Introduction to Electronics

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for TokyoHackerSpace.org

This booklet is accompanied by a slide presentation. Be sure to progress through both together.

The basics – voltage, current and resistance

Without going into too much detail (this IS supposed to be fun and informal after all), we do need to discuss three very important aspects of electricity. In fact, these three aspects are locked together and affect each other directly. They are current, voltage, and resistance.

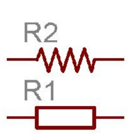
Current is the continuous movement of electrons through the conductors of a circuit. Conductors are the wires that form paths for the electrons to flow through. Let's imagine a river for a moment. The river bed is the conductor. The water is electrons. The flow of water through the riverbed is current. Current is stated in Amps (A, milliamps mA, micro-amps uA).

More specifically, we call this DIRECT current (DC). The water will only flow in one direction. Electronics do not behave exactly the same way as a river, but it is a decent analogy for most properties.

Another form of current is Alternating Current (AC). An alternating current will switch directions several times per second. For example, The power outlet of a home in the United States has 120VAC 60Hz. That's 120 volts alternating current switching at 60 hertz (times per second).

It is important to have an understanding of AC, since it is the foundation of most analog signals. Since the world around us is analog, we can't interact with it without understanding analog. However, for today's lesson, we are going to stick to direct current. It is quite easy to understand, and is useful in many simple analog applications, as well as being the foundation of digital electronics.

Returning to our water analogy, water flowing from a high mounting will create a strong current (regardless of the quantity of flow). Water flowing from a small hill will create a comparatively weak current. In physics we call this "potential energy." In electronics, we call it Voltage: the force motivating electrons to flow (If you want to be picky, the proper scientific name is Electro-motive force). Voltage is measured in Volts (V, mV).



When electrons push and shove each other through a conductor, they create friction and heat. This friction RESISTS motion, and thus we call it resistance. The resistance to motion is greatly affected by the type of material the electrons are attempting to flow through.

Returning to the river analogy, the riverbed itself offers up some resistance to current (such as rocks or narrow sections). Also, we can clearly see that a dam creates a large resistance to current (as well as an ability to control the current down river, and protect the villagers).

Resistance causes a voltage loss. We often say something like "three volts are lost in/through/across this resistor."

There is an important rule associated with this concept: *What goes into a circuit must be used up or come out.*

The total voltage going into a circuit at the positive connection, minus the voltage consumed by the parts of the circuit, must equal ZERO at the negative connection.

Resistance is measured in Ohms (Ohms, K-Ohms, Meg-Ohms).

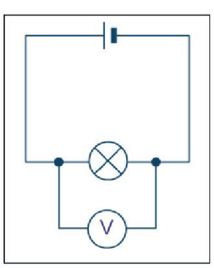
Lab 1

Now that you understand the basics, let's get started! We will start by getting familiar with the single most important tool in your electronics arsenal: the Multi-meter. We can use it to take voltage, current, and resistance measurements, as well as check that a circuit is unbroken. For lab one, we will concentrate on voltage and resistance, and we will finish by examining in more detail the relationship of voltage, current, and resistance.

A multi-meter is a convenient tool to measure all three aspect of electricity. Modern meters also take additional measurements. It consists of a rotary knob in the center for selecting the measurement and range you would like to work with, two probes (black and red), and some form of readout (either digital or a moving needle).

When using any meter, always set it to the highest measurable value first, then work down the scale for more accuracy. Starting from the 'bottom up' can damage older analog meters.

- **Measuring DC voltage**



*Measuring the **voltage** across X*

We will start with the most obvious setting: V for voltage.

- Turn the knob to the DC voltage scale. We will measure the 9 volt battery, so choose a setting that is ABOVE 9 volts.
- Touch the red probe to the + side of the battery. Touch the black probe to the – side of the battery. What does the readout say?
- Now reverse the probes on the battery and observe the readout.

- **Measuring AC voltage**

Now is a good time to talk about meter safety. It is important to be sure not to touch the exposed metal probes when using the meter. It is not so dangerous with DC, but AC can be lethal. In the following task, it is critical that you be careful and observant.

