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Lab Electronics Reference: Tips, Techniques, and Generally Useful Information for the Labs

This guide contains some useful reference information to help get you started on your labs. It explains how to interpret the various and mysterious codes on the packages of common electronic components. It also gives some tips on good breadboarding practices. Electronics projects can be a lot of fun, and we hope that you will have fun doing your projects this semester and learn a lot in the process.

0.1 Reading Device Packages

Electronic devices come in all sorts of interesting packages of different shapes, sizes, and colors. There are some standardized package codes that you will probably find useful in building your circuits. In the case of small parts, such as resistors and some capacitors, it is also good to know how to read the codes to make sure that you have the correct part, without having to rely on the label of the parts bin from which you picked it. It is very easy for people to accidentally drop parts into adjacent bins, or entirely wrong bins.

0.1.1 Resistors

One of the better known package codes is the resistor color code. Resistors are usually marked with four colored bands, $c_1c_2c_3c_4$, in a place code that is interpreted numerically as

$$R = c_1c_2 \times 10^{c_3} \quad \text{tolerance} = \begin{cases} \pm 10\% & c_4 = \text{silver} \\ \pm 5\% & c_4 = \text{gold} \end{cases}$$

Note that this code is *not* standard scientific notation, because there is no decimal point in the mantissa. The colors are assigned numerical values that loosely go in order of the colors of the rainbow, as follows:

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

Thus, a resistor with a value of 270 Ω with a tolerance of ±5% would be marked Red–Violet–Brown–Gold. The beginning of the code is usually closer to the edge of the device body than

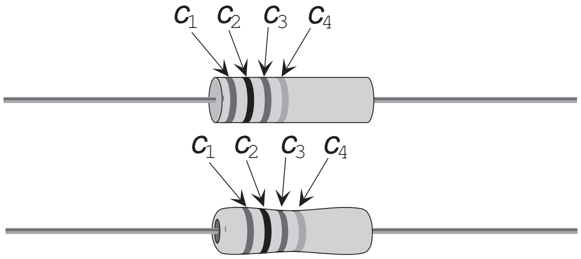


Figure 0.1: Typical resistor packages.

the end, as shown in Fig. 0.1, and you will never see a resistor that is marked with silver or gold at the beginning of the code.

Precision resistors (usually with a tolerance of ±1% or less) are sometimes marked with five colored bands, giving three significant figures before the exponent instead of two, and a stripe to indicate the tolerance. However, you will often find the same sort of place code (three significant figures and an exponent) printed on the resistor body as numbers. For example, a precision resistor marked 9012 would have a value of $901 \times 10^2\,\Omega$, or $90.1\,\text{k}\Omega$.

0.1.2 Capacitors

Capacitors are usually marked in one of two ways, each of which are illustrated in Fig. 0.2. The most convenient labeling scheme is when the value in microfarads is printed directly on the package, as shown on the right in Fig. 0.2. For example, a 47–microfarad capacitor rated for no more than 16 volts would be labeled with $47\,\mu$F $16\,$V. Capacitors with relatively large capacitance values are often marked in this way.

Many of the larger-capacitance devices (e.g., electrolytic capacitors and tantalum capacitors) are polarized in such a way that any DC voltage component must be in a particular direction across the capacitor, otherwise potentially dangerous things can happen, such as the capacitor exploding in your face. Sometimes the polarization is printed on the package with a + or − sign next to one of the leads. Additionally, an arrow is often printed on the package indicating the direction of the polarity. Capacitors with radial leads (i.e., both lead wires project from one end of the cylindrical package) often have one lead longer than the other, as shown on the bottom right in Fig. 0.2; in this case, the longer lead should be connected to the more positive voltage. Capacitors with axial leads (i.e., one lead wire projects from each end of the cylindrical package) often have a crimp at the positive end of the package body, as depicted on the top right in Fig. 0.2.

