Basics of Electricity/Electronics

http://www.cla.purdue.edu/vpa/etb/

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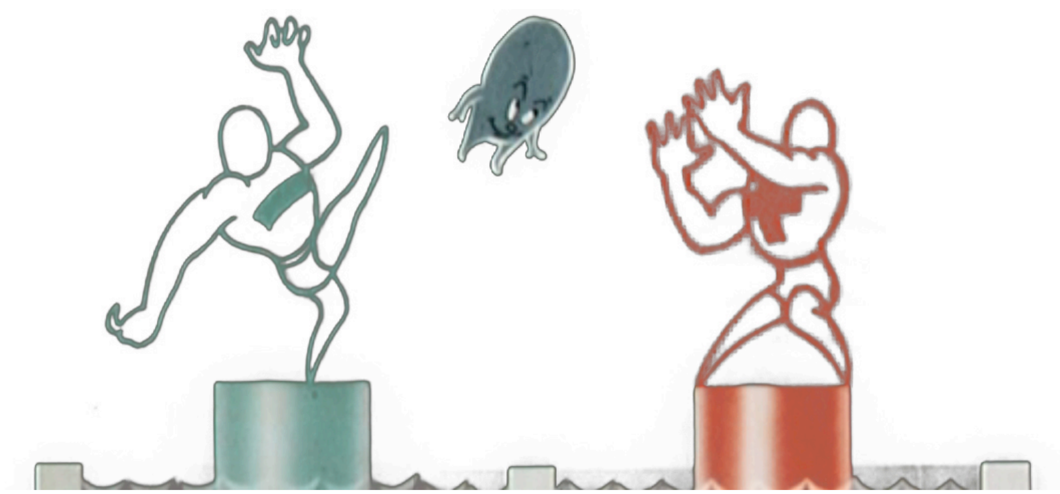
Required parts/supplies for this workshop:

Description	**Get it from Jameco.com**
power supply – AC/DC wall adapter (anything between 9 and 12V and 200–1500mA is fine)	PN 189579
multimeter (look in the cabinets in the Mac lab in STEW and FPRD 204)	PN 355207
breadboard	PN 20723
wires (solid core)	PN 126360
standard LED (around 1.7V, 20mA)	PN 253833
resistor 1kΩ	PN 690865
resistor 470Ω	PN 690785
capacitor 1000µF @ 25V	PN 93833
NPN transistor 2N2222	PN 803268 (10 pack)

Basics of Electricity/Electronics



What is electricity?

To answer this question we will watch an instructional film: “Principles of Electricity”, 1945, General Electric Research Laboratories. Scientific Advisors: Dr. Saul Dushman; Dr. Roman Smoluchowski; Dr. David Harker (from: www.archive.org)

Please try to find answers to the following questions while watching the film:

- What are electrons?
- What makes them move from atom to atom?
- What is Voltage?
- What is Current?
- What is Resistance?
- How do these three concepts relate to each other?
- What are conductors, what are insulators?

Electricity Basics – some answers to the questions above:

- Electron: Atoms consist of electrons (negative electrical charge), protons (positive electrical charge) and neutrons (no electrical charge). Normally an atom has an equal number of electrons and protons. Sometimes it is possible to dislodge one or more electrons from atoms (see next bullet point). These free electrons can move at high speed through metals, gases and a vacuum. They can also rest on on a surface (static charge).
- Mechanical friction, light, heat or a chemical reaction may remove electrons from a surface (e.g. by combing your hair with a plastic comb).
- Materials through which electrons travel are conductors. Materials through which electrons travel poorly or not at all are insulators.
- A stream of moving electrons is called an electrical current.

For the following concepts please also consult the course book "Physical Computing" (O'Sullivan/Igoe) chapter 1 (pp. 2-8) for a more detailed description of the basics of electricity.