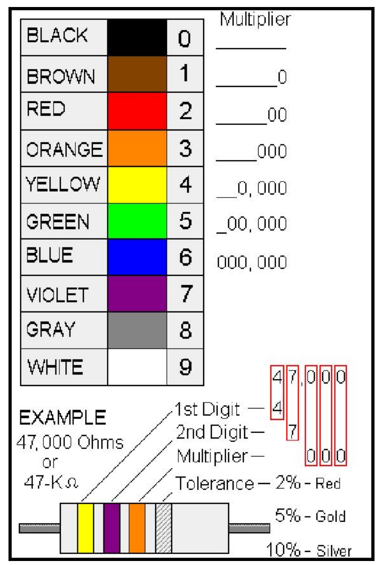
- § Turn the knob to the highest AC setting. We are about to measure the voltage available in a typical household outlet.
- § USING ONE HAND ONLY, insert the black probe into one of the slots on the outlet. Be sure to insert it fully.
- § Now insert the red probe into the other slot. What is the voltage at the outlet?
- § Swap the probes and measure again. How does the reading differ from those you took of the 9 volt battery?

o **Measuring resistors**

In your kit are several resistors. They are brown, with several colored bands painted on them. Take a look at the kit contents list. Notice that there are several values of resistor in the kit. It is time we sorted them out.

When measuring resistance, meter safety is generally not so important. However, by holding the probe tip to the resistor wire with your fingers, you will affect the meter reading. Essentially, the meter is reading both the resistance of the resistor, AND the resistance of your body, from one hand to the other. (Due to the nature of resistors in parallel, your affect on the reading is negligible, but it is important to note).

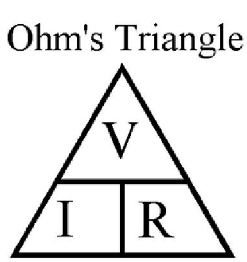
- § Turn the meter to the OHM setting. It looks like a horse-shoe. Let's start with the highest setting for now.
- § With the meter on its highest OHM setting, choose a resistor and hold a probe to each wire. What is the value of the resistor? If the value is low, you may need to turn the knob to a lower OHM setting for a more accurate reading.
- § Sort the resistors in your kit according to the kit contents list.



o **Thinking time: Resistor color code**

Look at the bands of color on the resistors you have sorted. These color bands are an easy way to mark values on the tiny resistors. Look at the resistor color code chart. Mix your resistors into a pile and see if you can sort them out and determine their values using only the color bands.

o **Thinking time: Ohms law**



Cover the variable you want to find and perform the resulting calculation *(Multiplication/Division)* as indicated.

Ohm's law is an equation that describes the relationship between voltage, current, and resistance. It is important to the electronics engineer, as it is used in every aspect of electronics. It is good to become comfortable using and manipulating it early. Thankfully the equation is exceedingly simple:

$$V = I \times R$$

V is voltage, I is current, R is resistance. Voltage equals current times resistance.

Look at the Ohm's law triangle. If you want to find current, cover I with your thumb. It is now clear to see that Current (I) is Voltage divided by Resistance.

- **Work out the following problems:**

  1: Your circuit has a 9 volt supply. You measure a circuit resistance of 1000 ohms. What is the circuit current?

  2: A component will be damaged if the current exceeds 14mA. You have a 5 volt supply. You must insert a resistor into the circuit to limit the current to the component to 14mA or less. What resistor should you use?

  3: You measured the resistance of an electric motor, and found it to be 1.5 Ohms while drawing 4 amps of current. What is the operating voltage of the motor?

Now that you understand the basics, we can progress quickly through the rest of the lessons. In this section, you learned about voltage, current and resistance, and how they relate. You learned how to use a multi-meter to measure voltage and resistance. You also learned about the resistor color code, and the most important equation for an electronics hobbyist to remember: Ohm's law. With these tools in hand (and in mind), you can conquer any aspect of the electronics world.

Diodes

Diodes are a special type of conductor called a semiconductor. In a semiconductor, two or more silicon materials are joined together to form a junction. Depending on the nature of each type of silicon material, different electrical properties may be exploited.