Smaller capacitances (e.g., ceramic disc capacitors) usually come in flat or oval packages with leads projecting in parallel from one side of the package body, as shown on the left in Fig. 0.2. These capacitors are generally marked with a place code, similar to that used for resistors, except that the code values are printed on the package using numerals, and the unit quantity is one picofarad (i.e., $10^{-12}\,$F). For example, the ceramic disc capacitor on the left in Fig. 0.2 that is marked 202 would have a value of $2000\,$pF. These capacitors are usually not polarized, and can be connected into a circuit in either direction.

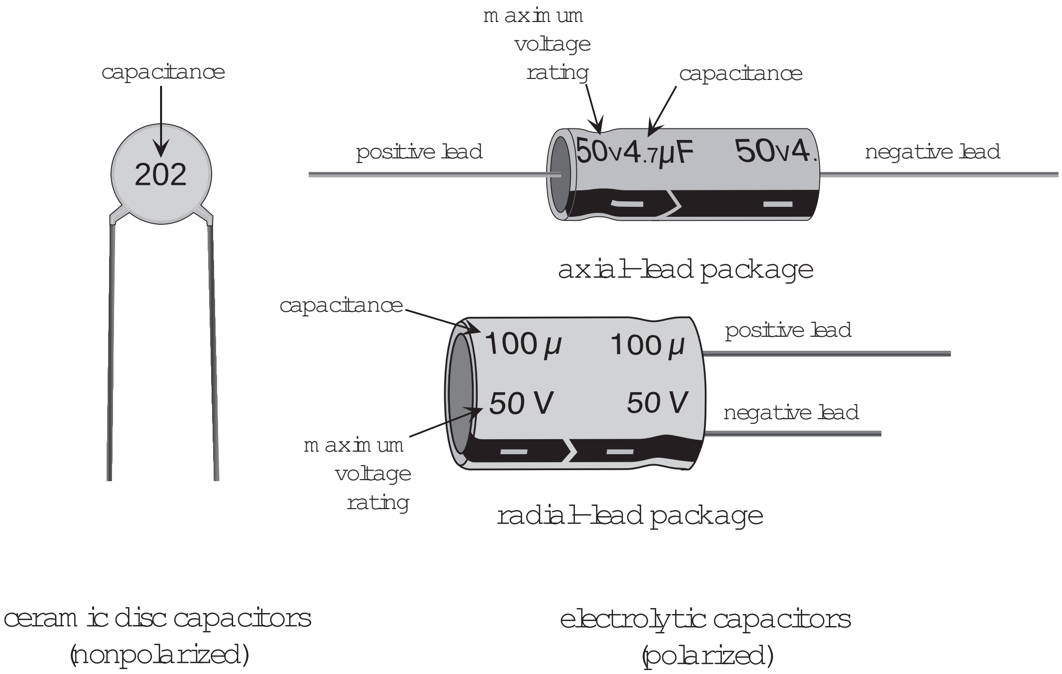
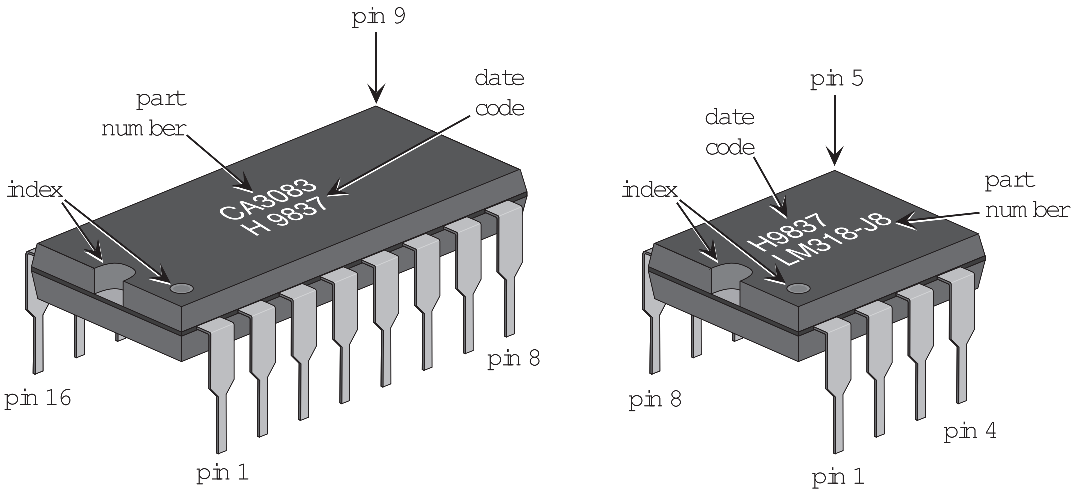


