LECTURE II

Integrated Circuits & Troubleshooting Equipment and Techniques

SECTION I

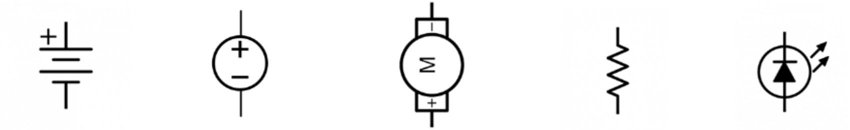
Circuit Topology

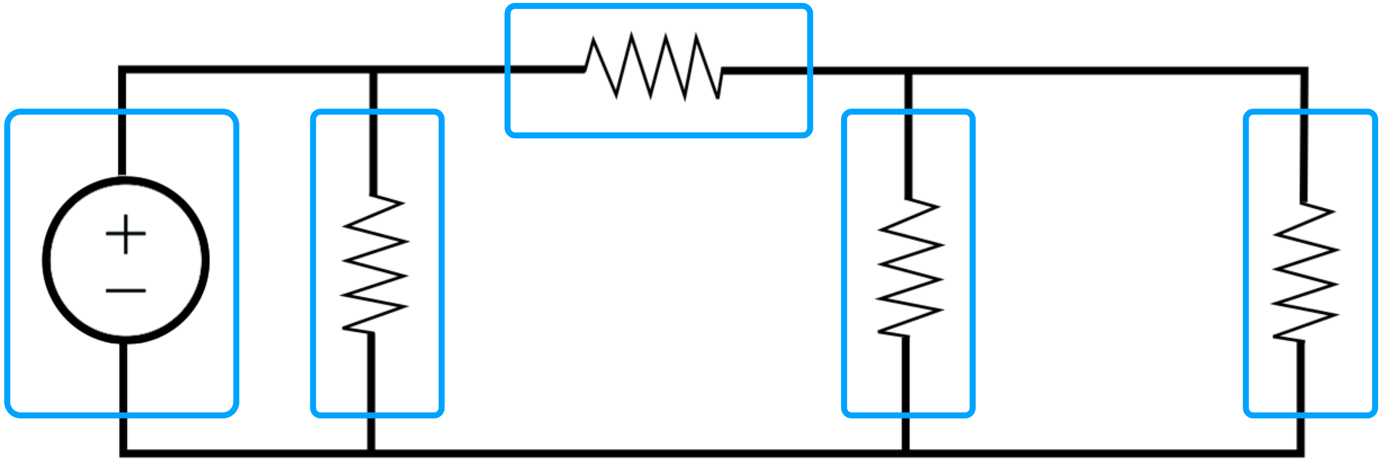
Circuits

- A circuit is a **closed loop** path where electrons can flow
- We can decompose a circuit into **branches**, **nodes**, and **loops** to analyze the voltage, current, and resistance across segments of the circuit
    - **Why?** Circuit analysis enables us to design, **debug**, and test the performance of circuits

Branches

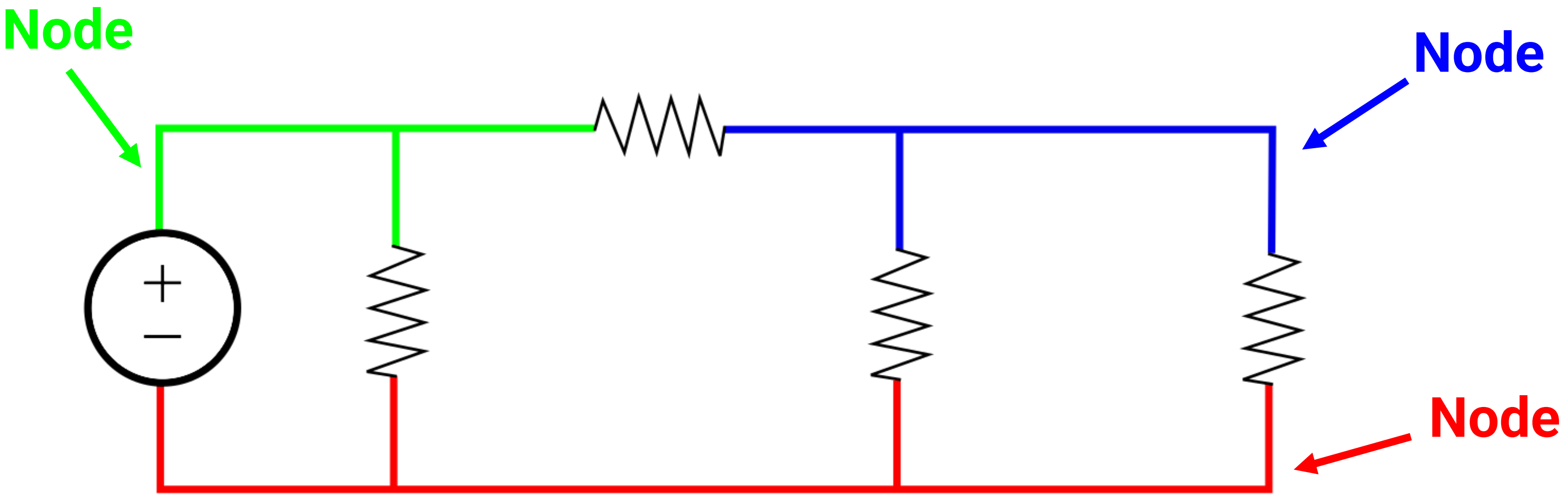
- A **branch** is generally a **two-terminal** circuit element





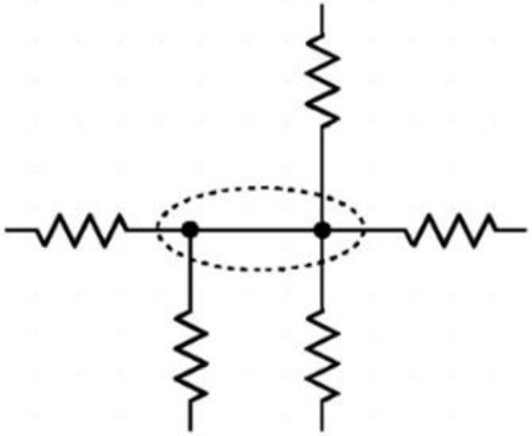
Nodes

- A **node** is a **connection** between two or more **branches**
- All points on the **same node** have the **same voltage and current**



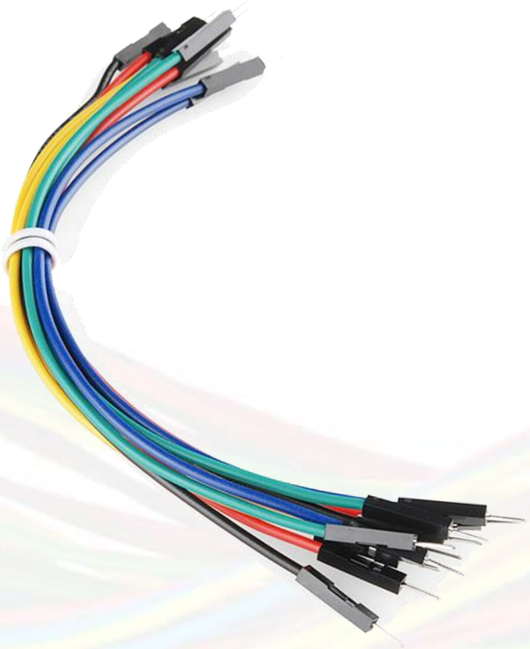
Nodes (Cont'd)

What is the voltage between these two points?



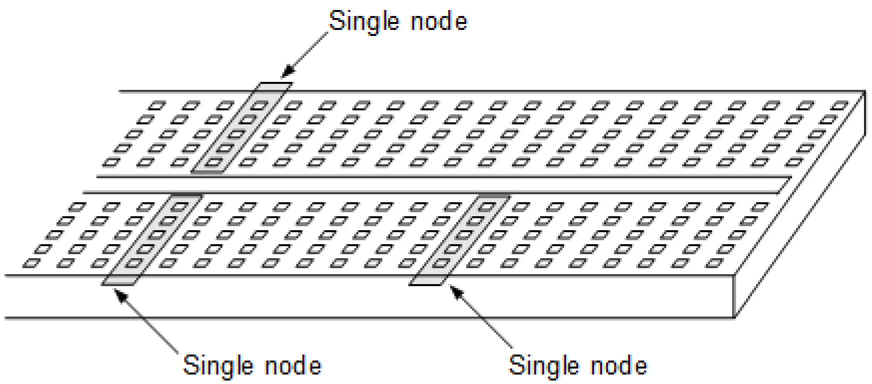
Nodes (Cont'd)

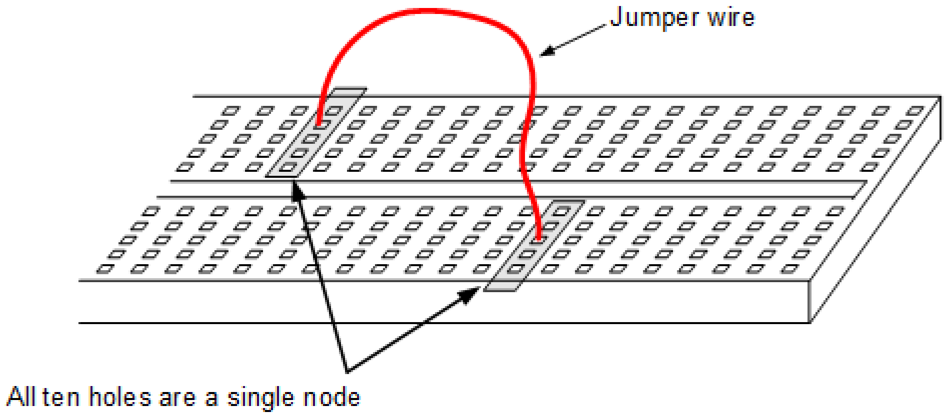
- **Wires** can be treated as **nodes**
  - .. if we assume that the wire has **no resistance** and there is **no voltage change** across the wire
    - This is acceptable for our course projects



Nodes (Cont'd)

- A breadboard **strip** be treated as a **single node**
- Connecting two strips with a jumper wire creates a larger **single node**

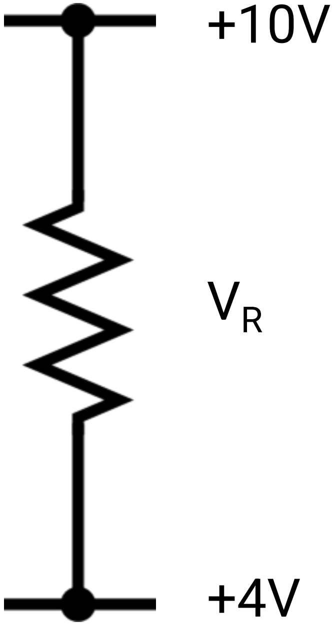




Voltage Drop

- Voltage drop is the **decrease of electric potential** (Volts) along the path of current flowing in a circuit
- We can calculate the voltage drop between two nodes (across a circuit component)
  - We must carefully define the **direction of current** and the **reference polarity** through the component
    - These affect the **sign** of the voltage drop

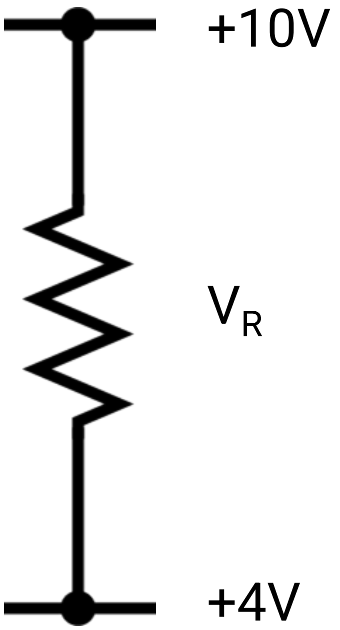
Calculating Voltage Drop



Find voltage drop $\mathbf{V_R}$

1. Determine the **sign** of $\mathbf{V_R}$
   a. Determine the **direction of current** and the **reference polarity**
2. Calculate $\mathbf{V_R}$ as the **difference in volts** between terminals, following the direction of current

Calculating Voltage Drop (Cont'd)



Find voltage drop $\mathbf{V_R}$

1. Determine the **sign** of $\mathbf{V_R}$
   a. Determine the **direction of current** and the **reference polarity**
2. Calculate $\mathbf{V_R}$ as the **difference in volts** between terminals, following the direction of current

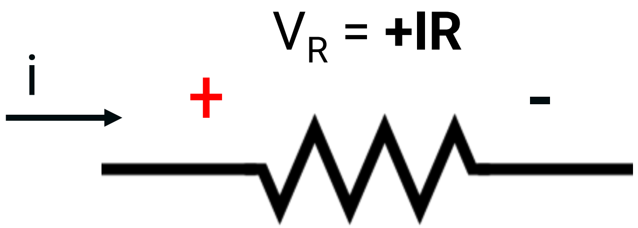
Let's Pause and Discuss...