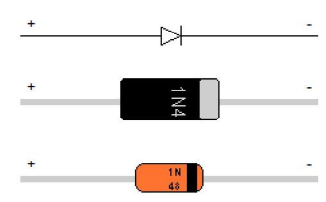


Figure 2: Orientation of diodes

In the case of a diode, two materials form a junction which allows current to flow in one direction, but block current from flowing in the other direction. This makes diodes useful in a number of ways.

Think back to our discussion of Alternating Current (AC). AC flows in one direction, then switches and flows in the other direction. It will make this switch several times a second.

AC is not desirable in many types of circuits. Inserting diodes into the circuit will block the current from reversing direction. However, during that period of time in which current is attempting to flow in reverse, there will be no forward flow. Thus, the output of our diode will be positive pulses of DC voltage. This is called rectified AC, and the configuration of diodes is called a bridge rectifier.

In order for a diode junction to operate, some voltage is lost (as is true of all components, remember?). 0.7 volts on average is lost in a typical diode junction, although this value will vary somewhat.

Light Emitting Diodes (LEDs) are a special type of diode. An LED diode junction utilizes the voltage loss within the junction to emit either visible or infrared light. *Unlike typical diodes however, an LED can be easily damaged by too much current.* ***We must protect the LED with a current limiting resistor, or it will burn out.***

The schematic symbol of an LED is the same as a diode, with the addition of a ray of light (an arrow) emitting from it.

Lab 2

o **Checking continuity**

Another measurement function of most multi-meters is the continuity check. Continuity simply means that the circuit is continuous and unbroken. It is a very useful check for cabling, diodes, switches, and tracing wires through a circuit board.

§ Set the meter to the continuity check mode and tap the probe tips together. The meter should beep, and the screen will flash to 0 (some meters use c or another indicator of continuity).

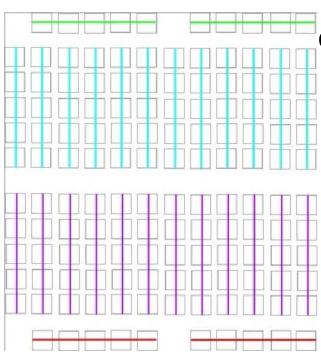
The action on the readout may be familiar by now. Continuity checking is actually a form of resistance measurement. When a path has zero (or close to zero) resistance, it is said to be continuous. "The blue wire is continuous, but the red wire has a break somewhere." Another way to say this is that "the blue wire is a short, but the red wire is an open."

Don't let the terms short and open confuse you. They are neither good nor bad. It depends on the circumstances. For example, an "open" cable is bad. The wire has broken somewhere, and will not pass a signal. A shorted WIRE is good. It is electrically connected from one end to the other. A shorted CABLE is bad. One wire is somehow connected to another wire. A shorted battery is bad. The terminals are connected together. An open battery is good. The terminals are not connected. Context determines if a short/open condition is good or bad.

o **Checking a diode, checking an LED**

§ Set the meter to one of the following modes: diode, continuity, or resistance.
§ Check both the diode and the LED.
§ Reverse the probes and check the parts again.

How does the schematic illustration relate to the physical part?



o **What is a breadboard and how does it work?**

§ Your kit included a breadboard. It is a white board with many holes in it.
§ Grab two wires from the wire kit and insert them into the bread board.
§ Use the multi-meter to probe the board. Which holes are connected? Which holes are not?
§ Confirm your understanding of the breadboard layout by looking at the illustration.

- **Our first circuit, lighting an LED**

  Its now time to build our first circuit!

  You will need your breadboard, wire kit, AA battery holder, one LED, and one 470 ohm resistor.

  - Build the **LAB 2** circuit on the breadboard to light the LED.
  - Measure the voltage output of the AA battery holder. Given that the resistor is about 470 ohms, predict the current at the LED? (Hint: use Ohm's law)

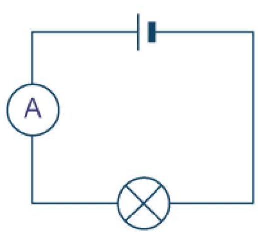
- **Measuring current**

  Now that we have a working circuit, we can finally use the current measurement function of the multi-meter.

  Look at the front of the meter. Notice that there are two places in which the red probe may be plugged? Take note of the current ranges for each position.

