Hardware Workshop One
Fundamentals

Day 1 Start

Motivation

- Have no spring/summer activities in ECE
- Review some concepts learned in ECE110
- Learn some new concepts for ECE212 & ECE231
- Have some ideas about how to build and debug a circuit
- Build something practical out of simple components
- Get motivated to design/build on your own and have fun

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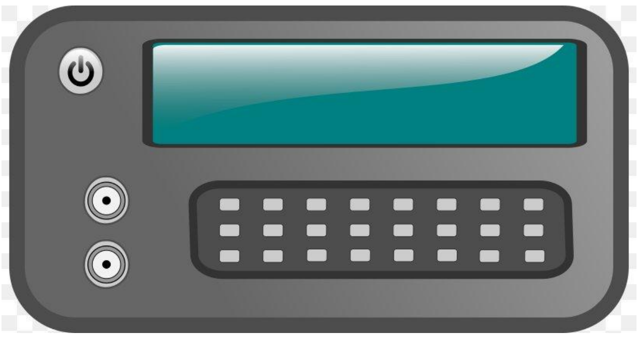
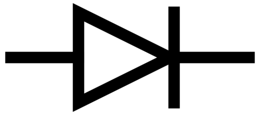
Hardware Workshop: (4 Day Program)

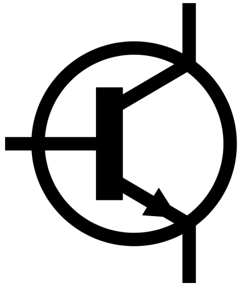
- Phase One: Review of Ece110
  - Resistor, Capacitor, Inductor
  - Series and Parallel Circuits
  - Breadboard
  - Soldering
  - Digital Multimeter
  - Function Generator
  - Oscilloscope

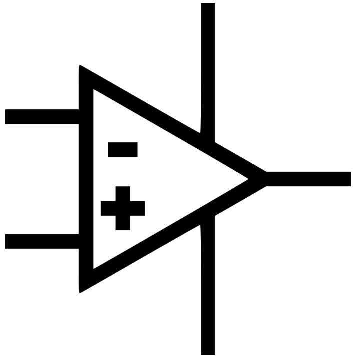


Hardware Workshop: (4 Day Program)

- Phase Two: Introduction to Ece212/231
  - Semiconductor
  - Diode and LED
  - Types of Transistors
  - NPN and PNP Connections
  - Astable Multivibrator
  - Operational Amplifiers

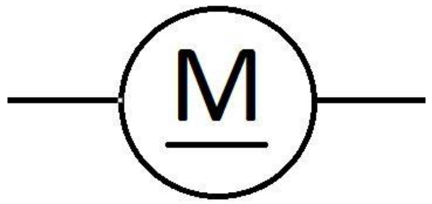


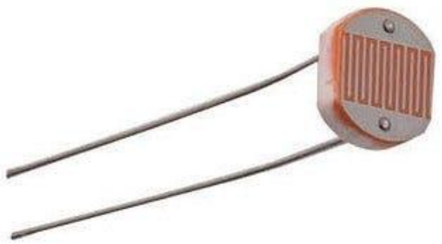


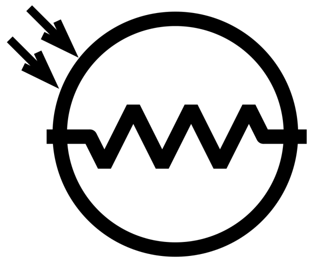


Hardware Workshop: (4 Day Program)

- Phase Three: Application Part 1
  - DC Motors
  - Pulse Width Modulation
  - H-Bridge
  - Photoresistors
  - Phototransistors
  - Colour Detection

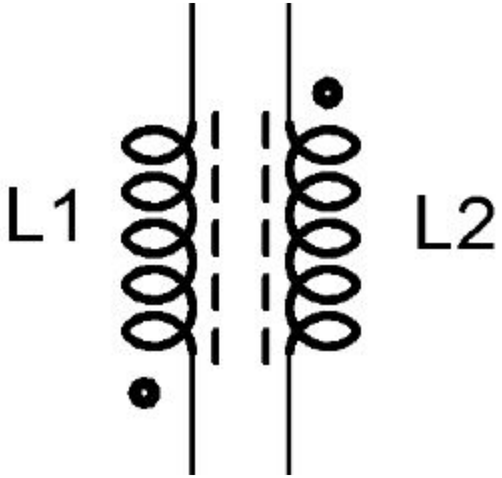






Hardware Workshop: (4 Day Program)

- Phase Four: Application Part 2
  - Coupled Inductors
  - Joule Thief
  - Generators
  - Workshop Competition

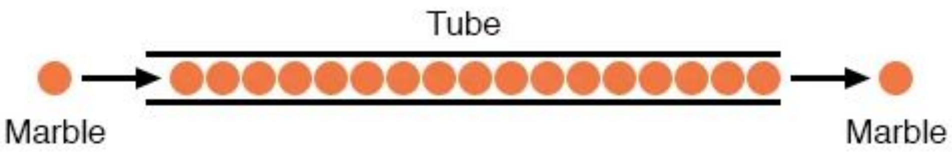


Review

Resistor, Capacitor & Inductor

Free Electron

- Current is the flow of charge
- Free electrons carry charge
- Number of free electrons determines conductivity of a material
- Current (*I, i*) is charge in motion
- Conventional current is in the opposite direction of electrical current



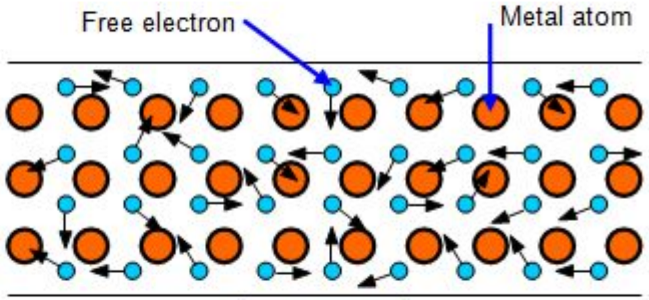


Figure 1(a)

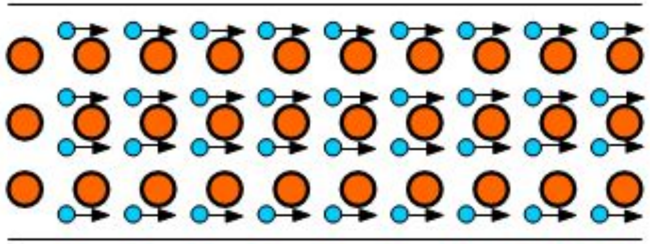
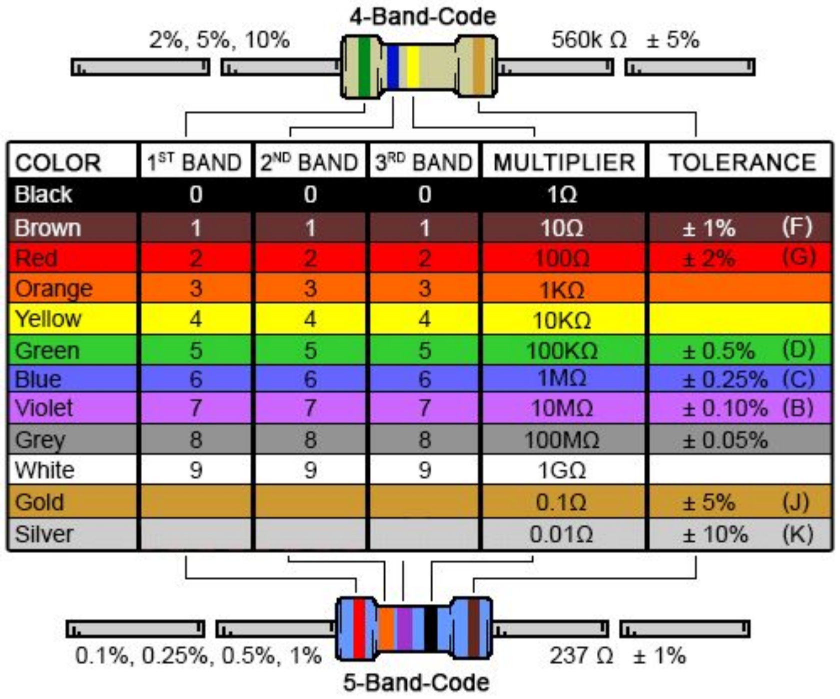


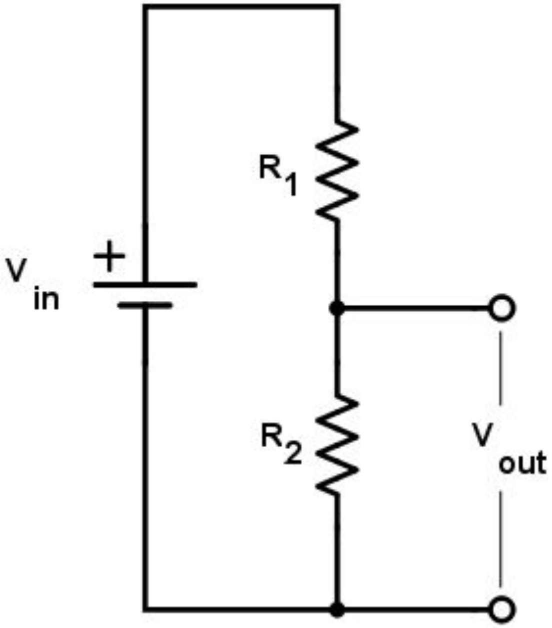
Figure 1(b)

Resistor

- Opposes flow of current
- Usage:
  - Limits current
  - Turns current into voltage
  - Works as a Voltage Divider

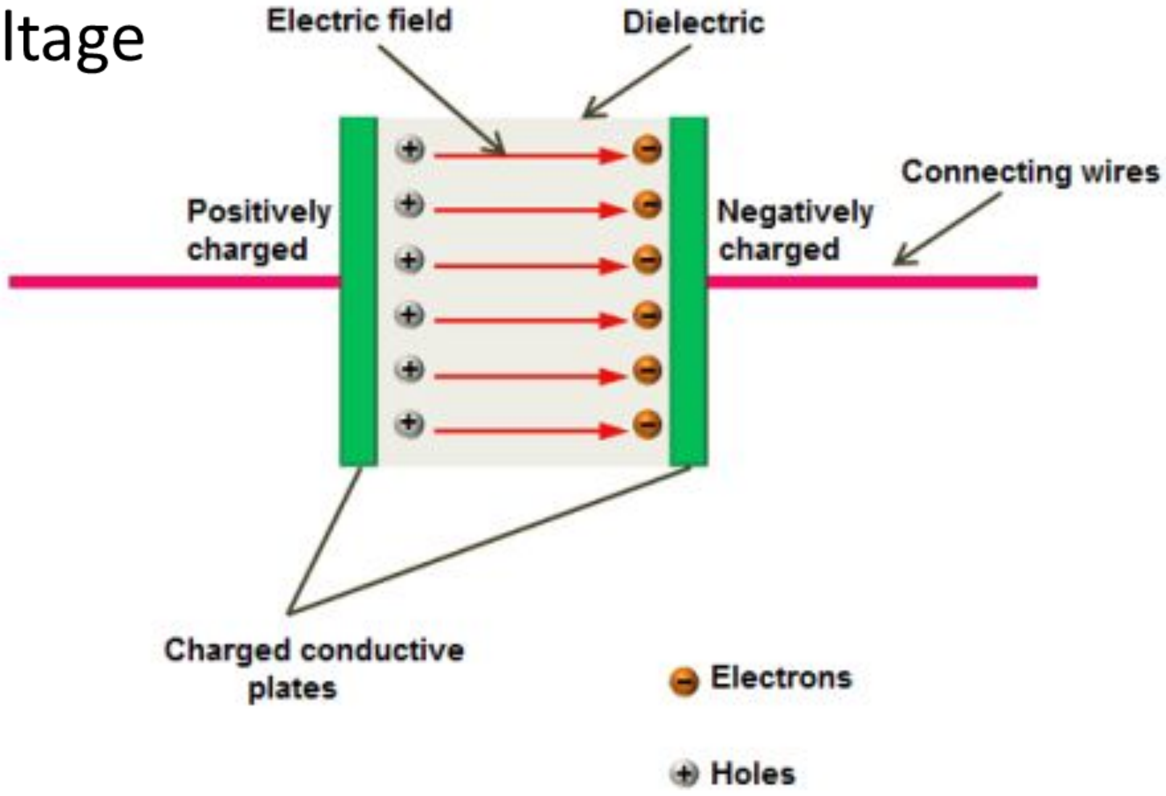


COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8	100MΩ	± 0.05%
White	9	9	9	1GΩ	
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)



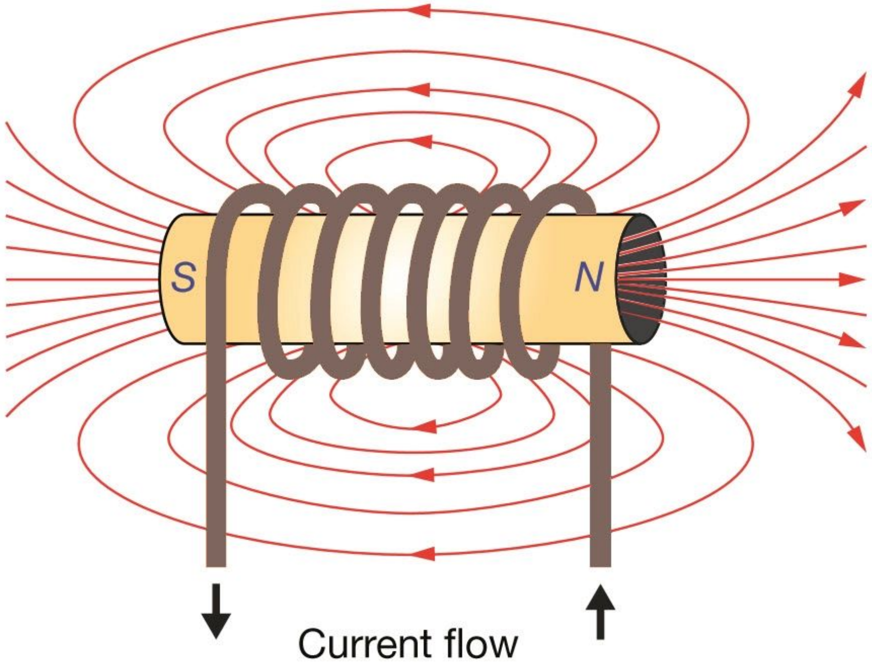
Capacitor

- Stores energy in an electric field
- Opposes sudden changes in voltage
- Z = $\frac{1}{jwC}$



Inductor

- Stores energy in a magnetic field
- Opposes sudden changes in current
- Z = jwL



Series and Parallel Connections

Elements Symbol	RESISTOR 	CAPACITOR 	INDUCTOR 
Denoted by	R	C	L
Equation	$R = \frac{V}{I}$	$C = \frac{Q}{V}$	$L = \frac{V_L}{(di/dt)}$
Series	$R_T = R_1 + R_2$	$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$	$L_T = L_1 + L_2$
Parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$	$C_T = C_1 + C_2$	$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2}$

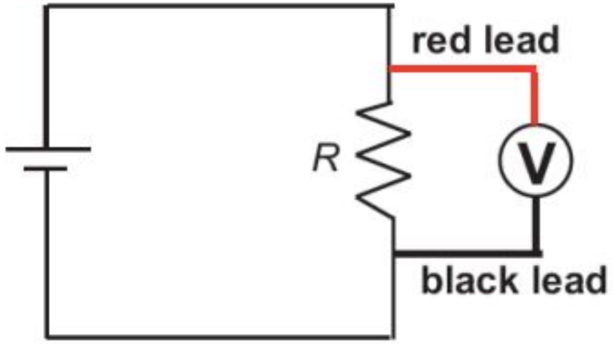
Review

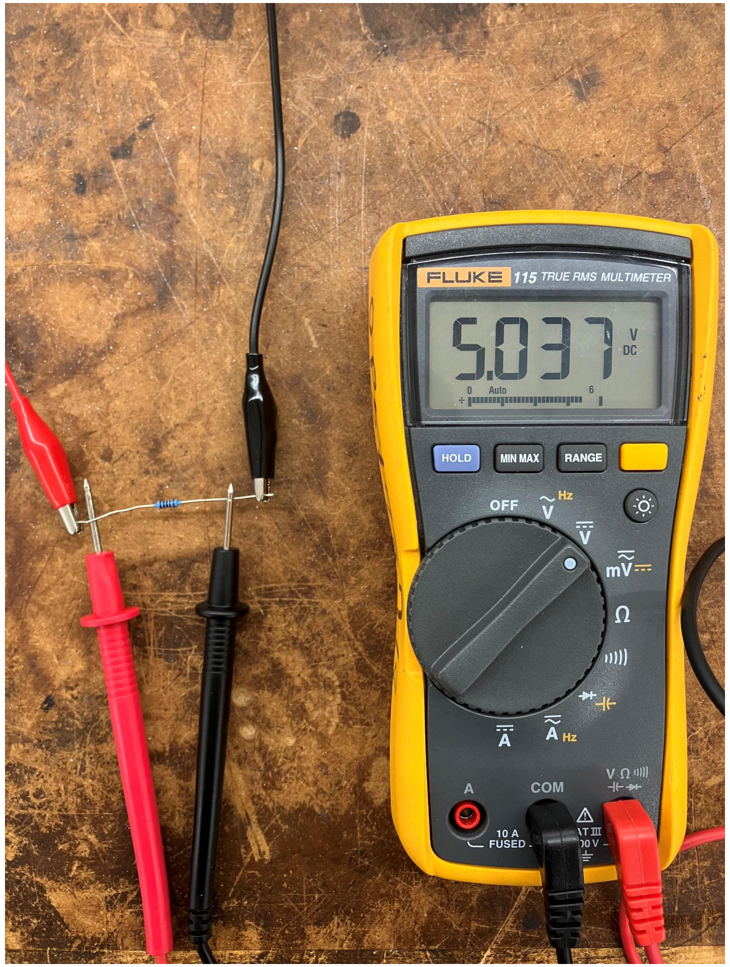
Digital Multi-Meter (DMM) & Breadboard

DMM

Using the DMM as a Voltmeter

- Plug Red Probe into V/Ω
- Select AC/DC based on type of measurements
- Connect the Voltmeter in parallel with the circuit
- The DMM will measure the voltage across its probes

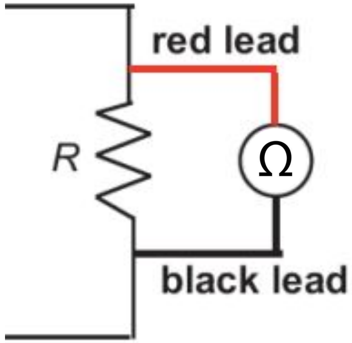




DMM

Using the DMM as an Ohmmeter

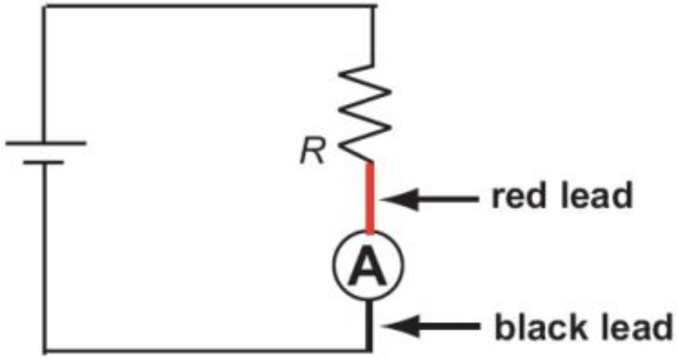
- Plug Red Probe into V/Ω
- Connect the Ohmmeter in parallel with the circuit with no source
- The DMM will measure the resistance between its probes

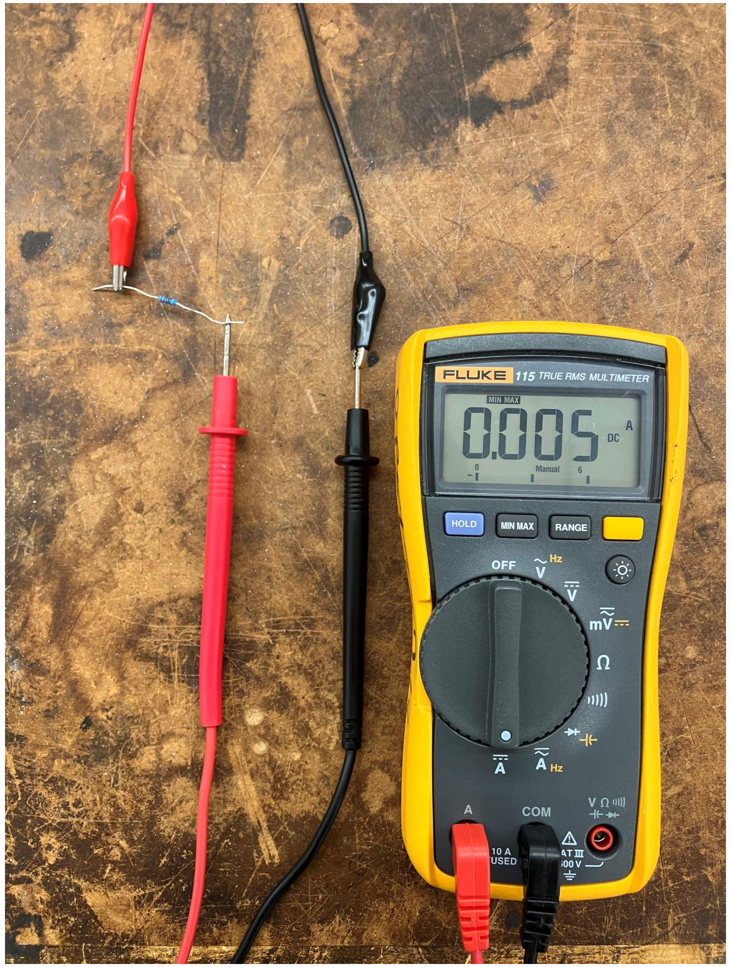


DMM

Using the DMM as an Ammeter

- Plug the Red Probe into A
- Select AC/DC based on type of measurements
- Connect the ammeter in series with the circuit
- The DMM will act as a short and measure the current through its probes