Voltage Drop Sign Convention

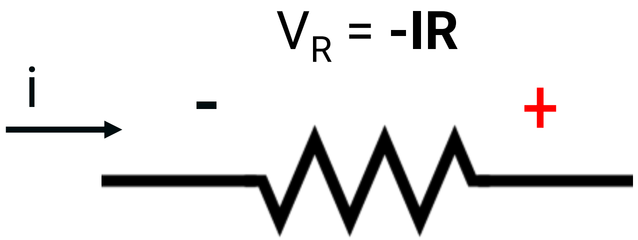
- In circuit analysis, **current direction** through a circuit and a voltage drop **reference polarity** are arbitrary
  - Ex) You can define the **reference polarity** of the resistor's voltage drop to be either of the following:

  - However, **you must be consistent**. Do not change the reference polarity or direction of current between calculations.

Voltage Drop Sign Convention (Cont'd)

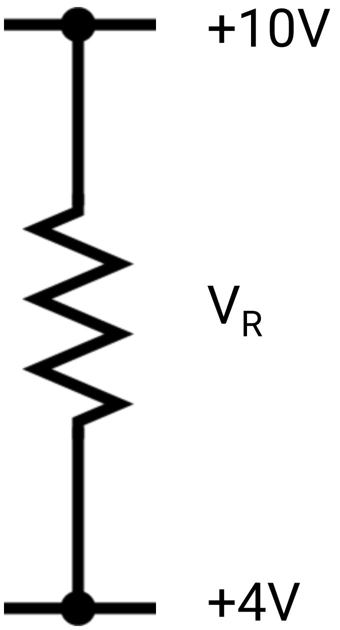


- The sign of the voltage drop is **positive** if current flows from **+** to **-** terminals



- The sign of the voltage drop is **negative** if current flows **-** to **+** terminals

Calculating Voltage Drop (Cont'd)

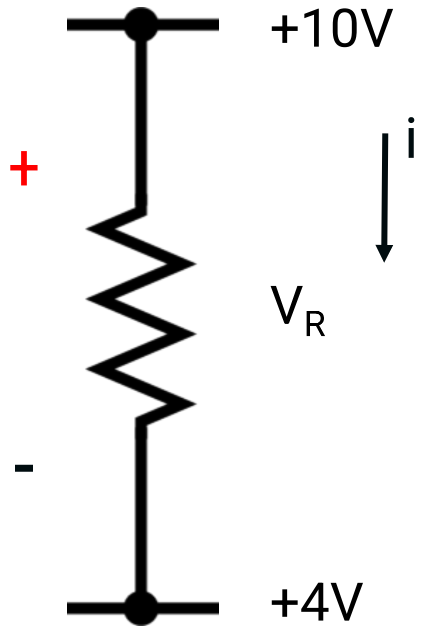


Find voltage drop $\mathbf{V_R}$

1. Determine the **sign** of $\mathbf{V_R}$
   a. Determine the **direction of current** and the **reference polarity**
2. Calculate $\mathbf{V_R}$ as the **difference in volts** between terminals, following the direction of current

Unpause

Calculating Voltage Drop (Cont'd)

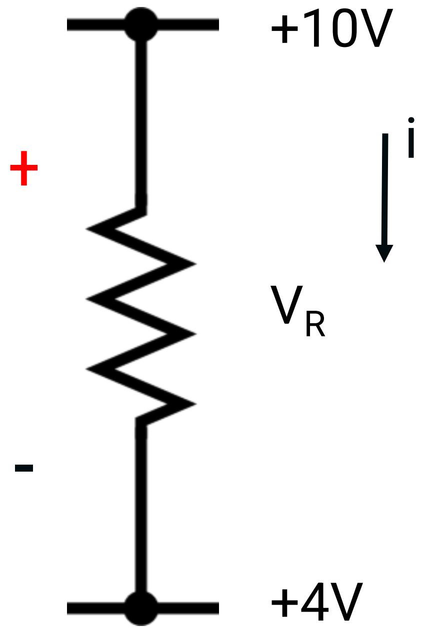


Find voltage drop $\mathbf{V_R}$

1. Determine the **sign** of $\mathbf{V_R}$
   a. Determine the **direction of current** and the **reference polarity**
2. Calculate $\mathbf{V_R}$ as the **difference in volts** between terminals, following the direction of current

We define current direction and the reference polarity as such. Current flows from **+** to **-** terminals; therefore, V = **+IR**

Calculating Voltage Drop (Cont'd)



Find voltage drop $\mathbf{V_R}$

1. Determine the **sign** of $\mathbf{V_R}$
   a. Determine the **direction of current** and the **reference polarity**
2. Calculate $\mathbf{V_R}$ as the **difference in volts** between terminals, following the direction of current

$$V_R = 10V - 4V = \boxed{6V}$$

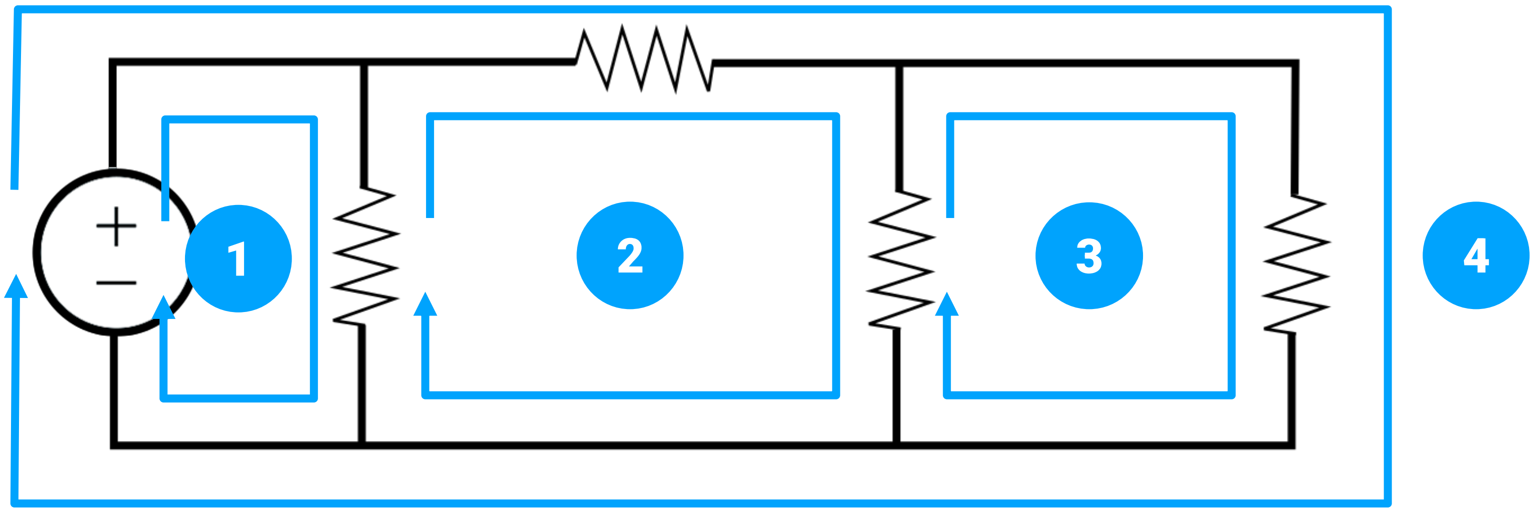
Please submit questions about the lecture content.

Nobody has responded yet.

Hang tight! Responses are coming in.

Loops

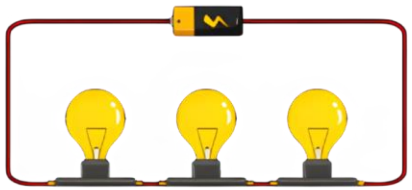
- A **loop** is a **closed path** through circuit elements
  - It starts at any node and ends at the same node
  - A loop does not pass through any node more than once



Series and Parallel Circuits

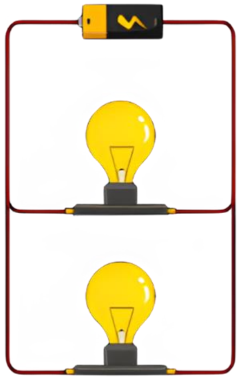
Series

- Two or more elements are in **series** if they exclusively share a single node
- Elements in series carry the **same current**



Parallel

- Two or more elements are in **parallel** if they are connected to the same two nodes
- Elements in parallel have the **same voltage** across them

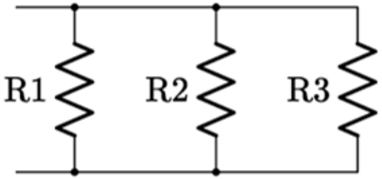


Series and Parallel Circuits

- If **multiple resistors** are arranged **in series or parallel**, we can treat them as having a **single equivalent resistance**

Parallel

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$



Series

$$R_{eq} = R_1 + R_2 + R_3$$

Resistors in Series

Ex) Given R_1 = 10Ω, R_2 = 30Ω, and R_3 = 70Ω, we will find the equivalent resistance.

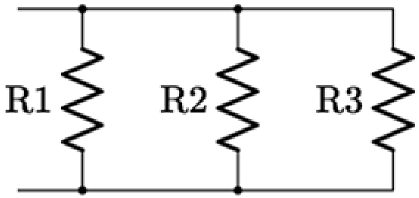
$$R_{eq} = R_1 + R_2 + R_3$$

$$R_{eq} = 10\Omega + 30\Omega + 70\Omega$$

$$\boxed{R_{eq} = 110\Omega}$$

Resistors in Parallel

Ex) Given R_1 = 10Ω, R_2 = 30Ω, and R_3 = 70Ω, we will find the equivalent resistance.