  ATTEMPTING TO MEASURE A CURRENT ABOVE THE RANGE OF THE METER WILL BLOW THE METER FUSE AND POSSIBLY CAUSE METER DAMAGE.

  It is important to have a reasonable estimate of the expected current before attempting to measure it. In order to measure current, we must break into the circuit and insert the meter, such that the current flows through the meter.

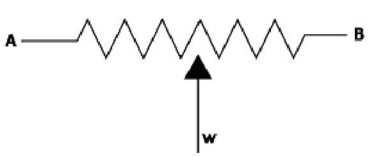


*Measuring the **current** through X*

- Start by disconnecting the positive lead of the battery from the breadboard.
- Insert a wire from your wire kit in its place.
- Now connect the red probe to the positive lead of the battery, and the black probe to the connection on the breadboard. Your LED should again be light, and now the meter should read the current in the circuit.

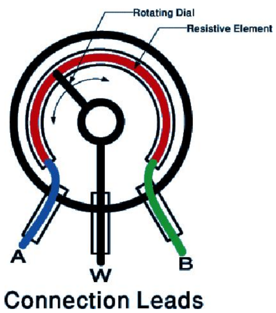
More about resistors – the variable resistor and voltage divider

A variable resistor is one that can change its resistance (simple!) Knobs and sliders on stereo equipment are perfect examples. Variable resistors are also called potentiometers. Pots come in two flavors: Linear and Logarithmic. Logarithmic pots are used for audio gear, as it more closely matches the human ear. Linear pots are used for everything else.



The variable resistor is one long resistor that is divided in two by a third wire, called the wiper. The wiper can slide up and down the resistor. From point A to the wiper is one resistance, and from the wiper to point B is another. In effect, the variable resistor is actually TWO resistors. This configuration is called a voltage divider.

Imagine for a moment that 5 volts is connected across the A and B leads of a variable resistor. The voltage at the wiper would be variable, from 0 to 5 volts, depending on the position of the knob.



Lab 3

o **Investigating the Variable Resistor:**

§ Identify the variable resistor in your kit. What is the total resistance of the pot? (Hint: measure the ends)

§ Observe the action of the wiper by measuring the resistance from the center pin to one of the outer pins.

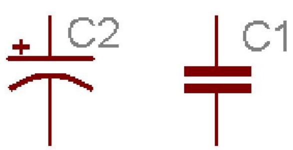
§ Build the **Lab 3** circuit on your breadboard. What is the purpose of the fixed (470 Ohm) resistor? What will happen to the LED if the fixed resistor is eliminated? Why?

§ Measure the voltage at the output of the voltage divider (the wiper of the VR) while sweeping the knob.

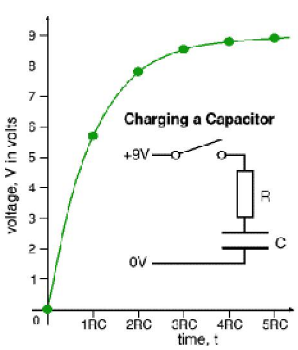
o **Thinking time:**

Using Ohm's law, determine the minimum and maximum current applied to the LED. Confirm your calculations by inserting the current meter between the pot's center pin and the LED.

What is a capacitor?



A capacitor is made up of two metallic plates, separated by a gap. This gap could be air, paper, a fluid, or a combination of all three. As current is applied to the capacitor, a difference of potential is created in the two plates (one becomes positively charged, while the other becomes negatively charged). The gap material provides just enough distance between the plates that they do not short out, yet close enough that the electrons and protons are attracted to each other (much like trying to hold two magnets apart).

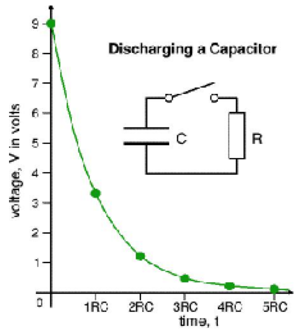


When the current is removed, the bond between protons and electrons is still strong enough to keep them in the plates. If we now provide a new path for them to move on, the capacitor will discharge the protons and electrons. In effect, the capacitor is a fast acting battery.