Current (I)
Current is the quantity of electrons passing a given point. The unit of current is the Ampere. One Ampere is 6,280,000,000,000,000,000 electrons passing a point in one second. Electrical current flows from a region of high charge or potential to a region of low potential. To make confusion worse there exist two notions about the direction in which current flows: *Conventional Current* assumes that current flows out of the positive terminal, through the circuit and into the negative terminal of the source. This was the convention chosen during the discovery of electricity. They were wrong! *Electron Flow* is what actually happens and electrons flow out of the negative terminal, through the circuit and into the positive terminal of the source. However, the concept of Conventional Current is still applied to almost all the circuit schematics today, so we will use it extensively in this class.

Voltage (V or E)
Voltage is electrical pressure or force. Voltage is sometimes referred to as Potential. Voltage Drop is the difference in Voltage between the two ends of a conductor through which current is flowing.

Power (P)
The work performed by an electrical current is called Power. The unit of Power is the Watt.

Resistance (R)
Conductors are not perfect. They resist to some degree the flow of current. The unit of resistance is the Ohm.

Load
The part of the circuit which performs work (e.g. a motor, a light bulb or a LED, etc.) is called Load.

Ohm's Law
A set of rules that show the relationships among Current, Voltage, Power and Resistance. Given any two of the above, one is able to calculate the other two using the following formulas:

$$E = I \times R$$
$$I = E / R$$
$$R = E / I$$
$$P = E \times I$$

Direct Current Electricity
An electrical current can flow in either of two directions through a conductor. If it flows in only one direction whether steadily or in pulses, it is called direct current (DC). Almost all the projects in class will be powered by DC electricity. In order to be able to work with DC we need to convert the alternating current (AC) from the outlets into a direct current, which we use to power our circuits. A wall adapter transforms AC into DC, the wall adapter in our lab kit transforms 120 VAC into 9/12VDC. The maximum current it can provide is 1000mA (1A). The wall adapter has two wires that

go to our circuits – one for positive power supply and one for negative (ground, or GND).

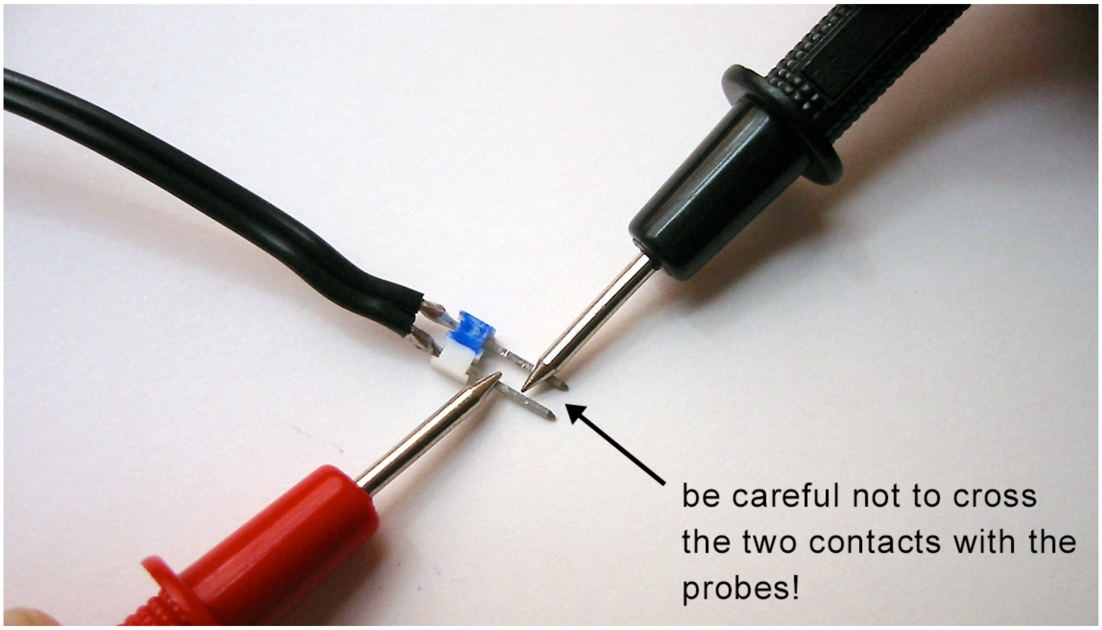
Please also read chapters 2 and 3 in our course book "Physical Computing" (pp. 9 -48) in addition to following the following examples, descriptions and experiments:

We take our power supply and cut off its plug – we want to replace it with a header that fits better in our prototyping boards. Solder the header to the power supply's two wires as illustrated in the following picture. To prevent the solder joints from breaking put a blob of hot glue around them:

Since direct current only flows in one direction, we have to be able to easily determine the positive and negative side of the power supply. Remember that we assume the conventional current flow from positive to negative when we work with circuits! By convention, positive is always marked with red and negative is always marked with black or blue.

A multimeter is a useful tool that helps us finding the positive and negative side of the power supply. On the multimeter's rotary selection knob we see different sections for measuring voltage (volt-meter), current (am-meter) and resistance (ohm-meter), hence the name: multimeter.

The multimeter has two test probes – one red (for positive) and one black (for negative). We know that our power supply has an output of 9/12VDC, so we first need to set the multimeter's scale to Volts (DC not AC) and then to a maximum amplitude of 20V. If we put the multimeter's positive probe on the power supply's positive side and the negative probe on the negative side, we should get a read-out of roughly 9/12VDC on the multimeter's display.



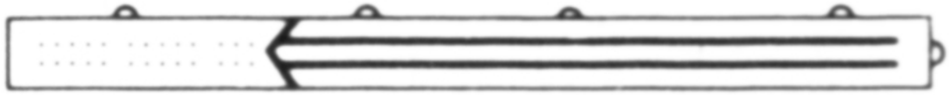
Take a red marker and mark the side of the power supply's header connected to the multimeter's red probe red – this is your positive power supply. Or mark the other side black or red. This is very important. You can blow a circuit easily by applying the voltage in the wrong direction.

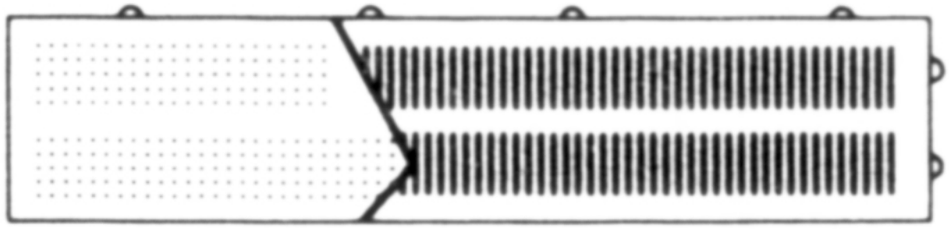
Just in case the read-out shows -9/12VDC (negative!) then we have placed the probes in the exact opposite way. Switch them and you should get a positive 9/12VDC reading. Finally, also mark the sides of the power supply's header properly!

Breadboard

Breadboards are useful solderless prototyping boards that allow you to test out circuits quickly. In general it is a good idea to build every circuit on a breadboard first before you even think about soldering the parts together. Thus, it is important to understand how a breadboard works.

The type of breadboard we are going to use in the following workshops is similar to the one displayed below. It consists of two long rows on each side (called bus rows) and many holes in the center, divided by a gap. Holes in the bus rows are connected horizontally, holes in the center are connected vertically (in columns). The detail below shows this difference – the horizontal line shows one of the bus rows, the two vertical lines emphasize two columns in the center. Physically, the holes underneath each of these lines are connected with a metal strip.





The bus rows, usually 2 on each side, are reserved for positive power and ground. The holes in the center columns are for components. The divider between the columns will be very useful when we start working with ICs (Integrated Circuits). It assures that each pin of the IC has its own column for other parts to be connected to it.

Finally, a word of caution for working with your breadboard: always disconnect the power from the breadboard when you want to reconfigure the circuit. Never plug in or unplug a part from your breadboard circuit with the power still applied to the board. This can cause a shorted circuit or, even worse, you can get zapped from the electrical current flowing through the circuit.

We just have to take a brief look at some actual electronic components and then we are ready to put together our first circuit...