$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_{eq}} = \frac{1}{10\Omega} + \frac{1}{30\Omega} + \frac{1}{70\Omega}$$

$$\frac{1}{R_{eq}} = \frac{31}{210}\Omega$$

$$R_{eq} = \frac{210}{31}\Omega$$

$$\boxed{R_{eq} \simeq 6.77\Omega}$$

Please submit questions about the lecture content.

Nobody has responded yet.

Hang tight! Responses are coming in.

SECTION II

Kirchhoff’s Laws

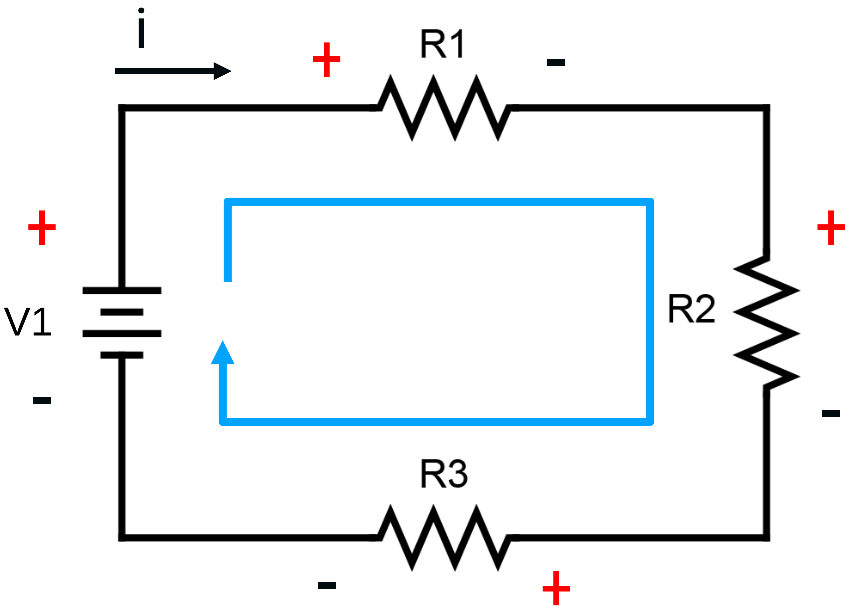
Kirchhoff's Voltage Law (KVL)

- The **sum of all voltage drops** in a closed loop **is equal to zero**

$$\Sigma V_i = 0$$

- Ex) We can apply KVL to the schematic on the right

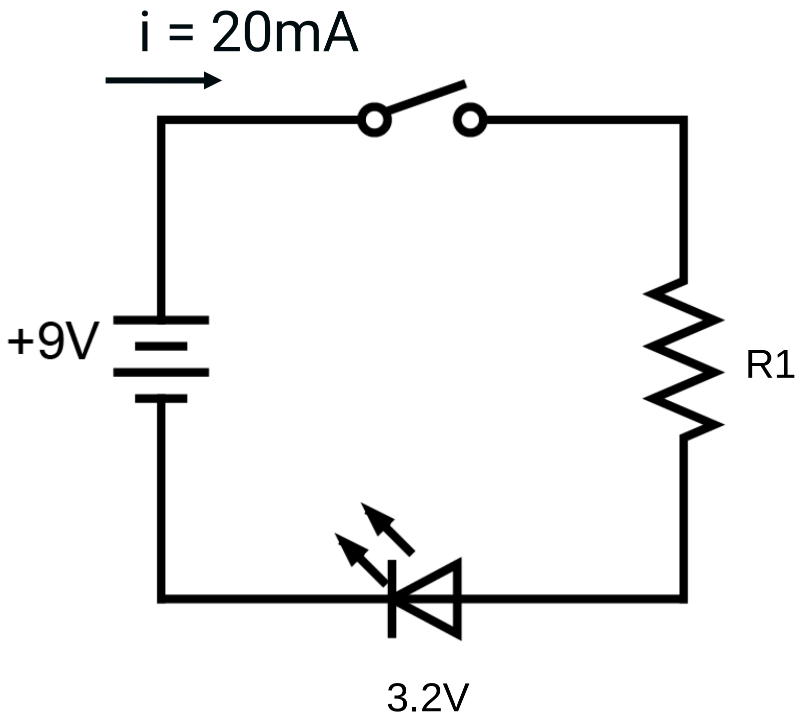
$$V_{R1} + V_{R2} + V_{R3} - V_1 = 0$$



Applying KVL to a Single Loop

Let’s use KVL to solve for the value of **R1**

1) Determine current direction and reference polarities
2) Create an equation for the voltage drops in the loop
3) Solve the equation for **R1**

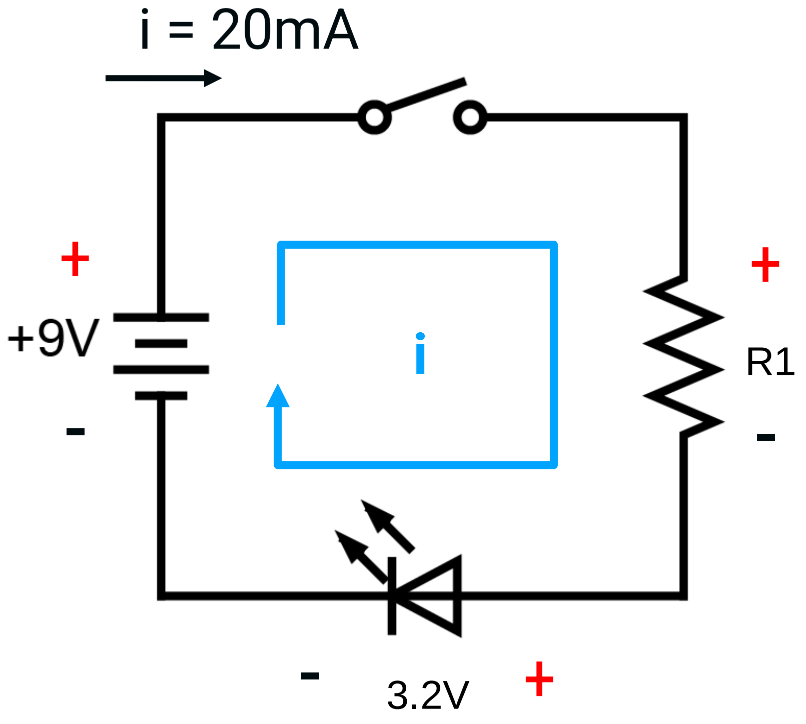


Assume the switch is **closed**

Applying KVL to a Single Loop (Cont'd)

Let's use KVL to solve for the value of **R1**

1) Determine current direction and reference polarities
2) Create an equation for the voltage drops in the loop
3) Solve the equation for **R1**



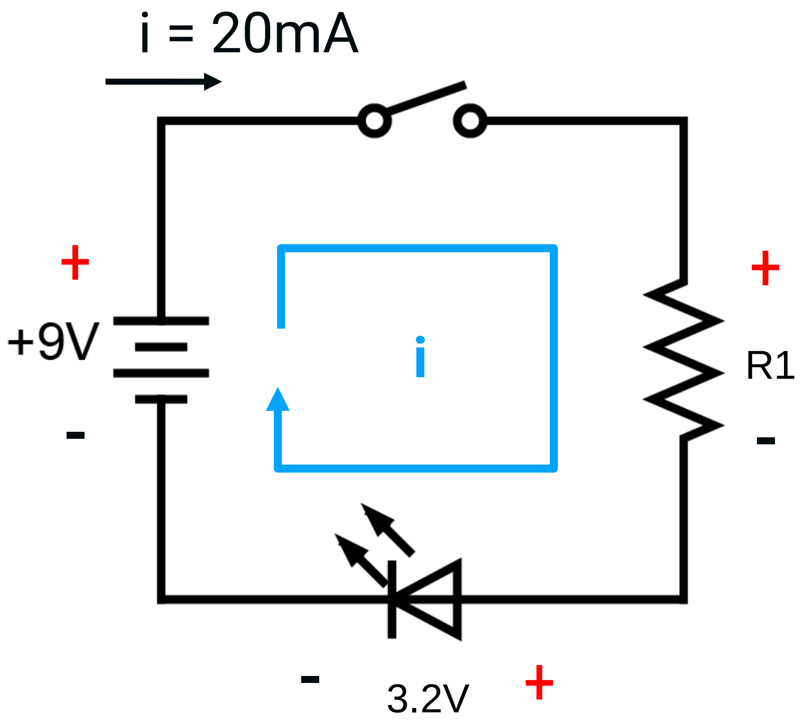
Assume the switch is **closed**

Applying KVL to a Single Loop (Cont'd)

Let's use KVL to solve for the value of **R1**

1) Determine current direction and reference polarities
2) Create an equation for the voltage drops in the loop
3) Solve the equation for **R1**

$$V_{R1} + V_{LED} - V_{Batt} = 0$$



Assume the switch is **closed**

Applying KVL to a Single Loop (Cont'd)

Let's use KVL to solve for the value of **R1**

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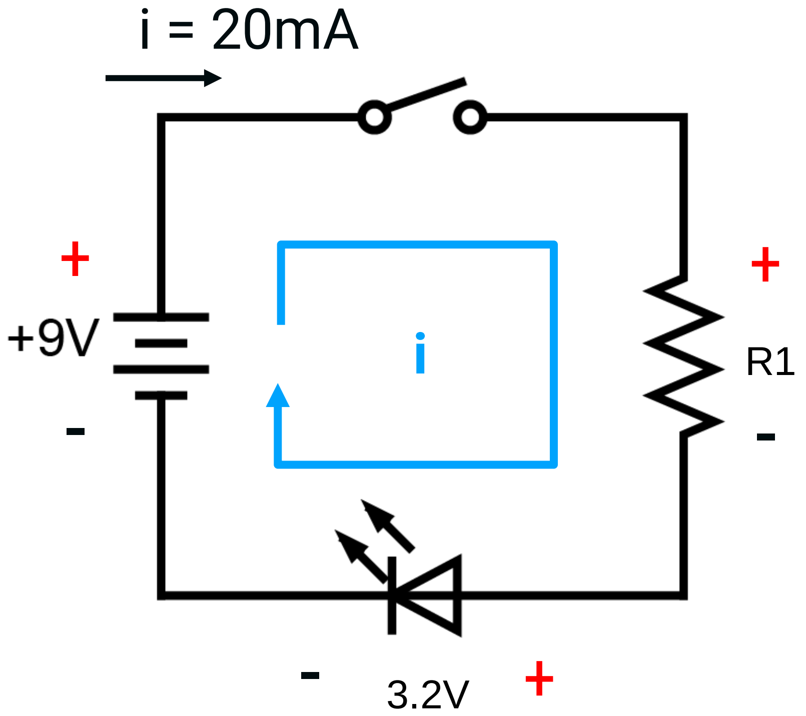
$$V_{R1} + V_{LED} - V_{Batt} = 0$$



Assume the switch is **closed**

Applying KVL to a Single Loop (Cont'd)