What is different about a capacitor as compared to a battery, is that a capacitor can discharge all it's stored capacitance in a very short period of time (micro-seconds). The bright, quick burst of light from a camera flash is the result of a discharging capacitor.

There are two important ways in which capacitors are used. First is the bulk storage capacitor. This configuration exploits the battery effect of a capacitor to filter noise in power lines, or to provide a short boost of power to a circuit. It can also be used as a temporary storage tank (for example in solar circuits or boost chargers). In this configuration, the capacitor is connected in parallel (along side another part).

The other configuration is DC blocking. Let's return once more to AC current. Remember that the direction of AC current shifts back and forth. If we were to put a capacitor in series (in line) then the AC signal would pass through. It would be slightly delayed by the action of the capacitor. When current is flowing in one direction, it charges the capacitor plate on that side. When the AC signal switches directions, the capacitor will discharge the stored current to the other end (think of it as 'store and forward').



However, if we now introduce a DC signal on top of the AC line, the capacitor would still charge up on the positive side. However, since the DC signal does not switch directions, the capacitor would never discharge. Thus it simply blocks the DC signal from moving forward, while passing the AC signal unaffected.

Lab 4

Build **circuit 3** on the breadboard. R3 can be any resistor value.
Press and hold the button (or flip the switch). After a few moments, release the button (or flip the switch back to it's off position) and observe the LED. How long does it remain lit? How is this possible? What is the capacitor doing? What is R3 doing?
Change the values of C1 and R3 and observe their effects.

Let's have some fun!

Build one of the three remaining circuits and experiment!

- **LED flasher**
  Change the resistor and capacitor values to alter the flash rate and Duty Cycle. Duty cycle is the relationship of ON time vs. OFF time. For example, a 50% duty cycle has an equal on vs. off time.
  Can you alter the circuit to replace the two resistors with the variable resistor?
  Can you visualize the output of pin 3? (hint: ask your instructor about an Oscilloscope)

- **Buzzer**
  Change the resistor and capacitor values to alter the flash rate and Duty Cycle. Duty cycle is the relationship of ON time vs. OFF time. For example, a 50% duty cycle has an equal on vs. off time.
  Can you alter the circuit to replace the two resistors with the variable resistor?
  What is the importance of the capacitor connected to the speaker? What happens when you remove it? Can you measure the output (hint: ask the instructor about an Oscilloscope)

- **Ohm's law practice**
  An incandescent lamp is a simple resistor. As current passes through the filament, the friction caused by resistance is converted into heat and light. Measure the resistance of a regular household lamp. Now go look at the Ohm's law wheel on the slides. Notice that there is a power section . Power is measured in Watts. On the end of the bulb, the wattage is shown. Given the resistance you measured, the wattage stated on the lamp, and a known voltage of 110VAC, what is the CURRENT of the lamp? Double check that all 4 values jive.

  Another practical resistor example is a typical speaker coil. Most are 4 or 8 ohms. Measure the resistance of a speaker cabinet. If you happen to know the power output of the amplifier, you can calculate the maximum voltage or current passing through the speaker coil.

Congratulations! You have completed the Electronics 101 lab!
Stay tuned for Electronics 120!

In the meantime, might I suggest you do a web search for projects containing the 555 timer IC and practice your circuit building skill. Check the resources for other great ideas.

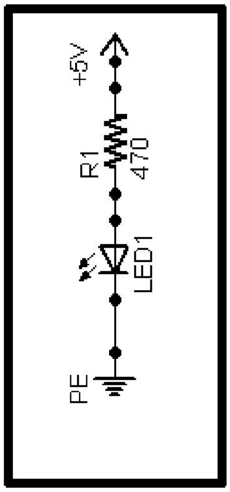
Future Electronics course topics (may) include:
All about transistors
Basics of digital logic
Operational amplifiers and signal conditioning
Motors, servos, and steppers
Introduction to microcontrollers – writing code, downloading, reading and writing IO ports, PC coms
Microcontrollers 2 – PWM, stepper motor control, and encoders
Circuit prototyping and soldering utilizing through-hole, dead bug, and surface mount techniques
Designing your own printed circuit boards 1 – getting to know Eagle
Designing your own printed circuit boards 2 – the etching at home processes
Circuit simulation using SPICE

