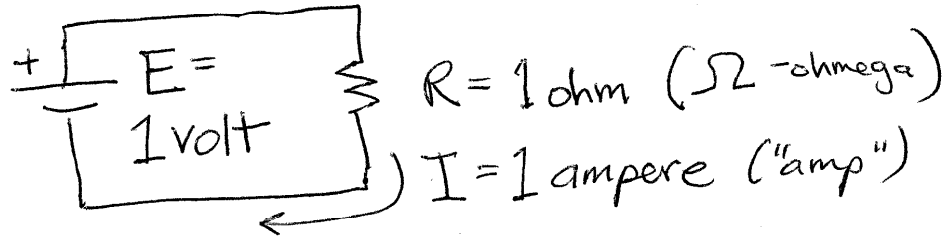
The common concept behind these three words is *resistance*. Resistance is measured in *ohms*. If a substance has a very high resistance, we call it an insulator. If it has a very low resistance we call it a conductor.

Circuit design is normally simplified by assigning insulators infinite resistance and conductors zero resistance.

The following figure introduces the symbol for a resistor and illustrates the basic relationship between voltage, current and resistance.

This is described mathematically by the famous formula $E = I \times R$. (E stands for Electromotive force, and somewhere along the line, current became represented in physics and electronics by the letter “I”).

resistor : 



thus :

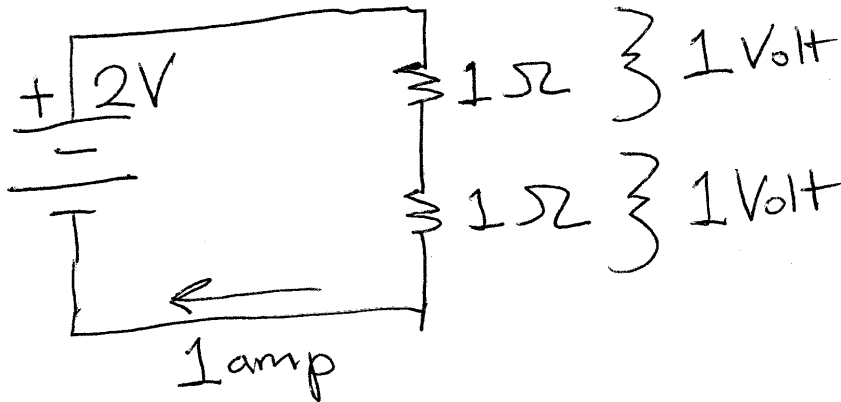


Figure 1.2 Drawing showing $E = I \times R$.

I included the second drawing to illustrate something that is important in electronics. Notice that I show 2 volts across the circuit containing two resistors. Per $E = I \times R$, the *voltage drop* across each resistor is 1 volt. If you assume that the bottom wire is zero volts (as we normally do), then the top of the battery is 2 volts, and the voltage between the two resistors is *one* volt. We can say that those two resistors *divided* the total voltage. This concept is used all the time in electronics.

Real-world values for voltage and current.

Factually, one amp is a LOT of current. You might find that much current running through a light bulb, but not usually through a little electronic circuit. Correspondingly, 1 ohm is a very SMALL resistance. Our first challenge, which I hope is a small one, is to come up with names for component values that are more realistic in the context of most electronics. Electronics uses the commonly-used physics prefixes for changing the orders of magnitude of units of measurement. These are less common in the U. S. than they are

in Europe. A thousand ohms is 1K (literally spoken “k”) ohms, short for a kilo-ohm. And one thousandth of an ampere is a “milliamp” commonly written “mA.” Voltages are similarly handled, though 1 to 10 volts ARE realistic voltages in electronics. You will run into circuits that handle, on the high side kilo-volts (kV), and on the low side milli-volts (mV) or even micro-volts (μV). That odd symbol for “micro” is the Greek small letter “mu.” I should mention, while on the subject, “nano-,” meaning a billionth (in U.S. parlance) and “pico-,” meaning a trillionth. You are probably already familiar with “mega-“ for a million, “giga-“ for a billion and maybe even “tera-“ for a trillion, from computer lingo.