Let's use KVL to solve for the value of **R1**

3) Solve the equation for **R1**

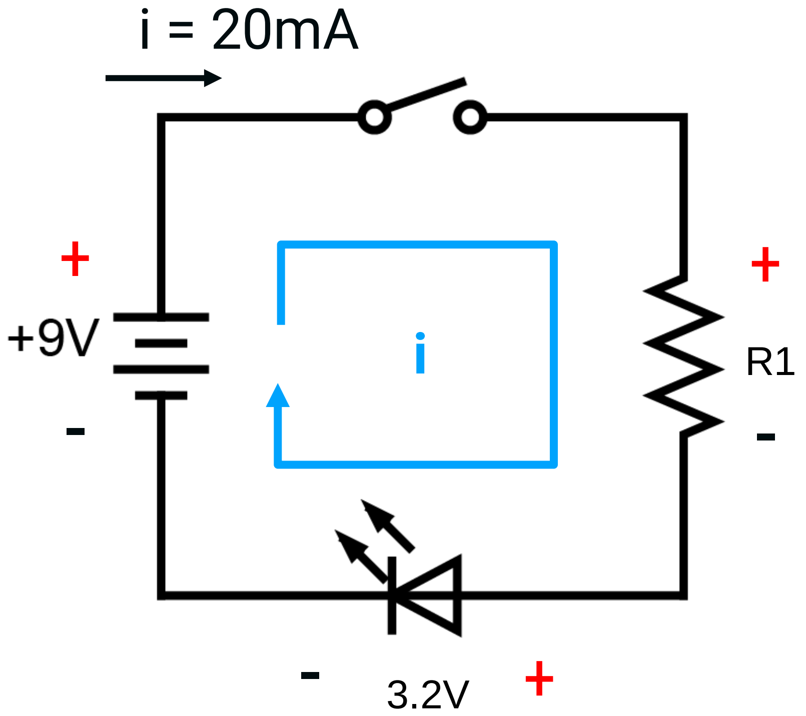
$$V_{R1} + V_{LED} - V_{Batt} = 0$$

Ohm's Law

$$(I \cdot R1) + 3.2V - 9V = 0$$

$$(20mA \cdot R1) + 3.2V - 9V = 0$$

$$\boxed{R1 = 290\Omega}$$



Assume the switch is **closed**

Please submit questions about the lecture content.

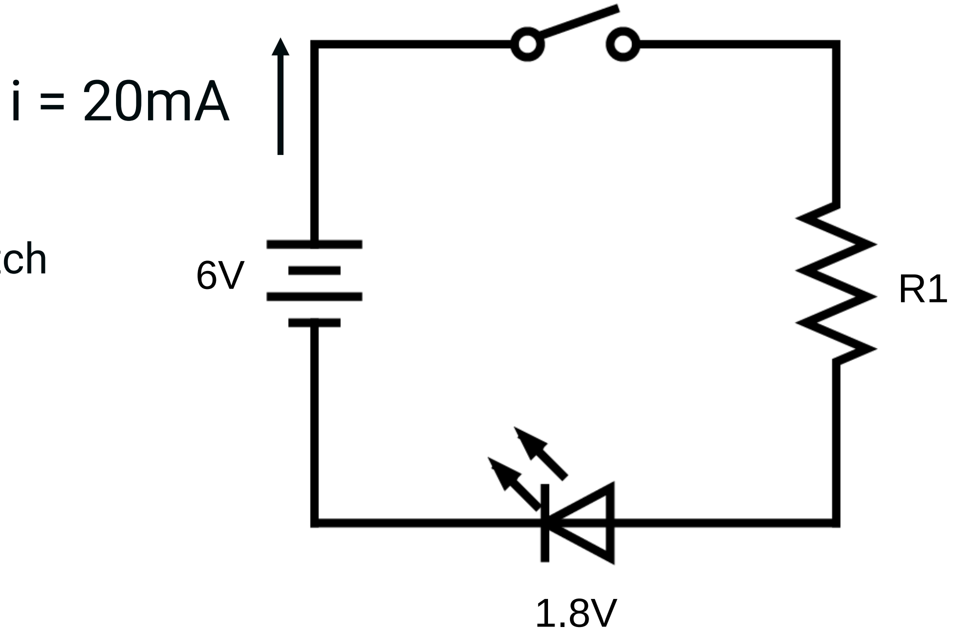
Nobody has responded yet.

Hang tight! Responses are coming in.

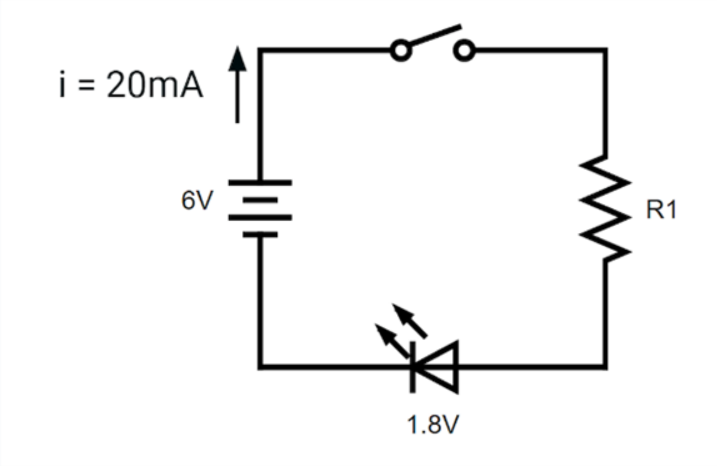
Applying KVL to a Single Loop

I Cir-quit! Find the value of **R1** in the circuit below.

Assume the switch
is **closed**

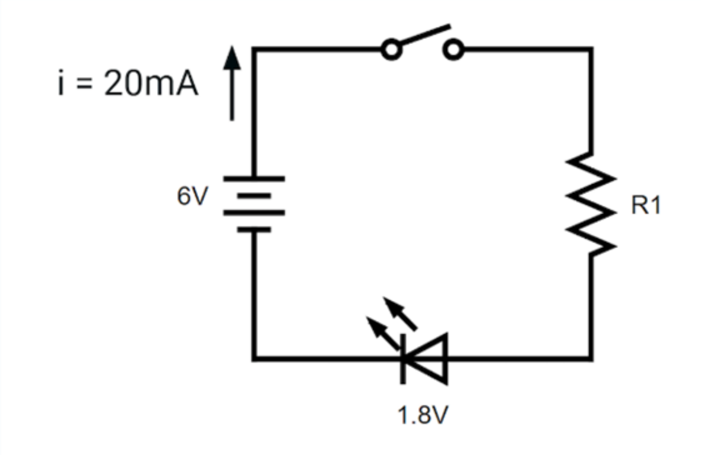


Find the value of R1 in the circuit below. (Assume the switch is closed.)



- 290Ω
- 340Ω
- 210Ω
- 170Ω
- None of the above

Find the value of R1 in the circuit below. (Assume the switch is closed.)



290Ω

0%

340Ω

0%

210Ω

0%

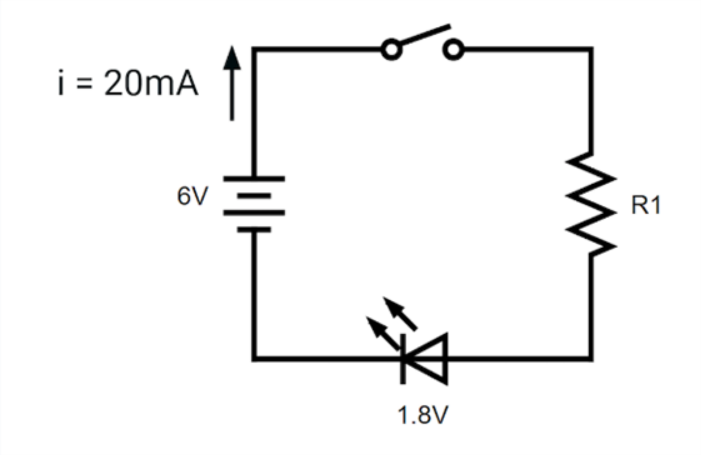
170Ω

0%

None of the above

0%

Find the value of R1 in the circuit below. (Assume the switch is closed.)



290Ω
0%

340Ω
0%

210Ω
0%

170Ω
0%

None of the above
0%

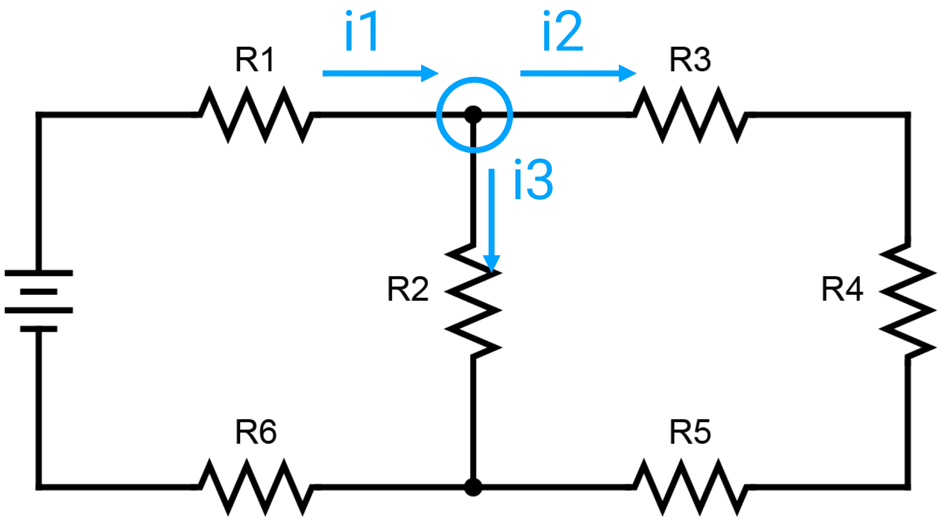
Kirchhoff's Current Law (KCL)

- The **sum of currents** passing through a node **is equal to zero**

$$\Sigma I_i = 0 \qquad I_{in} = I_{out}$$

- Ex) We can apply KCL to the schematic on the right

$$I1 = I2 + I3$$



Please submit questions about the lecture content.

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SECTION III

Multimeters

What is a Multimeter?

