LECTURE II

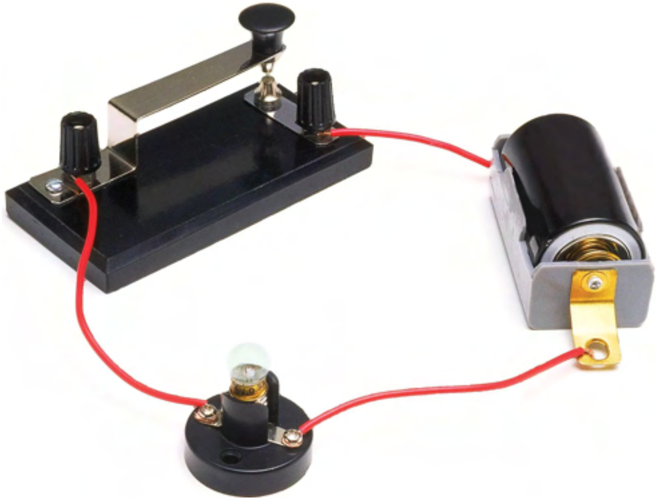
Integrated Circuits & Troubleshooting Equipment and Techniques

SECTION I

Circuit Topology

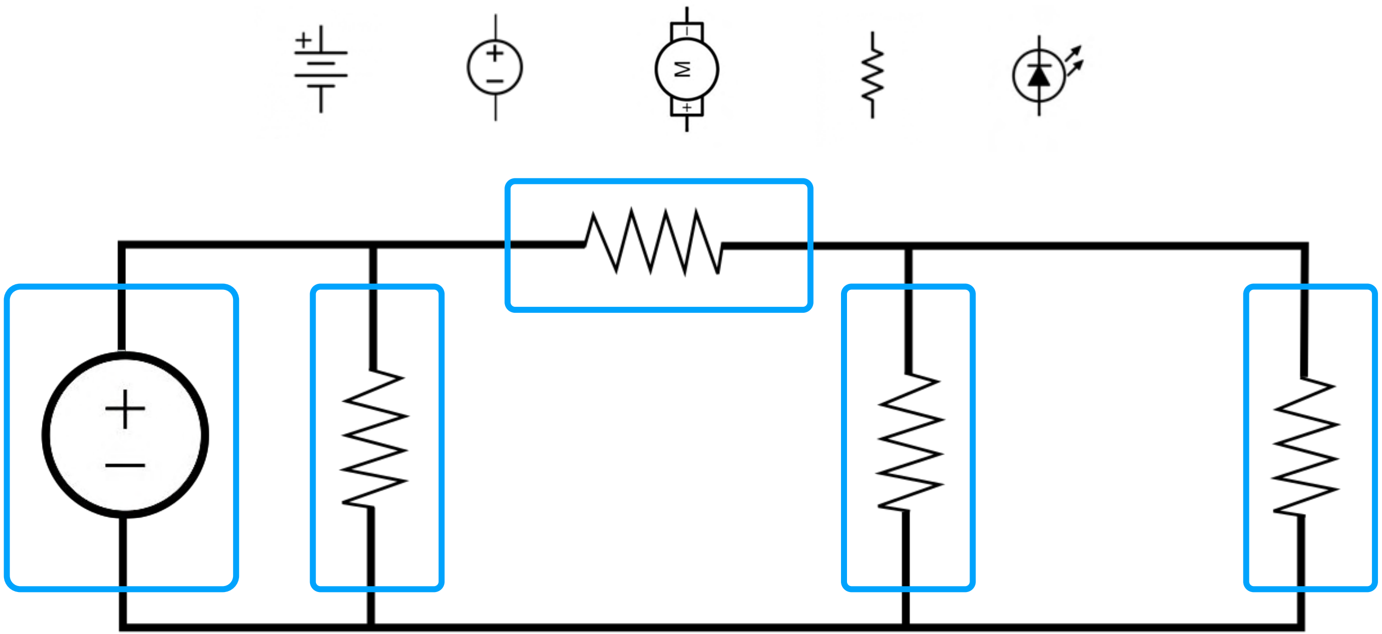
Circuits

- 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



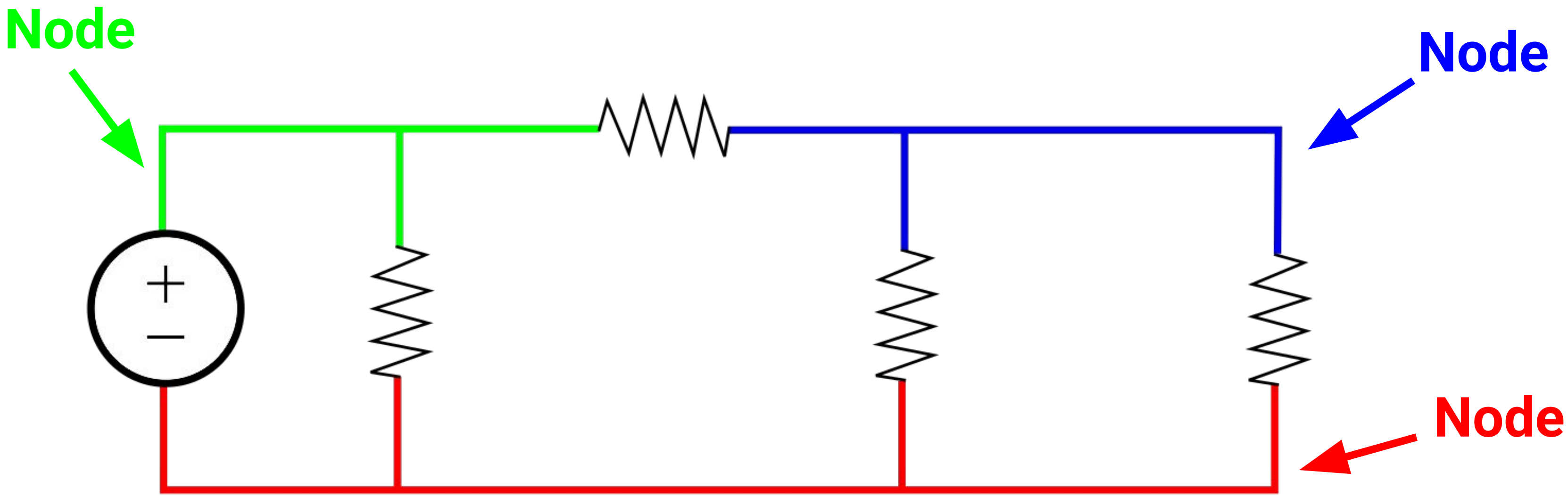
Branches

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