Practical:

Re-draw the circuit in the bottom of figure 1.2 using more realistic values, so that current is in the range of 1-10 mA. Double-check your math! Can you do the calculations in your head? (NOTE: You will see these values written “ma” and “mv”, etc., in other literature. It doesn’t make a big difference. I will capitalize the letters standing for electrical units in this course.) Now calculate the current in your circuit for a more realistic battery voltage of 1.5 volts (if you haven’t yet.)

Input and Output – Signals.

Anyone schooled in computing or other “flow” processes is familiar with the terms “input” and “output.” I hope I do not have to get too involved defining these. The basic idea is that you set up a process, provide it with some “input” and it’s supposed to give you some desired “output.” In the more theoretical forms of this, it is often possible to describe the relationship between the input and the output of a process mathematically. This is also the case with many electronic processes.

Essentially, a circuit is used to implement a process. There may be several different ways to get identical or similar results. The exact methods chosen are up to the designer of the circuit (or process.) This gets us into the whole realm of engineering, which deals not only with basic workability, but also with factors like cost, efficiency, safety, reliability, and durability. As a “beginner” in electronics (whatever that is) your first concern is likely to be *workability*.

In electronics we speak of the input and output of a circuit as “signals.” Let’s look this one up: “the electrical impulses transmitted or received.” Well, that’s not as simple as I would have liked. Let’s simplify this definition to something along the line of “an electronic incident.” I hope that communicates. The concept does not carry any particular connotations regarding duration or meaning. It’s a very abstract and general term. What goes into a circuit can be considered a signal and what the circuit does to the input signal results in the output signal. Going back to the circuit in Figure 1.2, you could say that the input to the circuit was a signal of plus two volts. And if you take the output as the point between the two resistors, then the output signal was one volt, half of the input signal.

You could call the process implemented by this circuit “divide in half” and express the circuit mathematically as $V_{out}=1/2xV_{in}$. Am I going too fast for anyone?

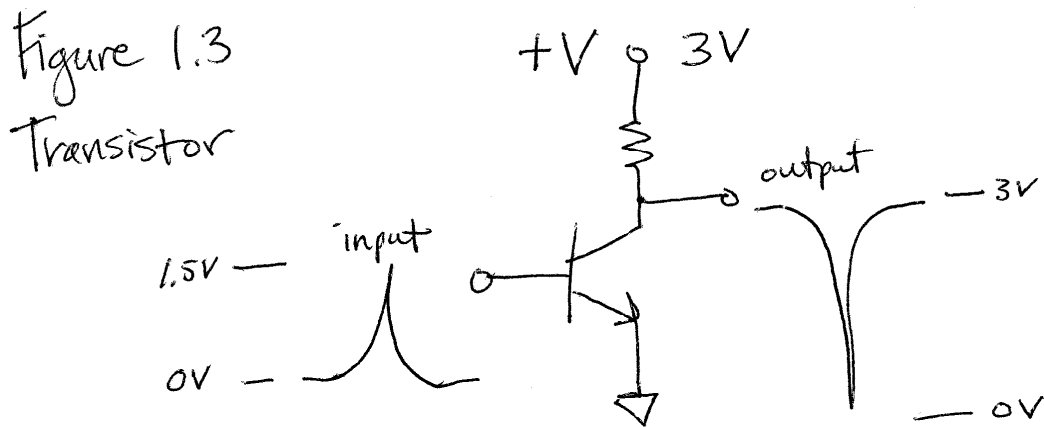
We are almost ready to break loose. What do you want your circuit to do? Let’s first finish the list of basic components.

The amplifier.

We are going to have to confront amplification sooner or later, so it might as well be sooner. We have all heard of amplifiers. They – well, they *amplify*. You saw in Figure 1.2 a simple implementation of what could be, and sometime is, referred to as a “divider.” It is more properly known as an “attenuator.” But how do you do the opposite – get a bigger signal out than you put in? The answer to that question is almost the whole field of electronics in a nutshell. There are “millions” (probably not that many) ways to amplify. Amplification (“gain” as it is sometimes referred to) is the mainstay, the bread and butter, of electronics. Amplification is what Tesla was trying to achieve with his devices before vacuum tubes were invented. It’s an absolute rock-bottom basic.