Resources:

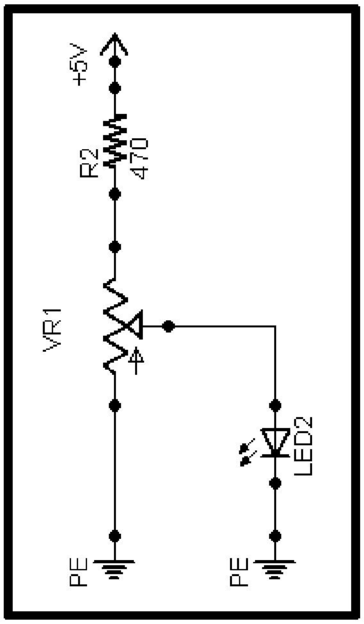
Http://www.allaboutcircuits.com
Http://electronics.howstuffworks.com

Additional figures:

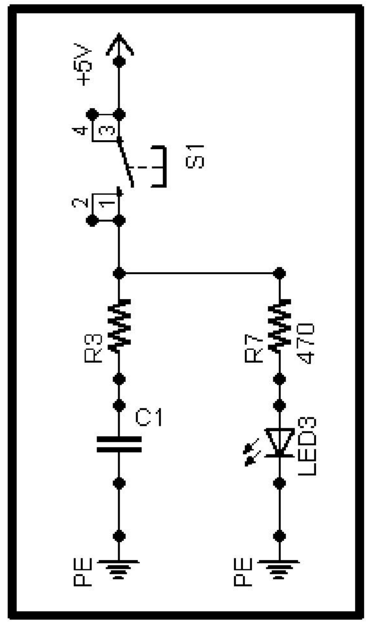
Lab 1

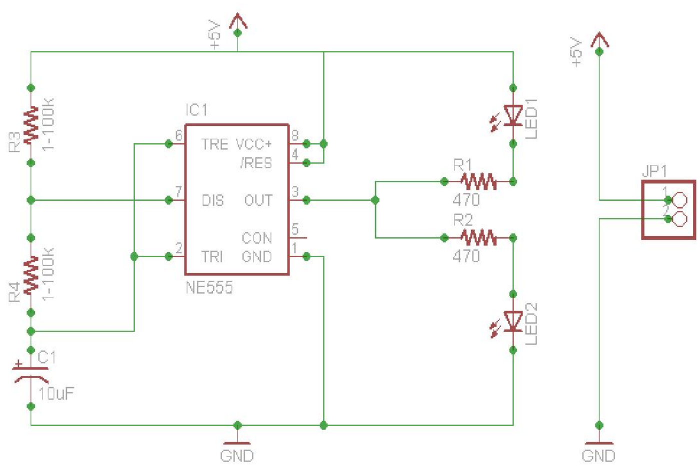


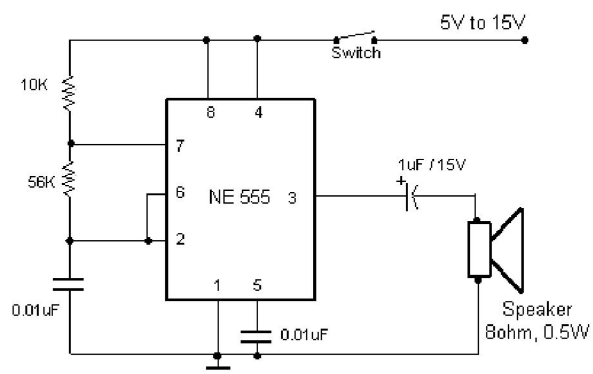
Lab 2



Lab 3







Prototyping supplies	**Resistors**	**Capacitors**
Breadboard	5 x 1K ohm	1uF
Wire kit	5 x 10K ohm	10uF
9 volt battery clip	5 x 51K ohm	22uF
AAA x 4 battery case	5 x 120K ohm	100uF
	6 x 470 ohm (for LEDs)	
Integrated Circuits		
NE555 timer IC		
Additional parts		
6 x Red LEDs	1K ohm Variable Resistor	8 ohm speaker
Switch	Push Button	