CSE/ECE 474 Resource Guide:

Basics of electronics hardware and breadboarding

University of Washington **V 0.1   30-Mar-2023**

Learning Objectives:
After completing this unit, students will be able to

- Visually identify basic electronic components by site and explain their high level uses.
- Visually identify the basic electronics tools required in 474
- Demonstrate the use of the basic electronics tools used in 474
- Build an LED controlled by a power source, switch, and a current limiting resistor using a solderless breadboard.
- Use a digital multimeter (DMM) to make Voltage, Current, and Resistance Measurements.

Materials:
These are materials we have reviewed. Criteria for inclusion:

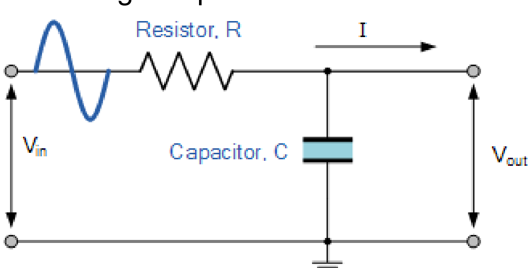
- SHORT videos that are to the point
- CORRECT information
- APPLICABLE to ECE474

Unit 1: Components, Tools, and Basics

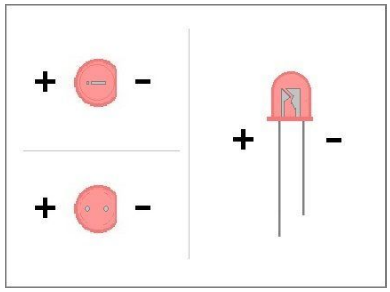
The common parts used in almost all electrical circuits are: resistors, capacitors, LEDs, inductors, and transistors. In this course, we will mainly be working with resistors, capacitors, LEDs. You can find more information about all these parts on this website. [LINK]

Resistors: The name resistor essential defines what resistors do. They resist the flow of current in a circuit. Here is a great video that includes analogies and also explains applications [LINK]. Note that we will mainly be using this so we can lower the voltage to an appropriate value to power our parts from our power source.

Capacitors: We won't be using capacitors that often in the class. However, it is important to know what it is and how it can be used for hardware filtering of noise. [LINK]. The following image is of a low pass filter built using a capacitor.



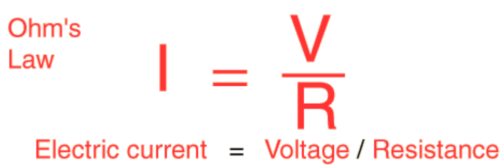
LEDs: LEDs stand for light emitting diodes. This is the light bulb in your circuit. Note that there is an easy way to identify the polarity of a LED. I like to use the flight side on the base of the LED to easily identify the negative side. Note to apply the proper voltage and diode have peculiar behavior.



Transistors: Transistors are the building blocks of computers. They are essentially switches that open and close based on a provided input. By lining many of these in parallel and series, we can build complex logic circuits. These are also useful in power electronics to turn on and off large power sources using smaller power sources. Note that there are many different types of transistors. [LINK]

Important Laws & Equations:

Ohm's Law: Ohm's law dictates the relationship between current, voltage, and resistance. V = IR. Here is a great video that talks about it. [LINK]



Capacitance: Capacitance is a capacitor's ability to store charge in its plates. A capacitor like a micro-reservoir that can be used to control peaks in current; thus, it is very useful for filtering signal and power for sensitive electronic devices. [LINK]

Basic Tools:

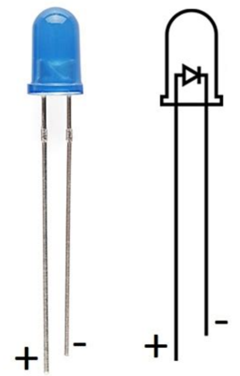
Wire cutters and stripper [Basic Hand Tool Intro]

Describe AWG and explain why **#22 solid wire** is essential for breadboarding. [Good Stack Exchange Answer]

- What is AWG? **American Wire Gauge** - it is a measure of wire thickness.
    - Note that *bigger* AWG numbers mean *smaller* wires!
    - It is useful to know how much current it can handle.
    - Here is a good chart that tells you the rating of AWGs.
      Demonstrate cutting, stripping and plugging in a wire. [Basic Breadboard Intro]