- A **multimeter** is an instrument used to measure the electrical properties of a circuit, including…
    - Voltage
    - Current
    - Resistance
    - Continuity
    - And More!
- Today, we typically use **digital multimeters** or **DMMs**

What is a Multimeter? (Cont'd)

- There are **two main varieties** of digital multimeters:
  - **Manual-ranging multimeters** require the user to manually select an appropriate measurement range
    - Less convenient for quick use
    - Often less expensive than auto-ranging MMs
  - **Auto-ranging multimeters** (shown on the right) automatically select the measurement range
    - The user only needs to select the measurement type

Multimeter Probes

- The multimeter has **two probes**:
  - The **red probe** is associated with the positive side of a component/connection
    - Plug it into the **VΩmA** multimeter port
  - The **black probe** is associated with **COM**
    - Plug it into the **COM** multimeter port
    - **COM** or **common** is the reference point from which the red probe measures voltage, current, etc.
      - **Common is not ground**

Measuring Voltage

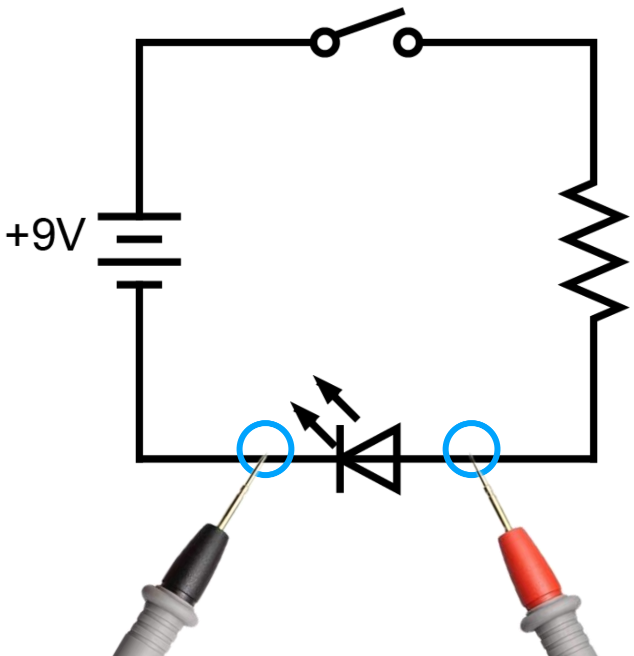
How to **measure DC voltage** with an auto-ranging multimeter:

1) Connect the probes to **VΩmA** and **COM**
2) Set the dial to **DC Voltage**
3) Place the **red probe** on one node and the **black probe** on the node to be used as the reference point
4) Read the display
    - The display value is the voltage drop from the node at the **red probe** to the node at the **black probe**

Measuring Voltage (Cont'd)

I/A

Measure the DC voltage across a powered 3.2V LED in a simple circuit to confirm its nominal forward voltage



Measuring Resistance

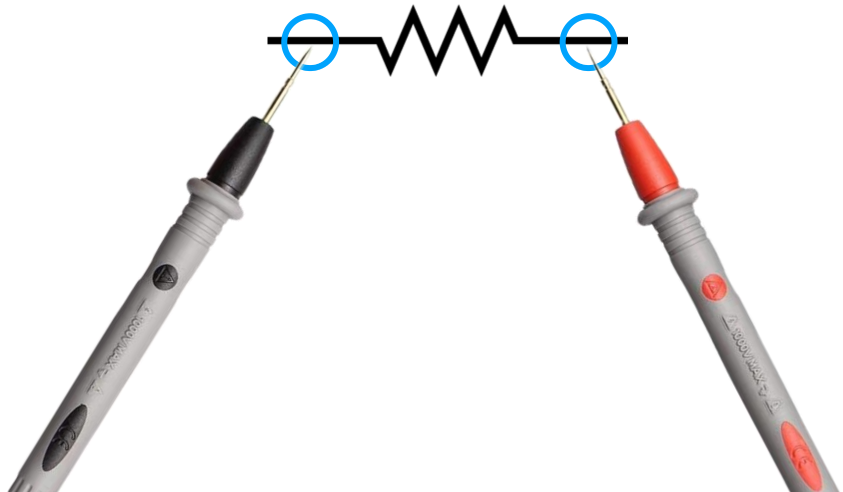
How to **measure resistance** with an auto-ranging multimeter:

1) Connect the probes to **VΩmA** and **COM**
2) Set the dial to **Ohms**
3) **Disconnect the component** from the live circuit
4) Place a probe on each terminal of the component
5) Read the display

Measuring Resistance (Cont'd)

I/A

Measure the resistance across a resistor of a known resistance value to confirm the value



Measuring Current

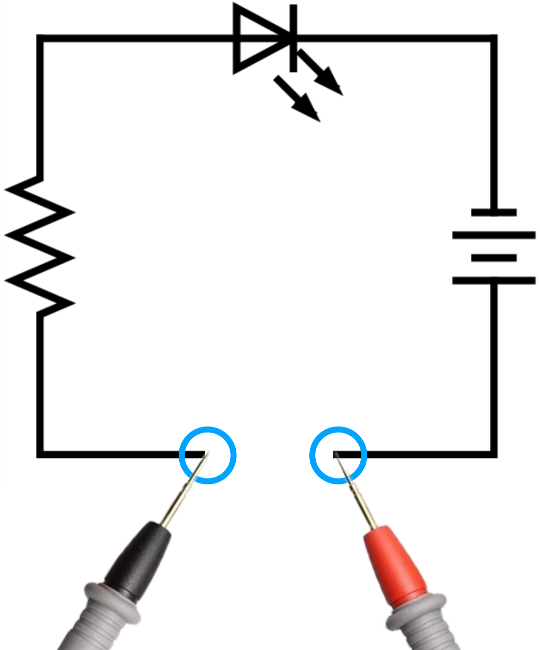
How to **measure DC current** with an auto-ranging multimeter:

1) Connect the probes to **VΩmA** and **COM**
2) Set the dial to **DC Current**
3) Place the probes in **series** with components in the circuit
4) Read the display

Measuring Current (Cont'd)

I/A

Measure the DC current across a simple LED circuit.
Calculate the expected current value and confirm it with the DMM



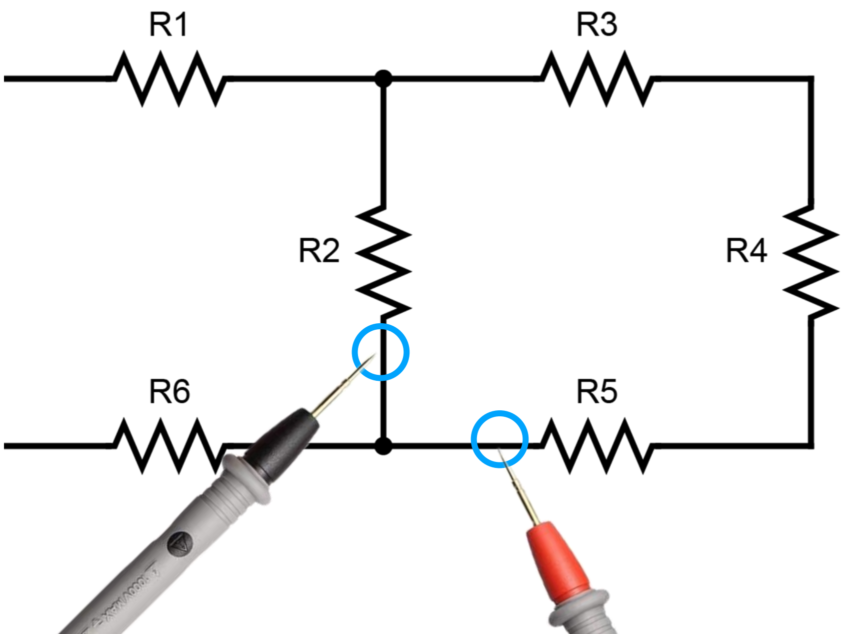
Testing Continuity

How to **test continuity** with an auto-ranging multimeter:

1) Connect the probes to **VΩmA** and **COM**
2) Set the dial to **Continuity**
3) **Disconnect the power source** from the circuit
4) Place the probes on the circuit
5) The DMM **beeps** if there is a continuous path between the probes

Testing Continuity (Cont'd)

Test the continuity across any two points on a circuit which lie on the same node. The DMM should beep



SECTION IV

Troubleshooting Circuits

How To Troubleshoot a Circuit

Circuit not working? Follow these steps to **find the issue**:

1) Check the **power supply** and **ground**
    - Is the power supply is providing the correct voltage?
        - Use a DMM to **measure voltage**
    - Check the power and ground connections to the circuit
2) Visually **inspect the circuit**
    - Look for loose connections, damaged components, cold solder joints, etc.
        - Use a DMM for **continuity tests**

How To Troubleshoot a Circuit (Cont'd)

Circuit not working? Follow these steps to **find the issue**:

3) Verify the **schematic diagram**
    - Make sure you understand the circuit's functionality based on the schematic
4) Verify the **physical circuit design**
    - The circuit should match the **schematic diagram**. Go node-by-node and make sure every component is properly connected
    - Check the component values against the schematic
        - Use a DMM to **measure the resistor values**

How To Troubleshoot a Circuit (Cont’d)

Ideally, at this point, you have found the *potential issue*.
Here’s how you verify the issue:

- Suspect a faulty component?
  1) **Replace the component** and test the circuit again
  2) Circuit still not functioning? Test the “faulty” component on a working circuit
     - If the “faulty” component works on another circuit, then go back to the start. Try to identify a new issue.
     - If it doesn’t work, then use the replacement component. However, there’s still work to be done:Your circuit still functions, so there must be another issue.

How To Troubleshoot a Circuit (Cont’d)

Ideally, at this point, you have found the *potential issue.*
Here’s how you verify the issue:

- Loose wire? Poor connection?
    1) Re-solder or replace connections as needed and test the circuit again
    2) If the circuit still fails, **test the connections again** with the multimeter. It’s possible to solder poorly on even the second or third try.

Please submit questions about the lecture content.

Nobody has responded yet.

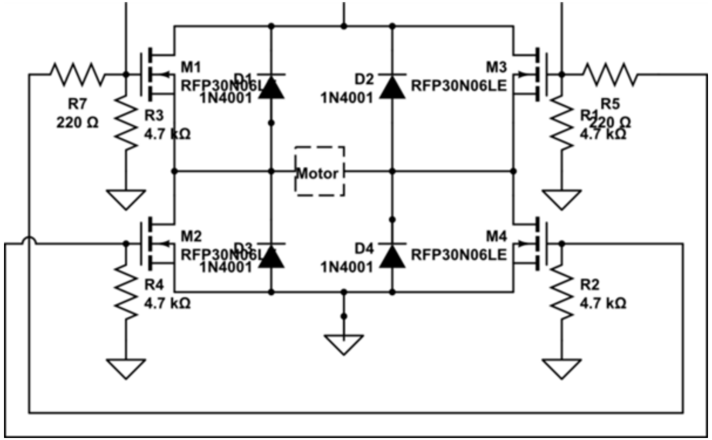
Hang tight! Responses are coming in.

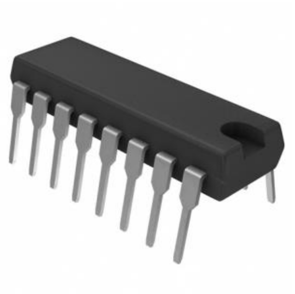
SECTION V

Integrated Circuits

Integrated Circuits

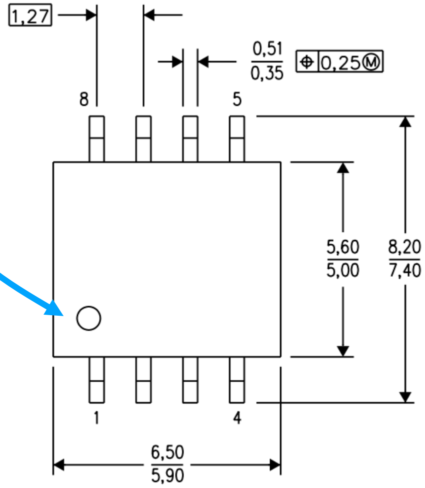
- An **integrated circuit** (**IC**, **chip**, **microchip**) is a set of electronic circuits on one small flat piece of semiconductor material
  - Electronic components are **integrated** on the chip
  - Complex circuits can be **scaled down** and **mass-produced**





Integrated Circuits

- The **functions** and **pin layout** of an IC are specified in its **datasheet**
- The **notch/dot** on the IC indicates its **orientation**



