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
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 _____ a location (a.k.a. node) must equal the current flowing _____ of the location
  - ...or put another way...
  - The sum of current at any location must _____

Kirchhoff's Current Law

- Reminder: KCL says _____________
- Start by defining a ______ for each current
  - It does not matter what direction we choose
  - When we solve for one of the currents we may get a __________ current
  - "Negative" sign simply means the direction is __________ of our original indication
- In the examples to the right the top two examples the directions chosen are fine but physically in violation of KCL...
- ...but KCL helps us arrive at a consistent result since solving for one of the current values indicates...
  - The ______ of i1 and i2 are the same
  - They always flow in the ______ direction of each other (if one flows in the other flows out or vice versa)

Kirchhoff's Voltage Law (KVL)

- The sum of voltages around a _____ (i.e. walking around and returning to the _________) 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
A Brief Summary

- KCL and KVL are _________ and _________ no matter what kind of devices are used
  - The yellow boxes could be ANY electronic device: resistors, batteries, switches, transistors, etc...KVL and KCL will still apply
  - In a few minutes, we'll learn a law that only applies to resistors (or any device that can be modeled as a resistor)
- Some KVL or KCL equations may be _________
  - Writing the equation for loop (v1,v2,v3) and (v3,v4,v5) may be sufficient and writing (v1,v2,v4,v5) may not be necessary
  - But as a novice, feel free to _________

KVL says:
\[ v_1 + v_2 + v_3 = 0 \]
\[ v_2 + v_3 + v_4 = 0 \]
\[ -v_3 + v_4 + v_5 = 0 \]

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

  **Hint:** Find a node or loop where there is only one unknown and that should cause a domino effect

- 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 certain _________ to flow
- Measured in Ohms (Ω)
- Ohm’s Law
  - \[ I = \_\_\_\_ \text{ or } V = \_\_\_\_ \]
  - \[ R \_\_ \Rightarrow I \_\_ \]

Ohm’s Law ONLY applies to resistors (or devices that can be modeled as a resistor such as switches and transistors)
**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...
  - $V_{dd} = +5V$, $R_1 = 400$ ohms, $R_2 = 600$ 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 $i$
    - $i = \ldots$
  - This alone lets us compute $V_1$ and $V_2$ since Ohm's law says
    - $V_1 = \ldots$ 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 "Vdd")
- In the left diagram we can easily see a KVL loop available
- There is still a KVL loop available in the right diagram

**Shortcut: Voltage Dividers**

- A shortcut application of KVL, KCL, and Ohm's law when two resistors are in series (must be in series)
- Recall the original problem and solution
  - $V_s = +5V$, $R_1 = 400$ ohms, $R_2 = 600$ ohms
  - $i = V_s / (R_1 + R_2) = 5/1000 = 5$ mA
  - $V_1 = i*R_1$, $V_2 = i*R_2 = 3V$
- When two resistors are in series we can deduce an expression for the voltage across one of them
  - (1) $i = \ldots$; (2) $V_1 = i*R_1$; (3) $V_2 = i*R_2$
  - Substituting our expression for $i$ into (2) and (3)
    - $V_1 = V_{tot} \frac{R_1}{R_1 + R_2}$ 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?
    - $\text{Gas} = \ldots$, $\text{Mileage} = \ldots$
### Solving Voltage & Current

- Reconsidering the circuit to the right with...
  - $V_s = +5\text{V}$, $R_1 = 400 \text{ ohms}$, $R_2 = 600 \text{ ohms}$
- Solve for the current through the circuit and voltages across each resistors (i.e. $V_1$ and $V_2$)
  - We can use the voltage divider concept to immediately arrive at the value of $V_2$
  - $V_2 = \ldots$

### A Problem...

- Given the following parameters...
  - $V_s = 5\text{V}$, $R_1 = 4$, $R_2 = 12$, $R_3 = 2$ and $R_4 = 10 \text{ ohms}$.
- Can we use the voltage divider concept to immediately solve the voltage across $R_2$ or do we need to first do some manipulation? What about $R_4$?
- First, find the total equivalent resistance ($R_{eq}$) seen by $V_s$ and then solve for the voltage across each resistor

### LEDs as Outputs and Switches/Buttons as Inputs
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

(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)

• 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↑ then i __ and thus LED brightness ___
  - i = V1/R1 = (V5-VLED) / R1
  - Usually R1 is a few hundred ohms (______ ohms)

Need for Series Resistor with LEDs

- 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

LED Connection Approaches

- Main Point: To be 'on', there must be a voltage difference across the LED making current flow.
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: We can model a button or switch as a resistor of either 0 ohms or inf. (very large) ohms
  – 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: ________________.

Connecting a Switch

• Switches only __________ 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 – Vsp
Vin = Vdd – ______ 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

Actual connection… …will be drawn like this

Summary

• KCL and KVL apply to **ALL** electronic devices
• Ohm’s law applies **ONLY** to resistors and governs the relationship between the current through and the voltage across a resistor
• A resistor network can be collapsed to a **single equivalent resistance** by applying series and parallel transformations
• If two or more resistors are in series, the voltage across any of those resistors can be quickly found by applying the **voltage divider equation**
• LEDs are used as digital outputs and must be wired in the correct direction
• Switches can be modeled as a **small (0) resistance when closed** or a **large (inf.) resistance when open**