Thanks for valuable guidance from Prof. Blake Hannaford

Unit 2: Build a basic circuit



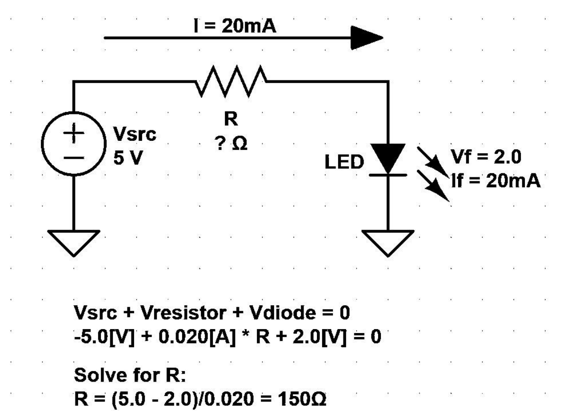
- Lay out parts: LED, Switch, Resistor, wire spool, solderless breadboard, power source (e.g. Arduino +5/gnd pins); explain connectivity pattern of breadboard [Basic Breadboard Intro]

Capacitance: (long wire == +)

LED Circuits:

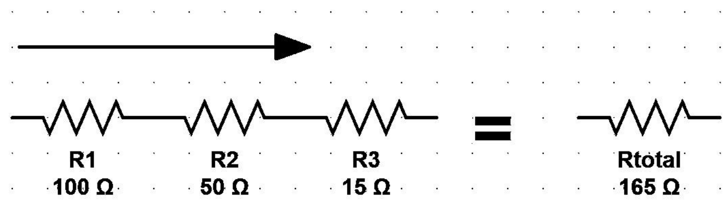
LEDs are wonderful devices used for indication in many electronic devices. Almost all LEDs--even the Red, Green, Blue (RGB) and high-powered LEDs in flashlights--connect to circuits in the same manner. They are relatively easy to use, albeit a couple of caveats that can get you into trouble: 1. LEDs only conduct in one direction. 2. They are easy to overdrive and burn out! On the first point, LEDs can conduct in the reverse directions, but that will destroy them. With the voltages we use in this lab, this shouldn't be a problem. If the proper resistance range is used, the LEDs will either glow or they will not. The second point builds on “the proper resistance range”. Incandescent light bulbs tend to self-regulate without adding resistors. LEDs on the other hand require current regulation. If the voltage source is large enough, the LED will glow very brightly for a short period of time, and then destroy itself. 5V is enough to quickly burn out an LED.

Although not a requirement in this lab, calculating the required resistance for an LED is quite easy with Ohm's Law. Consider the circuit below. On your Arduino , the source voltage will be 5 volts. The LED will have a specified forward voltage at a particular current (If). The values shown in the circuit below are from a common red LED, but should be close to the values you would find in the datasheet for your LED. (Note: The forward voltage on the red, green, yellow, blue, etc. are all different). In the circuit below, it doesn't matter if the resistor or the LED is first in the series connection. Just assume that the LED will have 2V across it when there is 20mA flowing through it. Your Arduino will have no trouble sourcing 5V, and you know 20mA is flowing through the unknown resistor. That means there is 3V remaining that needs to drop across the resistor. And according to Ohms law V= I*R and R=V/I. So 3V/0.020A = 150Ω. As a side note, 20mA is on the higher side for these common red LEDs. Usually I find the lowest current that will provide acceptable brightness to both reduce power consumption and increase LED life.



Series and Parallel:

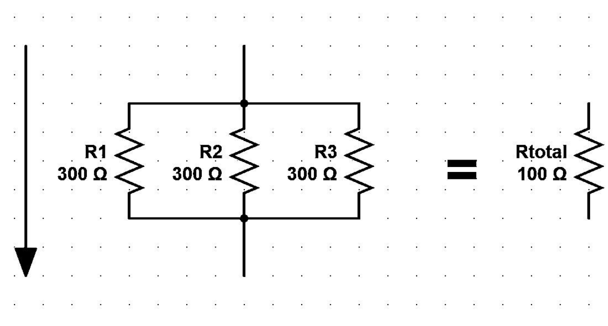
There are two fundamental ways to connect circuit components: Series or parallel. A series connection is shown in the circuit diagram above where a resistor is connected in series with an LED. Series connected circuits, by definition, require that the same current be flowing through each series connected component, which is why we knew that 20mA would flow through our unknown resistor if 20mA were flowing through the series connected LED.



A very useful property of resistance, is that resistors connected in series add.That is, the total resistance of two series connected resistors is simply the sum of those resistances. The same is true for any number of resistors connected in series. In general, the total resistance of any number of series connected resistors can be calculated with the following equation:

$$R_{TOTAL} = R_1 + R_2 + \ldots + R_n = \sum_{i=0}^{n} R_i$$

As is often the case, you will find that you need a resistance, but you don't have the correct value. Say you need 165Ω, and you only have 100Ω, 50Ω and 15Ω. Simply connect them end to end, and you are good to go.