Nodes

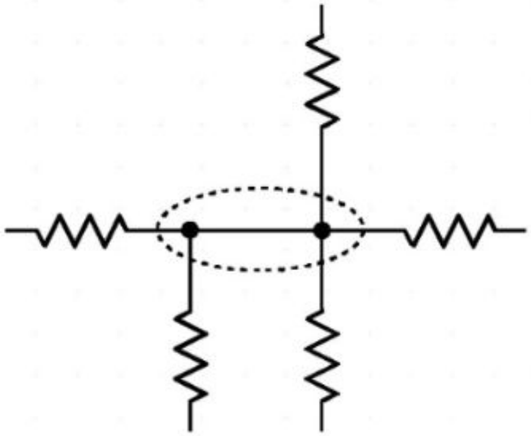
- A node is a **connection** between two or more **branches**
- All points on the **same node** have the **same voltage and current**



Nodes (Cont'd)

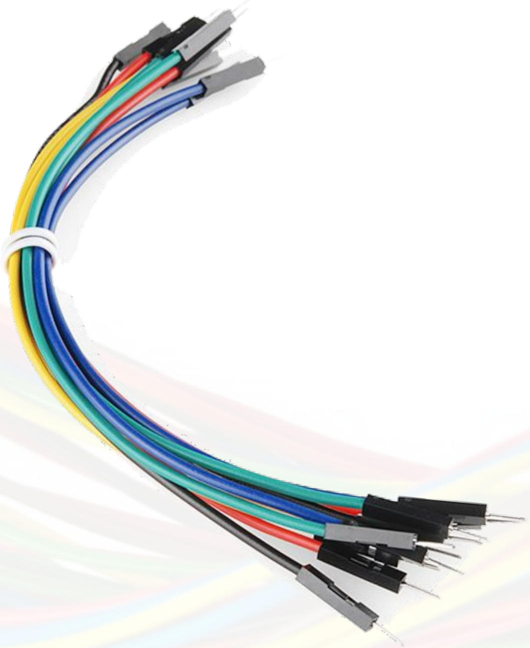
I/A

What is the voltage between these two points?



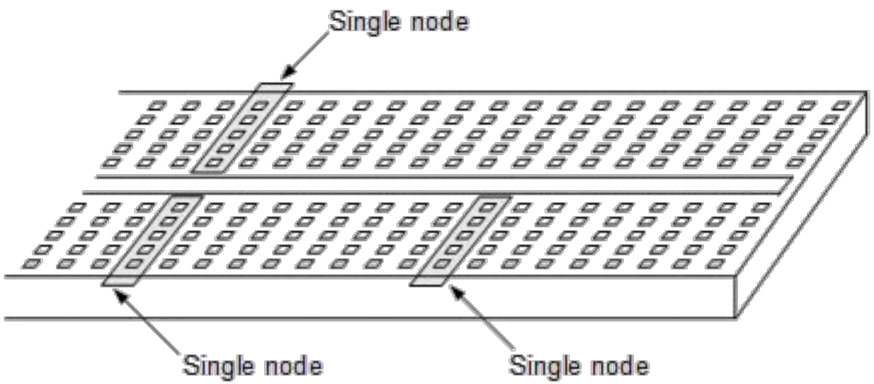
Nodes (Cont'd)