Figure 0.2: Typical capacitor packages. The capacitor shown to the left is a ceramic disc capacitor. Such capacitors can be connected with either polarity in a circuit and are generally available only in small capacitance values in the range of picofarads and nanofarads. The capacitors on the right are electrolytic capacitors. This kind of capacitor is polarized and must be connected with the positive lead connected to side of the circuit with the higher DC potential. Electrolytic capacitors come in larger capacitance values, usually in the range of microfarads and millifarads.

0.1.3 Integrated Circuits

Integrated circuits (ICs) now come in many different types of packages. The most common type for circuits that you will be using in lab is the *dual in-line pin* (DIP) package, which looks a little like a bug of some kind. The DIP package pins are numbered counterclockwise as you look down on the chip from the top, starting from the upper left corner with pin 1. The top of the chip is sometimes indicated by a notch in the middle of one of the narrow ends of the chip. In some cases, the location of pin 1 is also indicated by a small dot on the top of the chip.

Integrated circuits in DIP packages usually have their manufacturer's name or logo and some other cryptic letters and numbers stamped in white ink on the top surface of the black package. These letters and number sequences usually include a part number that identifies the chip and a date code which indicates when it was manufactured. The part number consists of a prefix code, a model number, and a suffix. In many cases, different semiconductor manufacturers use different prefix codes consisting of up to three alphabetic characters in front of the model number, even if the same IC is made by several different companies. The letters in the suffix of an IC part number usually indicate the package type



16–pin DIP package

8–pin DIP package

Figure 0.3: Typical integrated circuits in dual in-line pin (DIP) packages. DIP packages come in a variety of sizes with anywhere from 4 to 64 pins. The pins are numbered counter-clockwise around the chip. If you look down on the chip with the notch facing up, pin 1 is in the upper left corner, and the pins increase down the left side of the chip and then up the right hand side of the chip. The highest pin number is directly opposite pin 1. The location of pin 1 is often indicated by a small dimple in or dot on the top surface of the chip.

and rated temperature range. There are three different standards for temerature ranges: the military range is from −55°C to +125°C, the industrial range is from −25°C to +85°C, and the commercial range is from 0°C to +70°C. Commercial-grade parts are probably adequate for circuits intended for normal indoor use. Unfortunately, each manufacturer has its own set of suffix codes that change on a regular basis, so if you need to find out over which range of temperatures a particular part is rated, you should determine the manufacturer and consult the manufacturer's data sheet for that particular part.

The date code on most ICs comprises four digits which encode the week during which the chip was manufactured. The first two digits give the year, and the last two digits give the week of the year. For example, the date code of 9837, which is shown on the ICs depicted in Fig. 0.3, indicates that these chips were manufactured in the 37th week of 1998, which corresponds to the second week of September. Date codes can be useful in a number of different ways. For example, by looking at the date codes on the ICs in some commercial electronic equipment, you can sometimes get an estimate of when the equipment was manufactured. The vast majority of ICs have a very long shelf life, so you usually shouldn't worry about using an IC with an old date code.