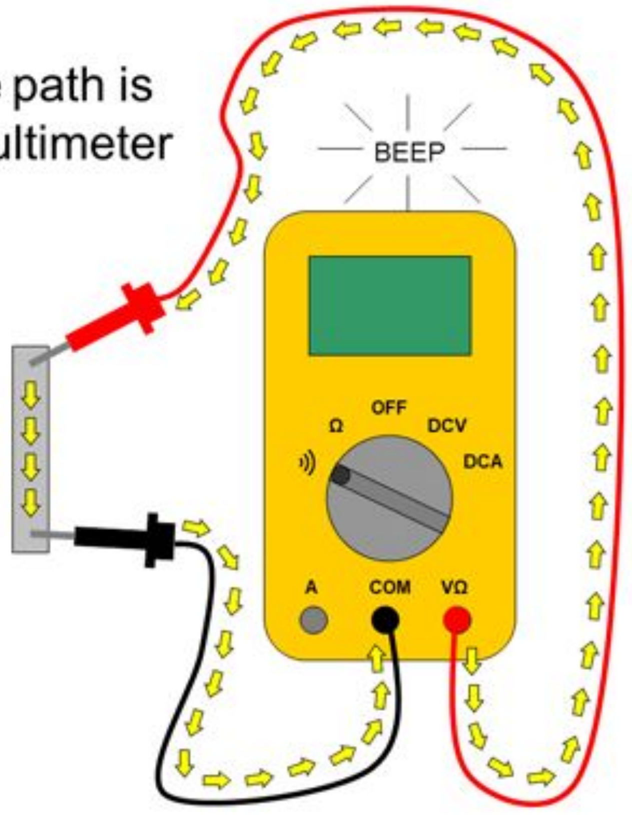




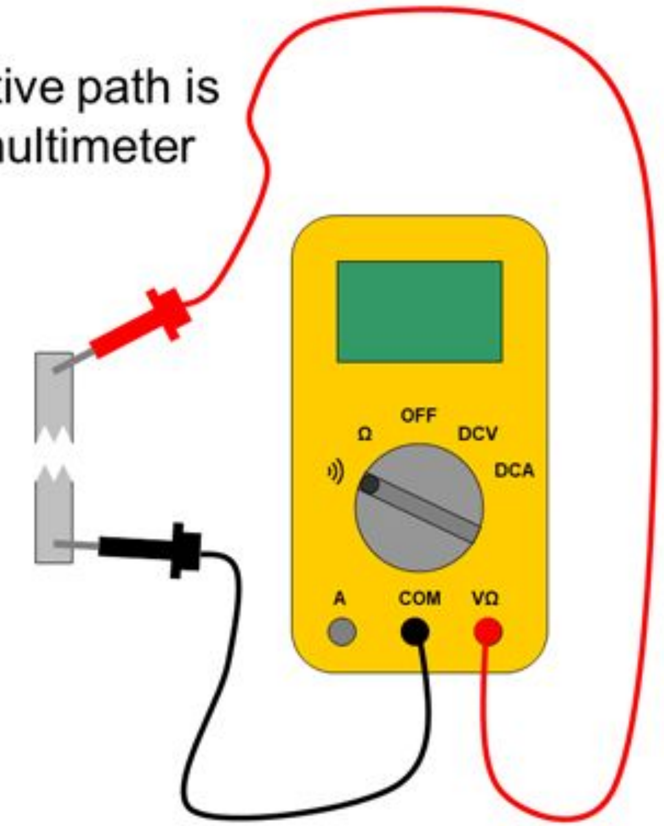
A1: Breadboard Connections

Use the continuity test on the digital multi-meter to find out how the breadboard is connected

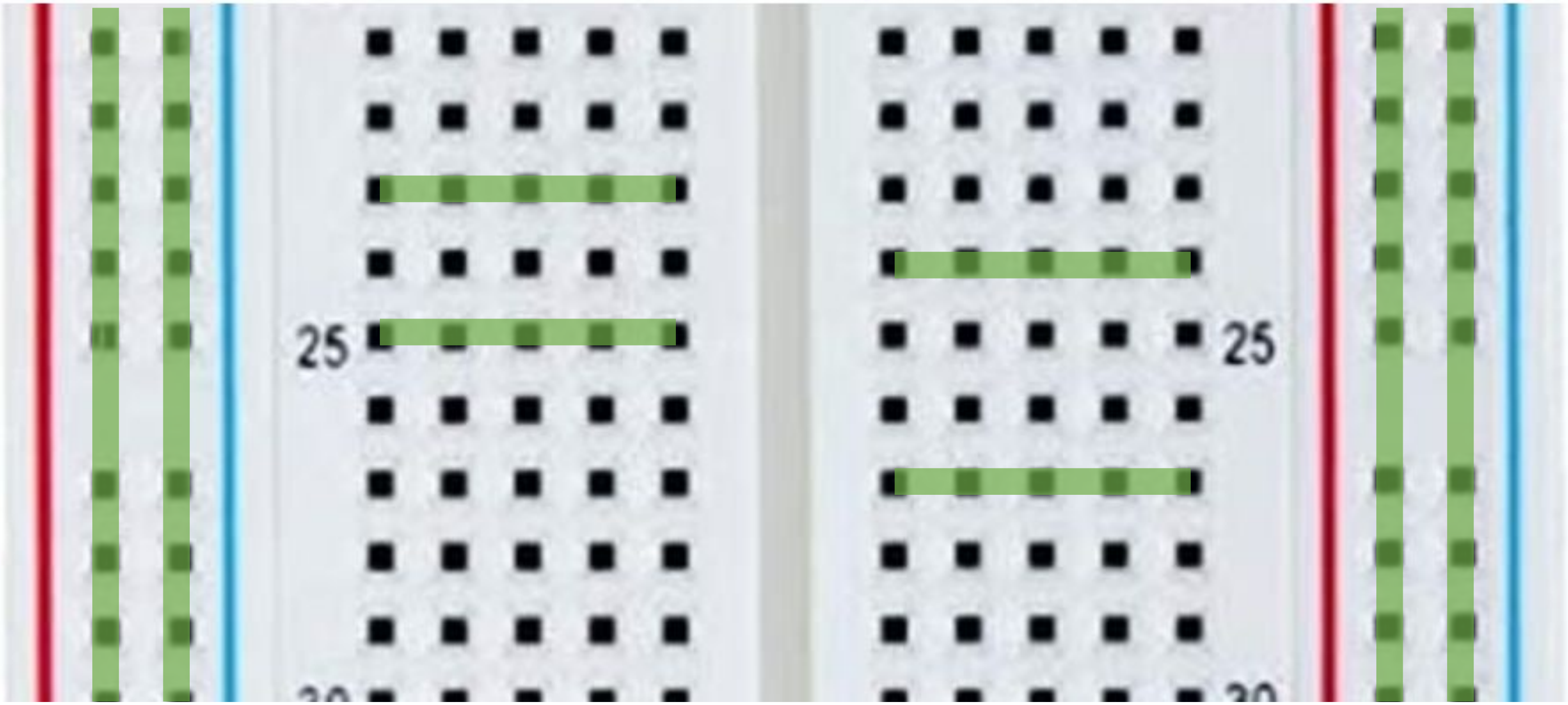
If a conductive path is formed, the multimeter will beep.



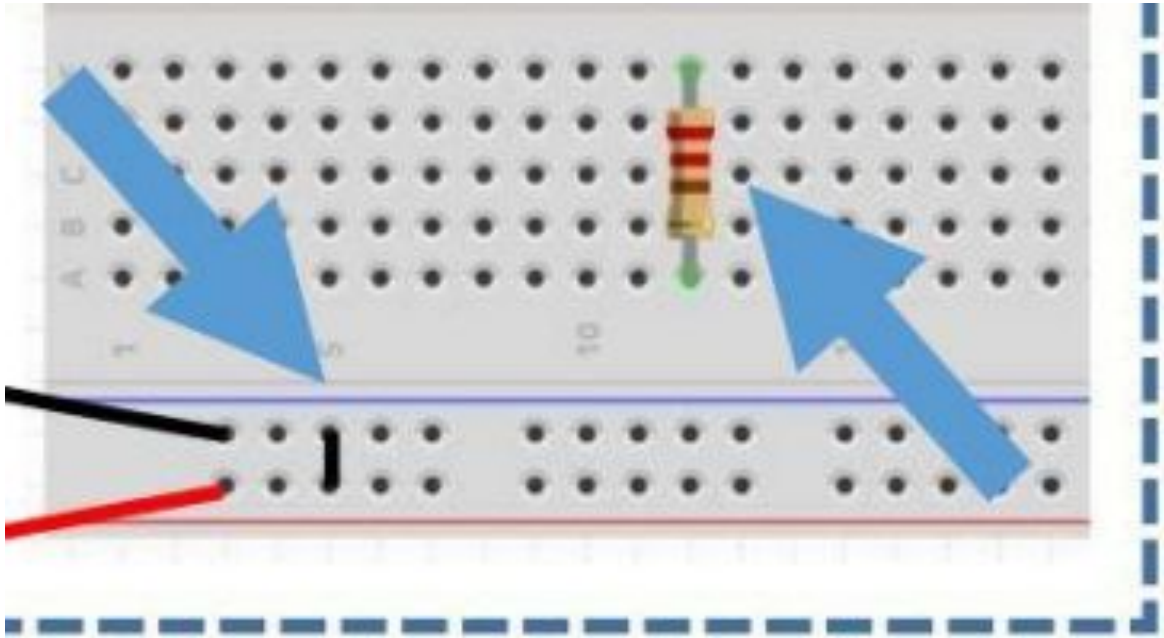
If the conductive path is broken, the multimeter will not beep.



A1: Breadboard Connections

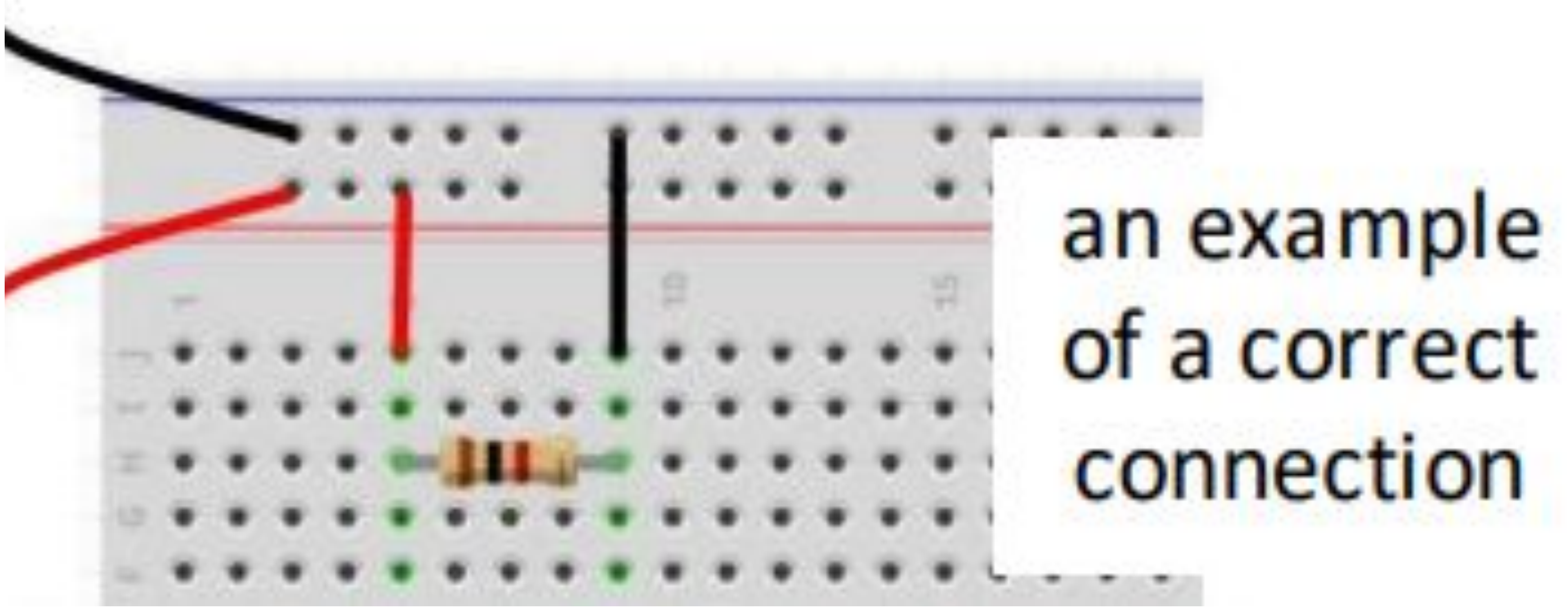


A1: Breadboard Connections



examples of wrong connections

A1: Breadboard Connections

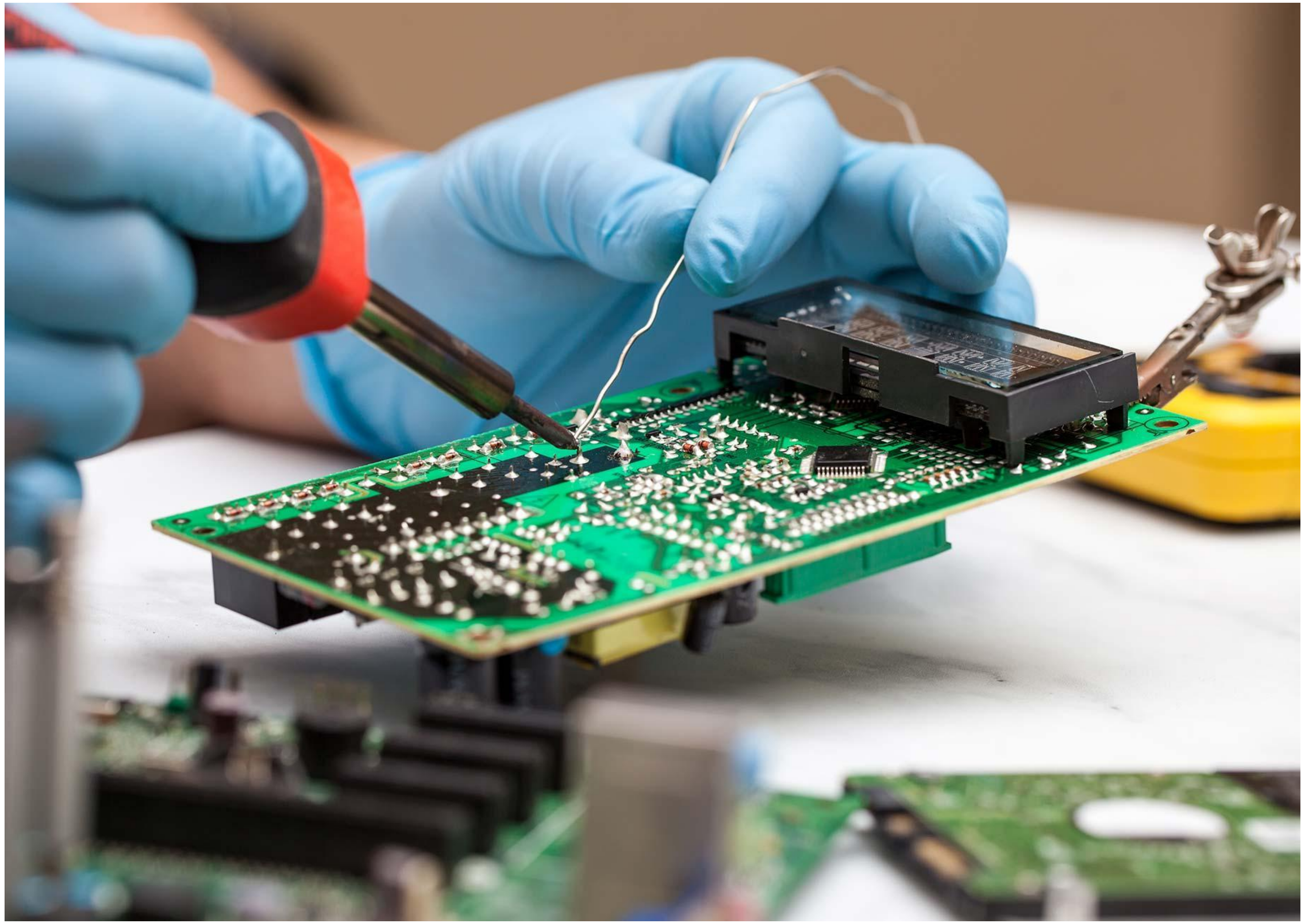


New

Soldering

Soldering

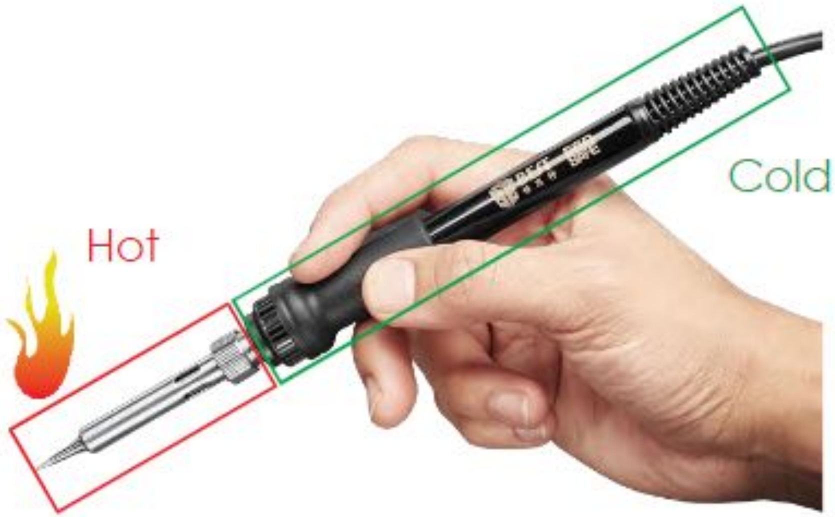
- The process of joining different types of metal by melting solder and using it as a kind of glue
- You'll need a soldering iron, soldering station, and helping stand



Soldering Iron

Used to melt the solder and heat the two wires you are connecting

Every iron has two regions – a **cold region** from where it is held and a **hot region** that reaches several hundred of degrees.

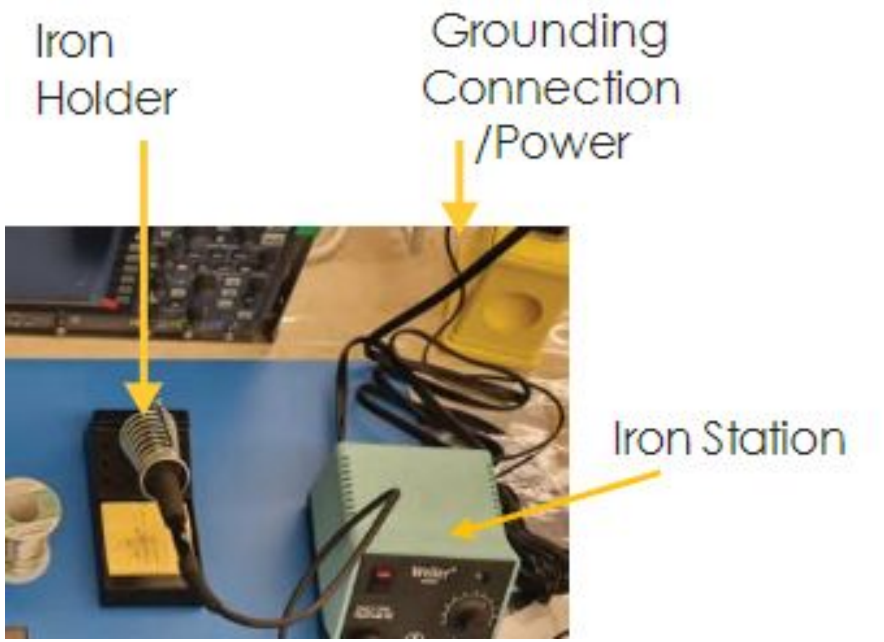


1. Operating temperature of iron very high. 316°C- 340°C Lead & 340°C – 370°C Lead free.
2. Keep Iron tip away from your skin or any flammable/combustible materials

Soldering Station: Safety

Safety standards when using a soldering iron

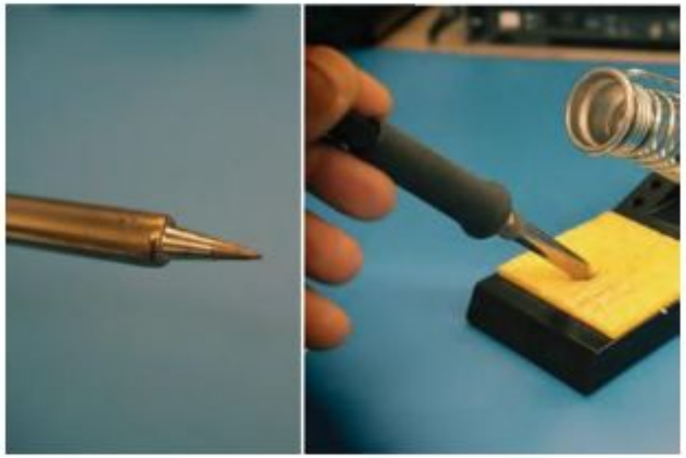
- Always assume the iron is hot
- Put the iron back to the station's iron holder after use
- Make sure any components being soldered together are disconnected from any power source



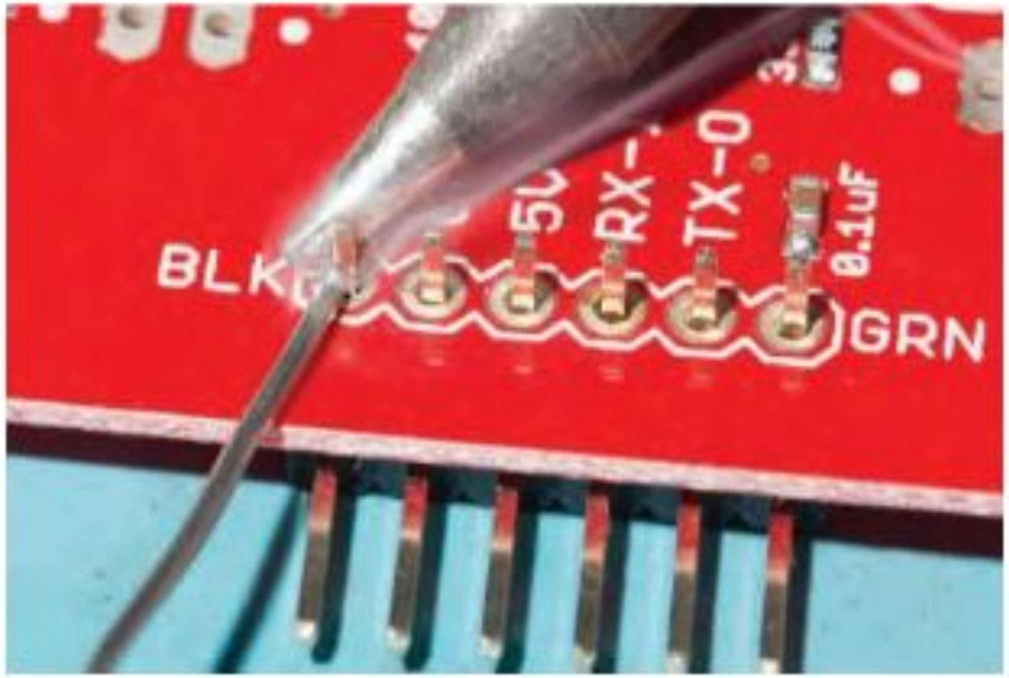
Soldering Station: Clean tip

Clean the tip before use

- Use iron holder’s wet sponge or brass sponge to remove the oxidation on the soldering iron tip
- Oxidation does not allow heat to transfer, hence, resulting in a poor connection dubbed “cold solder”



Soldering: The Process



To apply solder, heat the joint and melt solder onto the joint not the tip of the iron. Touch the iron tip to one side of the joint while feeding solder from the other.