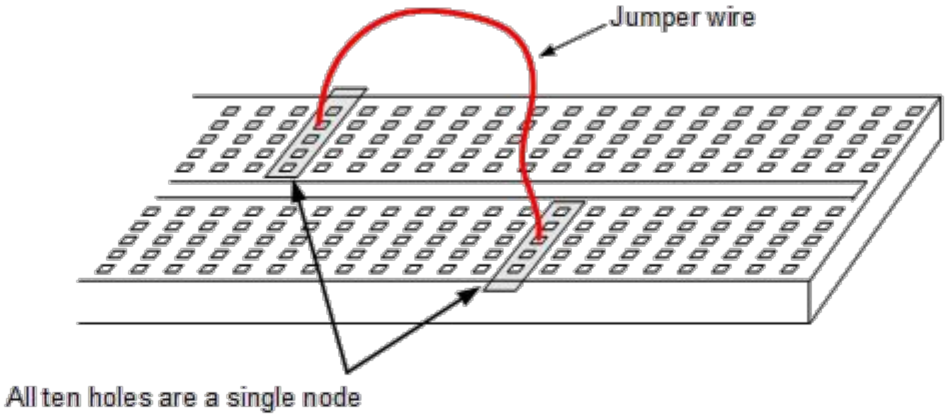
- **Wires** can be treated as **nodes**
  - .. if we assume that the wire has **no resistance** and there is **no voltage change** across the wire
    - This is acceptable for our course projects



Nodes (Cont’d)

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

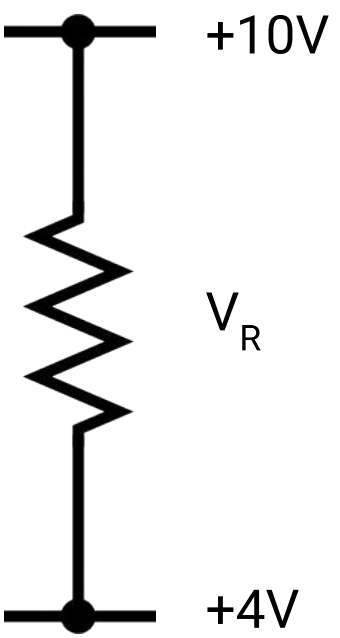




Voltage Drop

- **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

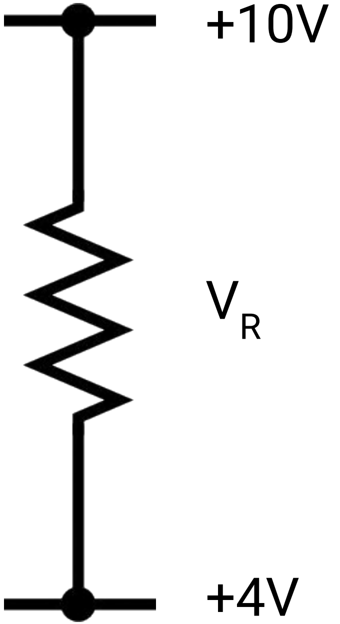
Calculating Voltage Drop



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

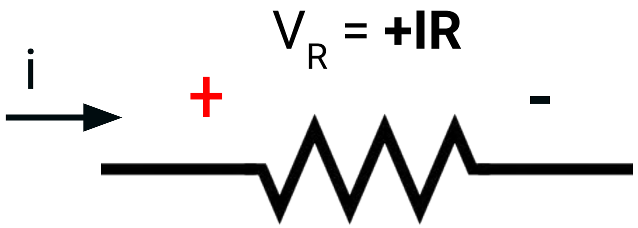
Let’s Pause and Discuss…

Voltage Drop Sign Convention

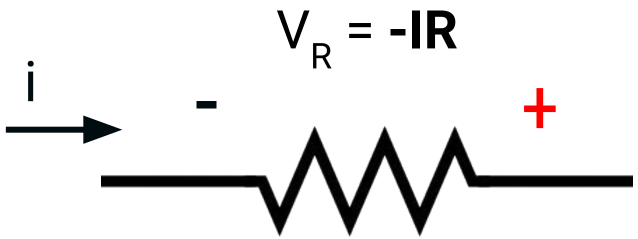
- In circuit analysis, **current direction** through a circuit and a voltage drop **reference polarity** are arbitrary
    - Ex) You can define the **reference polarity** of the resistor’s voltage drop to be either of the following:

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

Voltage Drop Sign Convention (Cont'd)

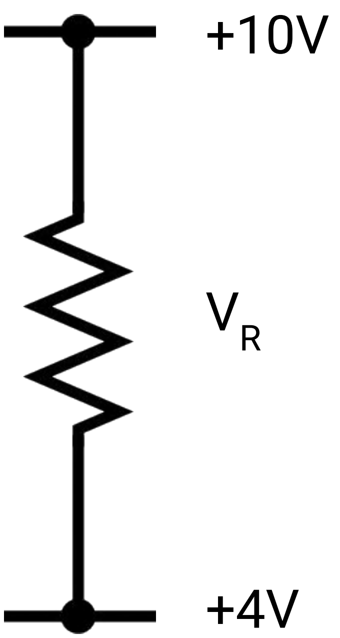


- The sign of the voltage drop is **positive** if current flows from **+** to **-** terminals