0.1.4 Diodes

Light-emitting diodes (LEDs) are useful display devices in many circuit applications. LEDs

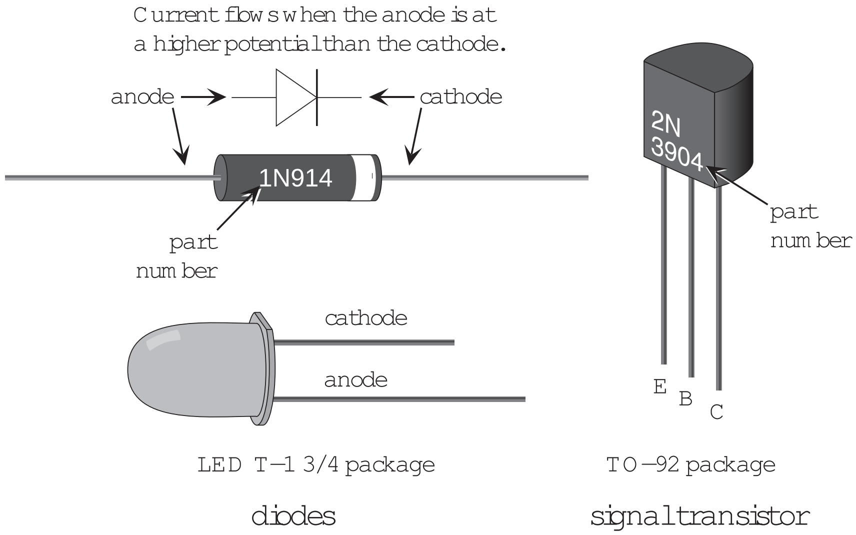


Figure 0.4: Typical discrete semiconductor packages.

come in a variety of packages. One of the more common packages for individual devices is the T–series package, which is shaped sort of like a thimble with two leads sticking out of the wider, flat end of the package, as shown in the lower left of Fig. 0.4. The cathode (i.e., most negative) lead usually has a flat spot next to it, while the anode (i.e., most positive) lead is usually slightly longer.

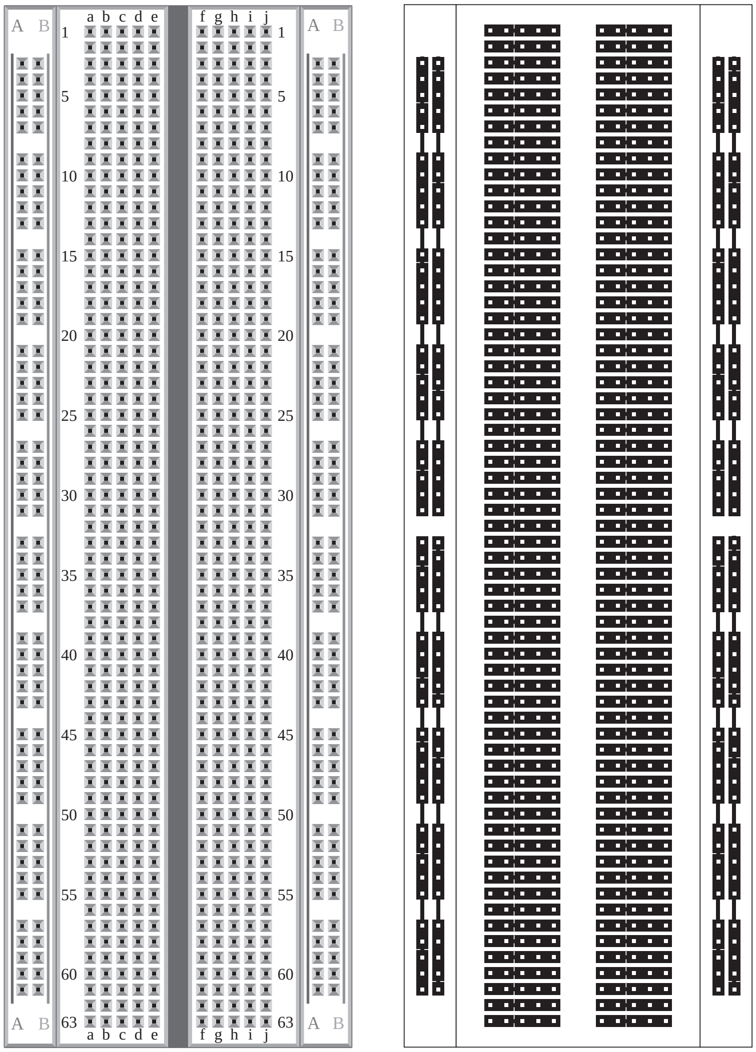
Rectifier and zener diodes usually come in axial–lead packages with a stripe or bevel marking the cathode end, as shown in the upper left of Fig. 0.4. Power diodes come in all sorts of strange packages, mostly having to do with facilitating good thermal connections to heat sinks, but most of the work that you will be doing in these labs will be relatively low-power stuff. Rectifier and zener diodes usually have part numbers that begin with 1N.