Electronics and Electronic Components

Electronics is the processing of electrical charges as information. Nam June Paik, one of the pioneers of the field of electronic art, makes this distinction very clear by commenting on "electricity" and "electronics": "Electricity deals with mass and weight; electronics deals with information: one is muscle, the other is nerve." (from: Gene Youngblood: Expanded Cinema, New York: Dutton, 1970, p. 137.)

Wires and Cables

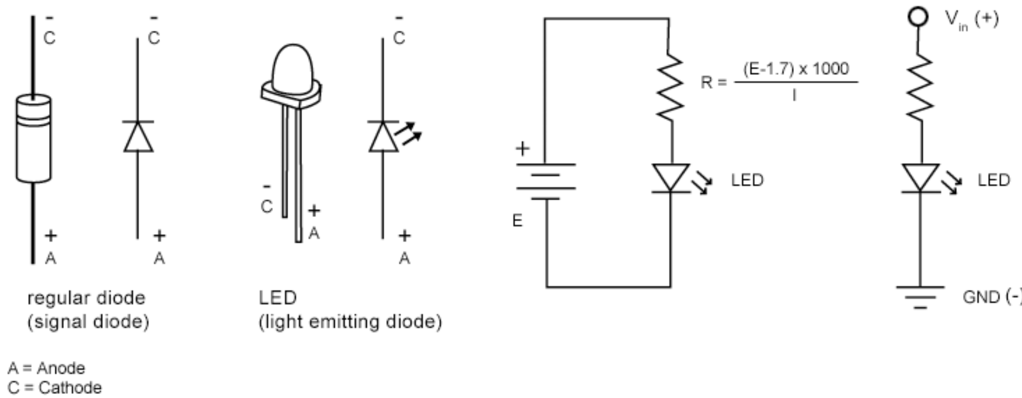
Wires and cables are used to carry an electrical current. Most wire is protected by an insulating covering of plastic or rubber. A wire can be either solid or stranded. Cables have one or more conductors and more insulation than ordinary wire. (see appendix: wire gauge table).

Diodes

A diode is an electronic device that allows current to flow through it in one direction only. It is a one-way turnstile for electrons. There are many different classes of diodes for many different purposes:

- small signal diodes
- rectifiers (power) diodes (e.g. in power supplies)
- switching diodes
- Zeners
- Light Emitting Diodes (LED)

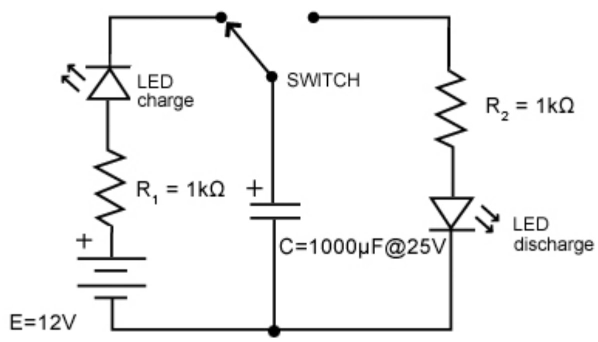
The following concentrates on the usage of Light Emitting Diodes (LEDs) in electronic circuits:



When using a LED in an electronic circuit, use the above formula to determine series resistance in Ohms. Never use a LED without a current limiting resistor in a circuit – in most cases it will explode if you do! R is resistance in Ohms, E is the supply voltage and I is the LED current in milliAmperes (mA). What value for R do we get with our 9/12 VDC power supply and a standard LED (1.7V voltage drop, 20mA current)?

Capacitors

Capacitors are electronic devices that store electrons. The simplest capacitor is two conductors separated by an insulating material called dielectric. The minus side of the capacitor is charged with electrons. These electrons in the charged capacitor will gradually leak through the dielectric until both conductor plates have an equal charge. The capacitor is then discharged. The ability to store electrons is called capacitance. Capacitance is specified in Farads. A 1-Farad capacitor connected to a 1 Volt supply will store 6,280,000,000,000,000,000 electrons. Once a capacitor has reached its maximum charge, it blocks DC voltage. This is used in electronic circuits to allow an alternating current (AC) signal to flow through a capacitor while it blocks DC. Sometimes capacitors are also used as smoothing or filtering device. Putting a capacitor across the plus and minus pole of a component filters out voltage spikes. Yet another use of capacitors makes use of their ability to store charge for high-speed use. This feature is applied for example in a photo flash. The following experiment illustrates the ability of capacitors to store an electrical charge.