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

Calculating Voltage Drop (Cont'd)

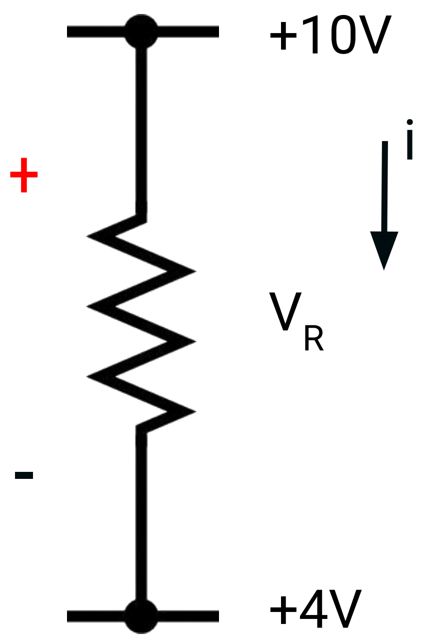


Find voltage drop $\mathbf{V_R}$

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)

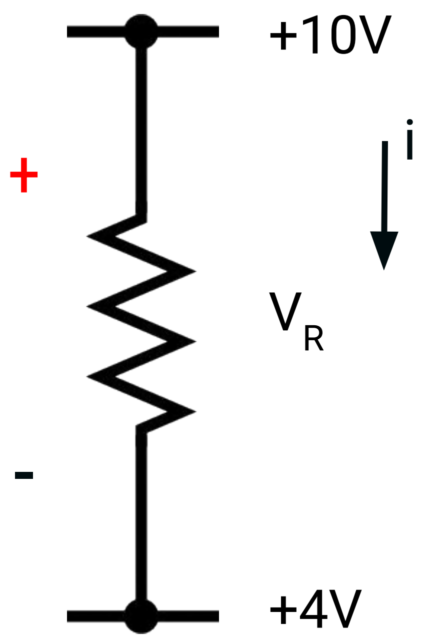


Find voltage drop $\mathbf{V_R}$

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)



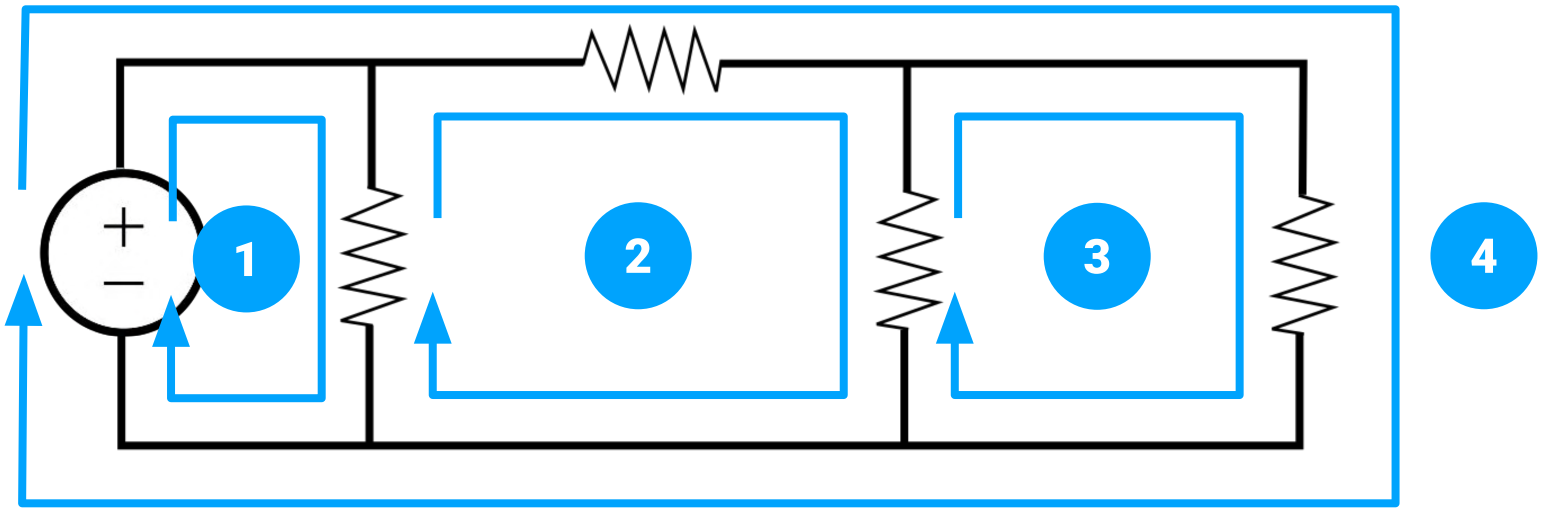
Find voltage drop V_R

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

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

Loops

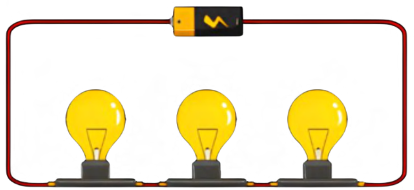
- A **loop** is a **closed path** through circuit elements
  - It starts at any node and ends at the same node
  - A loop does not pass through any node more than once



