Unit 1

Circuit Basics
KVL, KCL, Ohm's Law
LED Outputs
Buttons/Switch Inputs

VOLTAGE AND CURRENT

Current and Voltage

- Charge is measured in units of Coulombs
- Current – Amount of charge flowing through a __________ in a certain ____________
  - Measured in _______ = Coulombs per second
  - Current is usually denoted by the variable, I
- Voltage – Electric __________ energy
  - Analogous to mechanical potential energy (i.e. ________)
  - Must measure __________ points
  - Measured in Volts (V)
  - Common reference point: Ground (GND) = 0V
    - Often really connected to the ground

Current / Voltage Analogy

Charge = Water

Voltage Source = Water Pressure

- + V2 -
- + V1 -

GND
Meet The Components

- Most electronic circuits are modeled with the following components:
  - **Resistor**
    - Measures how well a material conducts electrons
  - **Capacitor & Inductor**
    - Measures material's ability to store charge and energy
  - **Transistor**
    - Basic amplification or switching technology

Kirchhoff's Laws

- Common sense rules that govern current and voltage
  - **Kirchhoff's Current Law (KCL)**
  - **Kirchhoff's Voltage Law (KVL)**

**Kirchhoff's Current Law (KCL)**
- The current flowing into a location (a.k.a. node) must equal the current flowing out of the location
- ...or put another way...
- The sum of current at any location must be zero

**Kirchhoff's Voltage Law (KVL)**
- The sum of voltages around a loop (i.e. walking around and returning to the start) must equal 0
- Define "polarity" of voltage and then be consistent as you go around the loop...obviously when you solve you may find a voltage to be negative which means you need to flip/reverse the polarity
**Nodes**

- **(Def.)** An **electric node** is the junction of _________ devices connected by wires.
- _________ voltage at any point of the node.
- How many nodes exist in the diagram to the right?

**Practice KCL and KVL**

- Use KCL to solve for i3, i4, and i6.
- Use KVL to solve for v3, v8, v5.

**Resistance and Ohms Law**

- Measure of how hard it is for current to flow through the substance.
- Resistance = ________________
  - How much ______ do you have to put to get a ____________ to flow.
- Measured in Ohms (____)
- Ohm’s Law
  - _________ or _________
  - R ___ => I ___

**Series & Parallel Resistance**

- Series resistors = one after the next with no other divergent path.
- Parallel resistors = Spanning the same two points.
- Series and parallel resistors can be combined to an equivalent resistor with value given as shown...
Solving Voltage & Current

- Given the circuit to the right, let...
  - \( V_{dd} = 5V, R_1 = 400 \text{ ohms}, R_2 = 600 \text{ ohms} \)
- Solve for the current through the circuit and voltages across each resistors (i.e. \( V_1 \) and \( V_2 \))
  - Since everything is in ________, KCL teaches us that the current through each component must be the ________, let’s call it \( i = \ldots \)
  - \( V_1 = \ldots \) and \( V_2 = \ldots \)
  - Though unneeded, KVL teaches us that
    - \( V_{dd} - V_1 - V_2 = 0 \) or that \( V_{dd} = V_1 + V_2 \)

Voltage Supply Drawings

- The voltage source (\( V_{dd} \)) in the left diagram (i.e. the circle connected to the “Rest of Circuit”) is shown in an alternate representation in the right diagram (i.e. the triangle labeled “\( V_{dd} \)”).
- In the left diagram we can easily see a KVL loop available
  - When two resistors are in series we can deduce an expression for the voltage across one of them
    - \( i = \ldots \)
  - Though unneeded, KVL teaches us that
    - \( V_1 = iR_1 \) and \( V_2 = iR_2 \)
  - Substituting our expression for \( i \): \( V_1 = V_{tot} \frac{R_1}{R_1 + R_2} \) and \( V_2 = V_{tot} \frac{R_2}{R_1 + R_2} \)
  - The voltage across one of the resistors is proportional to the value of that resistor and the total series resistance
    - If you need 10 gallons of gas to drive 500 miles, how much gas you have you used up after driving 200 miles?
      - Gas = ______, Mileage = ______
  - We can use the voltage divider concept to immediately arrive at the value of \( V_2 \)
    - \( V_2 = \ldots \)

Voltage Dividers

- \( V_s = +5V, R_1 = 400 \text{ ohms}, R_2 = 600 \text{ ohms} \)
- Recall our solution
  - \( i = \frac{V_s}{(R_1 + R_2)} = \frac{5}{1000} = 5 \text{ mA} \)
  - \( V_1 = iR_1 = 2V \) and \( V_2 = iR_2 = 3V \)
- When two resistors are in series we can deduce an expression for the voltage across one of them
  - \( i = \ldots \)
  - \( V_1 = iR_1 \) and \( V_2 = iR_2 \)
  - Substituting our expression for \( i \):
    - \( V_1 = V_{tot} \frac{R_1}{R_1 + R_2} \) and \( V_2 = V_{tot} \frac{R_2}{R_1 + R_2} \)
  - The voltage across one of the resistors is proportional to the value of that resistor and the total series resistance
  - If two resistors \( R_x \) and \( R_y \) are in series then voltage across \( R_x \) is:
    - \( V_x = \ldots \)

Solving Voltage & Current

- Reconsidering the circuit to the right with...
  - \( V_s = +5V, R_1 = 400 \text{ ohms}, R_2 = 600 \text{ ohms} \)
- Solve for the current through the circuit and voltages across each resistors (i.e. \( V_1 \) and \( V_2 \))
  - \( V_1 = \ldots \)
  - \( V_2 = \ldots \)
Solving Voltage & Current

- Consider the circuit on the right...
- What is the relationship between V1 and V3?
- Can you solve for the voltage V1 (in terms of Vs, R1, R2, R3)?
- Can you solve for the voltage V2 (in terms of Vs, R1, R2, R3)?