The fumes visible while soldering are Rosin/flux fumes (should be exhausted by the fume extractor see SDS for toxicity information)

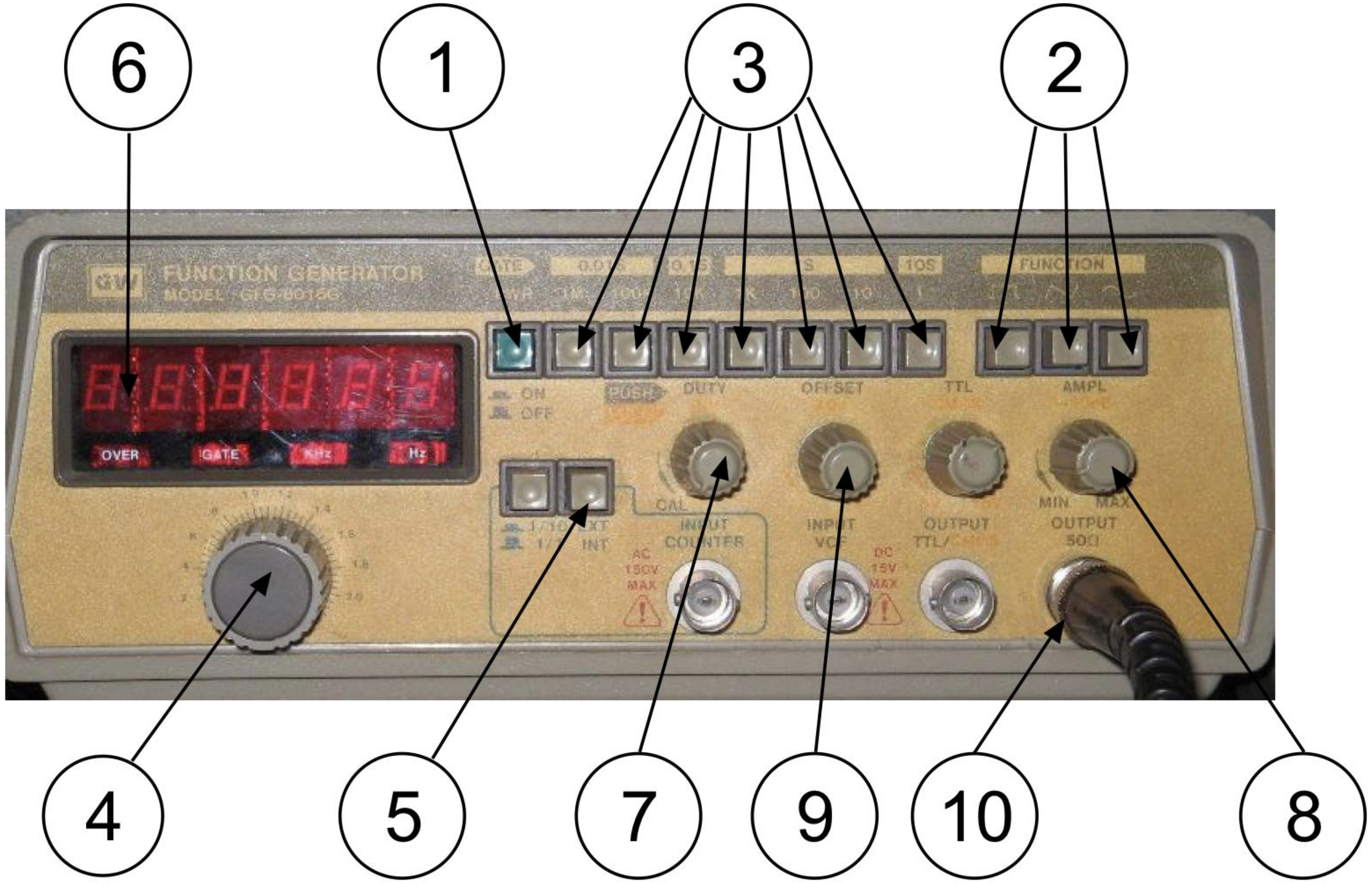
A2: Soldering Practice

1. Solder at least 4 resistors together to make the first letter of your name
2. As a requirement of your design, ensure you use at least 2 resistors of the same value directly in series with each other
3. Calculate equivalent resistance of your circuit
4. Verify your calculation with DMM

Review

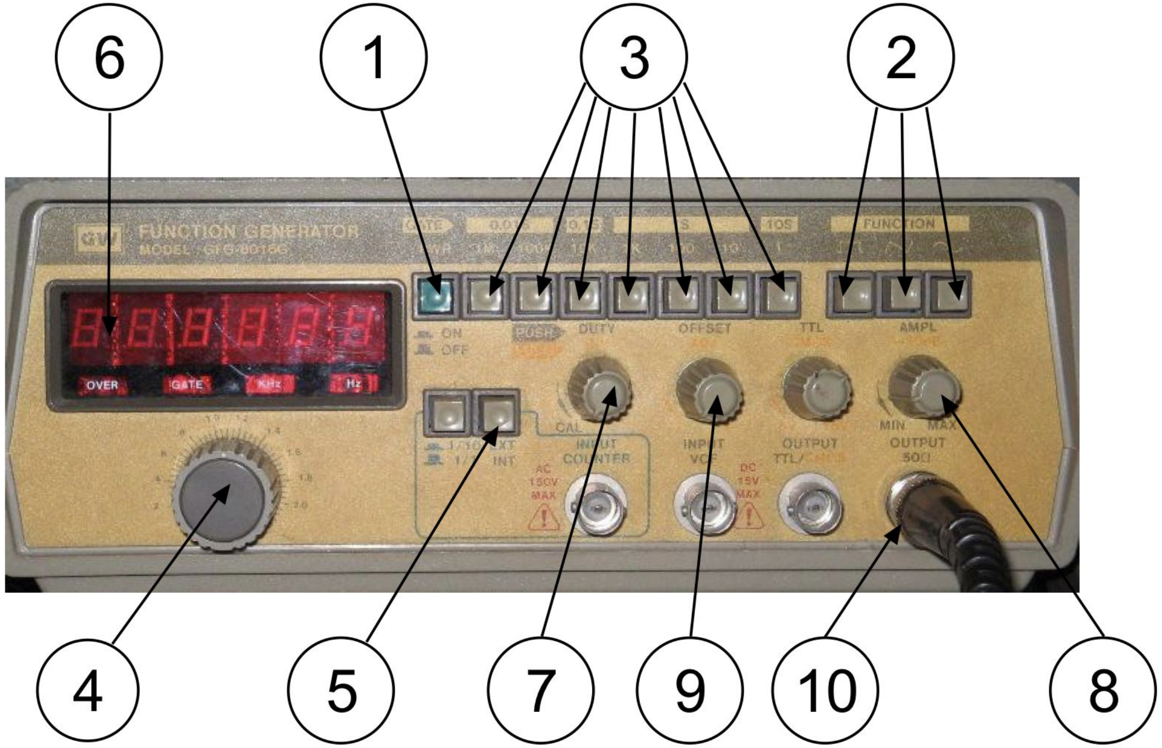
Oscilloscope & Function Generator

Function Generator



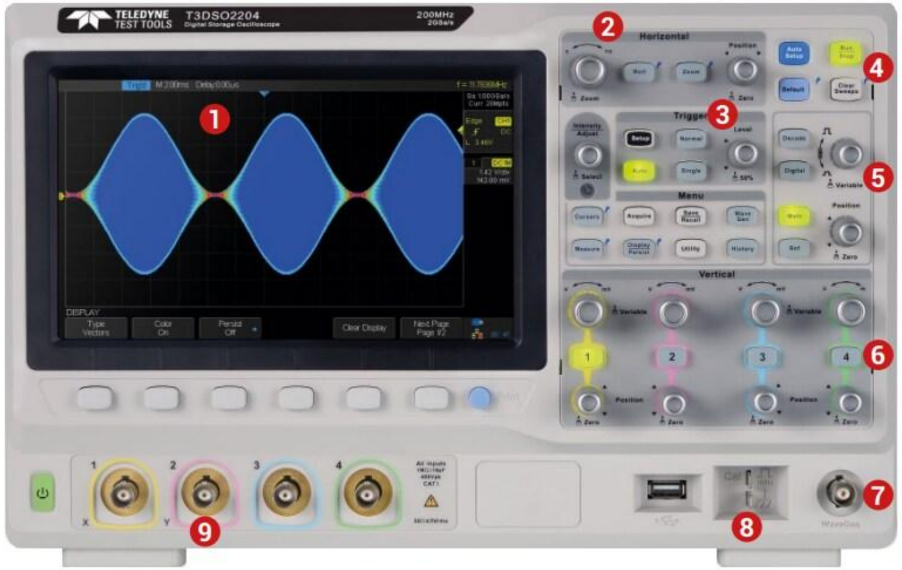
Function Generator

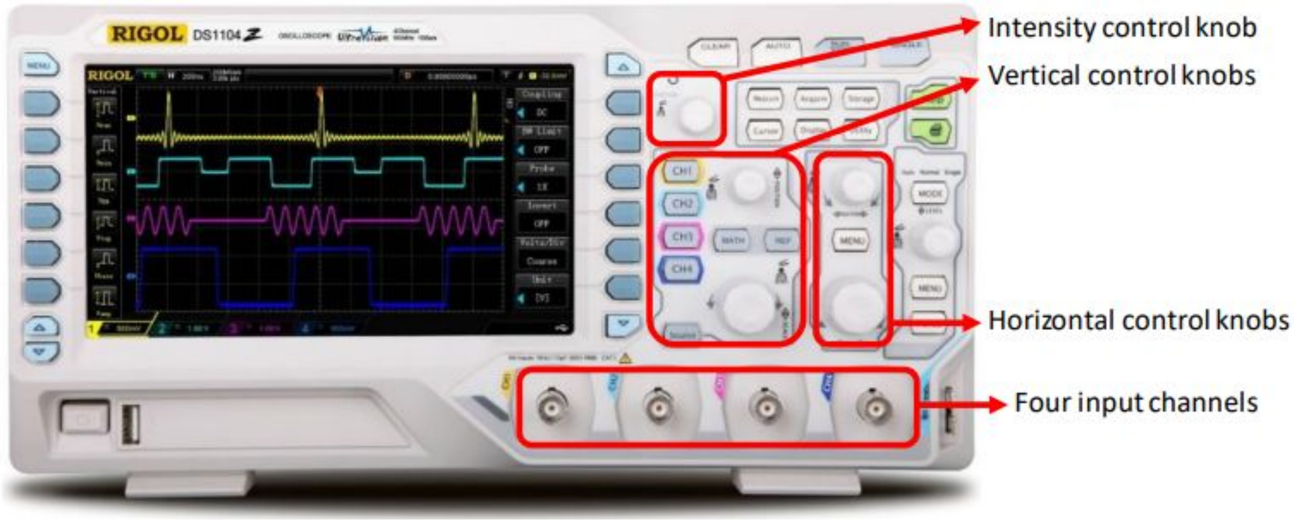
1. Power button
2. Signal shape selection
3. Frequency multiplier switch
4. Frequency dial
5. EXT/INT selector
6. Frequency display
7. Duty Control
8. Amplitude control
9. DC Offset control
10. Output BNC connector



Oscilloscope: Models

- There are many models with the same basic functionalities but may offer different features





Oscilloscope: Usage

- Determining the **frequency, amplitude, phase** of a signal, which is critical when debugging a circuit
- Identifying how much **noise** is in the circuit
- Identifying the **shape** of a wave -- sine, square, triangle, sawtooth, complex, etc.
- Quantifying phase differences between two different signals

Oscilloscope: Probes

- Have the same common ground for all the probes
- Be aware of the probe scaling (multiplication factor)

Attach the tip to the signal to be measured

Attach ground clip to a known ground

Oscilloscope: Adjusting

- Adjusting position and scale of the signal

Vertical Control:
Set value per grid
division to display

horizontal Control:
How many seconds per grid
division are displayed

Oscilloscope: Built-in Function Generator

- Create a signal
  - Select source
  - Select parameter with intensity knob
  - Turn output on
- Metal BNC connectors labeled source 1 & 2
  - Outputs of the integrated signal generator

Oscilloscope: Final Tips

Things to keep in mind:

- Check if the multiplication factor on the probe matches the setting on oscilloscope
- Properly connect the ground of the probe
- Adjust to proper scale to see the signal
    - If in doubt can use the “Auto” setup as a starting point

A3: Voltage Divider

- Use the built-in function generator of the oscilloscope to produce a 2V peak-to-peak 10kHz sine wave and measure it using the oscilloscope
- Use the previous circuit you soldered as a voltage divider, with the intention of halving the amplitude of the input signal. Recall its unique design specification. Measure this output signal
- Use the oscilloscope's cursors to verify the frequency and the amplitude

Hardware Workshop One
Fundamentals

Day 1 End

Hardware Workshop One

Diodes, Transistors and OpAmps

Day 2 Start

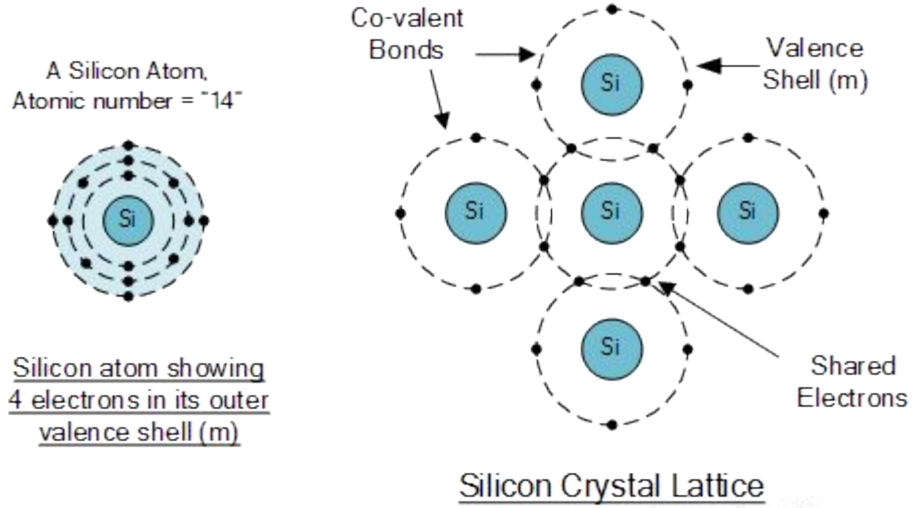
New

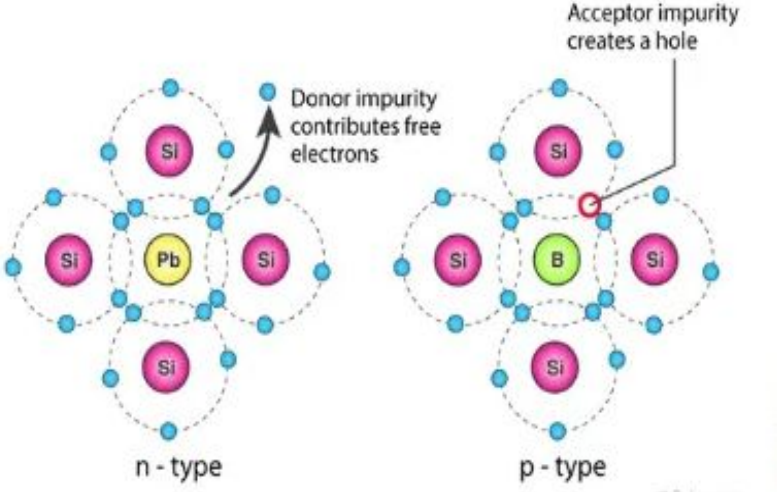
Diode

Semiconductor

- Commonly used semiconductor: silicon and germanium
  - Doped into N-type or P-type semiconductor
  - Useful for PN junctions

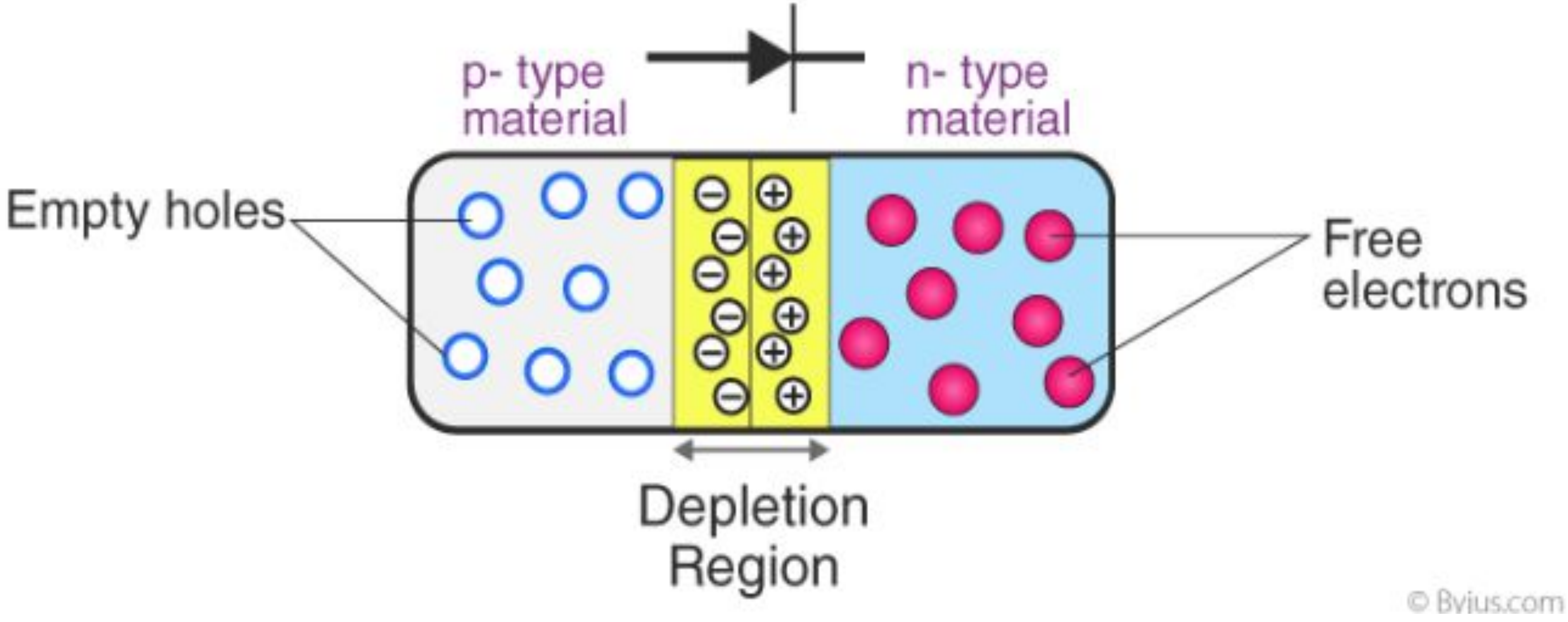
- Charge carrier: electrons or holes that contribute to the flow of current
  - N-type charge carrier: electron
  - P-type charge carrier: hole





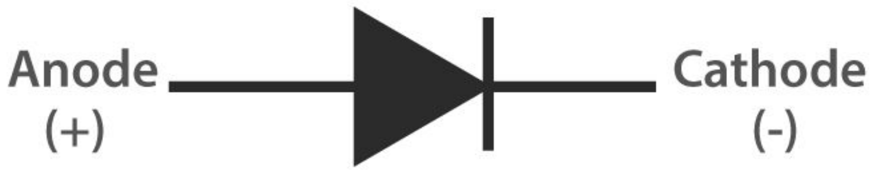
Semiconductor: PN Junction

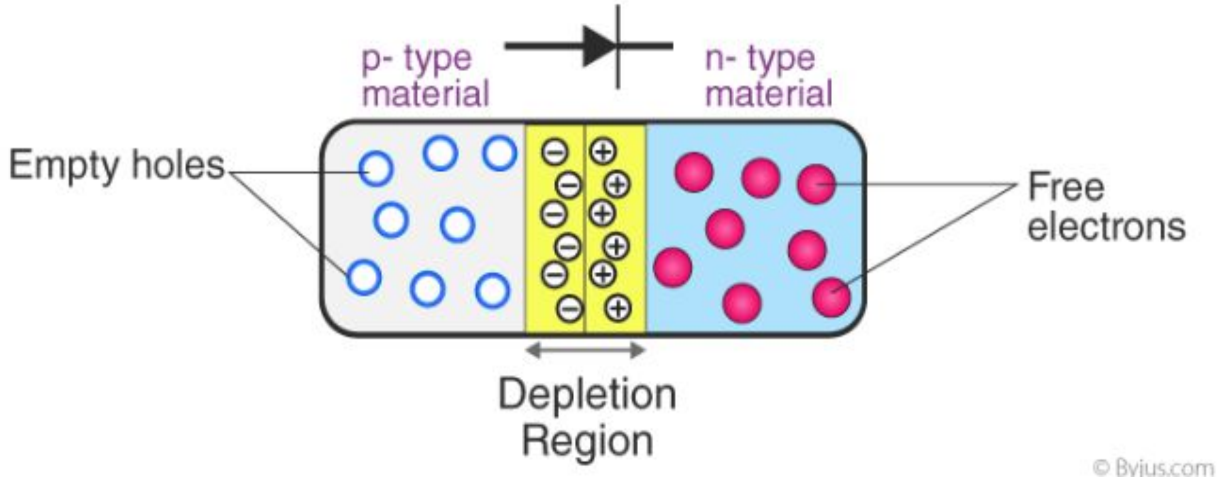
- Depletion region creates boundary inhibiting electron movement when unbiased.
- A voltage is required to overcome the boundary inhibiting electron movement (forward bias).