TEXAS INSTRUMENTS

www.ti.com

NA555, NE555, SA555, SE555

SLFS022I – SEPTEMBER 1973 – REVISED SEPTEMBER 2014

6 Pin Configuration and Functions

Pin Functions

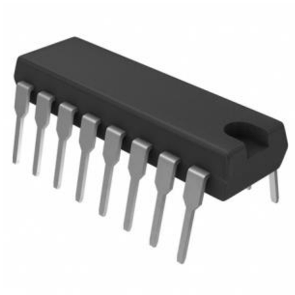
PIN			I/O	DESCRIPTION
NAME	D, P, PS, PW, JG	FK		
	NO.			
CONT	5	12	I/O	Controls comparator thresholds, Outputs 2/3 VCC, allows bypass capacitor connection
DISCH	7	17	O	Open collector output to discharge timing capacitor
GND	1	2	–	Ground
NC		1, 3, 4, 6, 8, 9, 11, 13, 14, 16, 18, 19	–	No internal connection
OUT	3	7	O	High current timer output signal
RESET	4	10	I	Active low reset input forces output and discharge low.
THRES	6	15	I	End of timing input. THRES > CONT sets output low and discharge low
TRIG	2	5	I	Start of timing input. TRIG < ½ CONT sets output high and discharge open
V_{CC}	8	20	–	Input supply voltage, 4.5 V to 16 V. (SE555 maximum is 18 V)

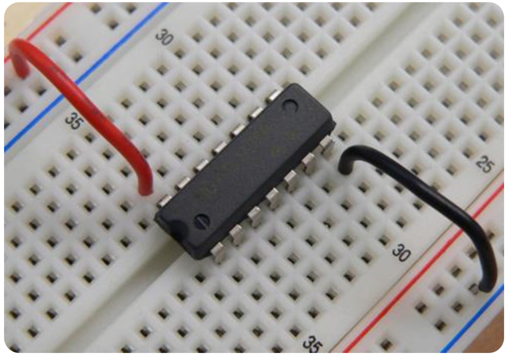
IC Packaging

- The actual semiconductor device is encased in **packaging**
  - The two main varieties of IC packaging are **surface mount** and **through-hole**
- **Surface mount packages** are mounted to the surface of a circuit board
  - These packages have **small leads** or **no leads** at all
  - Common subtypes are **SOIC** and **SOP** packages

IC Packaging (Cont'd)

- **Through-hole packages** have leads which stick through one side of a circuit board and are soldered onto the pads of the board's other side
  - We use a common subtype of through-hole packaging called the **Dual In-line Package** or **DIP**
    - DIP ICs can be **placed on the channel** of a standard breadboard





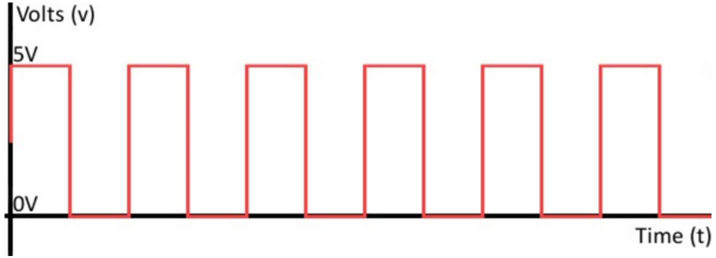
SECTION VI

555 Timer IC

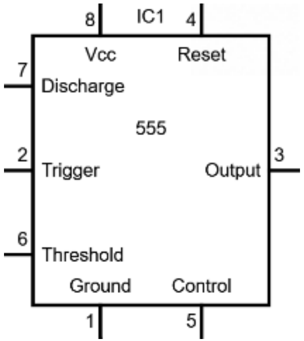
555 Timer IC

- The **555 Timer** is a chip used in various modes as a timer, pulse generator, wave oscillator, and an analog-to-digital signal converter
- In this course, the 555 Timer will be used in **astable mode** to generate an **oscillating digital wave**

555 Timer DIP Package



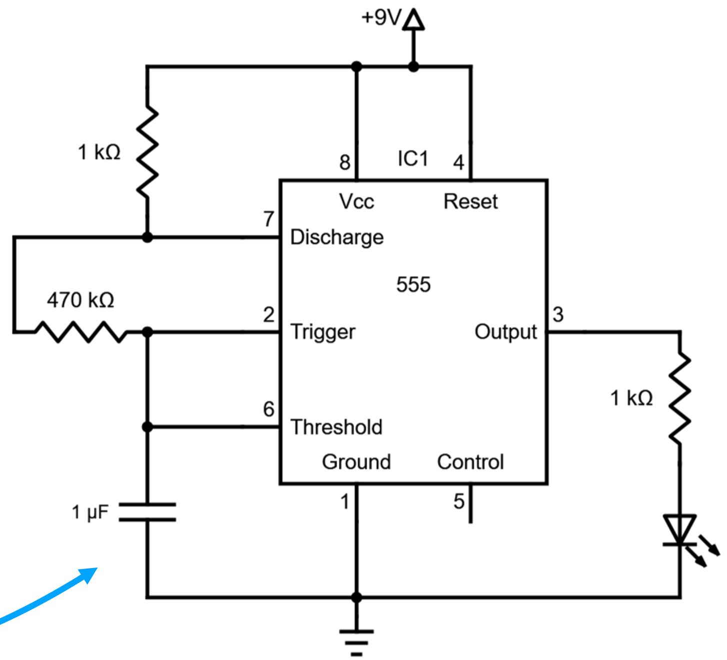
Oscillating Digital Waveform



555 Timer Schematic Symbol

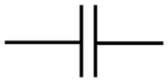
Blinking LED Circuit

- To further examine the astable-mode behavior of the 555 Timer, we will use it in a **blinking LED circuit** as an example
- The function of the the circuit is to **cycle an LED** ON and OFF at a constant frequency
- The circuit's timing relies on a **capacitor**



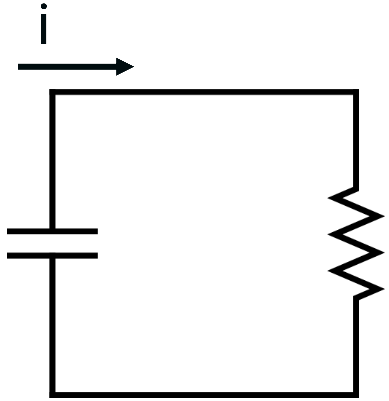
Capacitors

- A capacitor stores electrical energy which it charges and discharges
    - The ability of a capacitor to store energy is its **capacitance**, measured in **Farads** (**F**)
- Unlike a battery, a capacitor can only briefly store a small amount of energy
- When a capacitor is connected to a voltage source, it charges until it reaches the **same voltage** as the voltage source



RC Circuit

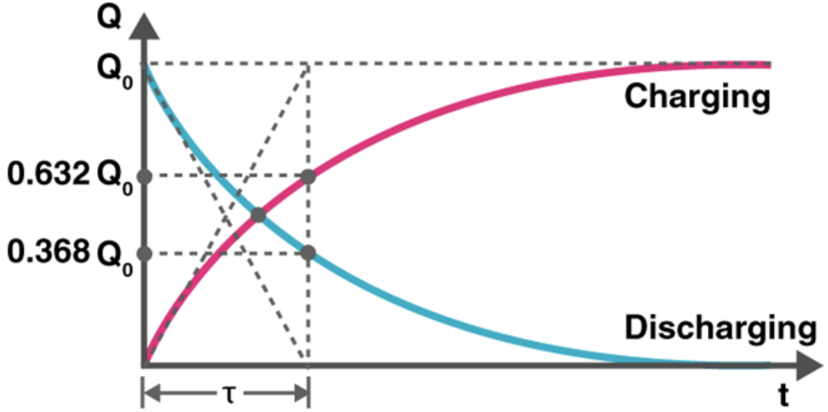
- Consider a simple circuit with a resistor and capacitor in series (a **resistor-capacitor** or **RC circuit**):
  - When the circuit is first closed, the fully-charged capacitor discharges its stored energy through the resistor
  - The values of the **capacitor** and **resistor** affect the time it takes to discharge the capacitor
    - The same is true for when the capacitor is charged by a voltage source



RC Circuit (Cont'd)

$$\tau = RC$$

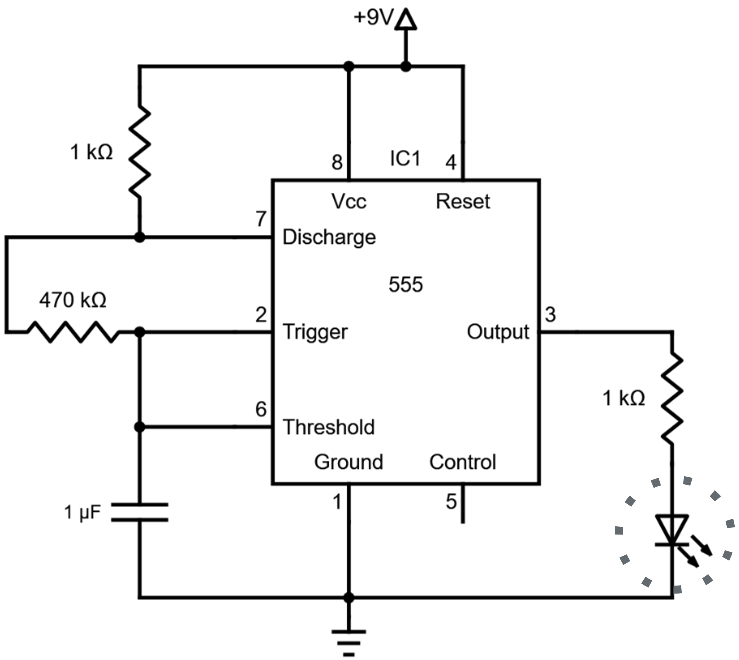
- The time it takes for the capacitor to climb from 0% to 63% of the full charge is the **same** as the time it takes for the capacitor to discharge from 100% to 37% charge
- That time, **τ** (**tau**), is the **product of resistance and capacitance** in the RC circuit



Blinking LED Circuit (Cont'd)

How It Works

1) The 555 timer **turns ON the LED** when the capacitor is below 33% or **1/3 charge**
2) The chip **charges** the capacitor to a **threshold** point of 2/3 (around 67%)
3) The chip **turns OFF the LED** when the capacitor is above 67% or **2/3 charge**
4) The chip **discharges** the capacitor until it reaches the **trigger** point of 1/3 charge



Blinking LED Circuit (Cont'd)

How It Works

1) The 555 timer **turns ON the LED** when the capacitor is below 33% or **1/3 charge**

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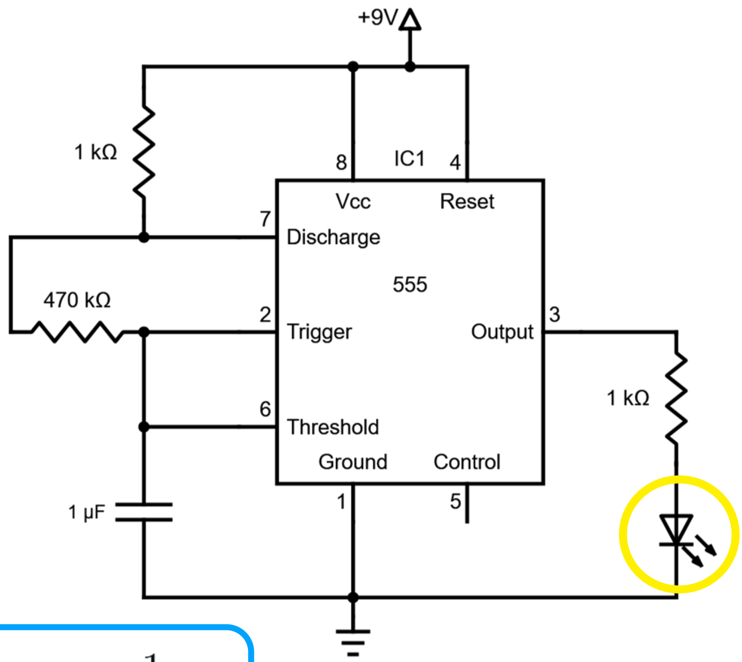

$$V_{cap} < \frac{1}{3}V_{cc}$$

Blinking LED Circuit (Cont'd)