Series and Parallel Circuits

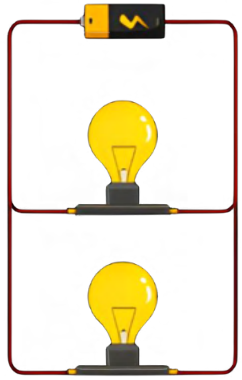
Series

- 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

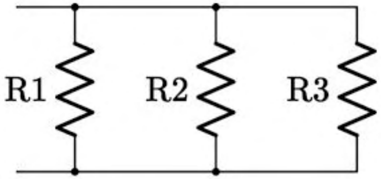


Series and Parallel Circuits

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

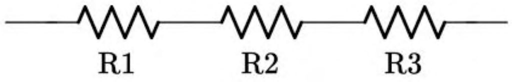
Parallel

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



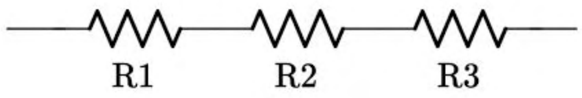
Series

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



Resistors in Series

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



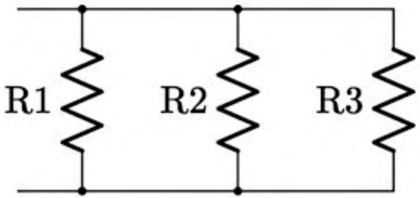
$$R_{eq} = R_1 + R_2 + R_3$$

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

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

Resistors in Parallel

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



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

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

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

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

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

SECTION II

Kirchhoff's Laws

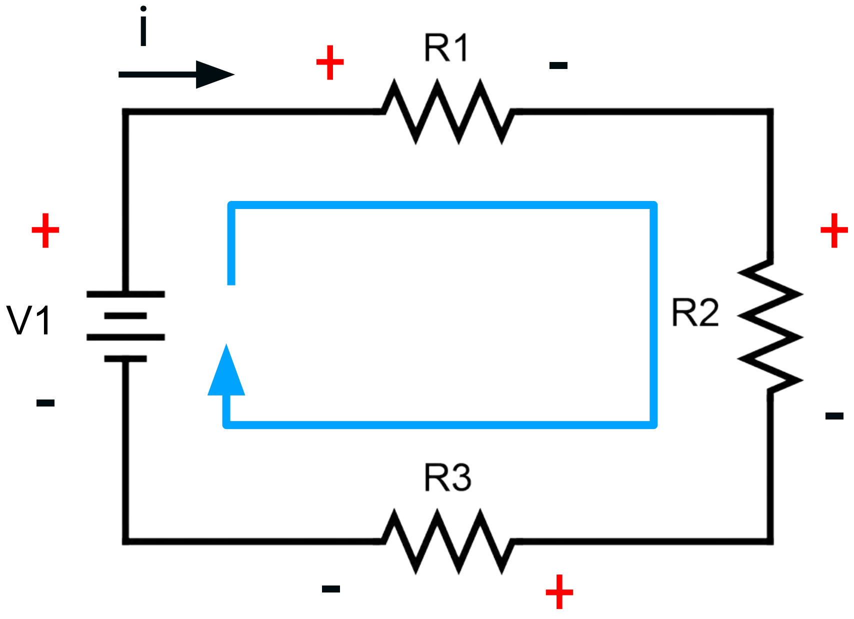
Kirchhoff's Voltage Law (KVL)