Diode

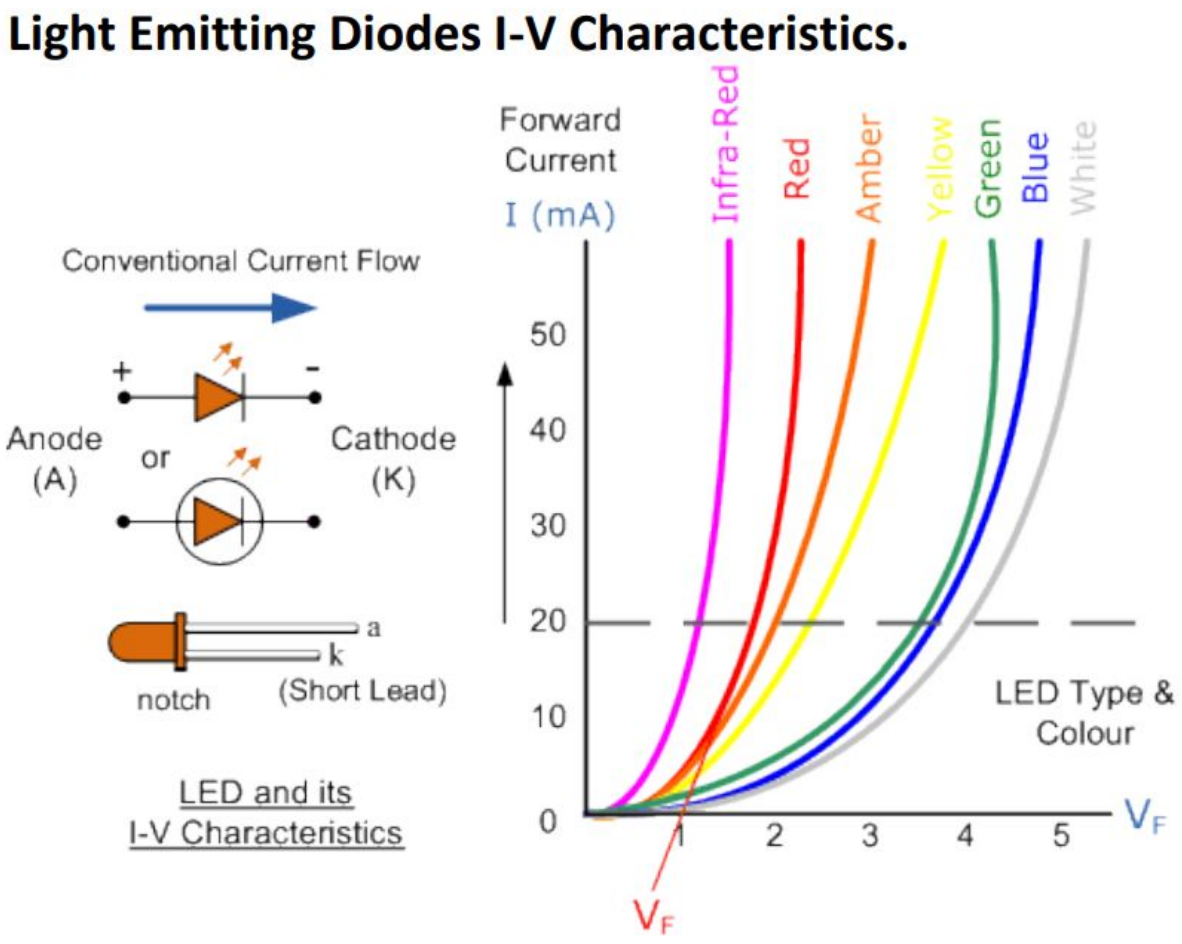
- Only allow current to pass in one direction
- Basically a PN junction
- Forward voltage required to overcome depletion region (typically 0.7V)



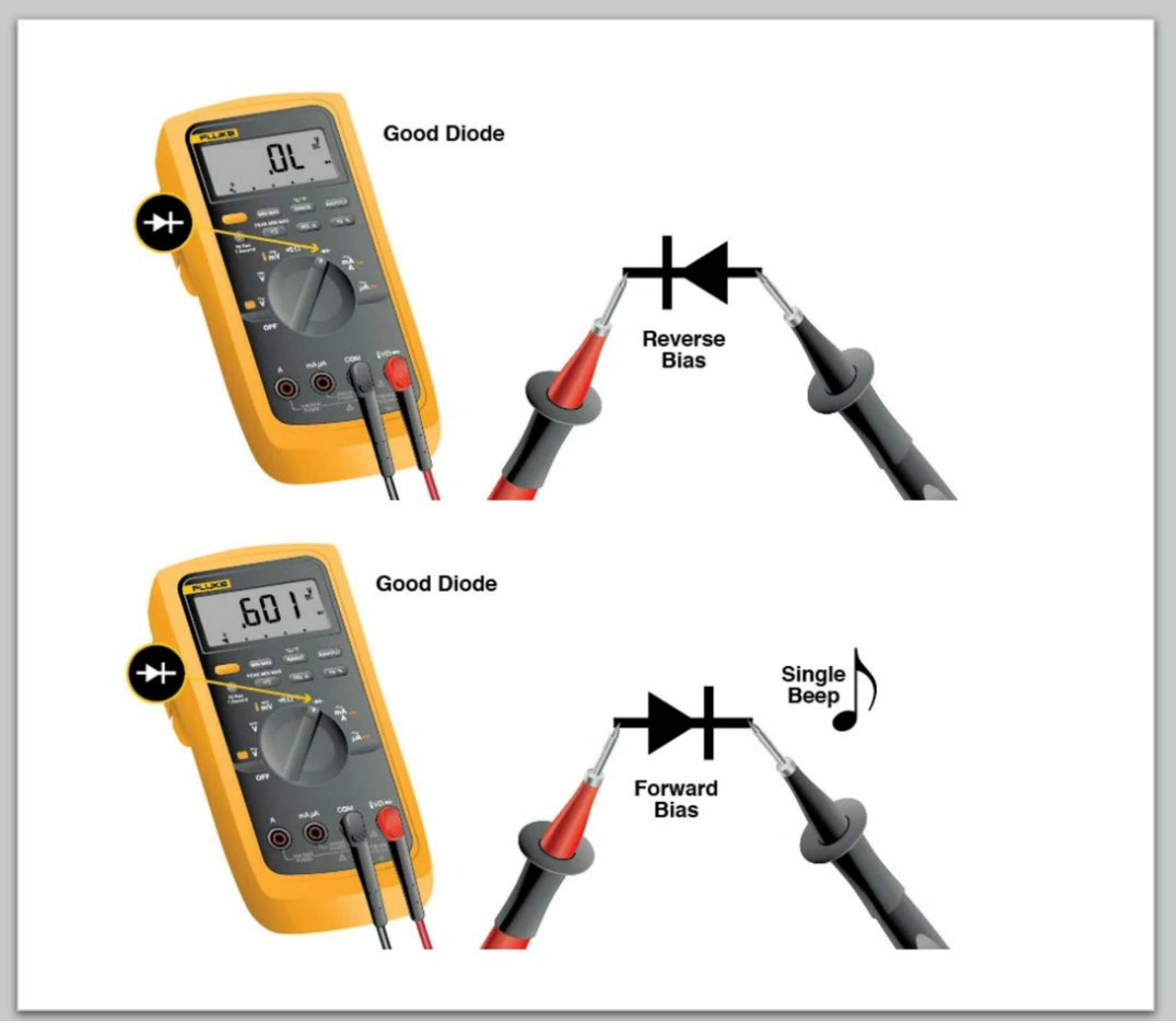


LED (Light Emitting Diode)

- Act like a diode but emit light when on
- Require higher voltage to turn on (2.8 – 3.6V)
- Made of gallium arsenide and gallium phosphide whose electrons emit light when transferring energy

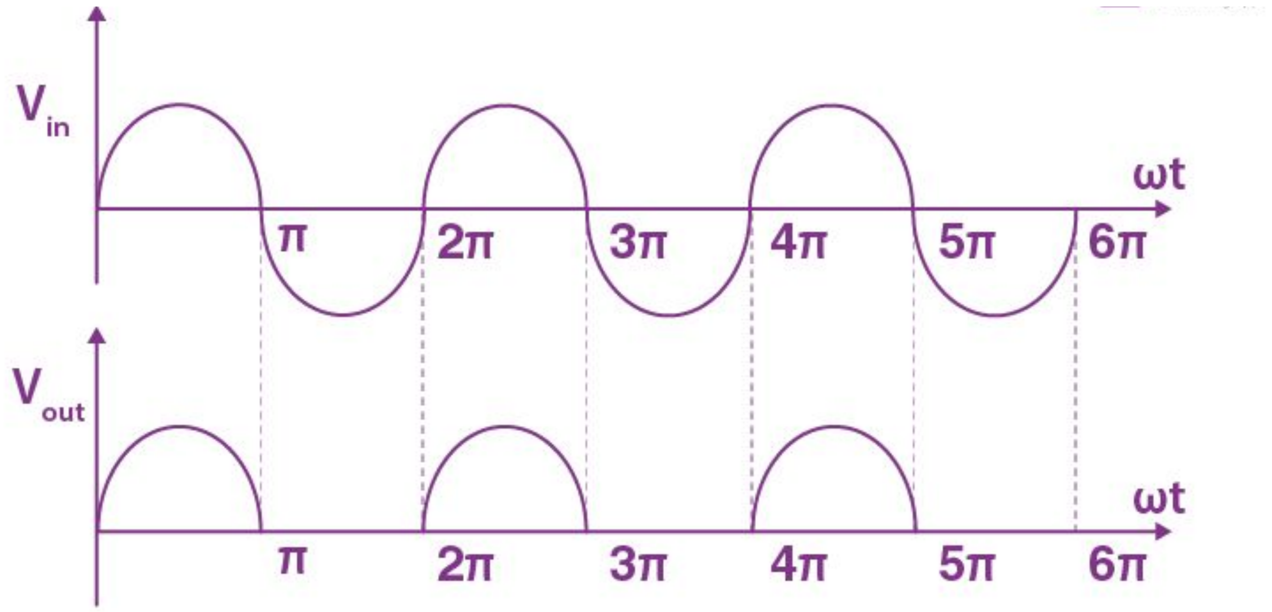


A4: Testing Diodes by DMM



A5: Half-Wave Rectifier

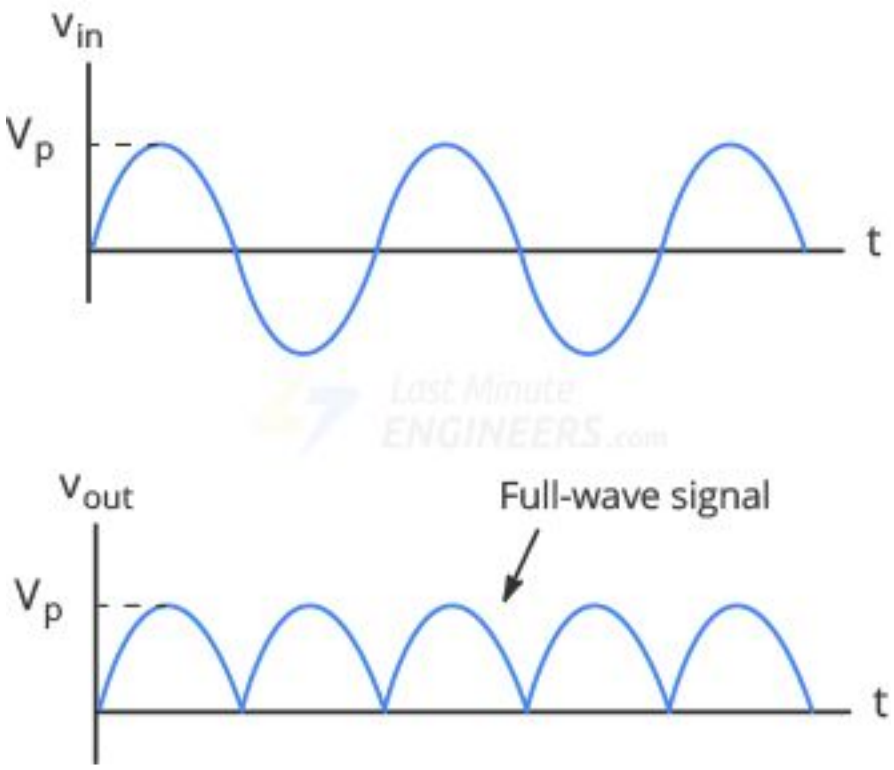
- Try to use one diode to turn AC into only one polarity.

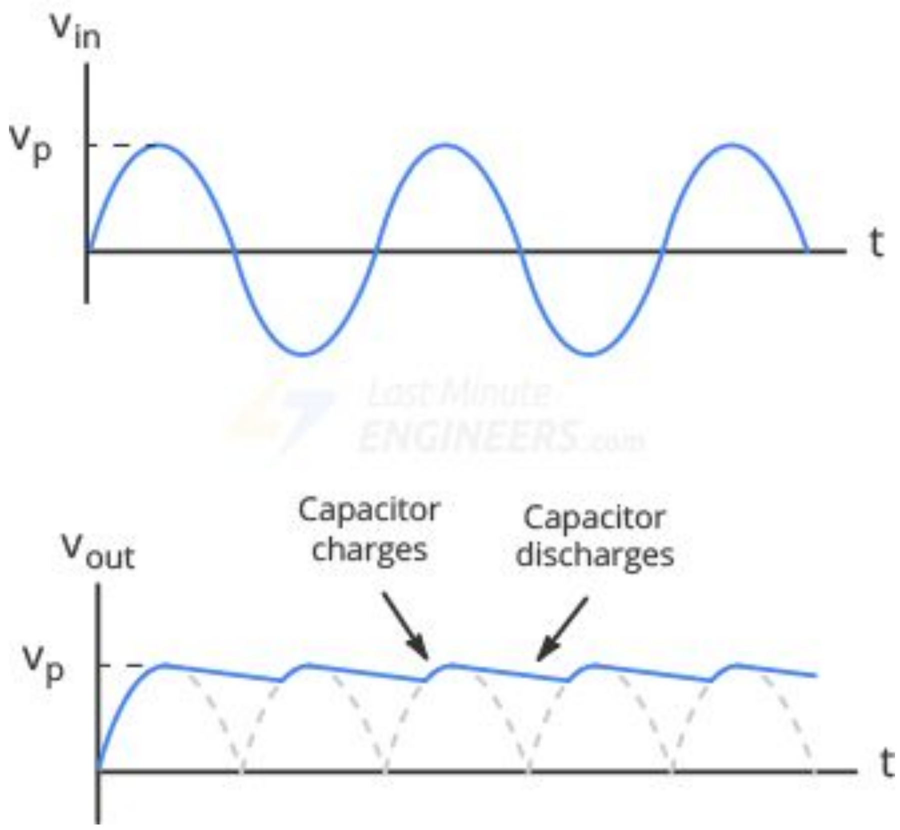


- Measure the waveform of the output using oscilloscope.

A5: Full-Wave Rectifier

- Challenge now: Can you build a rectifier which turns the other half into the same polarity?





A5: Full-Wave Rectifier

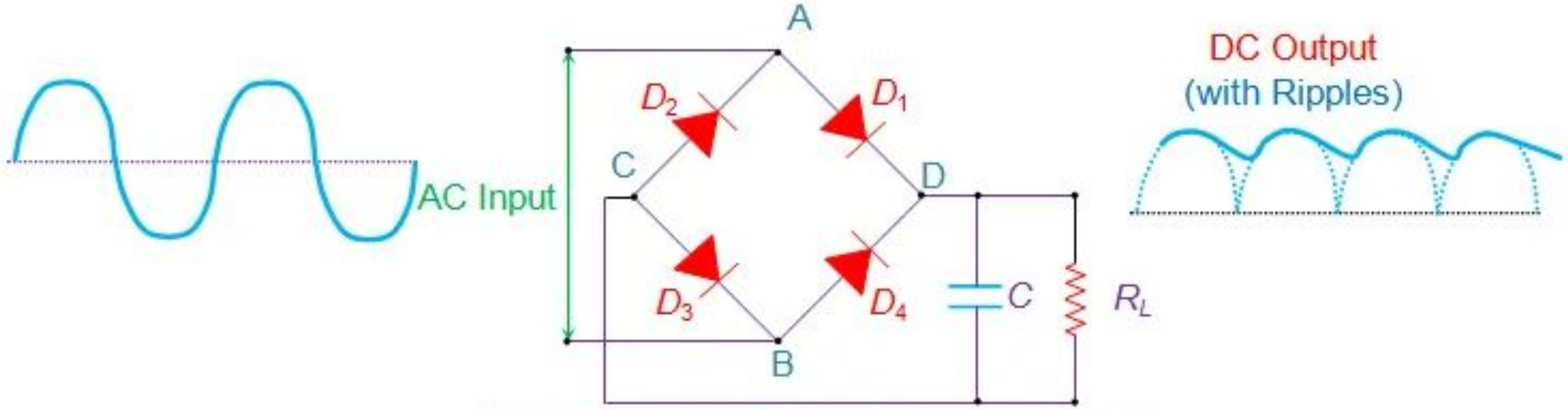


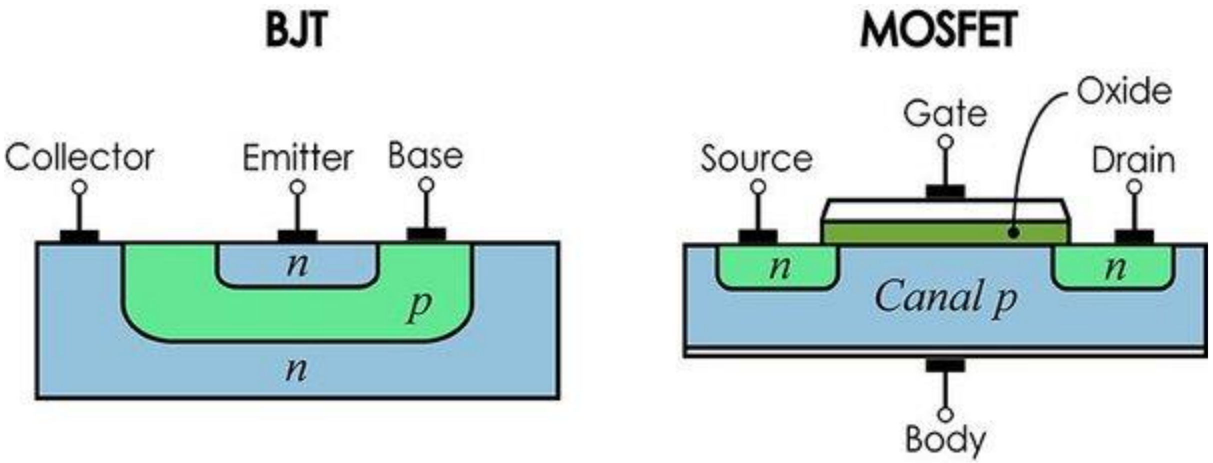
Figure 4 Bridge Rectifier with a RC Filter