In this experiment, when the switch is moved toward the left side (battery), the capacitor is charged. In this process the LED lights up but gradually fades. When the capacitor is fully charged there is no current flowing through the LED anymore. Now, when we flip the switch over to the right side, the capacitor discharges. This process is again visualized by an LED that gradually dims.

ATTENTION! Capacitors can store a charge for a considerable time after the power to them has been switched off. This charge can be extremely dangerous! A large electrolytic capacitor charged to only 5 or 10 Volts can melt the tip of a screwdriver placed across its terminals! Never touch the terminals of high voltage capacitors, such as used in TV sets or in a photoflash – these charges can be lethal!

Transistors

A transistor can be used as a switch and signal amplifier. It is an electronic device with three contacts: the emitter (E), base (B) and collector (C). A very small current on the transistor's base can control a much larger current flowing through a passage between collector and emitter. The following drawing shows the concept behind an NPN transistor using a water analogy (I found it in my old Kosmos "Electronic Junior" book from Germany). If there is no water flowing down the base channel, the gate between the collector and the emitter channel is closed, no water can flow from the collector to the emitter. If there is water flowing down the base channel it lifts the gate that normally blocks the collector/emitter channel. Once this gate is open, water flows from the collector to the emitter.

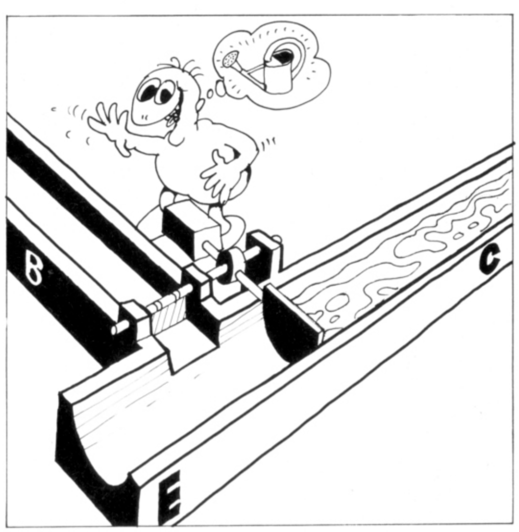


Bild 60. „Wasser-Transistor" (gesperrter Zustand)

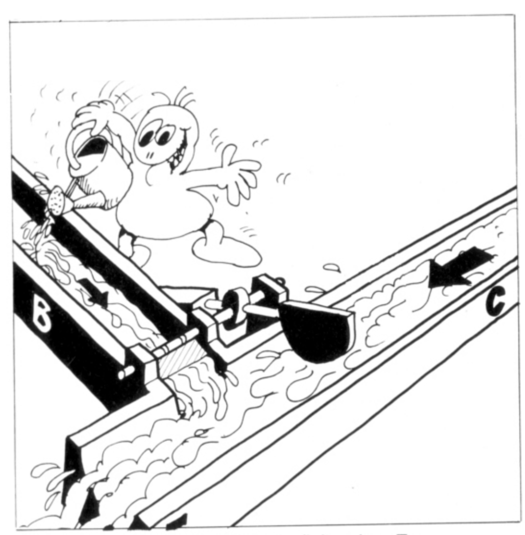
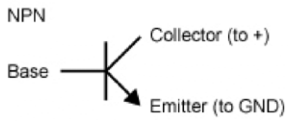
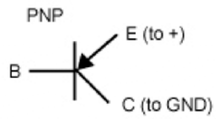
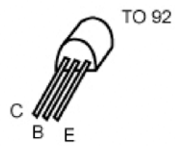