I am going to use the subject of amplification to introduce the most ubiquitous component in the entire electronics arsenal – the transistor. Though tubes were invented before transistors, they are not simpler or more basic than transistors, so there is no need to study them to understand electronics.

Figure 1.3 shows a transistor circuit amplifying an input signal. The input is a little “blip,” and the output “blip” is bigger. How is this made to happen? Well, one answer is: do you really want or need to know? Let’s pursue that line of reasoning for a while and see where it gets us.



This is a very simple circuit. You could actually build it and see if you could get it to work. You would need some sort of meter to measure the voltages. A 1.5 volt “blip” is applied to the input terminal. Somehow, this causes a 3 volt “blip” on the output. A few added components would allow the circuit to tolerate a wider range of input voltages, and could be used to “tweak” it to find the “sweet spot” where its amplification abilities

would be the greatest. Note also I have added a few new symbols here. I have eliminated the battery symbol and replaced it with a little circle with “+V” by it at the top and a little unlabeled triangle at the bottom. This triangle always stands for “the zero voltage point in the circuit” sometimes also called “ground” or “common.”

I could give you a set of graphs showing you the relationship between the input and output signals for this circuit, and you should be able to use that information, all by itself, to design all sorts of variations on the basic amplifier shown here. Are you curious how it works? Well, most texts don't even care whether you are or aren't; they just tell you anyway. But I want to make a point here: Basic electronic design, on the level I usually work and which most of you will work, consists of taking components with descriptions of the “processes” they perform, and figuring out how to fit them together to do something useful. It is not necessary to have a full understanding of why those components are able to do those things. And that is what “practical” electronics is all about. It's not about solid-state physics, or semiconductors, or n-type and p-type channels or all that other stuff. It's cool to know what that all means, but unless you are in the business of figuring out how to manufacture those components, you won't actually use that understanding very much. My major task in this course is to keep your interest long enough for you to feel that you know enough to do something with electronics components that interests you. So, do you mind if we save semiconductor theory for an appendix? If so, let's forge ahead.

AC-DC

No, not the rock band, or...whatever. I was hoping somehow that anyone reading this course would be magically familiar with these concepts so that I wouldn't have to think up explanations for them. If you think you are, try skipping to the next section.

AC = Alternating Current. DC = Direct Current.

Back when I was a student I went through a tiny hell learning some of the math associated with alternating currents. All of it was based on the assumption that you were working with pure frequencies, like the 60 cycles per second (now known as “Hertz”) that comes out of U.S. wall outlets. That all breaks down if you have a complex AC signal.

DC? Well, that's just batteries, or things that could stand in for batteries (commonly known as “power supplies”). It's 1.5 volts or 150 volts or something and it just sits there. As soon as it starts changing, you get into the world of AC.

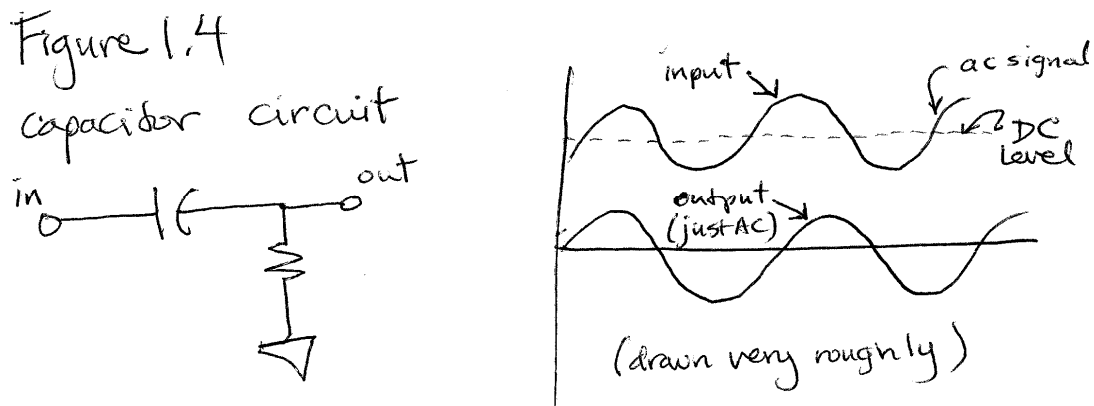
Most of electronic devices involve AC. You can even include computer logic in that category, as well as all of audio and radio. When you get into opto-electronics (light-emitting diodes, lasers, etc.) you begin to go beyond AC.