- 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

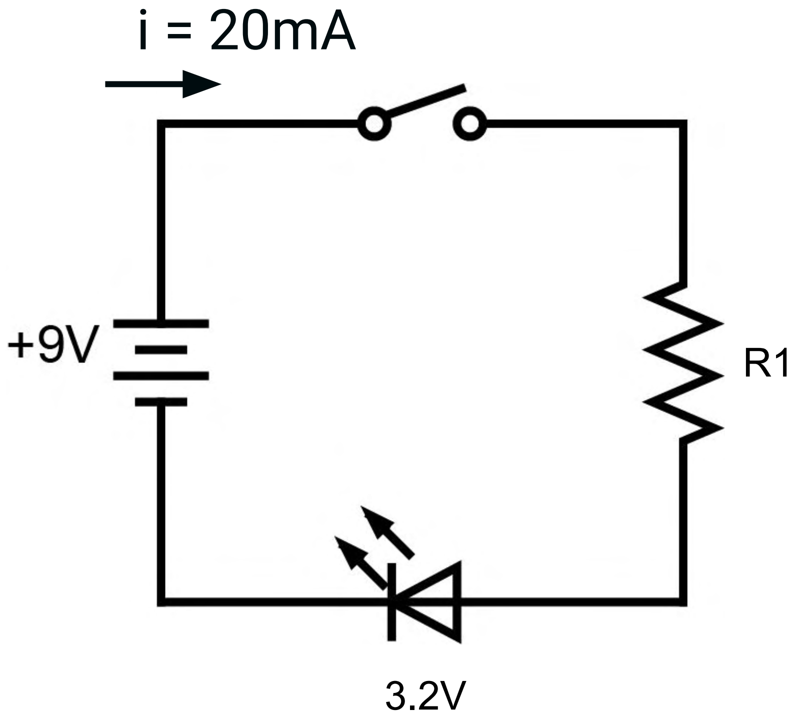
$$V_{R1} + V_{R2} + V_{R3} - V_1 = 0$$



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
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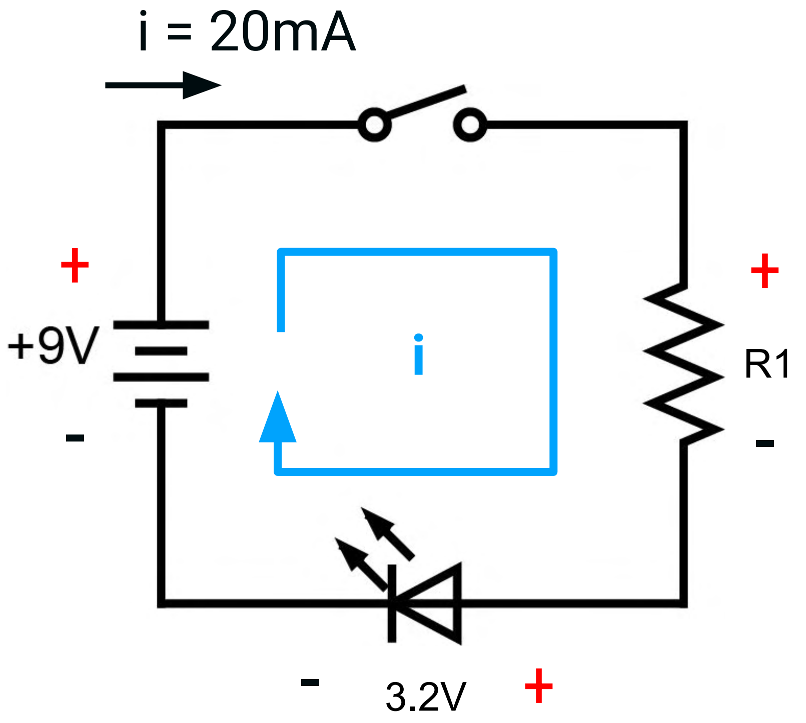