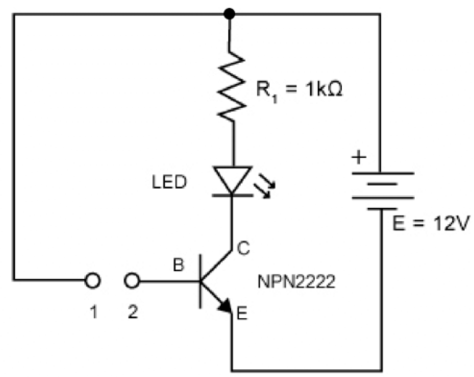
Bild 61. „Wasser-Transistor" (leitender Zustand)

Power transistors allow a small signal to switch a larger load. Low power transistors which do small switching functions are called signal transistors. Transistors come in several types: bipolar; field effect (FET); unijunction transistors, etc. Bipolar transistors are most commonly used, they come in two types: NPN and PNP.







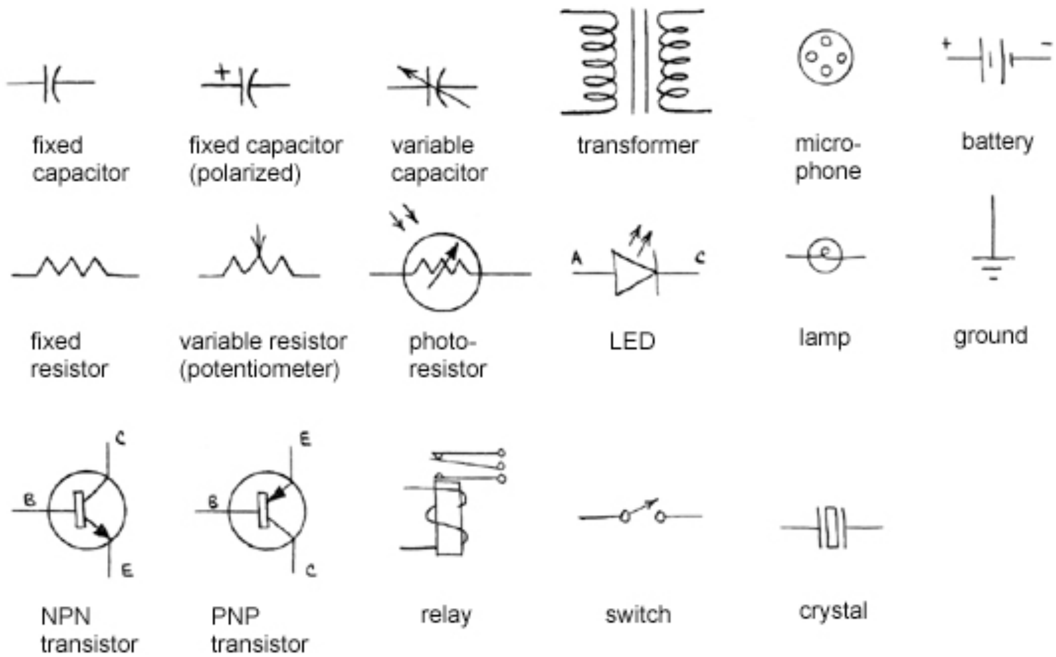


The above experiment uses a **NPN transistor** and demonstrates the transistor's ability to amplify a very small current. Close the gap between contact 1 and 2 just by bridging the contacts with your finger. A very small current flows through your finger (the current increases if your finger is wet). This small current is enough for the transistor to open its Collector–Emitter passage – the LED glows. Warning! Do not bridge the gap with a piece of wire, this will destroy the transistor since too much current will flow into the transistor’s base.