How It Works

1) The 555 timer **turns ON the LED** when the capacitor is below 33% or **1/3 charge**
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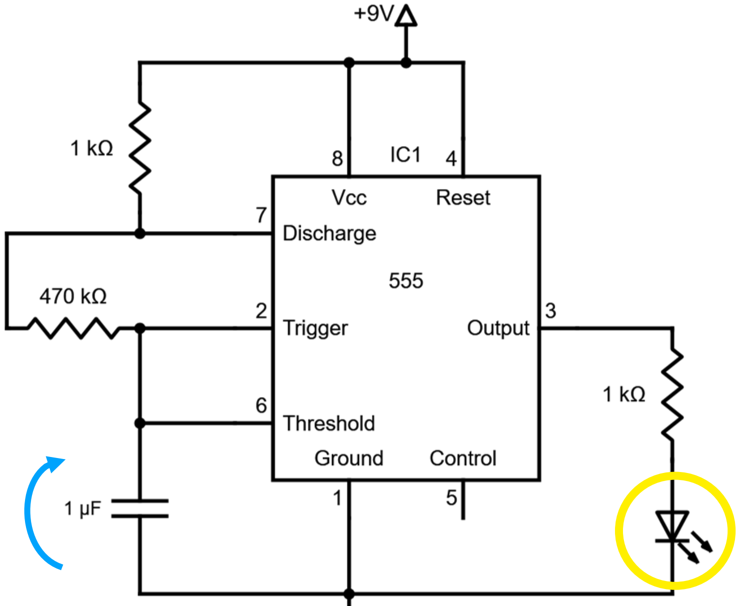

$$\frac{1}{3}V_{cc} \leq V_{cap} \leq \frac{2}{3}V_{cc}$$

Blinking LED Circuit (Cont'd)

How It Works

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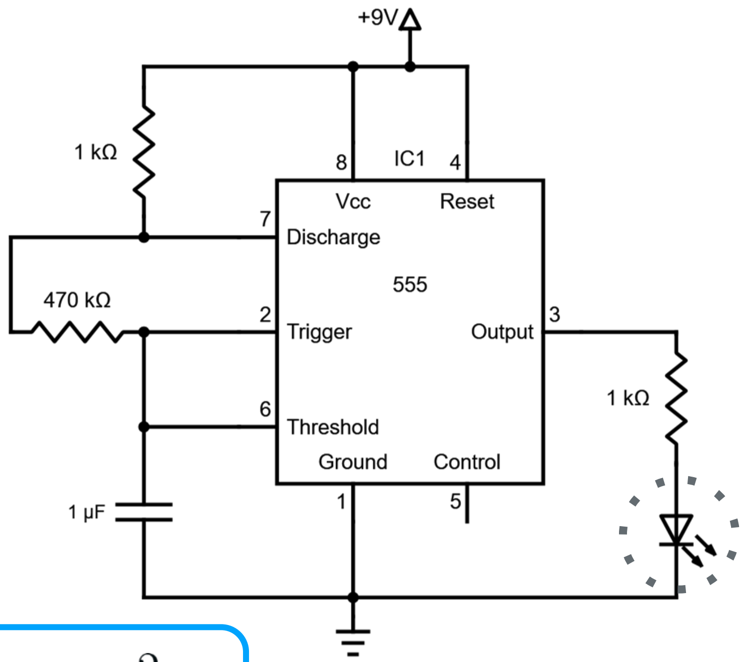

$$V_{cap} > \frac{2}{3}V_{cc}$$

Blinking LED Circuit (Cont'd)

How It Works

1) The 555 timer **turns ON the LED** when the capacitor is below 33% or **1/3 charge**
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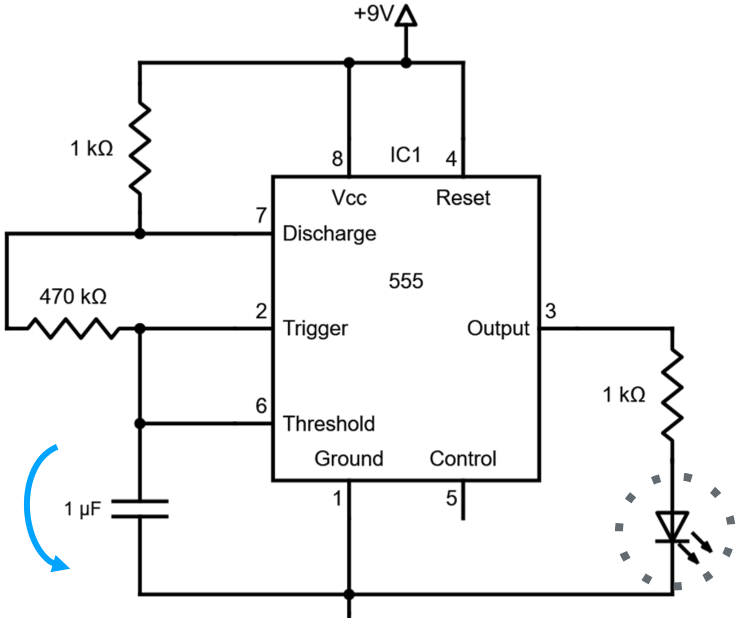

$$\frac{1}{3}V_{cc} \leq V_{cap} \leq \frac{2}{3}V_{cc}$$

Blinking LED Circuit (Cont'd)

How It Works

1) **The 555 timer turns ON the LED when the capacitor is below 33% or 1/3 charge**
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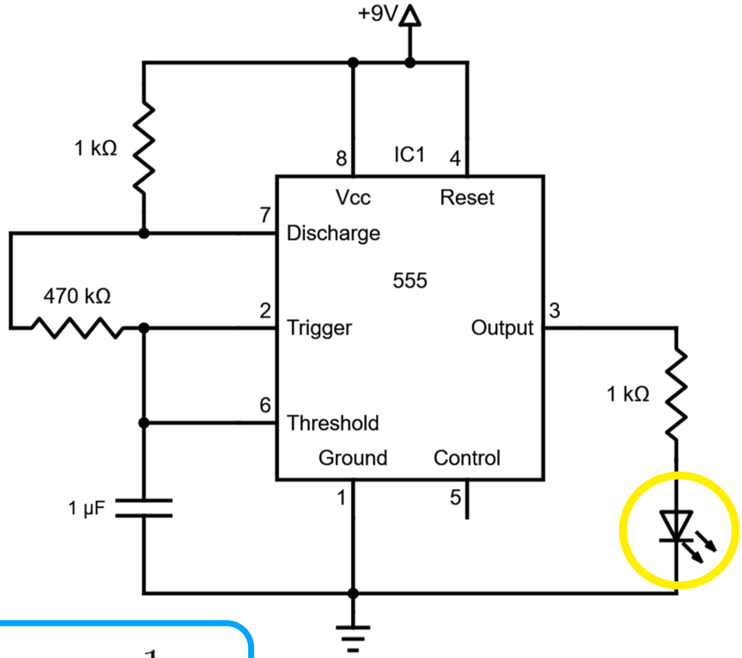


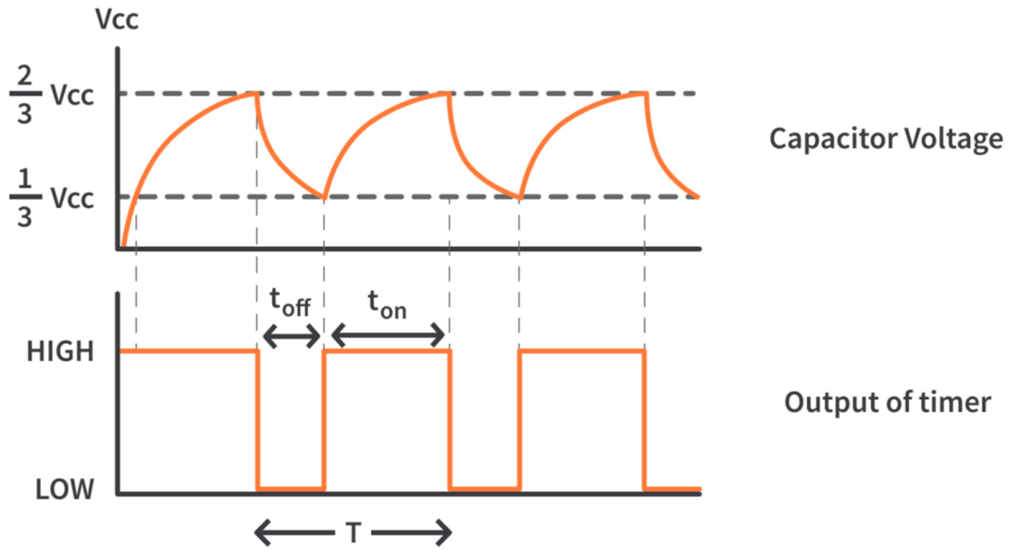
$$\boxed{V_{cap} < \frac{1}{3}V_{cc}}$$

Blinking LED Circuit (Cont'd)

Timing Diagram

- As the capacitor charges…
  - Output = **HIGH** voltage
- As the capacitor discharges…
  - Output = **LOW** voltage

- The output waveform is a **rectangular wave**

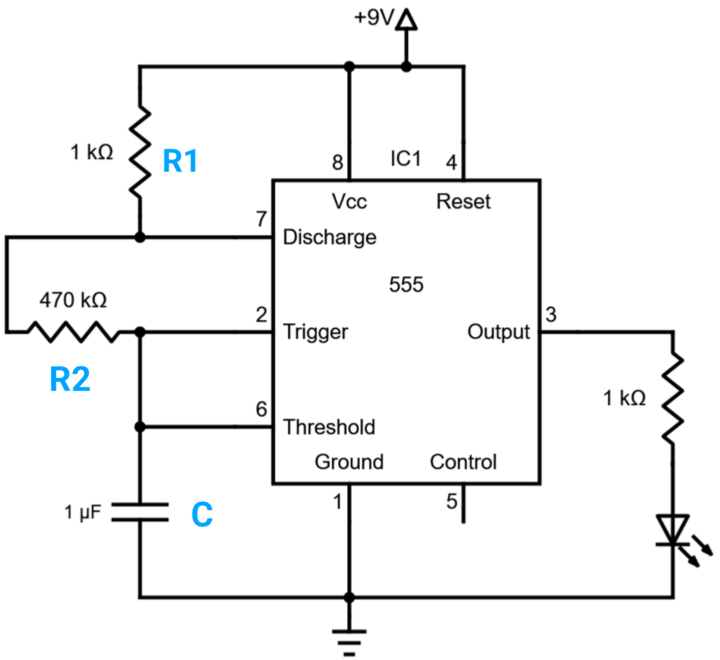


Blinking LED Circuit (Cont'd)

Timing Formula

$$t_{on} = 0.69 \cdot C \cdot (R_1 + R_2)$$
$$t_{off} = 0.69 \cdot C \cdot R_2$$

t_{on} : Length of high output pulse in seconds
t_{off} : Length of low output pulse in seconds
R_1 : Resistance of R_1 in Ohms
R_2 : Resistance of R_2 in Ohms
C : Capacitance of C in $Farads$