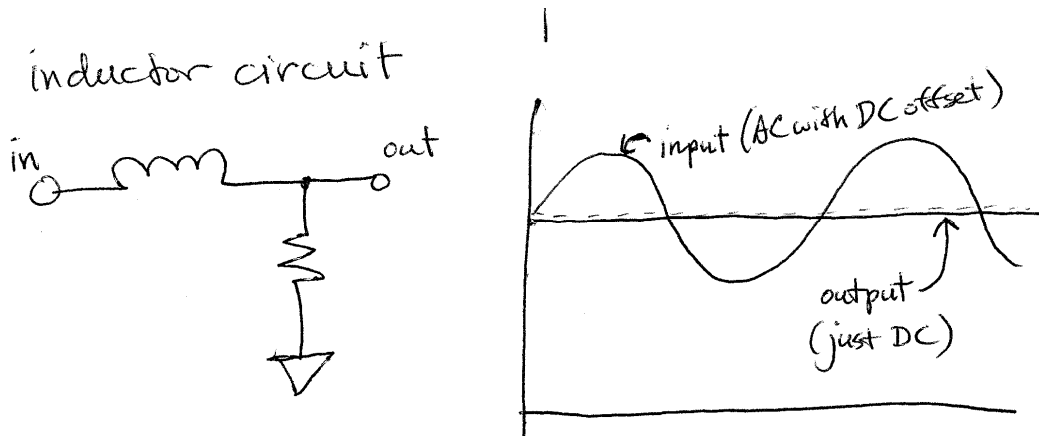
The inductor and the capacitor

With AC we get two new components. It is desirable to have a component that passes DC currents and blocks AC currents. This is the *inductor*. And we also need one that blocks DC currents and passes AC currents. This is the *capacitor*. Because of real-world limitations, we can't make totally perfect inductors and capacitors. But we can make ones that are quite workable for most applications. Another way to look at these is as temporary charge storage devices. The capacitor temporarily stores voltages and the inductor temporarily stores currents. The only way you can get a capacitor to store a voltage "permanently" is to connect it to a perfect insulator. And the only way you could get an inductor to "permanently" store a current would be to connect it to a perfect conductor. For most of us, such circuits would not be very practical. Temporary storage is good enough. These two components are very widely used in electronics.

In the following drawing I introduce the "time versus amplitude" diagram. I don't know if it has a more official name. Oscilloscopes display signals in this manner, and it is very helpful to sketch them this way as well. The horizontal direction is time. Actual units of time may or may not be indicated in a sketch. You may be more concerned with *relative* times. And the vertical direction is amplitude. It can be positive OR negative. In the classic diagram of this type, the input signal is either above or superimposed over the output signal. If it is confusing to draw them both on the same axes, each signal can have its own zero-amplitude line.

The top half of Figure 1.4 shows a capacitor blocking the DC component of the input signal and passing the AC component to the output. The bottom half shows an inductor passing the DC component of the input signal to the output and blocking the AC component.