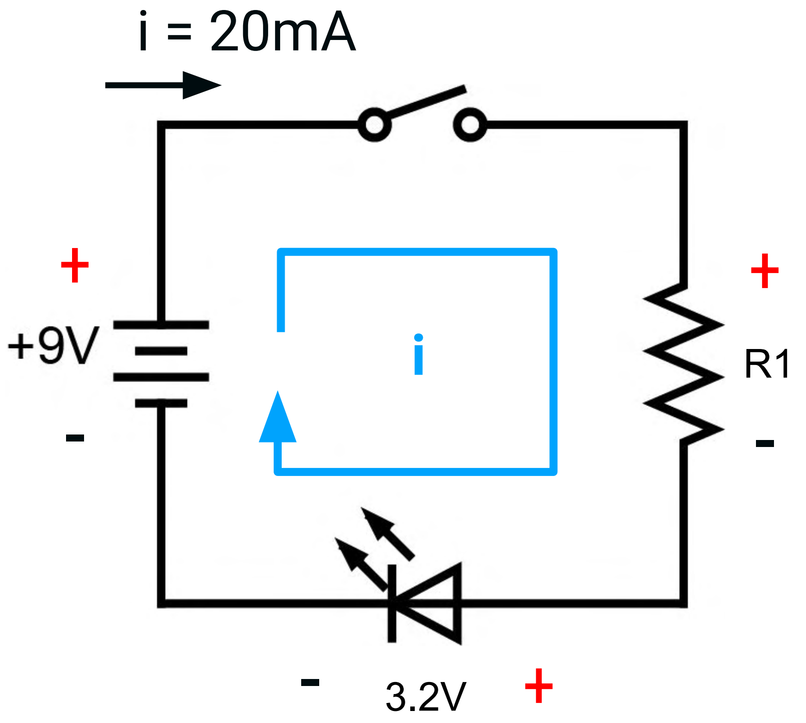
Assume the switch is **closed**

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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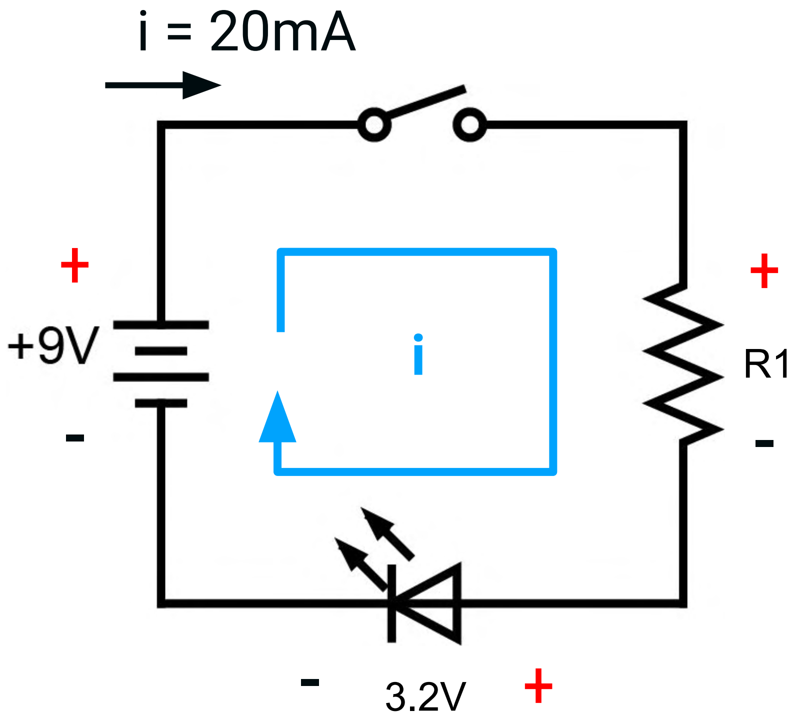