New

Transistor

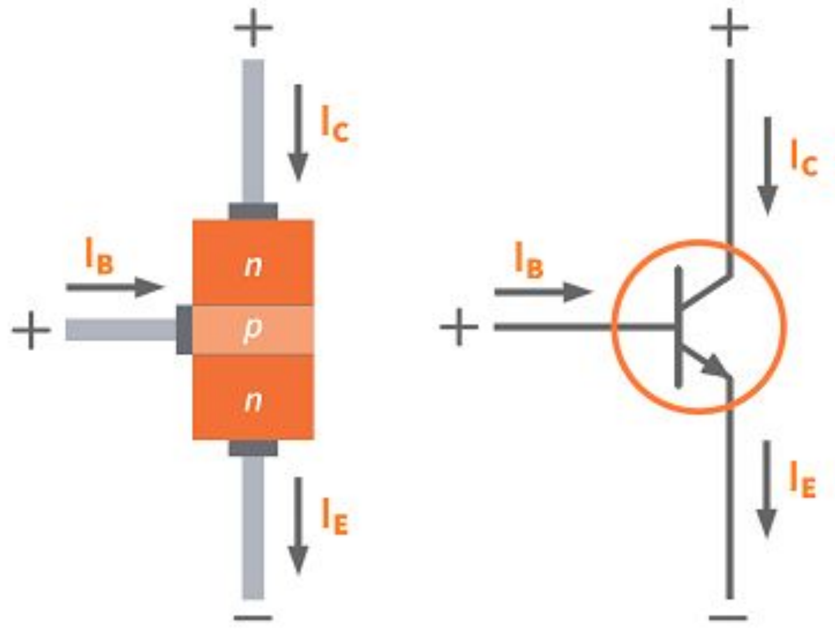
Transistor

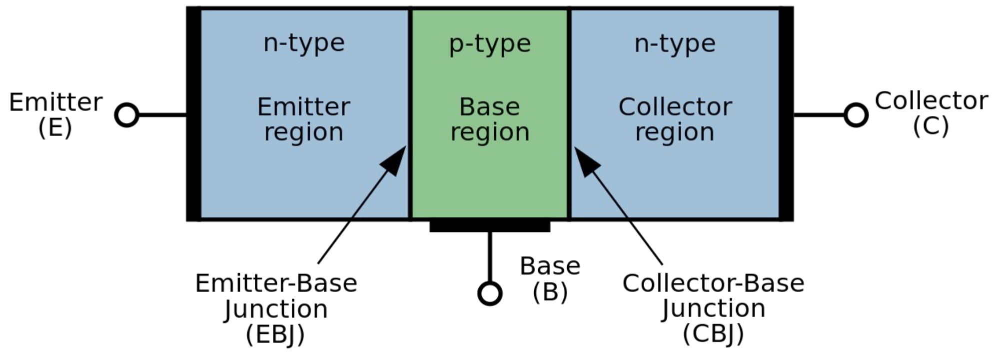
- Transistor is a semiconductor device used as a switch or to amplify electronic signals
- Transistors are widely used in modern electronics
- Types of transistor:
  - Bipolar junction transistor (BJT)
  - Metal-oxide-silicon field effect transistor (MOSFET)



Transistor (BJT)

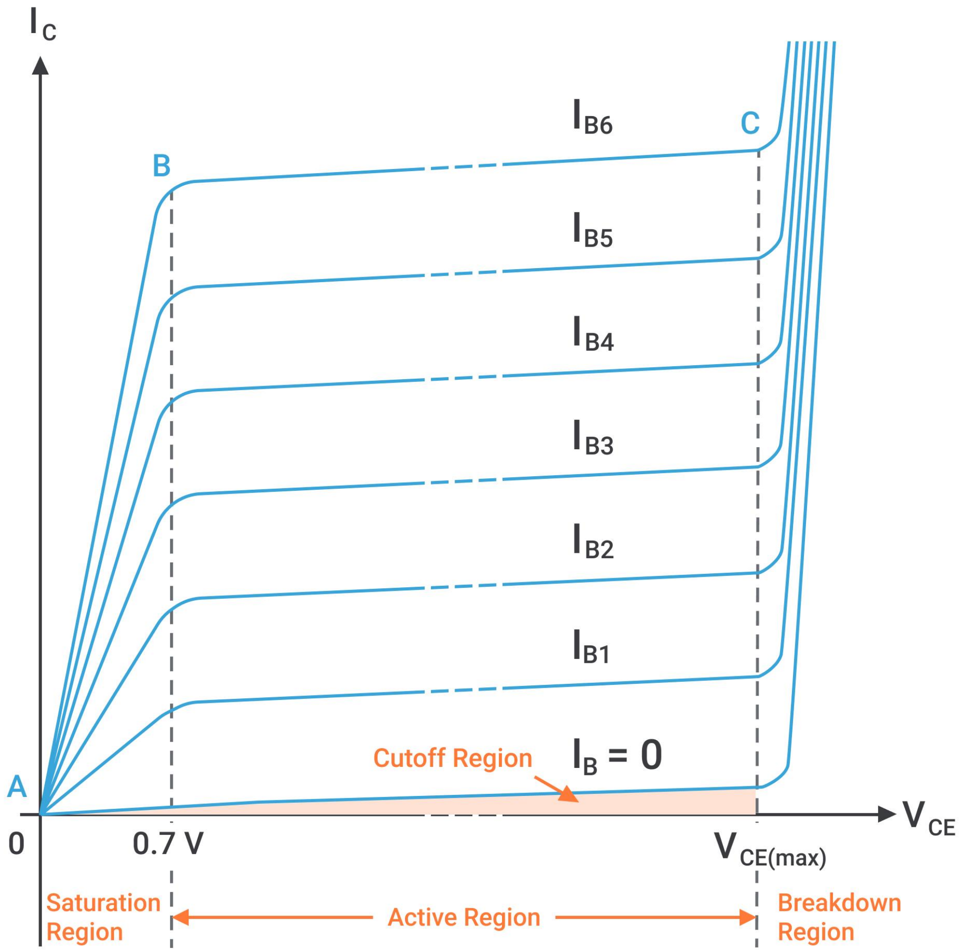
- Stack of doped semiconductor materials (NPN or PNP junctions)
- Base-Emitter junction controls the flow of current
- Can be used as switch or amplifier depends on mode of operation.





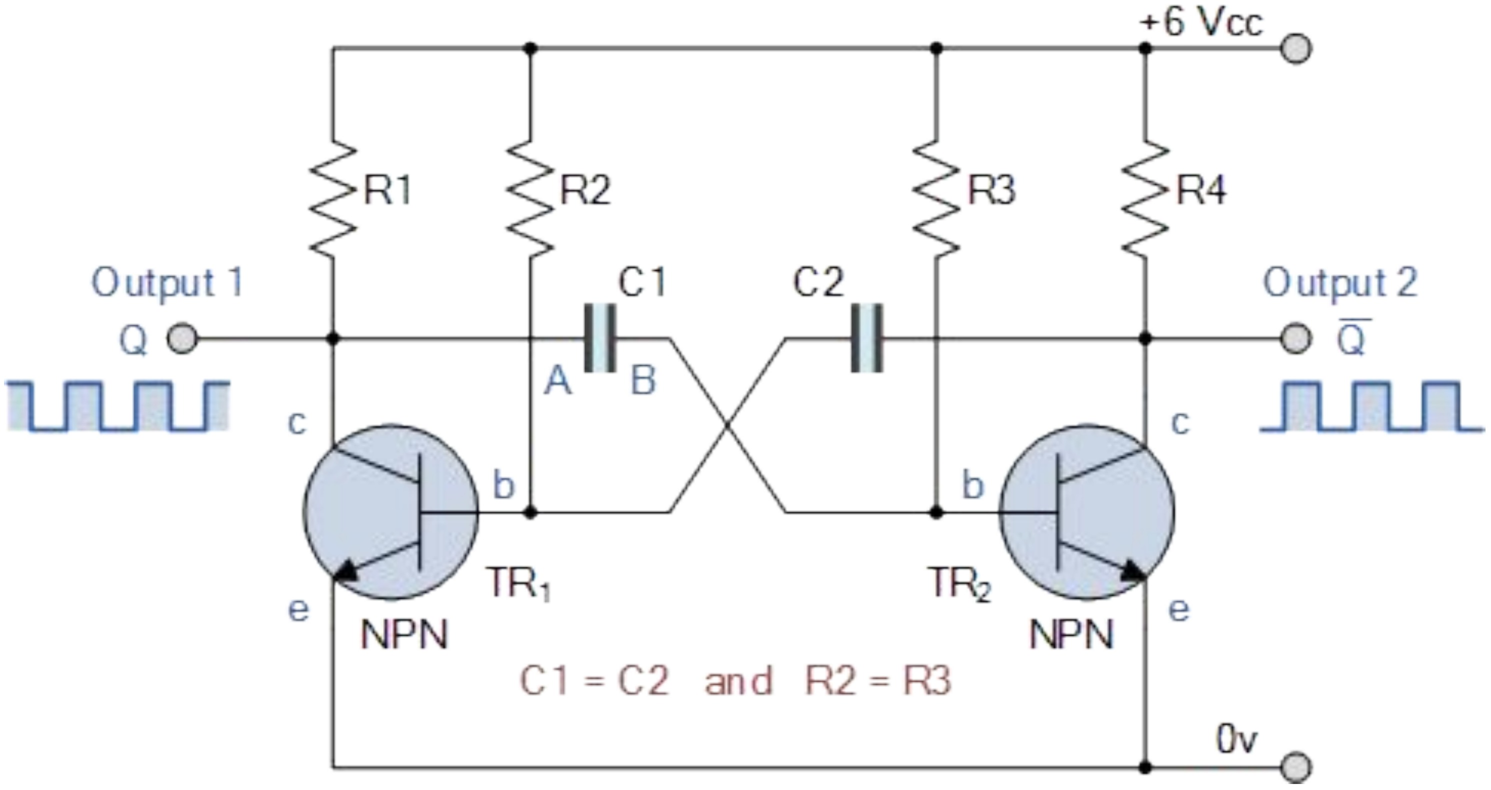
Transistor - BJT Operation Regions

1. Cut-Off: (Off Switch Region)
   - Base-Emitter and Base-Collector junction are both reverse biased
   - No current through Collector to Emitter
2. Saturation: (On Switch Region)
   - Base-Emitter and Base-Collector junction are both forward biased
   - Low impedance from Collector to Emitter
3. Active: (Amplifier Region)
   - Base-emitter forward biased and Base-collector reverse biased
   - Amplification of current controlled by Base-Emitter voltage

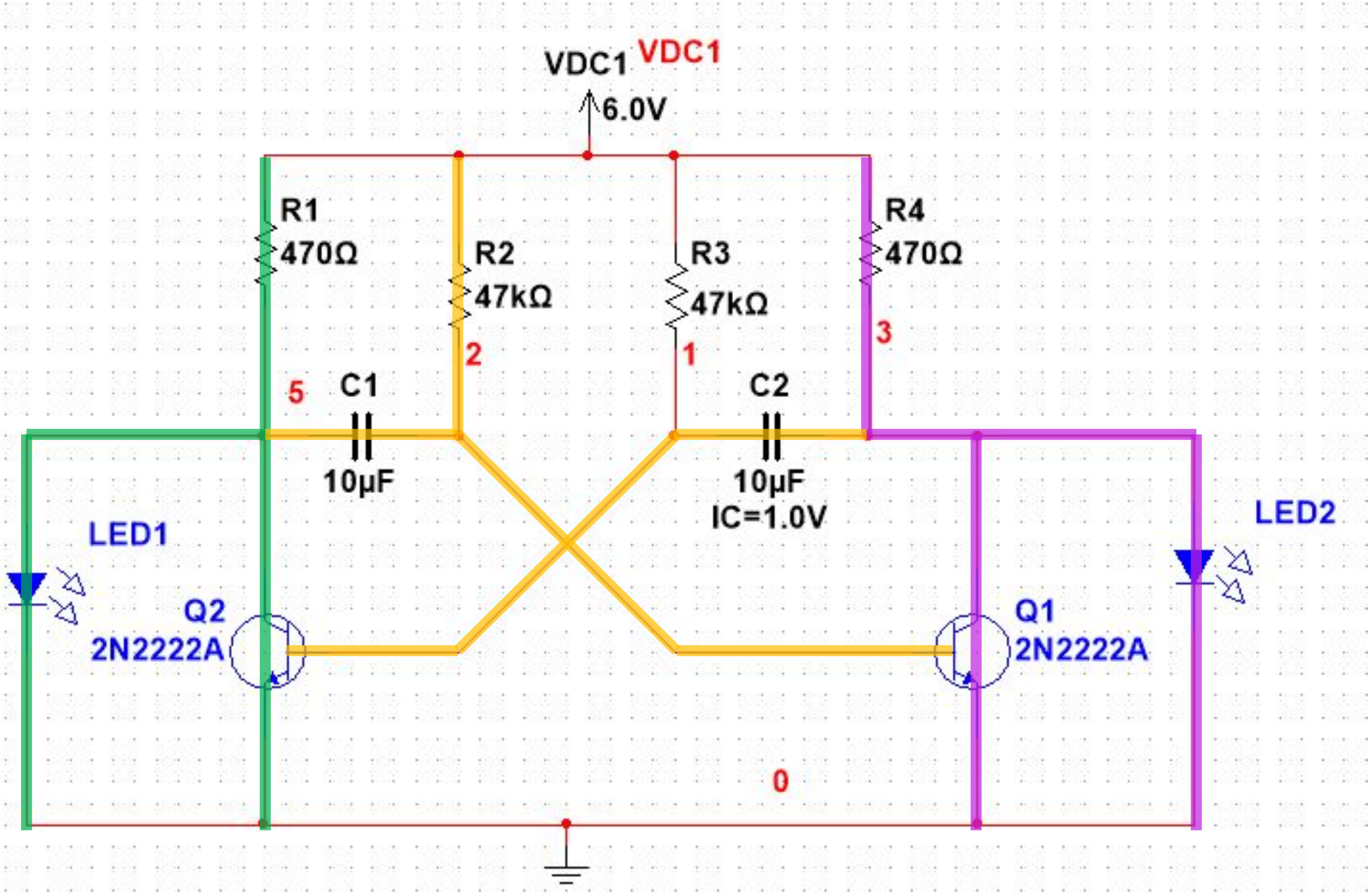


A6: Astable Multivibrator

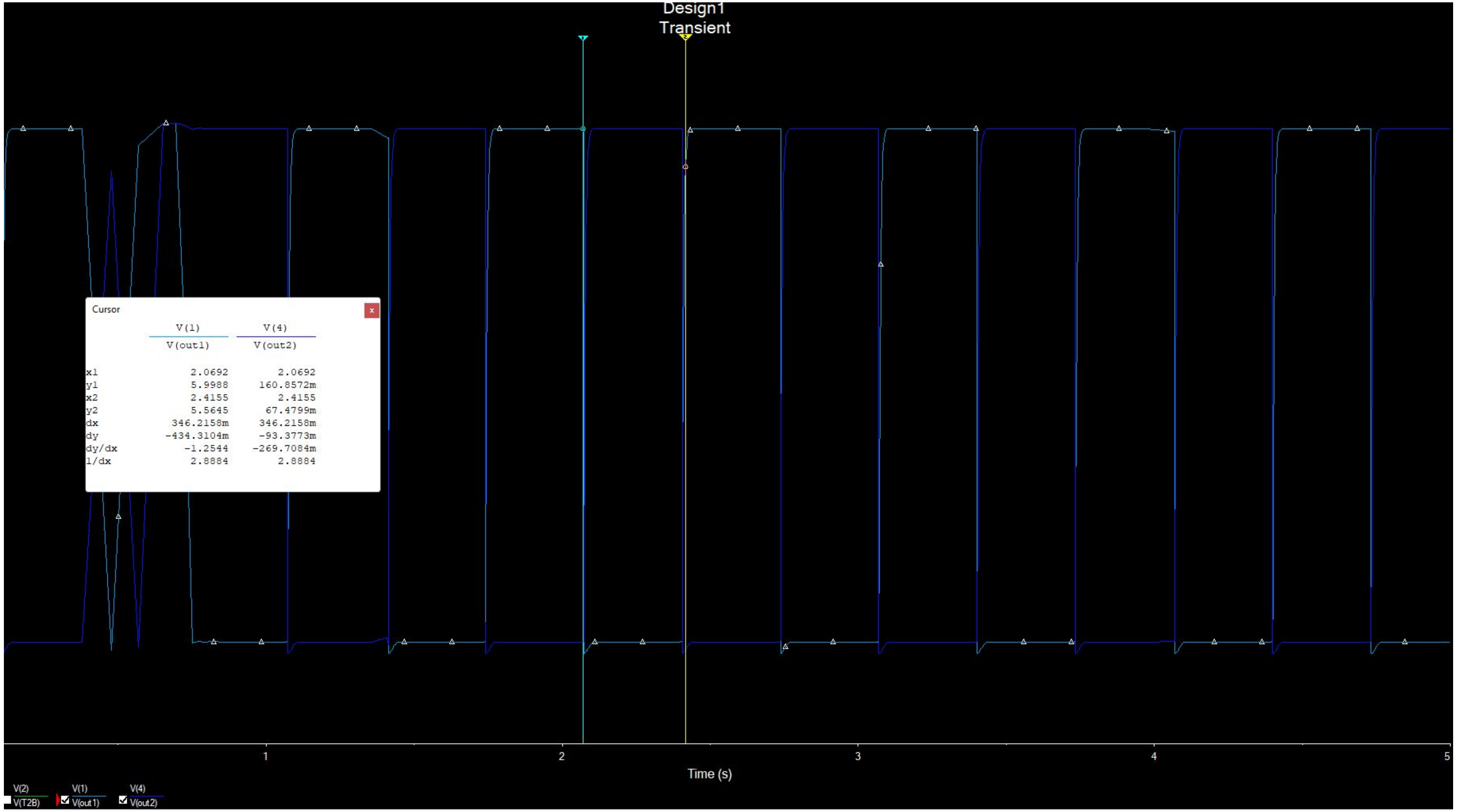
- Produces square waves
- Uses transistor as the switch to charge and discharge capacitors



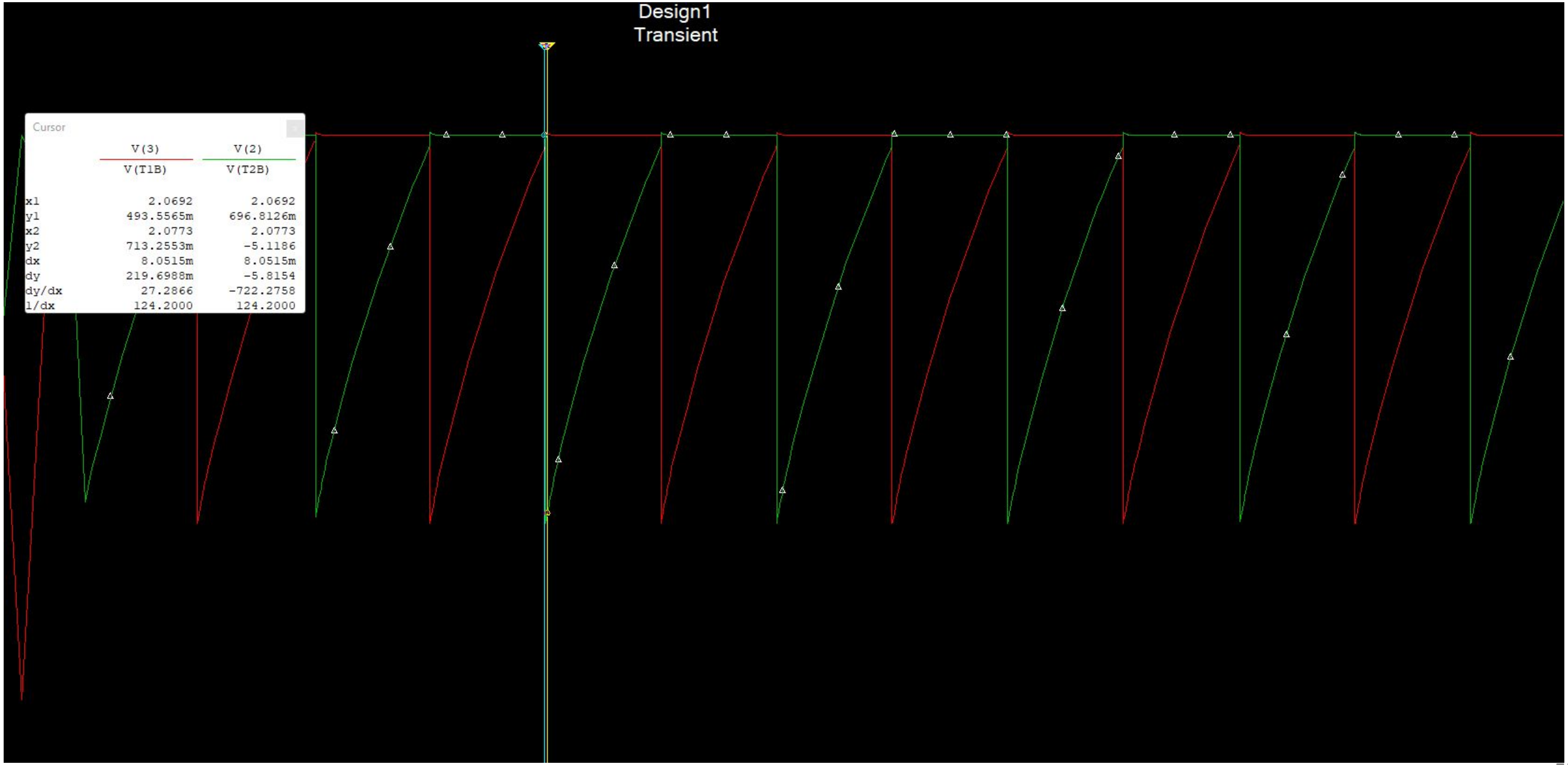
A6: Astable Multivibrator



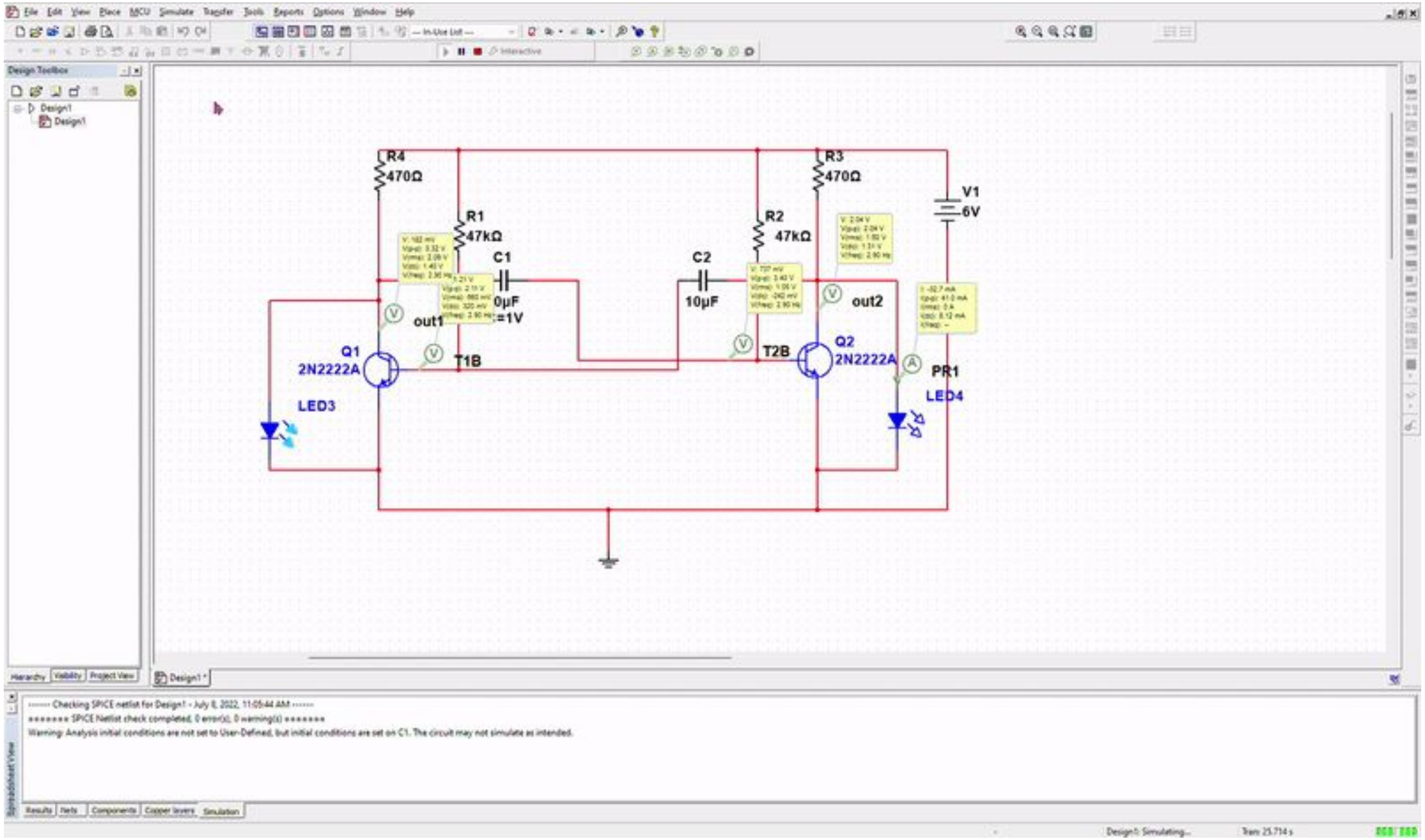
A6: Astable Multivibrator



A6: Astable Multivibrator



A6: Astable Multivibrator with LED Output (SWAP WITH LIVE DEMO)