0.1.5 Transistors

Individual transistors come in various packages, usually with three leads. One of the most common packages for signal transistors is the TO–92 plastic package, which is a cylindrical shape with a flat side, as shown on the right in Fig. 0.4. Looking at the flat side with the leads pointing down, the leads, from left to right, are often emitter, collector, and base. However, other orderings, such as emitter, base, and collector, are also commonly used, so it's best to check it out in a data book if you are not sure. Transistors often have part numbers that begin with 2N.

0.2 Breadboarding Basics

In order to get a circuit to function, we need to connect all of the components together and hook them up to the power supply. There are a number of different ways to connect electronic components together to build circuits. For the most part, you will be building



(a) (b)

Figure 0.5: Solderless breadboard (a) top view and (b) cutaway view showing how the holes in the top of the breadboard are connected internally with metal connections.

your circuits in this lab on a white plastic rectangle with a lot of little holes in it called *solderless breadboard*, which we usually just call *breadboard* or sometimes *protoboard*. The breadboard gives us a way to hook up a circuit quickly without having to spend a lot of time building a printed circuit board (PCB) and soldering all of the components together, only to find out that the circuit was not designed correctly in the first place. On the breadboard, we can test a new circuit design and easily fix or optimize the design. Once we have built a circuit that works well, we can then construct a more permanent version of the circuit on a PCB or some other substrate.

Figure 0.5a shows a top view of a typical breadboard. Running along the left and right edges of the breadboard are four long columns of holes, called busses; we usually use these to distribute power and ground to all of the components in the circuit. We plug the components into the central area on the breadboard; the gap in the middle is just wide enough for a DIP package to straddle it. In the middle of the breadboard, the five holes on the left of the gap (often labeled abcde at the top and bottom of the breadboard, a shown in Fig. 0.5a) in each row are shorted together. Likewise, the five holes on the right of the gap (often labeled fghij at the top and bottom of the breadboard, as shown in Fig. 0.5a) in each row are shorted together. Figure 0.5b shows how the holes in the top of the breadboard a connected internally with metal traces.

When you insert a bare wire or a component lead into a hole in the top of the breadboard, the wire goes between a pair of spring-loaded clips that both grip the wire mechanically and make a solid electrical connection between the wire and the metal inside the breadboard. In general, you should use #20 gauge, #22 gauge, or #24 gauge solid-core hook-up wire to make your connections on the breadboard. If you use wires of higher gauge (i.e., smaller diameter), the spring clips may not hold them tightly enough. If you use wires of lower gauge (i.e., larger diameters), you may overextend the internal spring clips, which can ruin the use of that hole in future designs. Some larger components, such as large electrolytic capacitors have relatively thick leads, so insert them into the breadboard carefully. To make a connection, strip one end of a piece of hook-up wire (you should strip away about 1 cm of the insulation) and insert the bare end into a hole in the breadboard. Measure the length of wire that you need to make the connection plus about 1 cm for inserting the other end into the other hole. You should try to keep the wires flat to the breadboard and as short as possible. Remove the wire and strip the other end of it. Finally, insert both ends of the wire into the breadboard. Here are a few general guidelines for wiring breadboards:

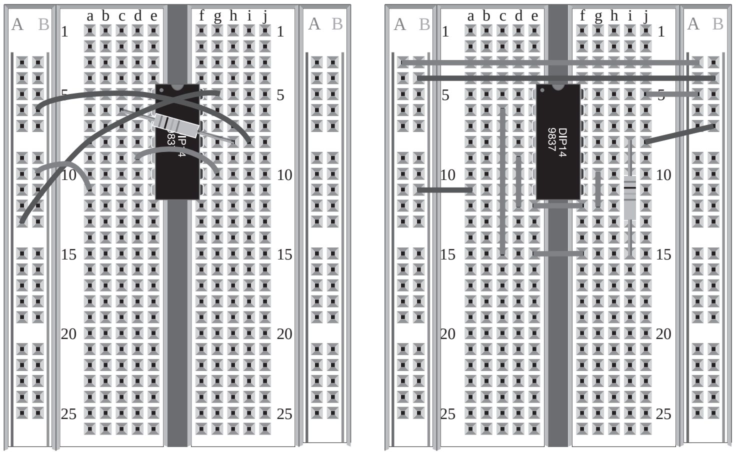
- Cut your wires to the right length. It's hard enough to debug a complicated circuit on a breadboard without having to cut through a morass of long loops of wire with a machete. If you keep your breadboard neat, it will be easier for you (or your lab instructor) to trace connections in your circuit and debug it.

- Cut off just enough insulation to make a good connection. If you cut off too much insulation, you might have bare wire sticking up out of the hole. Two such pieces of exposed bare wire could make contact and short something out. If you don't strip away enough insulation, then you may not be able to insert the wire in far enough to make good contact with the spring clips.

- Try to keep your wires flat to the breadboard, and try not to make wires loop over other wires or over ICs or other components. If you strap your chips into the breadboard with a bunch of wires, then you have to rip all of the wires out in the event that you need to remove the chip.

- Try to color-code connections of the same type, such as power and ground connections, using wires of different insulation colors. This practice makes it easier to follow connections in your circuit.

Figure 0.6 shows two different breadboarded versions of the same circuit connections. The version shown in Fig. 0.6a is messy with long wires looping over each other and over the IC. Moreover, the resistor in the circuit of Fig. 0.6a crosses over top of the IC. In this case, if



(a) (b)

Figure 0.6: Two alternative ways to wire the same circuit on a breadboard. (a) A messy version of the circuit with long wires that loop over each other and over the IC. (b) A neat version with short wires that don't cross each other and don't loop over the chip. You should always try and make your circuits look like that shown in part b rather than the one shown in part a. Neat circuits are much easier to follow, to debug, and to fix than are messy ones.

we had to remove the IC and replace it with another one, we would have to rip out almost all of the wires. The connections in this circuit are also hard to trace, because wires cross each other all over the place. Imagine what the breadboard would look like with a lot of other ICs and many more wires! On the other hand, the version of the circuit shown in Fig. 0.6b is connected together with a series of short wires that are flat to the breadboard. Note that none of the wires cross each other and that the IC is not strapped into place by the wires and the resistor. In this case, it is easy to replace the IC or the resistor without disturbing any of the other connections. Note how the resistor connects from one side of the chip to the other by making a series of 90° turns along unoccupied sections of the breadboard. You should always try to make your circuit look more like the one shown in Fig. 0.6b! It may take longer to be neat about your wiring, but, in the long run, the investment will pay off as time saved in debugging.

When you insert or remove an IC from your breadboard, you should be very careful, because the pins on the sides of the DIP package are made from thin metal that bends very easily. Many an IC has been ruined during one of these two processes. To insert a chip into the breadboard, place the chip down on the breadboard at the location at which you want to insert it. Make sure that the pins are aligned with the holes in the breadboard. Apply an even and gentle pressure on the top of the chip until it goes into place. For large chips, it is especially important to apply even pressure to both ends of the chip simultaneously. If you don't, it's very easy to smash half the pins against the bottom of the chip. To remove a chip, you need to pull it out straight up, pulling evenly on both the top and the bottom at once. There are special tools called *IC pullers* that look like a funny pair of tweezers that grab the top and bottom of an IC at the same time, so that you can pull out the chip uniformly. If you don't happen to have an IC puller handy, you can remove a chip by carefully prying up the top by a little bit and then the bottom and then alternate until the chip comes free from the holes in the breadboard. If you pull up on just one side until the pins come out of the holes, you will wind up bending half of the pins at the end of the chip opposite that on which you pulled. Sometimes the pins can be bent back, but more often than not, the chip is ruined.