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
- Voltage Source = Water Pressure
- Charge = Water
- Conductive Material (A Wire)
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 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

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

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 = _____ or V = _____
  – R __ => 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...
  - \( V_{dd} = +5V, R_1 = 400 \text{ ohms}, R_2 = 600 \text{ ohms} \)
  - Solve for the current through the circuit and voltages across each resistor (i.e. \( V_1 \) and \( V_2 \))
    - Since everything is in series, KCL teaches us that the current through each component must be the same, let's call it \( i \)
    - \( i = \frac{V_{dd}}{R_{tot}} \)
    - This alone lets us compute \( V_1 \) and \( V_2 \) since Ohm's law says
      - \( V_1 = ____ \) and \( V_2 = ____ \)
      - \( V_1 = ____ \) and \( V_2 = ____ \)
    - 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
- 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)
- When two resistors are in series we can deduce an expression for the voltage across one of them
  - (1) \( i = \frac{V_1}{R_1} \); (2) \( V_1 = i \times R_1 \); (3) \( V_2 = i \times R_2 \)
  - Substituting our expression for \( i \) into (2) and (3)
    - \( V_1 = V_{tot} \times \frac{R_1}{R_1 + R_2} \) and \( V_2 = V_{tot} \times \frac{R_2}{R_1 + R_2} \)
- 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 do you have used up after driving 200 miles?
    - Gas = ____________, Mileage = ____________

Memorize this. We will use it often!
1.17 Solving Voltage & Current

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

1.18 Solving Voltage & Current

- Consider the circuit on the right...
- What is the relationship between $V_1$ and $V_3$?
- Can you solve for the voltage $V_1$ (in terms of $V_s$, $R_1$, $R_2$, $R_3$)?
- Can you solve for the voltage $V_2$ (in terms of $V_s$, $R_1$, $R_2$, $R_3$)?

1.19 A Problem...

- Given the following parameters...
  - $V_s=5V$, $R_1=4$, $R_2 = 12$, $R_3 = 2$ and $R_4 = 10$ 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

1.20 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)

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 ___
  – $i = V_1/R_1 = (V_0-V_{LED}) / R_1$
  – Usually $R_1$ is a few hundred ohms (______ohms)

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
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

Important Note 1: We can model a button or switch as a resistor of either 0 ohms or inf. (very large) ohms

SW – When open a SW/PB looks like an _________ resistance (no current can flow)

Switches and pushbuttons can be in one of two configurations:
• ==
  – When closed a SW/PB looks like a _______ (R=0) and no voltage drops across it

_____ or _______

_____

• Question: What voltage does an open or closed switch (pushbutton) generate?
• Answer: ________________.

Pushbuttons are open by _________ and require you to push them to close the circuit (they then open when you release)

Important Note 2: • SW or PBs don’t produce digital 0’s or 1’s

SW Example pushbuttons
V = ??

• V = ??? (PWR/GND) is connected to your device

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

Analogy:

Vin = Vdd – ______ i

To calculate Vin:

Vin = Vdd – Vop
Vin = Vdd – ______ i

Vin = Vdd – ______ i
Thus, Vin = ______

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

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 **large (inf.) resistance when open**