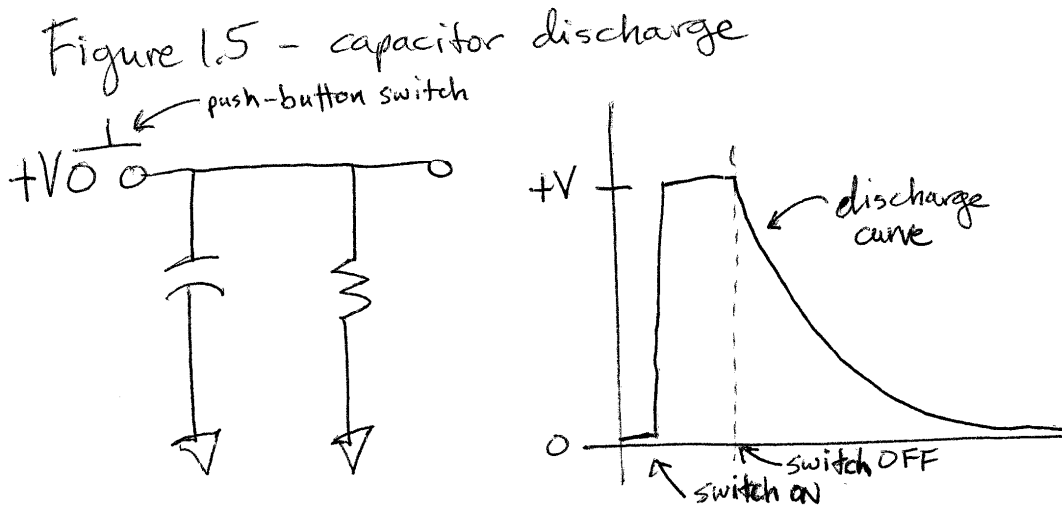




Capacitors and inductors have values. Capacitance is measured in Farads (F). Real-world values are usually in the range of micro-farads. Inductance is measured in Henries (H). Most inductors are also in the range of micro-henries.

These components are often used separately or together to “tune” circuits to specific frequencies. This is a big deal in radio technology. They are also used to “filter” out or “bypass” unwanted frequencies.

Capacitors, simpler to make and cheaper than inductors, are also used in timing circuits where extreme precision is not required. A capacitor, charged to some given voltage, will discharge very predictably through a resistor of known value. You can see this if you choose a very large capacitor and have a way of measuring the voltage across it.



A traditional electronics course would probably have you compute some “time constants” at this point. But I find myself normally taking this data off charts supplied by helpful engineers.

Analog versus Digital

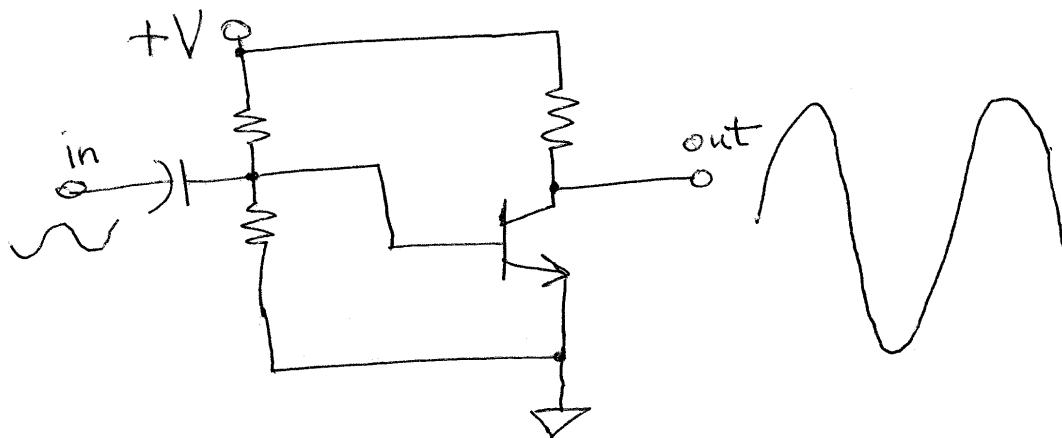
I don't know if you've ever thought this through, but the world is basically digital. Analog is an interesting word, closely related to "analogue" and "analogy" which means something used for comparison, or of similar magnitude or quality to something else. An "analog" clock, then, uses the analogy of a rotating planet to display the time. An analog meter or gauge uses the position of a needle to correspond to some value getting larger or smaller. But these days you see "digital" analog clocks and meters. Your computer screen is digital but it LOOKS analog. Why? The digital elements of your screen are so small that they became barely noticeable. When you take "natural" matter or energy down to its most basic parts, the apparent smoothness of it finally disappears and you get atomic particles that "jump" between separate energy states.