A Problem...

- Given the following parameters...
  - Vs=5V, R1=4, R2 = 12, R3 = 2 and R4 = 10 ohms.
- Can we use the voltage divider concept to immediately solve the voltage across R2 or do we need to first do some manipulation? What about R4?
  - First, find the total equivalent resistance ($R_{eq}$) seen by Vs and then solve for the voltage across each resistor.

Generating Inputs & Measuring Outputs

- Where do inputs to a digital circuit originate?
  - Usually as ________ from another digital circuit (i.e. USB connecting to your laptop's main processing system)
  - For our class right now: A __________ controlled by a human (can be on or off)
- How will we know what voltage is coming out of a digital circuit?
  - Could use a voltmeter or oscilloscope (don't be afraid to use the equipment in our lab!)
  - ________ are commonly used to show the status of a digital output to a human

LEDS AS OUTPUTS AND SWITCHES/BUTTONS AS INPUTS

- A button or switch (input stimulus)
- An LED
- Some digital processing/control
- Each key on your keyboard is essentially a digital input generated by a push button (pressed or not pressed)
- The status indicator on the Caps Lock button is simply an LED controlled by a digital output.
### (Light-Emitting) Diodes

- The simplest output we can control is an LED (Light-emitting diode) which is like a tiny light bulb.
- An LED glows (‘on’) when current _______ through it (i.e. when there is a voltage _________ across it).
- LEDs are polarized meaning they only work in one orientation (______ leg must be at higher voltage).

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### Need for Series Resistor with LEDs

- **Problem**: LEDs may allow too much current to flow which may blow out the LED.
- **Solution**: Use a series resistor to limit current.
  - Amount of current will determine ____________ of LED.
  - $R \uparrow$ then $i \downarrow$ and thus LED brightness ____. 
  - $i = V1/R1 = (V_s-V_{LED}) / R1$
  - Usually $R1$ is a few hundred ohms (_______ohms).

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### LED Connection Approaches

- When letting a digital output control an LED, the value (i.e. '0' = low or '1' = high voltage) that causes the LED to light up depends on how the circuit is wired.
  - Note: Gates can often ______ (take in) more current than they can ________ (push out), so option 2 may be preferred...but let’s not worry about this now...let’s use option 1.

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### Switch and PushButton Inputs

- Switches and pushbuttons can be in one of two configurations: ______ or _______.
  - Switches can be opened or closed and then ________ in that position until changed.
  - Pushbuttons are open by ________ and require you to push them to close the circuit (they then open when you release).
- Can be used as an input to digital device.
**Switches and Pushbuttons**

- Important Note 1:
  - When open a SW/PB looks like an _____ resistance (no current can flow)
  - When closed a SW/PB looks like a _____ (R=0) and no voltage drops across it

- **Question:** What voltage does an open or closed switch (pushbutton) generate?

- **Answer:**

- Important Note 2:
  - SW or PBs don't produce digital 0’s or 1’s ________, they control what voltage (PWR/GND) is connected to your device

**Connecting a Switch**

- Switches only help ________ the voltage going into a device, they do not produce a voltage (0V or 5V) by themselves

- **Option 1:** Attach one side to GND and the other side to the device
  - When the switch=open, nothing is connected to the device (a.k.a. “_______”)  
  - A floating input may sometimes appears as zero, and other times as a one.
  - We need the inputs to logic gates to be in either the 0 or 1 state...not floating

- **Option 2:**
  - When switch closed => _____ resistance connection from power to ground = ________ current flow...BAD!!! (This is known as a "short circuit").

**Preferred Wiring of Switches**

- Solution: Put GND on the far side and a "pull-up" resistor at the input side
  - "Pull-up resistor" used to hold the input high unless something is forcing it to a zero
  - SW open => Arduino input looks like inf. Resistance in series with Rp. Thus _____ through Rp and thus no voltage drop across Rp...Vin = ________
  - SW closed => Direct wire from GND to input...input = ________. Also current flowing from Vdd to GND is limited by Rp preventing a short circuit.
  - Usually Rp is large (10k ohms) to limit current

To calculate Vin:

Vin = Vdd – Vin
Vin = Vdd – Vr
Vr = Rp since in ___________ with resistance of Arduino input
Thus, Vin = ________

**Power & Ground Connections**

- Easy mistake when you’re just learning to wire up circuits:
  - Wire the inputs & outputs but forget to connect power and ground
- All circuits and chips require a connection to a power source and ground
  - Digital circuits (aka "gates")
  - Switches
  - Buttons

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Vin = floating = SW
Vin = unknown

Switch Closed = 0V (Logic 0) to input   
Switch Open = ??? (does not work)

Vin = floating = SW
Vin = unknown

Switch Closed = 0V (Logic 0) to input   
Switch Open = ??? (does not work)

Vin = floating = SW
Vin = unknown

Switch Closed = 0V (Logic 0) to input   
Switch Open = ??? (does not work)

Preferred: Use a pullup resistor

Main Point: Buttons & switches should have GND connected to one side & a pull-up resistor on the other