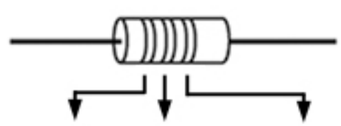
Appendix

See also our course book “Physical Computing”, Appendix C – Schematic Glossary” pp. 433-442

Electronic Component Symbols
In the following you see a chart with the circuit symbols of the most common electronic components (Source: Mims, Forrest M. III: “Getting Started in Electronics”, Radio Shack, 2000):



Determining resistor values

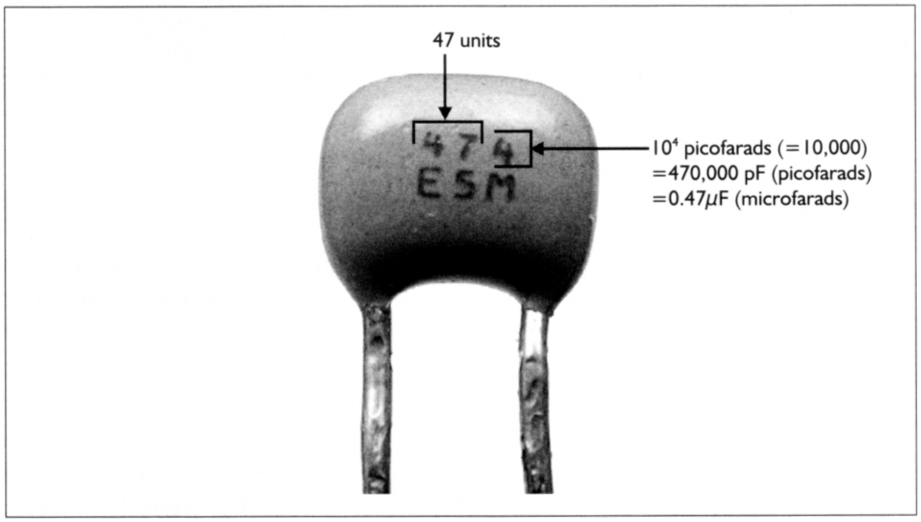


BLACK	0	0	x	1
BROWN	1	1	x	10
RED	2	2	x	100
ORANGE	3	3	x	1,000
YELLOW	4	4	x	10,000
GREEN	5	5	x	100,000
BLUE	6	6	x	1,000,000
VIOLET	7	7	x	10,000,000
GRAY	8	8	x	100,000,000
WHITE	9	9		--

The fourth band indicates accuracy (GOLD = +/- 5%, SILVER = +/- 10%, NO FOURTH BAND = +/- 20%)

Determining capacitor values
Source: Hrynkiw, Dave and Tilden, Mark W.: "Junkbots, Bugbots & Bots on Wheels", McGraw-Hill / Osborne: New York, 2002)

Figure 3-6
Monolithic capacitor code-breaking



Third Digit	Multiply the First Two Digits by This to Get Microfarads (μF)	Example
0	0.000001 (or divide by 1,000,000)	47 = 0.000047μF
1	0.00001 (or divide by 100,000)	471 = 0.00047μF
2	0.0001 (or divide by 10,000)	472 = 0.0047μF
3	0.001 (or divide by 1,000)	473 = 0.047μF
4	0.01 (or divide by 100)	474 = 0.47μF
5	0.1 (or divide by 10)	475 = 4.7μF
6	(not used)	
7	(not used)	
8	100 (or divide by 0.01) Note: *rarely* used	478 = 4700μF
9	10 (or divide by 0.1) Note: *rarely* used	479 = 470μF

Table 3-3
Capacitor Number Codes

American Wire Gauge (AWG) Table

AWG gauge	Diameter in mm	Resistance per 1000ft in Ω	Max. current for power transmission in A
6	4.1148	0.3951	37
8	3.2639	0.6282	24
10	2.58826	0.9989	15
12	2.05232	1.588	9.3
14	1.62814	2.525	5.9
16	1.29032	4.016	3.7
18	1.02362	6.385	2.3
20	0.8128	10.15	1.5
22	0.64516	16.14	0.92
24	0.51054	25.67	0.577
26	0.40386	40.81	0.361
28	0.32004	64.9	0.226
30	0.254	103.2	0.142

Multipliers
Finally, here is a table of the most common used abbreviations that determine the size or value of an electronic component:

M	mega –	x 1,000,000
K	kilo –	x 1,000
m	milli –	x 0,001
µ	micro –	x 0,000001
n	nano –	x 0,000000001
p	pico –	x 0,000000000001