Despite all this, there is "analog" and "digital" electronics. Technically you could say that digital electronics uses analog components in their most extreme operating states. So you just ignore all the "middle" values that a circuit goes through and only look at the extreme values and you get digital electronics. If you purposely try to avoid the extreme operating levels and stay within the "middle" levels, you get analog electronics. In both cases, the ultimate granularity of atomic phenomena is not an important consideration in current electronic technologies. Future technologies could change that.

Let's go back to our transistor amplifier to explore the basic practical differences between analog and digital circuits.

If you could carefully adjust (or "tweak," as previously mentioned) the circuit in Figure 1.3 so that the output would sit at 1.5 volts DC with no input signal, then applying a small AC signal to the input should result in a larger "analogue" to that signal at the output. We call this "linear" amplification. A practical circuit is shown in Figure 1.6.

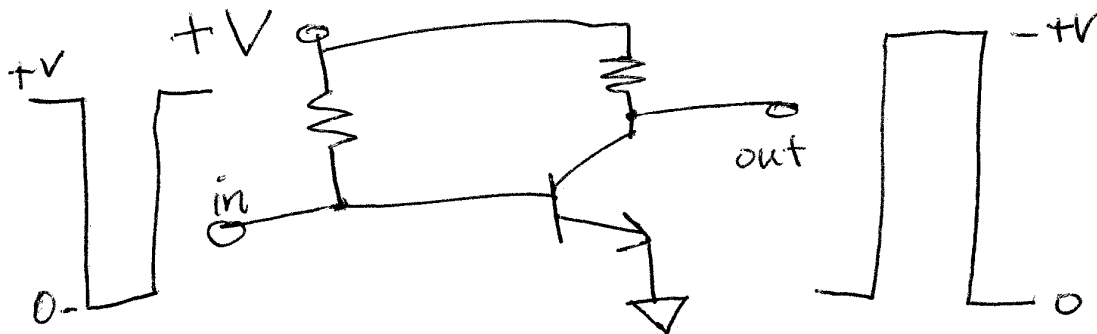
Figure 1.6 - linear amplification



The voltage divider at the input provides what is known as “bias.” This puts the device (hopefully) in the center of its linear operating range. Designing good stable bias circuits is pro work. There are some simple methods that are fairly reliable that I will introduce in the next part of this course. The “coupling” capacitor means that the DC level of the input signal will not throw off the bias voltage. In exchange for this feature, the circuit will no longer amplify DC signals. For a solution to this, we have “Op Amps” (later).

Figure 1.7 shows a “digital amplifier” commonly called a “switch.” This is actually just one way to operate an amplifier in “non-linear” mode. The transistor could be biased to be fully “on” with no input signal or fully “off.” In digital circuits, input signals are usually “dc-coupled.” The transistor, then, is being used as a non-linear dc amplifier. “Where is the amplification?” you might ask. The input and output signals have the same amplitude. A circuit of this type may not perform much amplification. But in most cases it *is* designed to amplify. It amplifies current instead of voltage. It might take 1mA or less of input current to provide 10 mA or more of output current.

Figure 1.7 - non-linear amplification



Polarity, and diodes

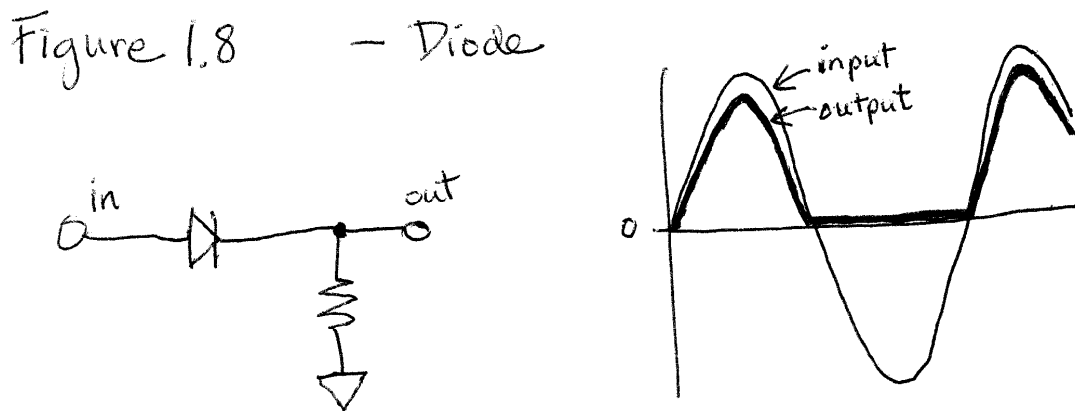
It seems long ago that engineers (Shockley) came up with the idea of the transistor. The older technology used for amplification was the vacuum tube (called a “valve” in the U.K.). Though how these devices work is an interesting subject we don’t need to cover that here. My point is that all electronic devices that amplify are used in a similar fashion. The device is set up so that a varying voltage at its input varies its resistance. When put in series with another similar device, or with a fixed resistor, you create, essentially, a variable voltage divider.