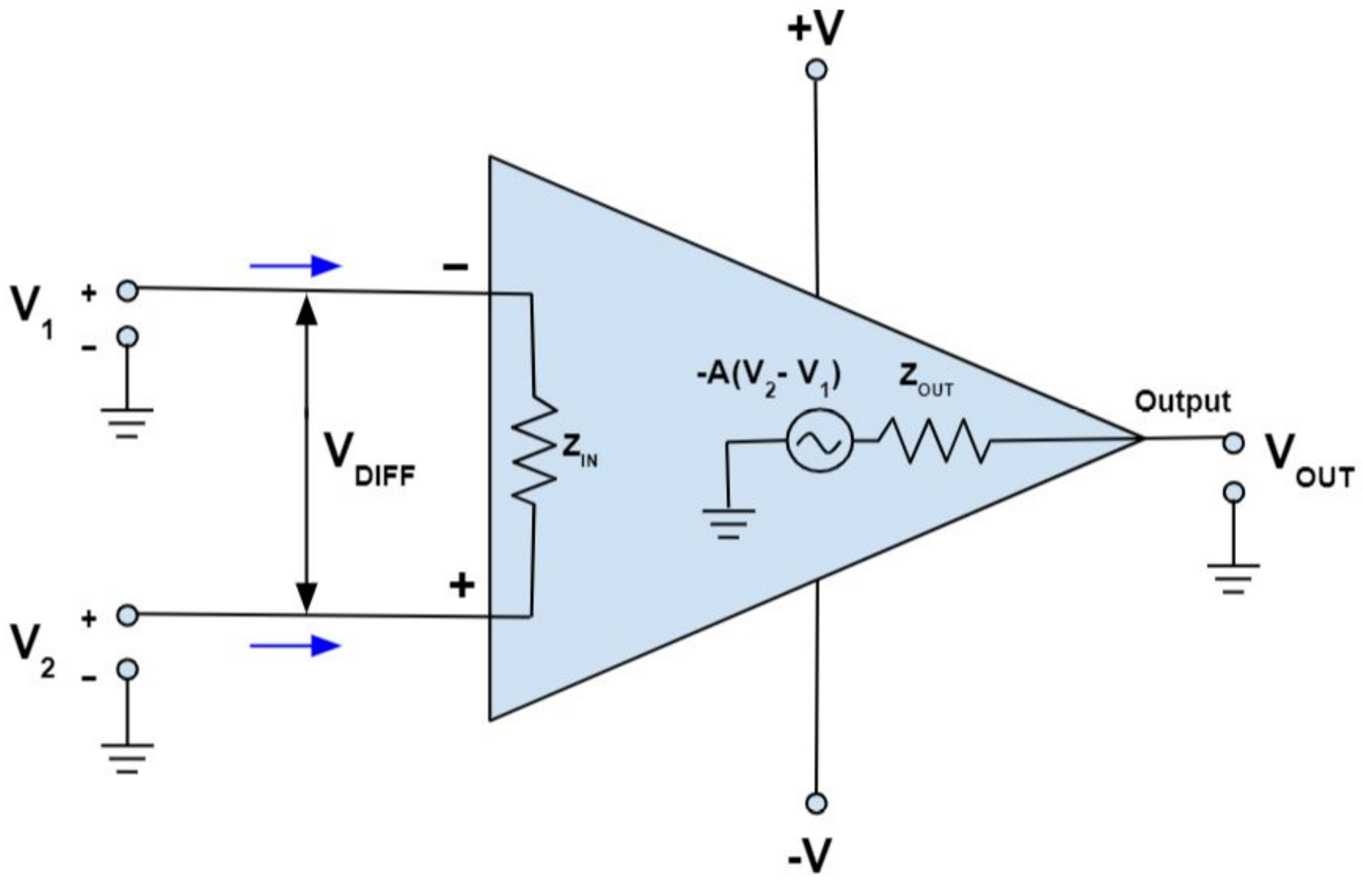
New

Operational Amplifiers

Operational Amplifier (Op Amp)

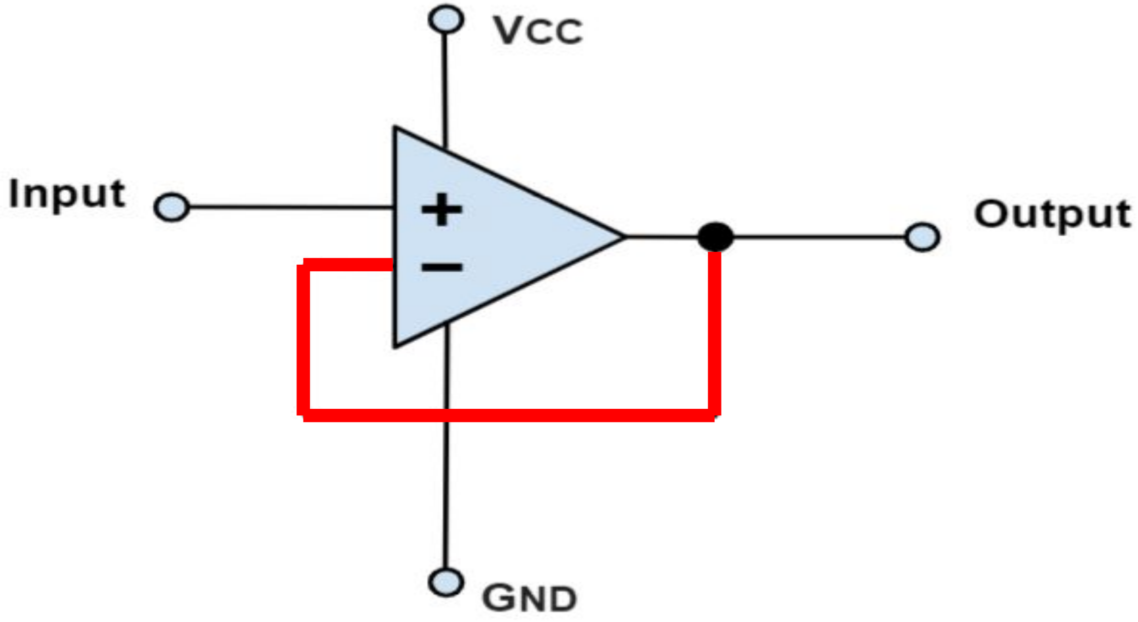
1. $Z_{in} \rightarrow \infty\ \Omega$ (open circuit)
2. $Z_{out} \rightarrow 0\ \Omega$ (short circuit)
3. $A \rightarrow \infty$ (very large gain)

- Output is capped by the V+/- rails in the top and bottom that power the Op Amp

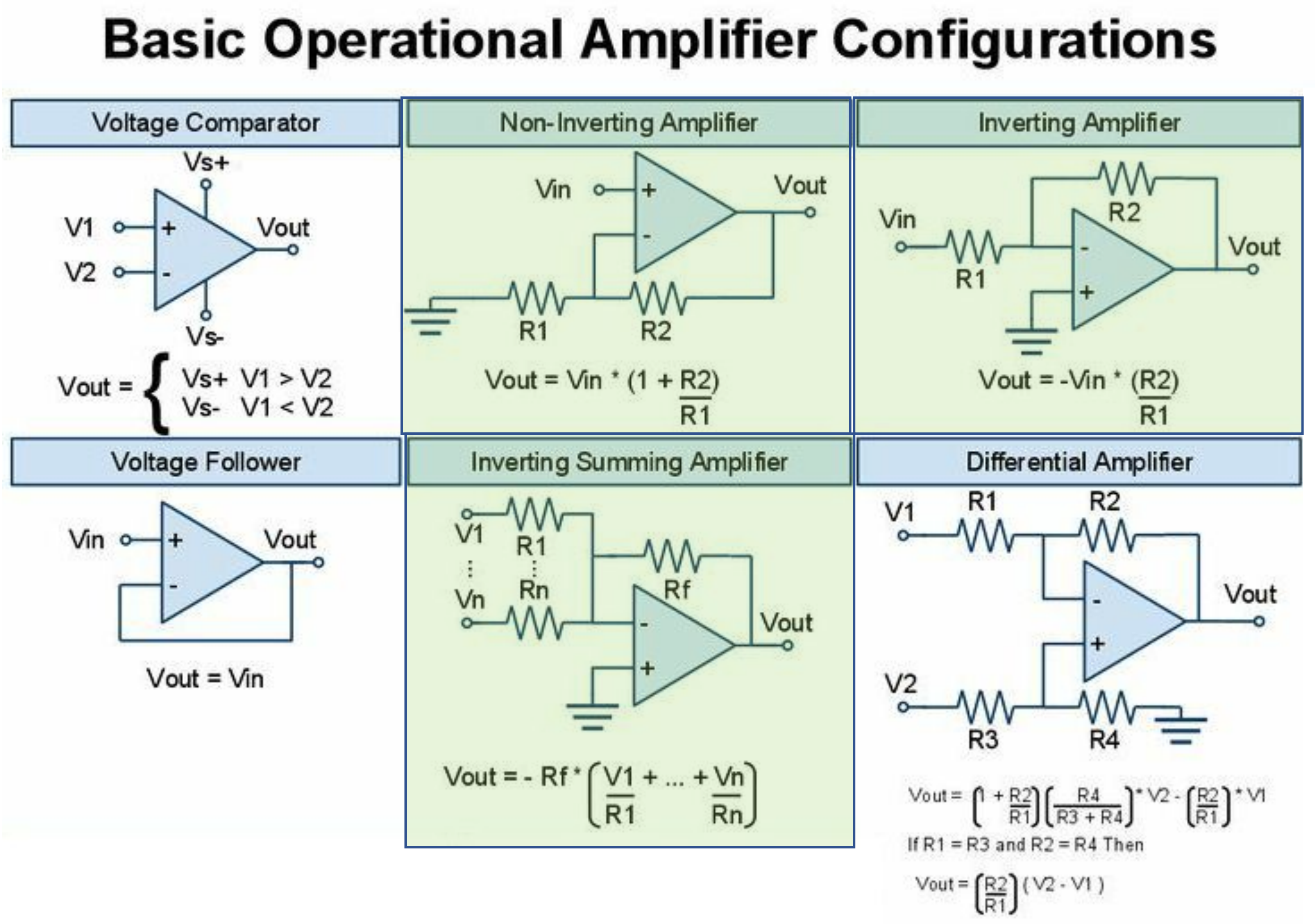


Op Amp: Stabilizing Output

- Negative feedback
  - Make the Op Amp dependent on the feedback of the output
  - Gives us some control in influencing the Op Amp's output through modifying the negative feedback wire
  - Use the input current to the +/- nodes = 0, voltages of the +/- nodes are a virtual short ($V_+ = V_-$), and KCL analysis to do this



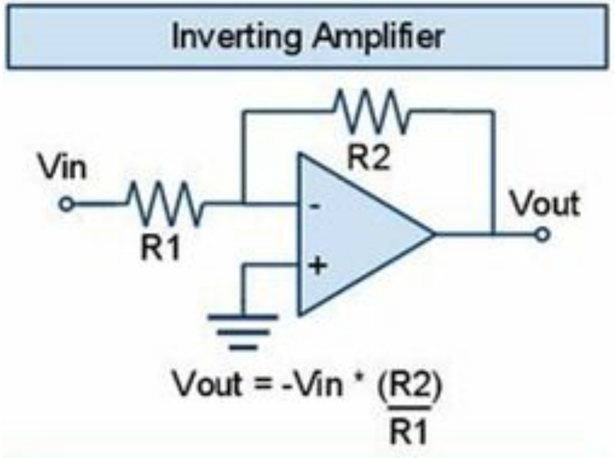
Op Amp: Configurations

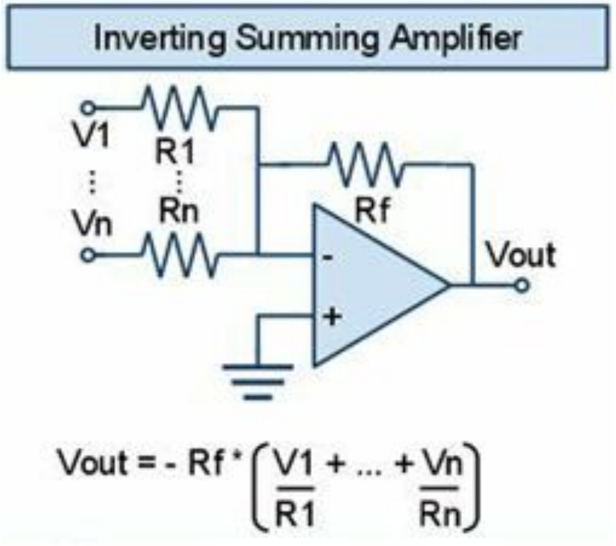


A7: Building Amplifiers

1. Try to build an inverting amplifier with Gain bigger than 5. What happens?

2. Build a summing Op Amp with 2 inputs and $V_{out} = -(V_1 + V_2)$





A8: Amplifying Astable Multivibrator

- Consider the Astable Multivibrator with only a 2.0V source
- Enough to charge and switch the transistors but not enough to power the LEDs
- Add an amplifier to one side of the circuit to make one LED flash on and off, while the other does not

Hardware Workshop One

Diodes, Transistors and OpAmps

Day 2 End

Hardware Workshop One

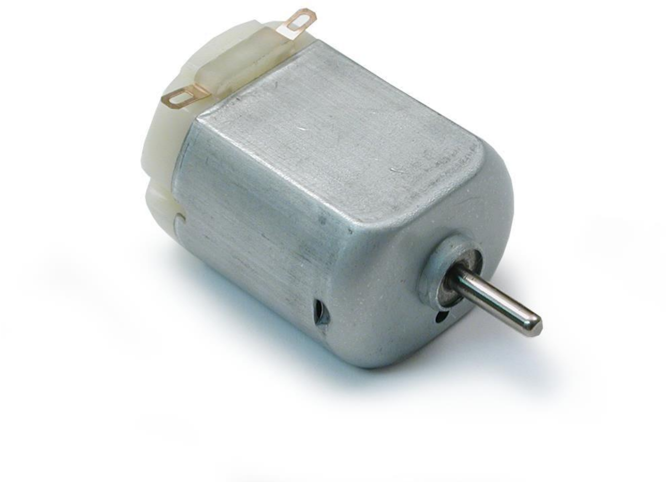
Motor Control and Light Sensors

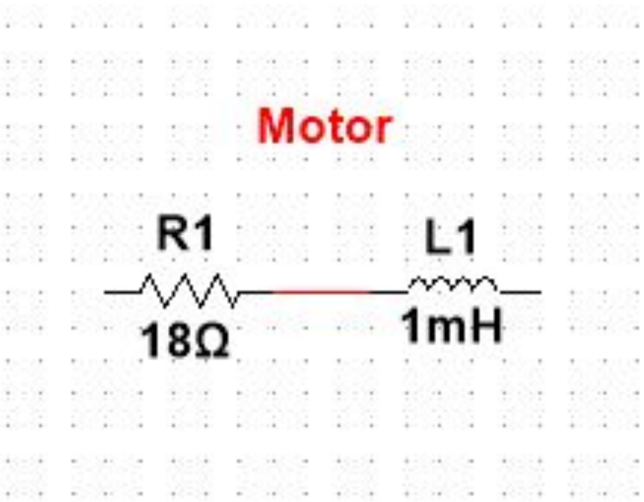
Day 3 Start

DC Motors

Modelling DC Motors

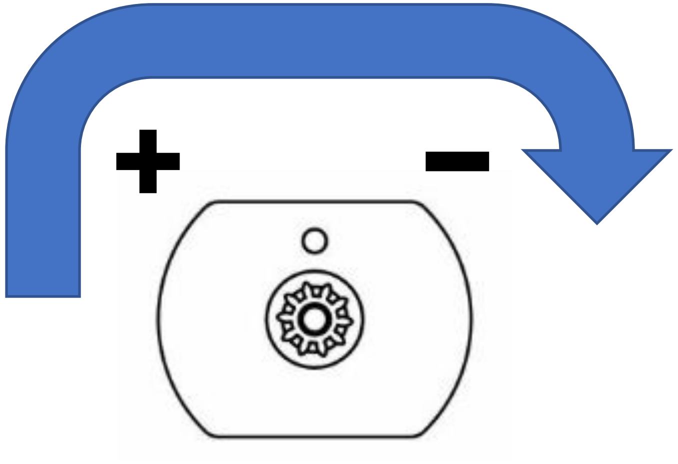
- Current flows into the motor
- Magnetic force is generated to spin the shaft
- How can we model this system?

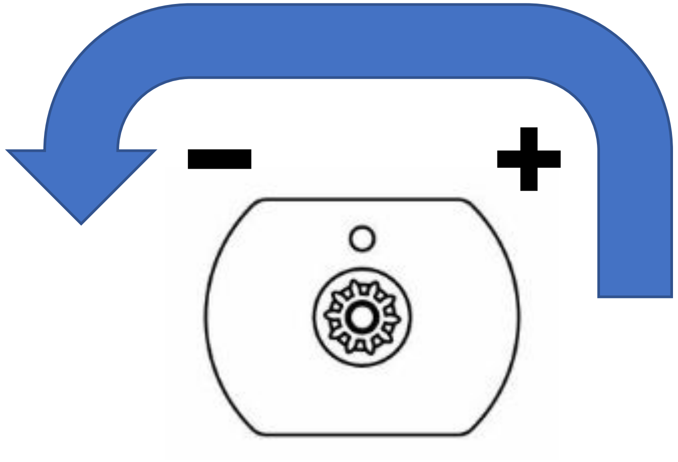




Modelling DC Motors

- What direction will the motor spin?