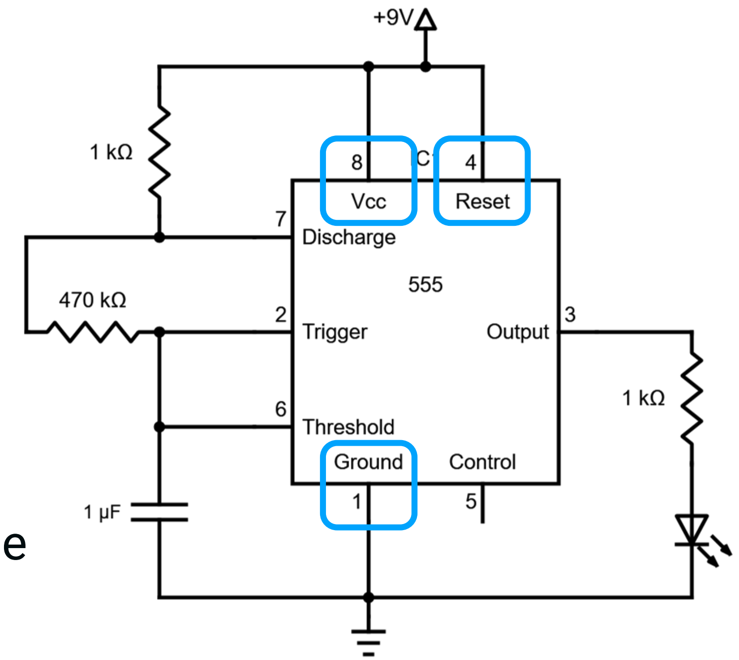


Blinking LED Circuit (Cont’d)

555 Timer Pin Layout

- Pin 8: **Power (Vcc)**
- Pin 1: **Ground (GND)**
  - **Vcc** and **GND** are connected to the terminals of the 9V source

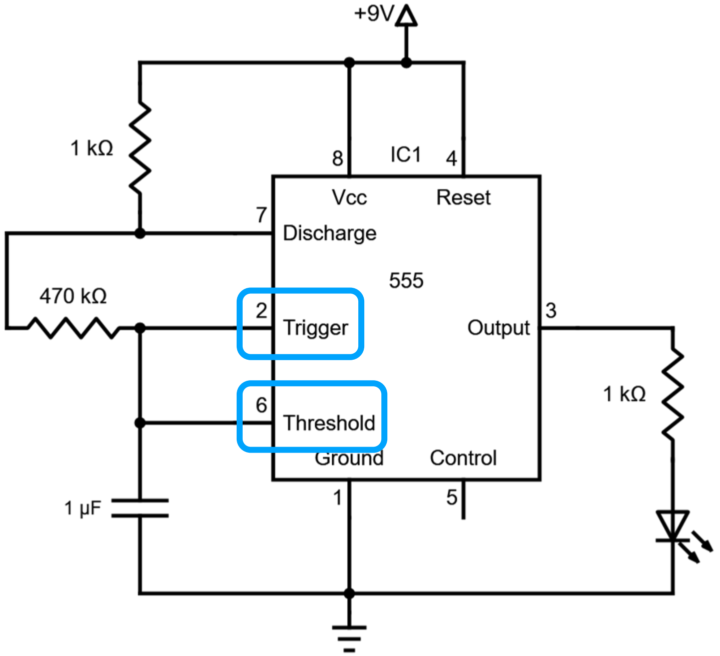
- Pin 4: **Reset (RST)**
  - Restarts the timer when at a LOW voltage
  - We connect the pin to the 9V source so that it never restarts



Blinking LED Circuit (Cont'd)

555 Timer Pin Layout

- Pin 2: **Trigger (TRIG)**
  - **Turns ON the Output pin** when the voltage across the capacitor drops below 1/3 Vcc
- Pin 6: **Threshold (THRS)**
  - **Turns OFF the Output** pin when the voltage across the capacitor reaches above 2/3 Vcc

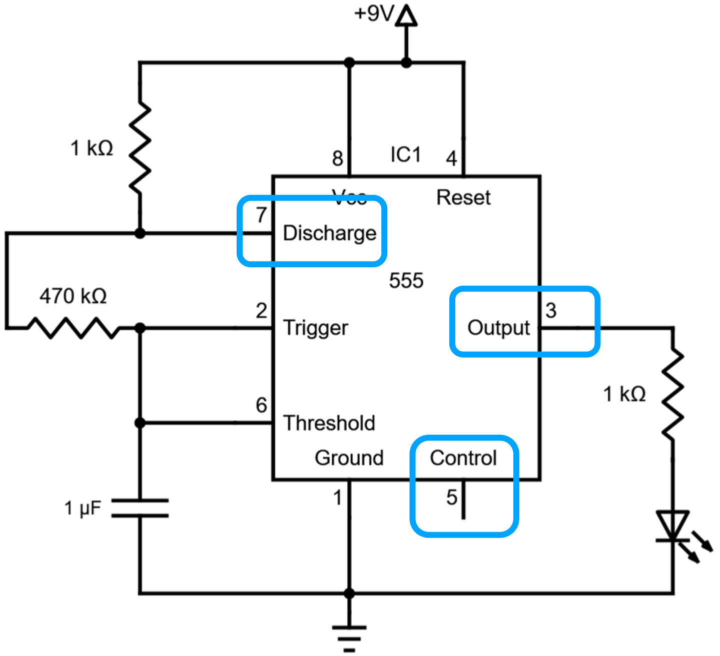


The **Trigger** and **Threshold** pins are at the same node

Blinking LED Circuit (Cont'd)

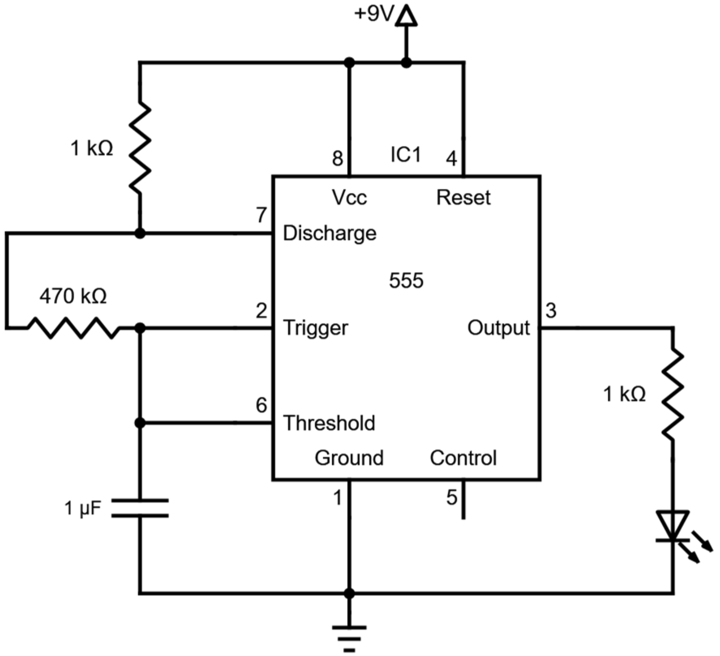
555 Timer Pin Layout

- Pin 3: **Output** (**OUT**)
  - Outputs only HIGH or LOW voltage
- Pin 5: **Control Voltage** (**CV**)
  - Controls the threshold and trigger levels, which are 2/3 and 1/3 Vcc, respectively, by default
- Pin 7: **Discharge** (**DIS**)
  - Discharges capacitor when the Output pin is LOW



Blinking LED Circuit (Cont'd)

- It is absolutely normal if you don't understand the circuit just yet
- **Review the slides** again and **begin the accompanying project** to solidify your understanding



Please submit questions about the lecture content.

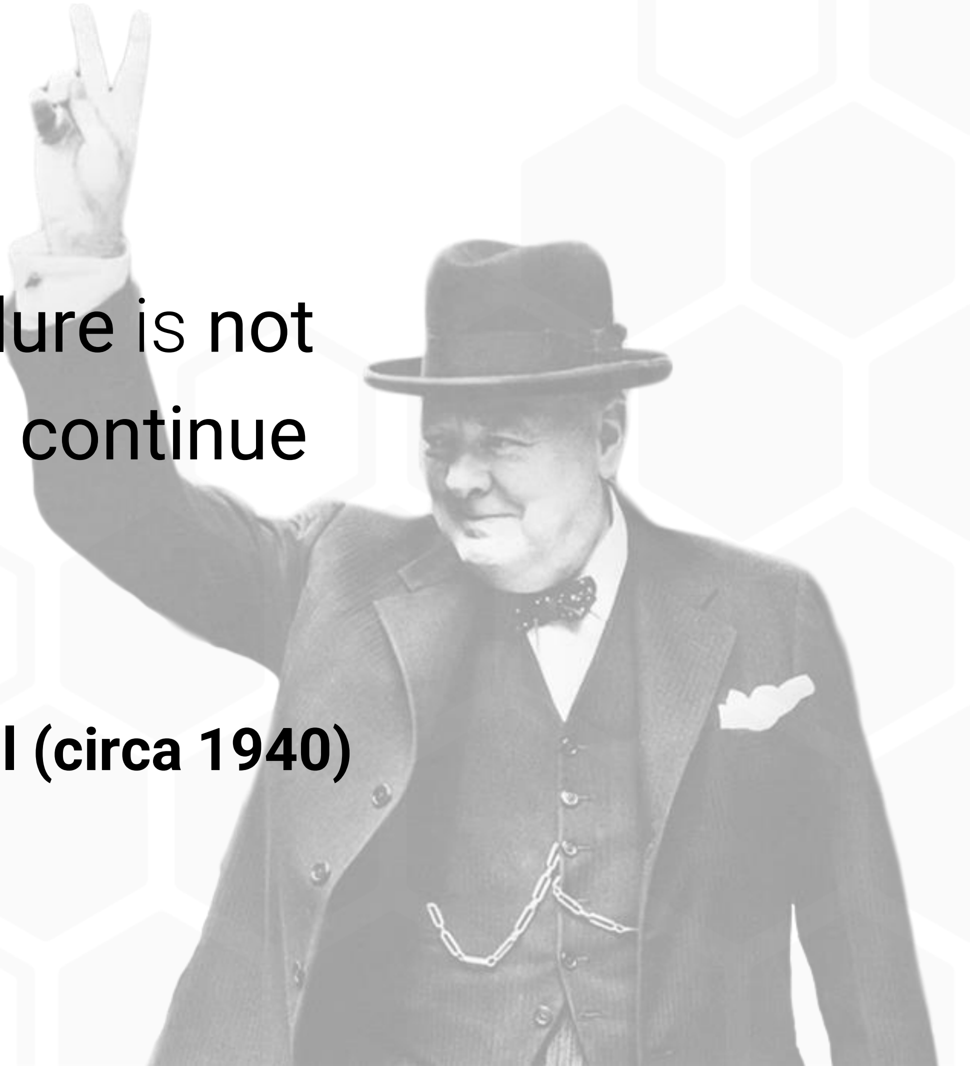
Nobody has responded yet.

Hang tight! Responses are coming in.

"Success is not final, failure is not fatal: it is the courage to continue debugging that counts."

Winston Churchill (circa 1940)

Famous Misquotes



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