Most, if not all, such devices operate this way only for one direction of DC current flow. In other words, if you put them in the circuit “backwards” they do not operate as expected. This means that transistors and transistor-based components, as well as some other components, such as some types of capacitors, have a “polarity.” The fact that

materials in transistors operate differently when their polarity is reversed has been used to create a two-terminal device called the “diode” (which essentially means “two ways”).

Used within its normal operating range, a diode made of semiconductor materials acts like a conductor in one direction and like an insulator in the other direction. This is very handy for certain uses. This action is also called “rectification” and the device can also be called a “rectifier.”

Figure 1.8 The basic diode in action.



Transformers

To complete our kit of basic electronic components, we have to visit the world of magnetics, and take a look at transformers. Transformer action is very handy in electronics. I don't know if it is totally 100 percent indispensable but it is for sure handy.

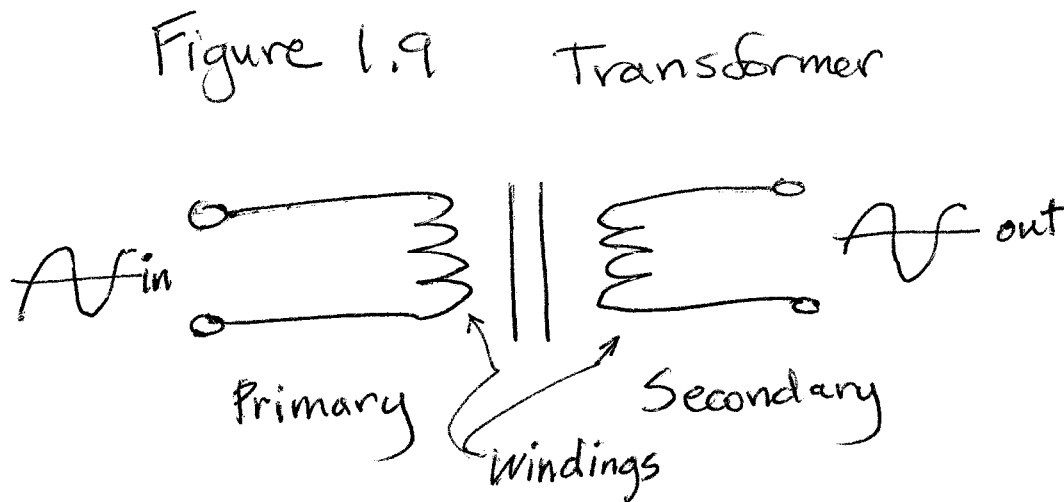
Transformer action allows you to take a signal that exists at a certain voltage level and change its voltage level. Now, you might say, we have already gone over that in voltage dividers and in amplifiers. And I would have to agree with you – we have. All I can say is that doing this with a transformer sometimes has certain advantages.

A transformer essentially consists of a pair of inductors. This is its simplest form. It consists of two inductors that are “coupled” to a greater or lesser extent so that they “talk” to each other. This communication is understood to take place because of the magnetic field generated around an inductor.

Whenever an electrical current flows, both electrical and magnetic fields are created around the component that the current is flowing through. These are in addition to whatever electrical and magnetic fields may already exist in the environment, such as those created by the earth, by power lines, or by radio transmitters. Electrical fields have to do with charge and voltage, and magnetic fields have to do with magnetism, which most of us have experienced by observing the physical pull of magnets.