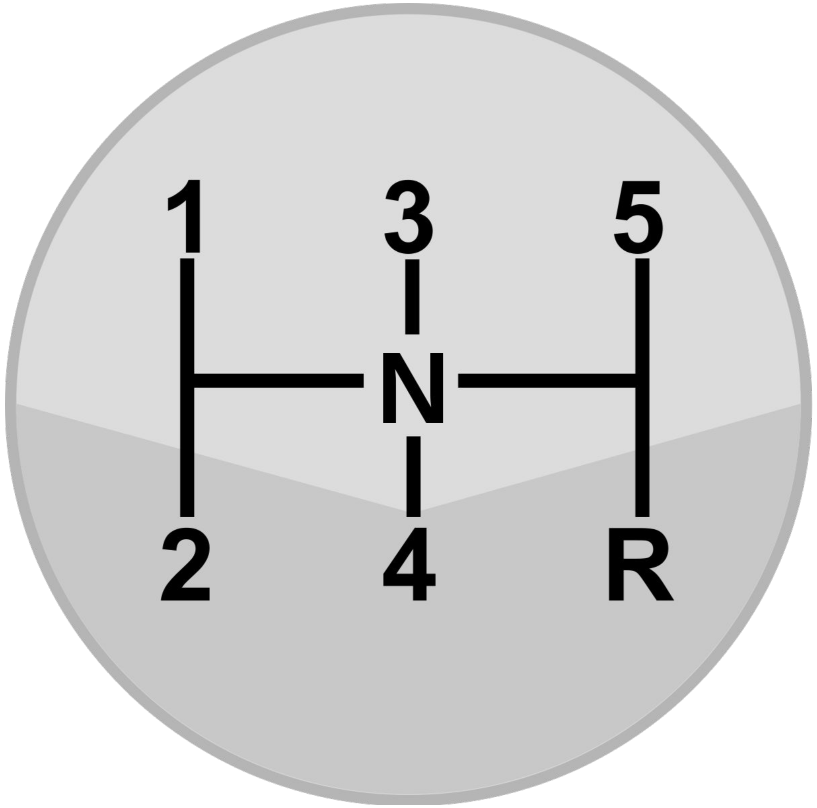


Modelling DC Motors: Important Attributes

We need to be able to implement:

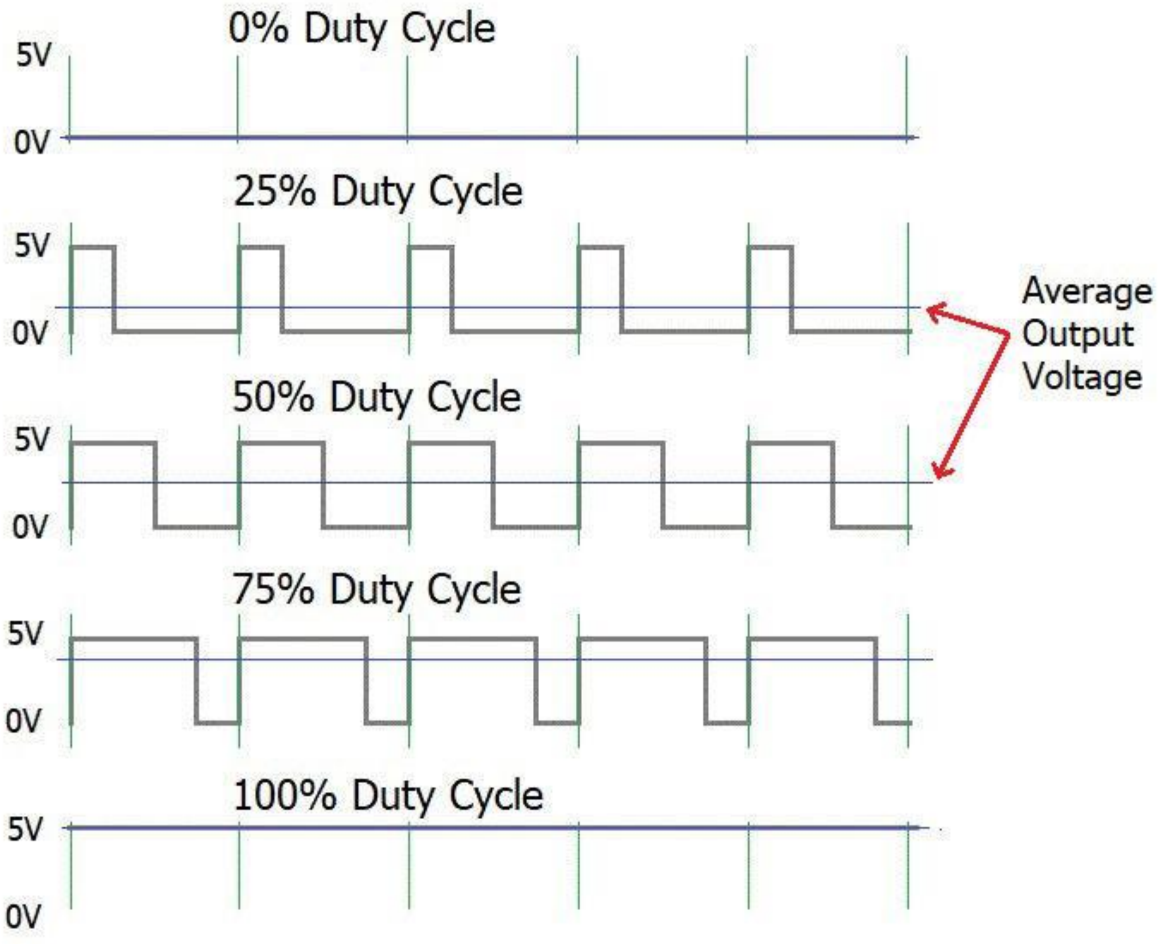
1. Variable Speed

2. Variable Direction



Pulse Width Modulation (PWM)

- What happens if I pulse my DC input voltage on and off very, very quickly?
- Light gets dimmer, as ON pulses get shorter and OFF pulses get longer



A9: Play with PWM and Motors

- Set up a PWM signal (10kHz, 10V) on your function generators and connect it directly to a DC motor
- Adjust the Duty Cycle of the PWM signal and observe how the RPM of the motor changes

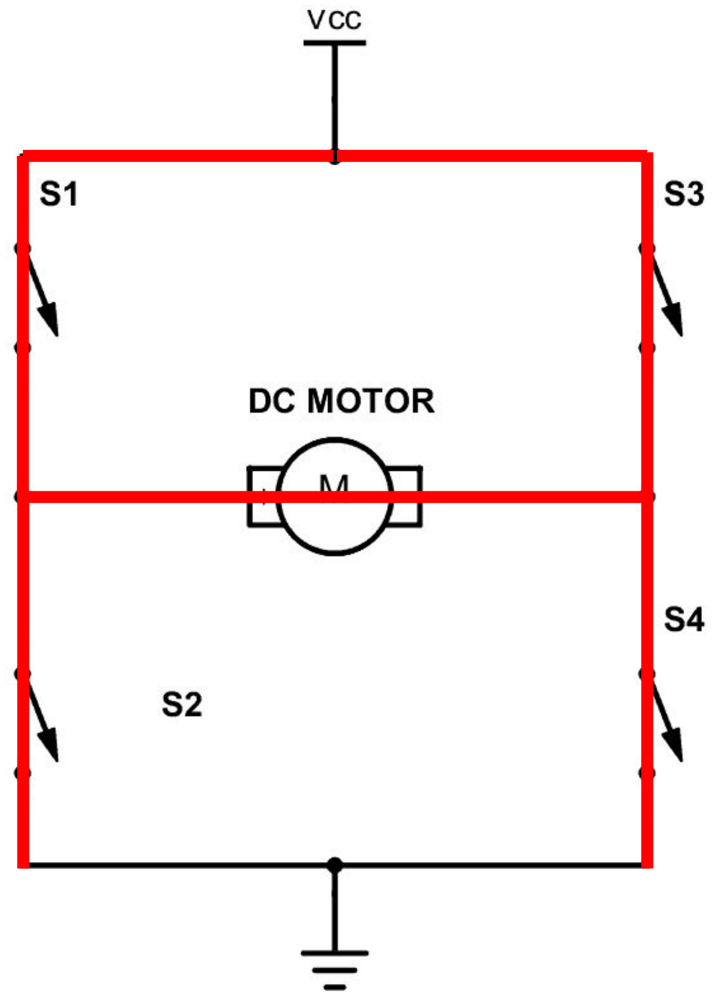
H-Bridge

So Far, Only One Direction

- How can we control the direction that the motor spins?

Solution: H-Bridge Circuit

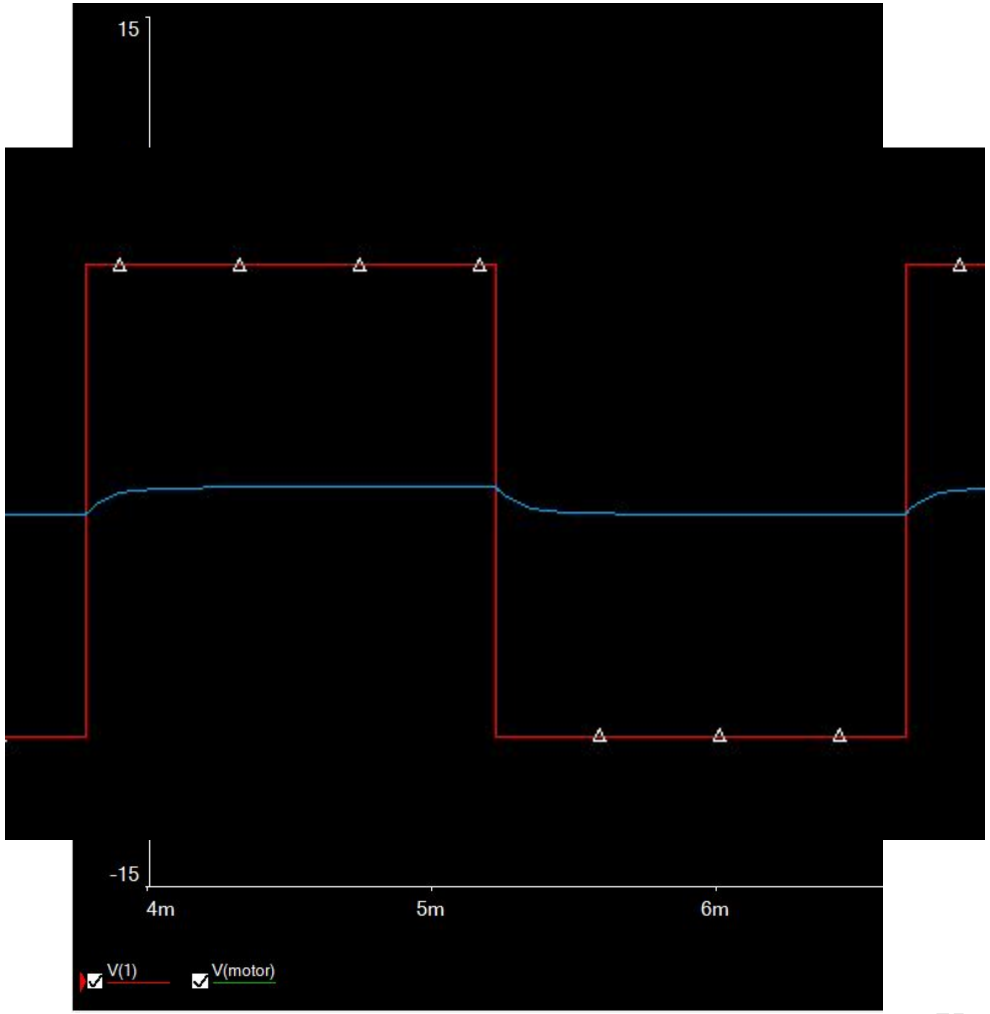
NPN Transistors



Modelling DC Motors

- What happens if we provide a DC Motor with AC voltage?

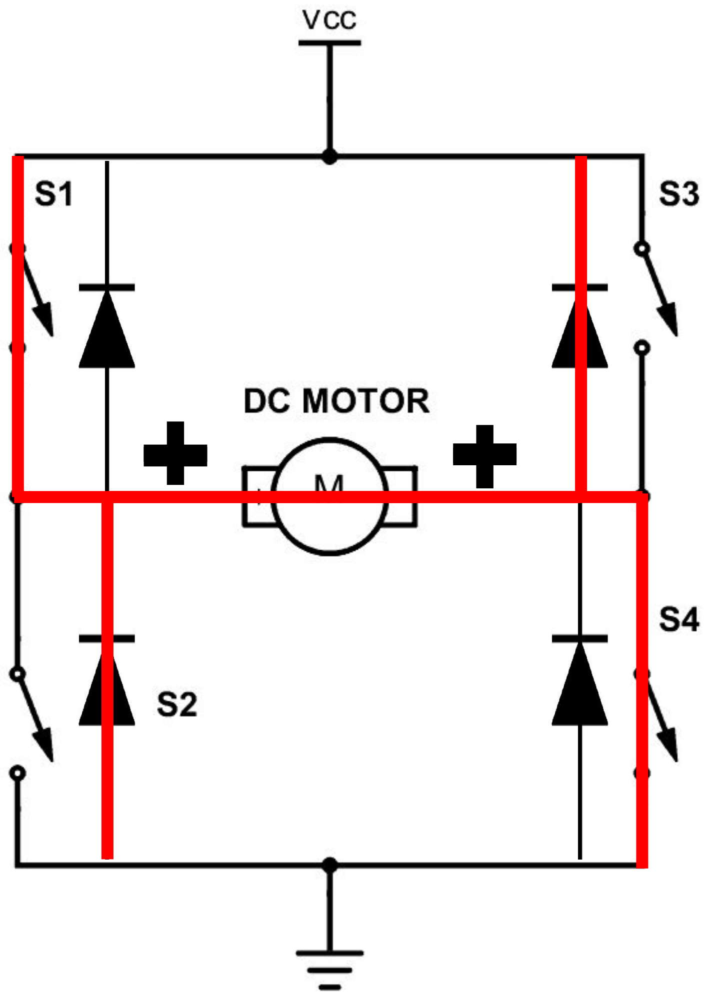
- The inductor in the motor will store up energy in a magnetic field
- When the voltage across it changes rapidly, it will want to discharge that energy, but in reverse polarity to the voltage that was across it



Flyback Diodes

- How do we prevent the motor's inductance spikes from damaging our transistors?

Solution: Flyback Diodes



A10: Build a Winch

- We can use an H-bridge circuit with
  - NPN transistors modelled as our switches
  - Resistive loads to mitigate shoot-through situations
  - Flyback diodes to manage inductive spikes
- Now let's build it: Build an H-bridge with V_{cc}: 10V power supply using the function generator and your DC Power Supply to power your switches.
  - Recall not to cause a shoot through scenario by powering SW1 and SW2 / SW3 and SW4 at the same time, as this will damage your transistors

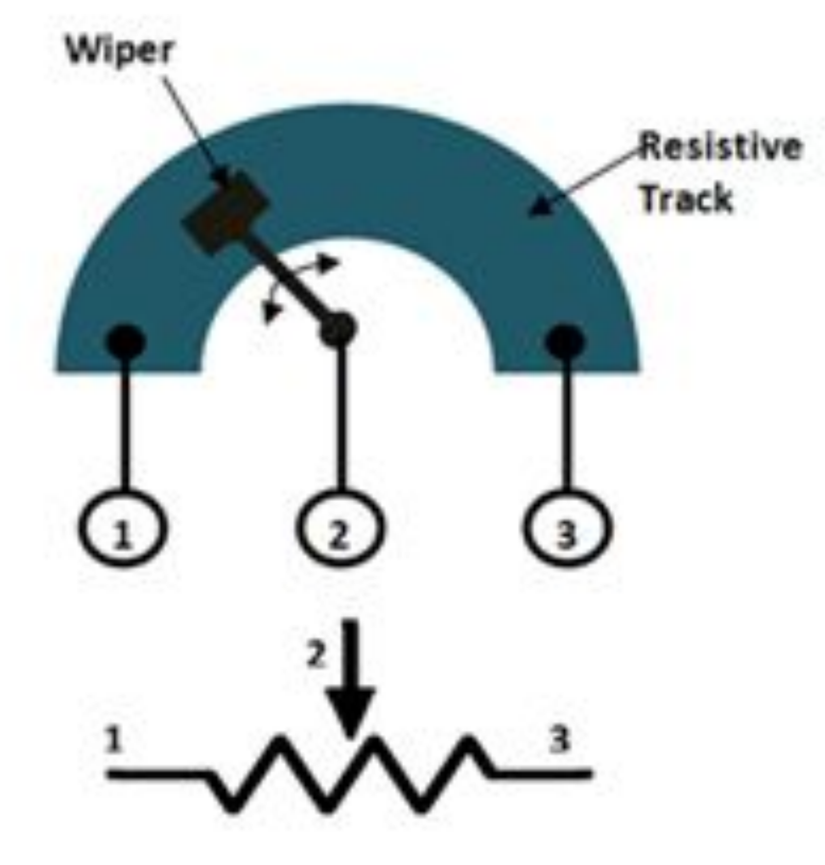
A11: Build a Better Winch

- How can we incorporate variable speed with PWM like we learned before into our H-Bridge Circuit?

Light / Colour Detector

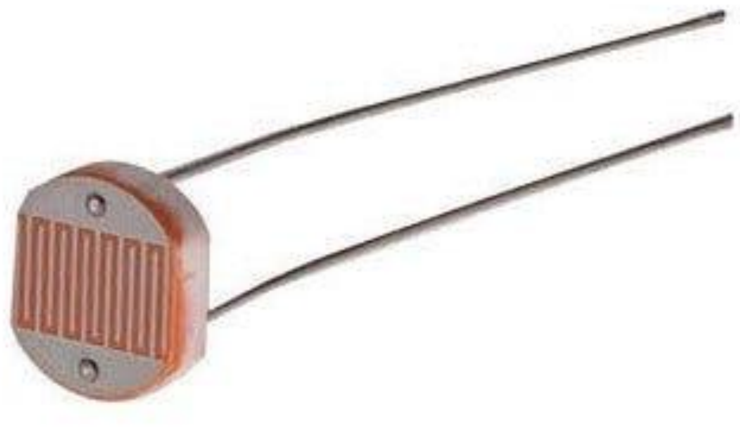
Variable Resistors: Potentiometers

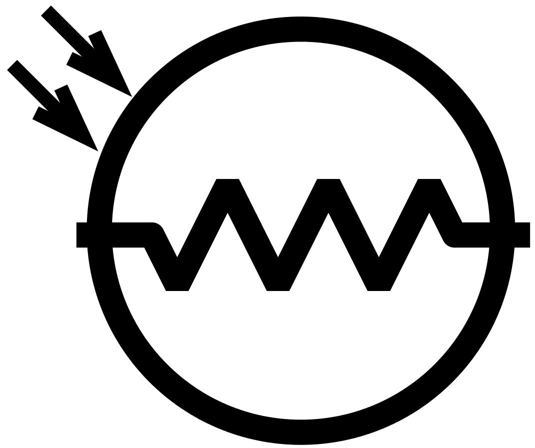
- Allow for resistance to be controlled by some external variable
- 10K Potentiometer (POT)
  - Ranges from 0 – 10kΩ
- Pins 1 -> 3 are set 10kΩ
- Pins 2 -> 1 or 2 -> 3 is a variable resistance depending on where the wiper is
  - More track between pins = More resistance



Variable Resistors: Photoresistors

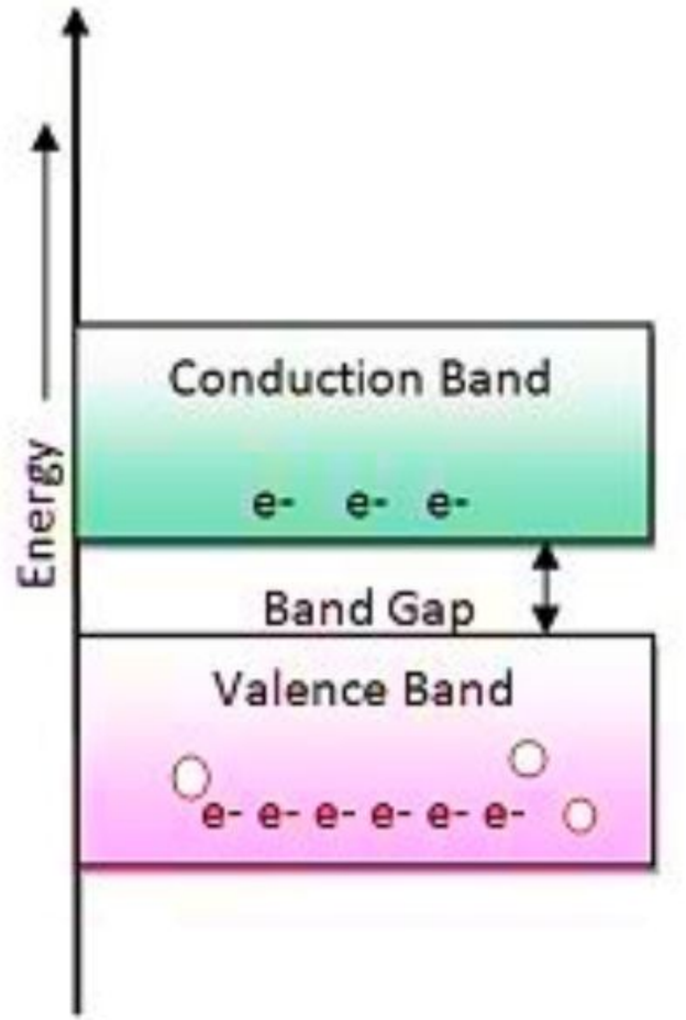
- Photocells, Light Dependent Resistor (LDR)
- Allows for resistance to be controlled by light
  - More light = Less resistance
  - More dark = Larger resistance





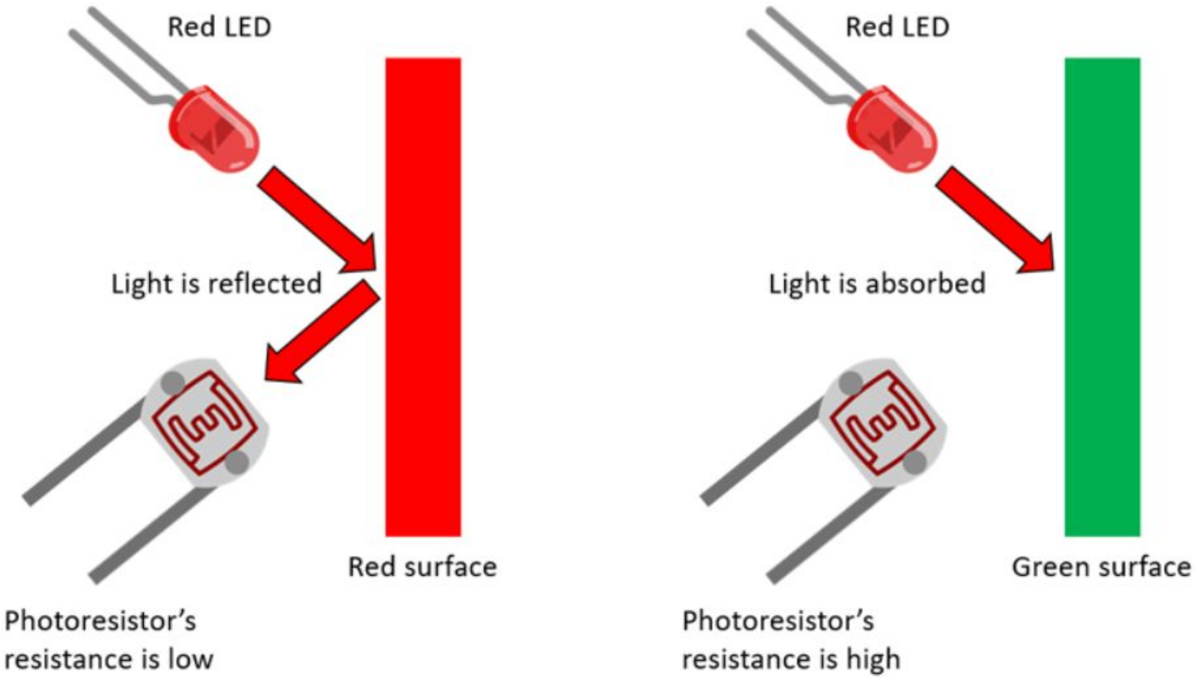
Photoconductive Effect

- Photoconductive Effect: When light shines on a material, electrical conductivity increases
- Photons excite electrons -> more energy in material -> more conductivity
- Property is prominent in materials like Cadmium Sulfide (CdS Photoresistors)