Parallel connections basically share the current flow. Instead of connected end-to-end, two parallel connected resistors would simply have each leg connected. In the convenient case of two parallel connected resistors that are the same value, the overall resistance is divided down by 2 since there are two current paths (e.g., 100Ω and 100Ω becomes 50Ω). For two resistors of any value, the following equation will give the overall resistance:

$$R_{TOTAL} = \frac{R_1 * R_2}{R_1 + R_2}$$

The math is slightly more complicated for n-number of parallel resistors:

$$\frac{1}{R_{TOTAL}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n} = \sum_{i=0}^{n} \frac{1}{R_i}$$

Thanks for valuable guidance from Prof. Blake Hannaford

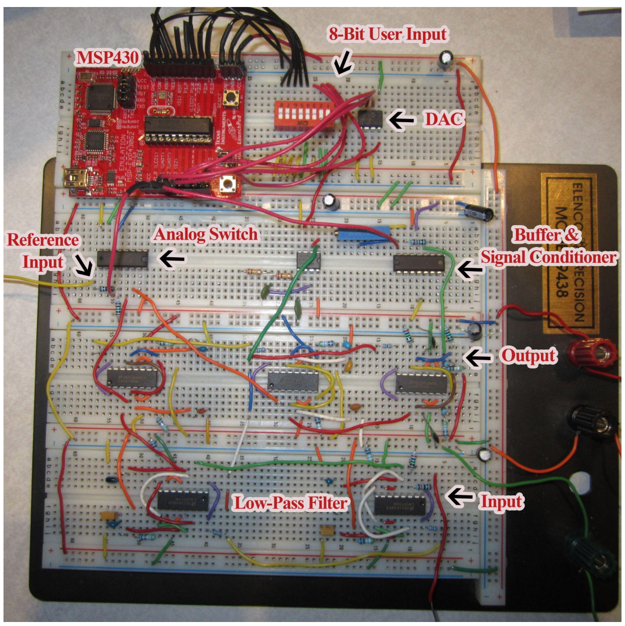
As it turns out, connecting components in this way also applies to capacitors, but it follows an opposite pattern compared to resistance. Parallel connected capacitors add up, and series connected capacitors decrease. For parallel connected capacitors, the following equation is true:

$$C_{TOTAL} = C_1 + C_2 + ... + C_n = \sum_{i=0}^{n} C_i$$

And for series connected capacitors:

$$\frac{1}{C_{TOTAL}} = \frac{1}{C_1} + \frac{1}{C_2} + ... + \frac{1}{C_n} = \sum_{i=0}^{n} \frac{1}{C_i}$$

Prototyping on a breadboard:



We will be using solderless breadboards in this lab to design or prototype circuits. The breadboard provides a solid, mechanical platform to quickly-assembly circuits. Breadboards can support extremely complex circuits. At left is a circuit I worked on in EE433 years ago. This is actually a triple breadboard unit with a fourth tacked onto the side. This wasn't the most efficient use of space, and if we were to revise one more time, we would have tightened everything up. Having short, clean connections is optimal, but sometimes if you build everything too tightly, it is very difficult to modify the circuitry. That's why we left so much room on the breadboards.

Breadboards are quite simple to use and will last many years if cared for properly. This [breadboard overview] from SparkFun provides excellent information on the history, construction and usage of solderless breadboards. A concise video on breadboarding can be found [here].

Although we won't cover circuit simulation in this course, there are many excellent and free software packages available. A very handy simulator, which is very useful for Arduino and breadboarding is [Tinkercad].

Unit 3: Voltage, Current, Ohms Law and your DMM.

[Voltage, Current, Resistance Explained (with Water Analogy) + Ohm's Law]

- Voltage = Pressure (the water pipe analogy)
- Current = Flow
- Resistance = Resistance to flow.
- V = IR (Ohm's Law)
- Measuring voltage with a digital multi-meter (DMM)
    - (I in = 0 on the DMM) [DMM Intro for ECEs]

[Measuring Voltage, Current, Resistance, Continuity in Simple DC Circuit]

- Demo **Voltage mode** with e.g. a voltage divider
- Demo **Resistance Mode** with a couple of resistors.
- **Current Mode**
    - Replugging into the current jack
    - Vin = 0 Rin ~=0.
    - Hazard: Don't hook current mode up to a voltage source (I = V/R, R~=0, I too big)
    - Demo current measurement with a series resistor. Verify Ohm's Law