Transformer action is considered to be basically a magnetic effect. You put a signal into one inductor, this creates a magnetic field around it which can be picked up by a second nearby inductor, and a signal will appear in this second inductor that is very similar to the one in the first inductor. You put these two coils together in a neat little package and you have what people call a “transformer.”

Figure 1.9 shows the symbol for a transformer and its nomenclature. The input side is called the “primary” and the output side is called the “secondary.” There may actually be more than one primary and more than one secondary in a transformer. Any of its windings *can* be used as either a primary or a secondary.



What we are always taught about transformers is that the voltage ratio between input and output is roughly the same as the ratio of windings in the input and output coils. Though there are other factors involved, this is the most important factor.

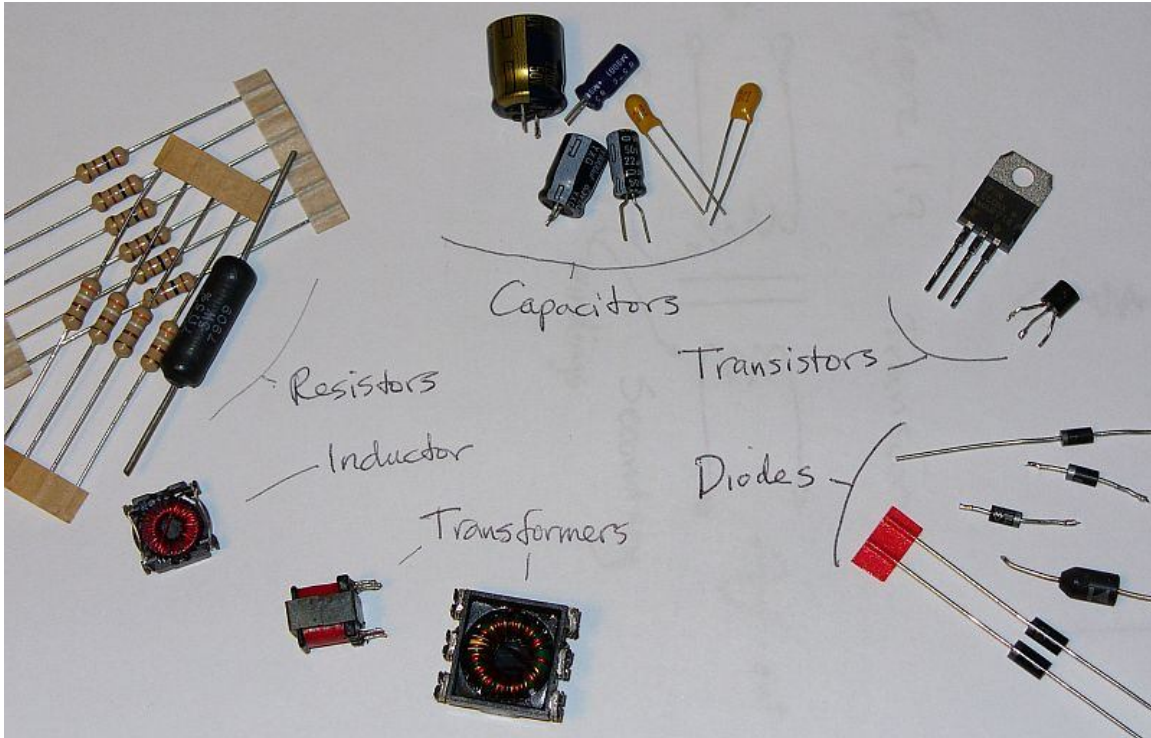
At low frequencies, transformers are used mostly in association with electrical power. In this application, transformers have the benefit of *electrical isolation*. In other words, the voltage level on the primary is isolated by insulating materials from the secondary. This is a safety point for human users.

At audio and radio frequencies transformers are often used for something technically known as “impedance matching.” The subject of *impedance* is not covered in this course.

Summary

You have now been introduced to all the basic components used in electronics. Figure 1.10 gives you an actual photograph of what these components look like in the real world. Further course sections will guide you through the practical uses of these

components, but feel free to dive in and create your own circuits. As long as you stick to battery power, you run minimal risk of doing anything dangerous.



© Larry Cox, 2009.