A12: Build a Phototransistor to Detect Colour

- Use both a potentiometer and photoresistor to tune a transistor to light up an LED only when a specific colour is detected
  - Note: Colours absorb other lighter colours and reflect other darker colours



Hardware Workshop One

Motor Control and Light Sensors

Day 3 End

Hardware Workshop One

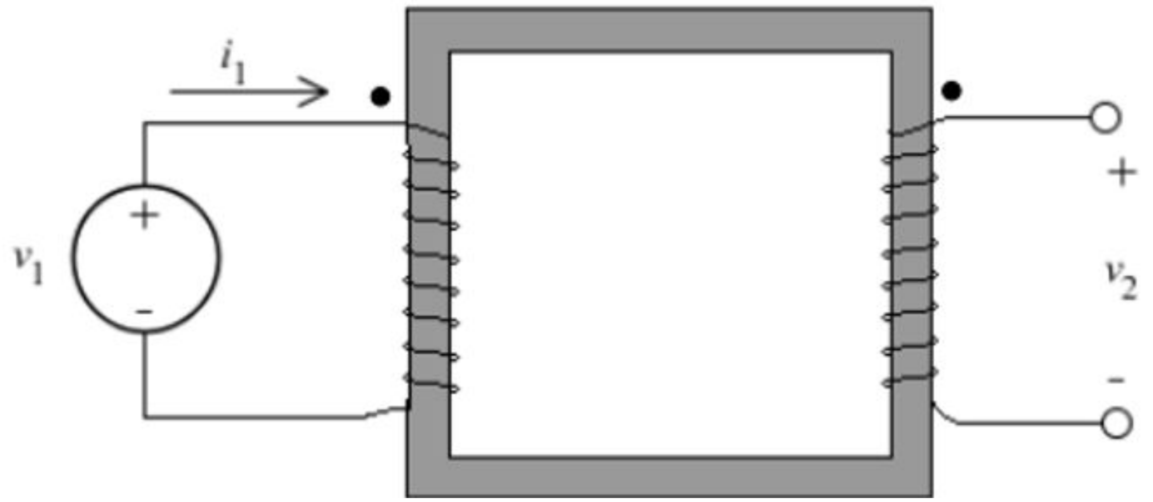
Generating Power

Day 4 Start

Coupled Inductors

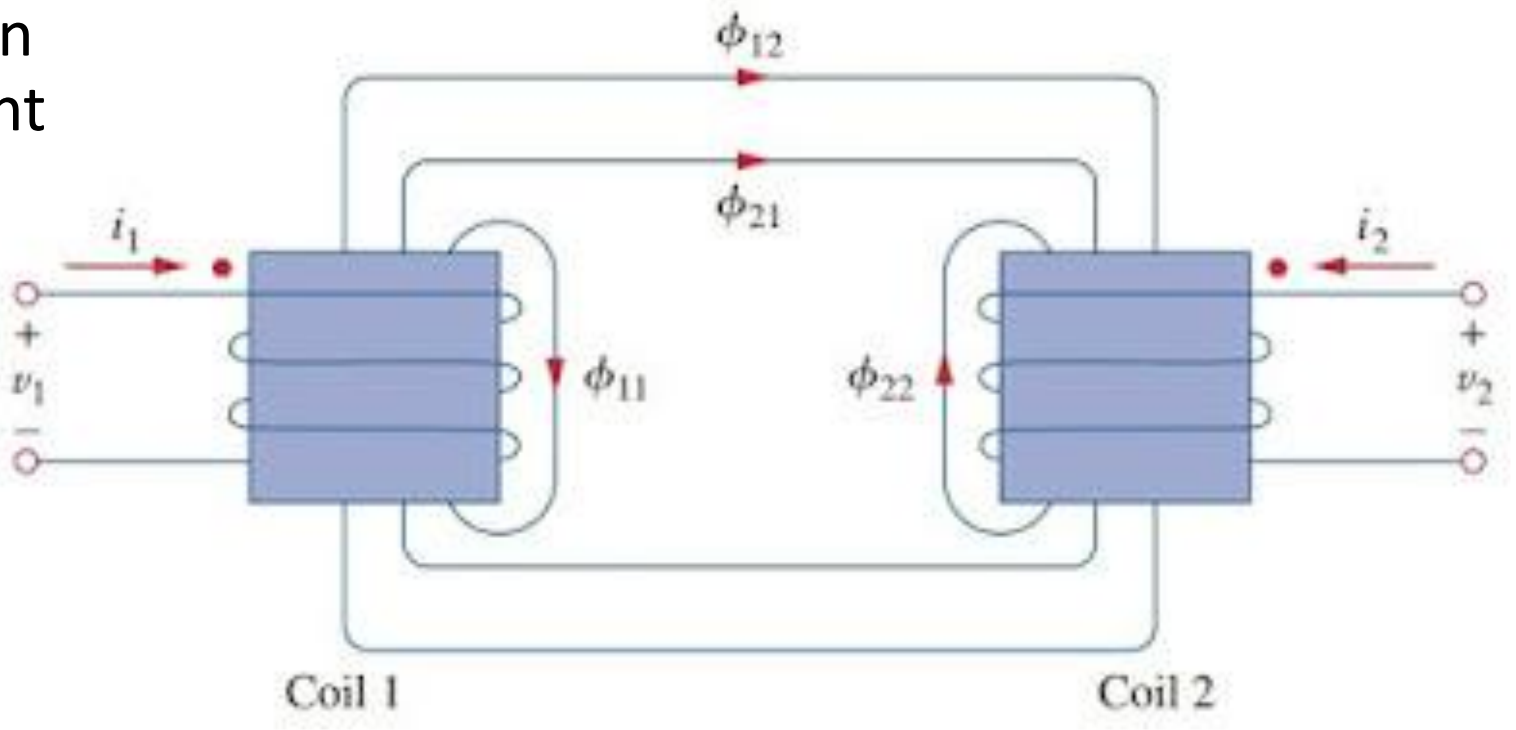
Coupled Inductor

- Two coils are placed nearby or winded on the same core
  - Magnetically coupled
- Magnetic core holds the magnetic flux
  - The same magnetic flux pass through two coils
  - Change of magnetic field in one coil will induce current in the other coil.

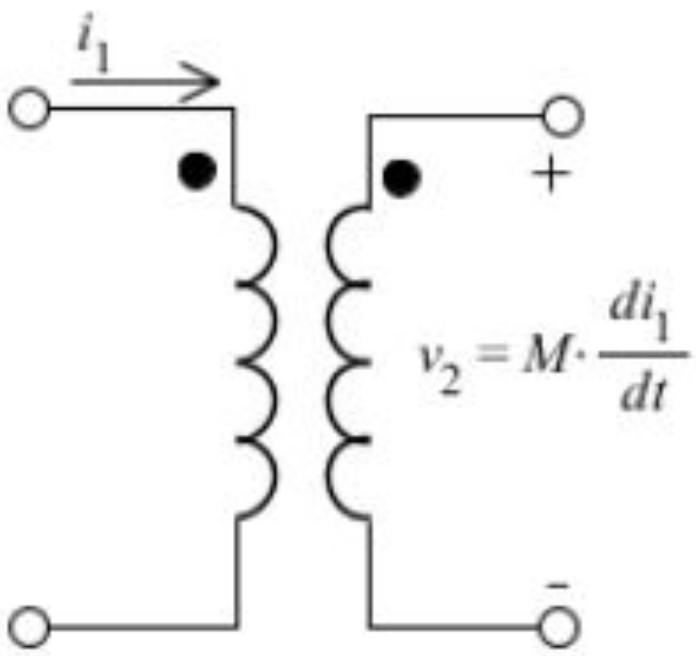


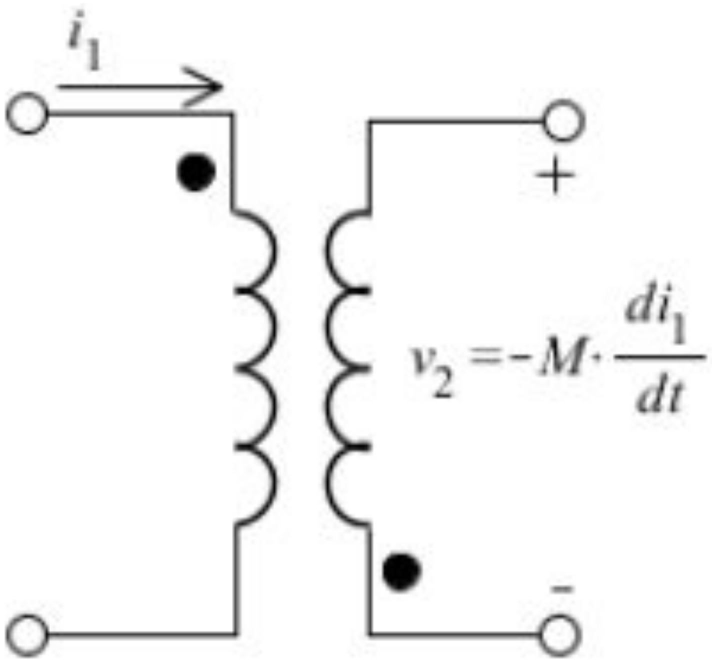
Coupled Inductor

- Dot convention:
  - With the same direction of magnetic flux, current flows into the dot
- Aiding mode:
  - Dot at the same side
- Opposing mode:
  - Dot at opposite side.

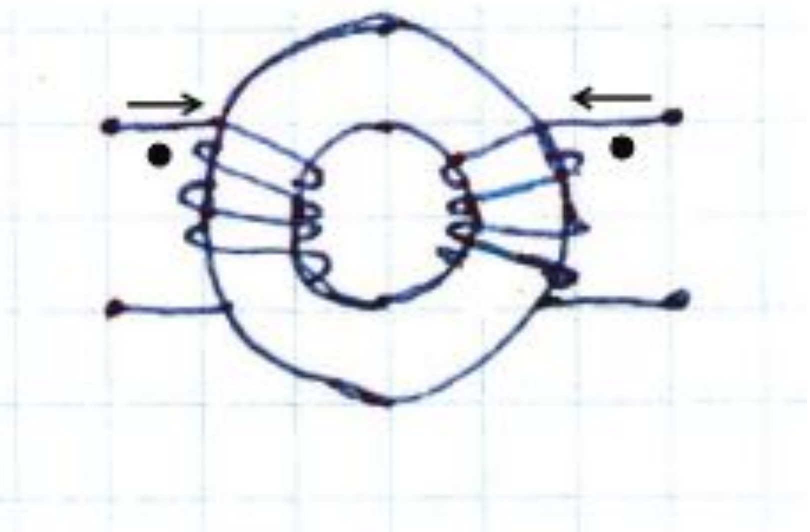


Coupled Inductor

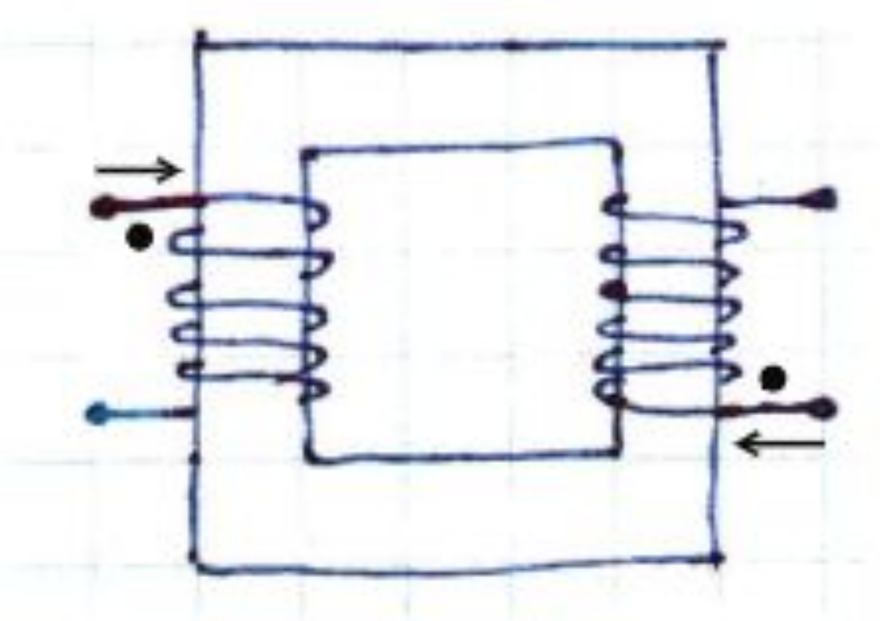




A13: Coupled Inductor



- Wind an aiding mode coupled inductor on a ferrite core and measure the primary & secondary side voltage using oscilloscope

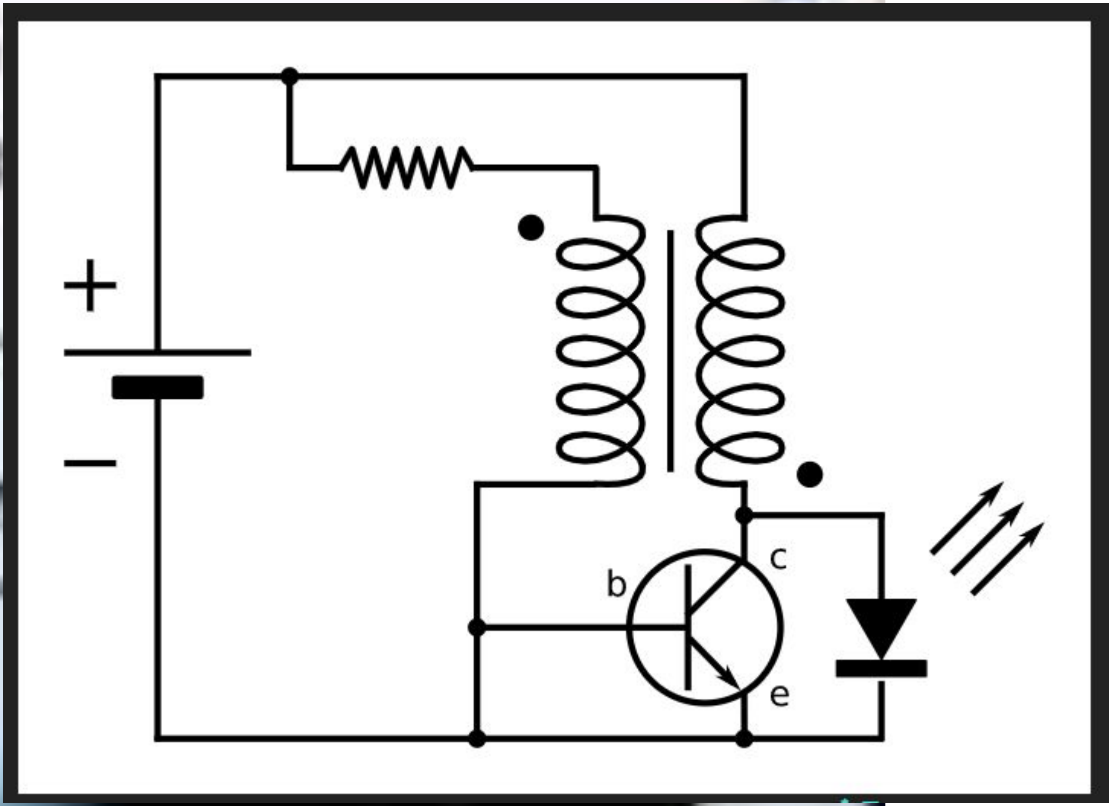


- Wind an opposing mode coupled inductor on a ferrite core and measure the primary & secondary side voltage using oscilloscope

Joule Thief

A14: Joule Thief

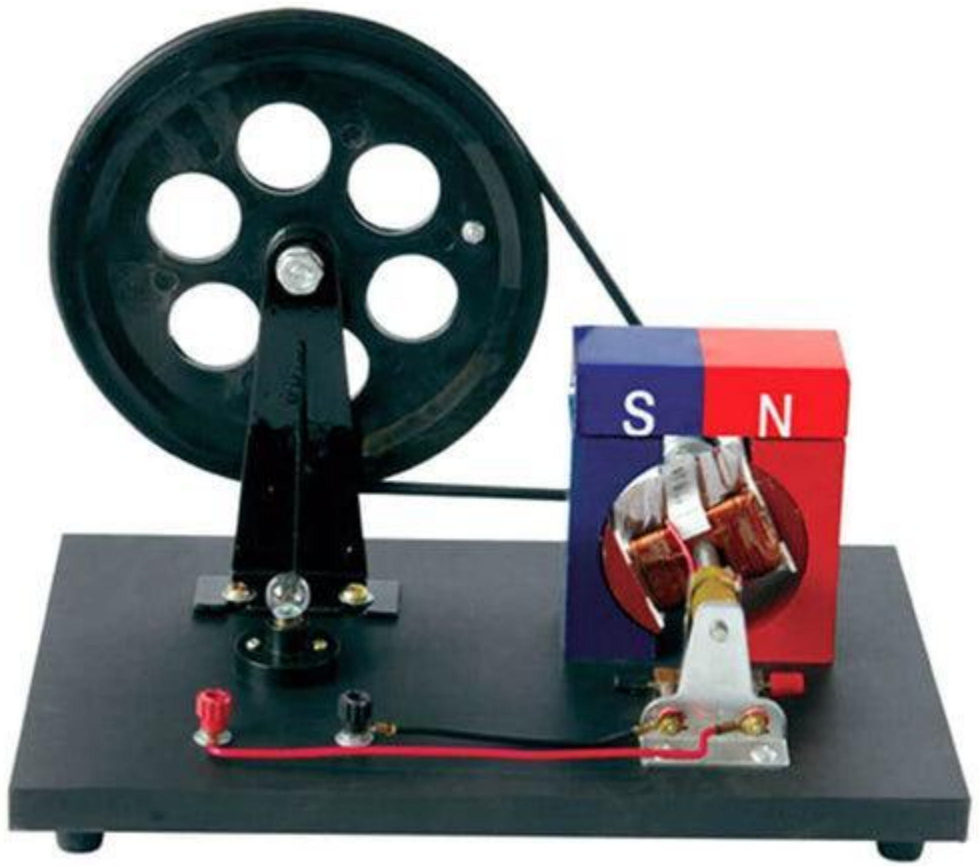
- The joule thief is a self-oscillating voltage booster using coupled inductor.
  - Convert constant low voltage to a periodical higher voltage.
- Typically used to drive small loads



Generators

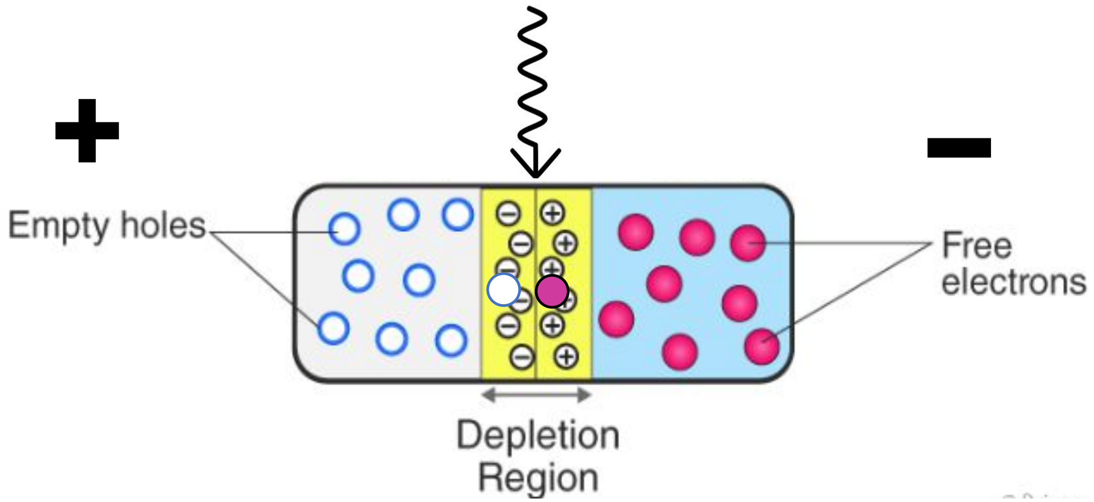
Hand Crank: Mechanical Energy

- Works through application of Faraday's Law
- Rotate the wheel with your hand via a crank
- Rotation of the magnets relative to the wound-up wire induces a current within wire
- Faster rotation = Faster movement through magnetic field = Stronger induced current



Solar Panels: Solar Energy

- Photovoltaic Effect:
  - Photons will excite electrons in the depletion zone of PN junction
  - Split electrons and holes are pushed to their respective sides
  - This creates a small potential difference across the junction



- Put enough photovoltaic cells in series or parallel with each other and you can get a substantial voltage

Day 4 Competition

Competition Outline (subject to change atm)

1. Generate the highest possible voltage you can from the tools you have been given to power your flashlight
2. You may use any of the tools / concepts we have covered
3. Bonus points if you manage to incorporate the Joule Thief circuit into your design in a practical manner
4. You cannot use the function generator or oscilloscope to generate any voltage

Hardware Workshop One

Generating Power

Day 4 End