Assume the switch is **closed**

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

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**

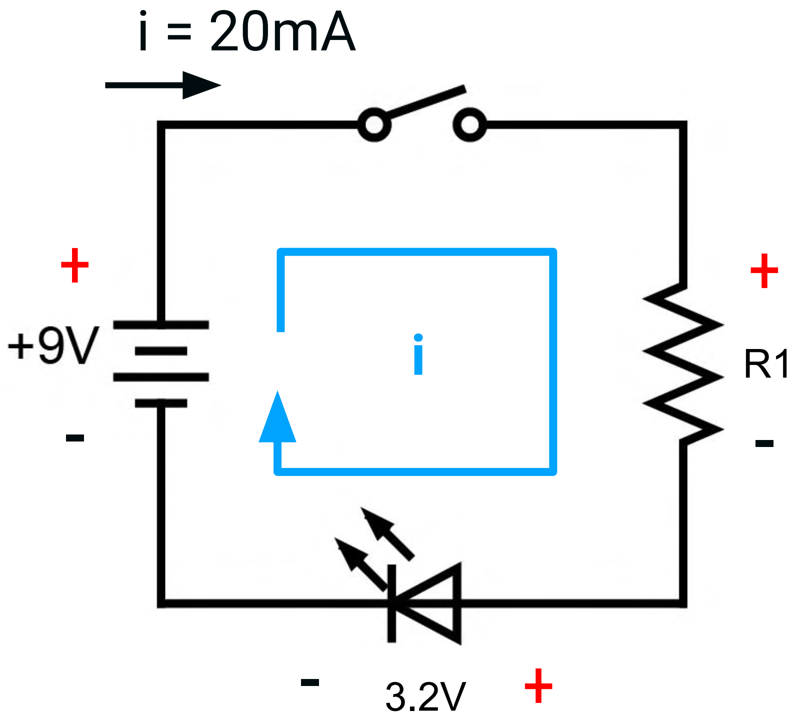
Ohm's Law

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

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

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

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

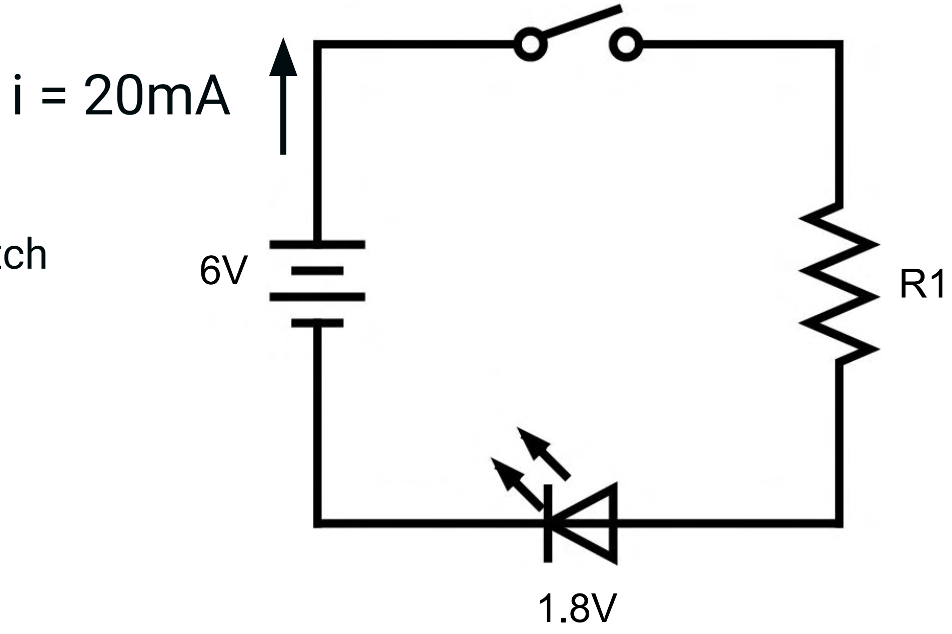


Assume the switch is **closed**

Applying KVL to a Single Loop

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

Assume the switch
is **closed**



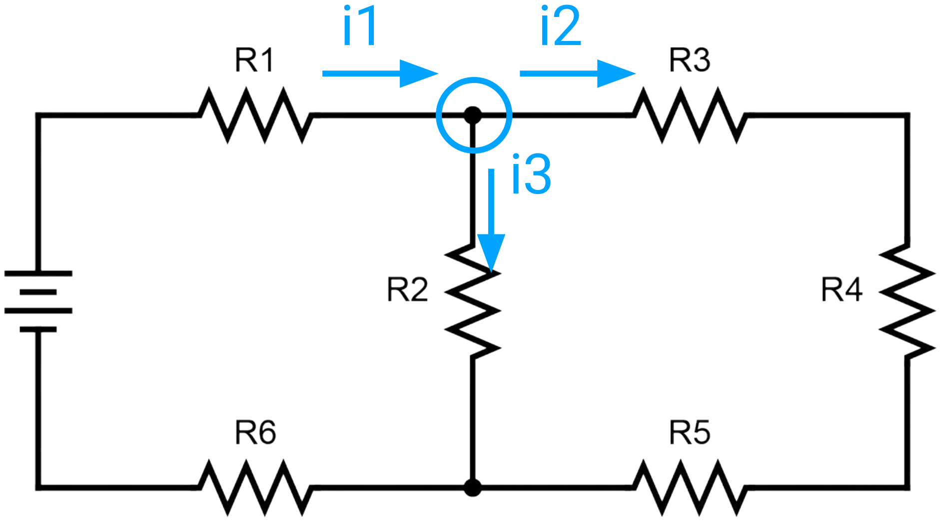
Kirchhoff's Current Law (KCL)

- 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

$$I1 = I2 + I3$$



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**

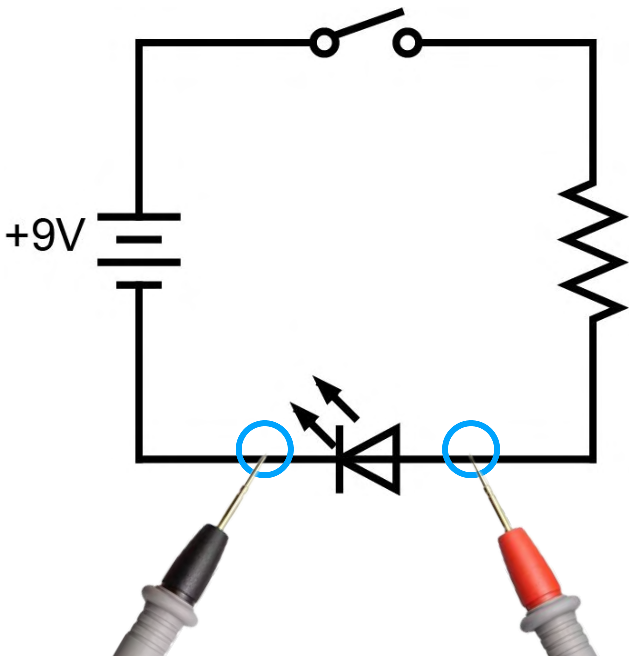
Measuring Voltage

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)

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



Measuring Resistance

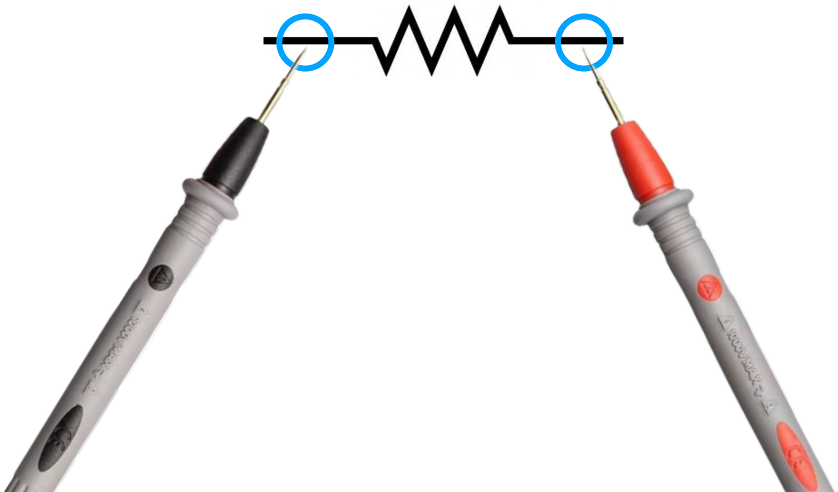
How to **measure resistance** with an auto-ranging multimeter:

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

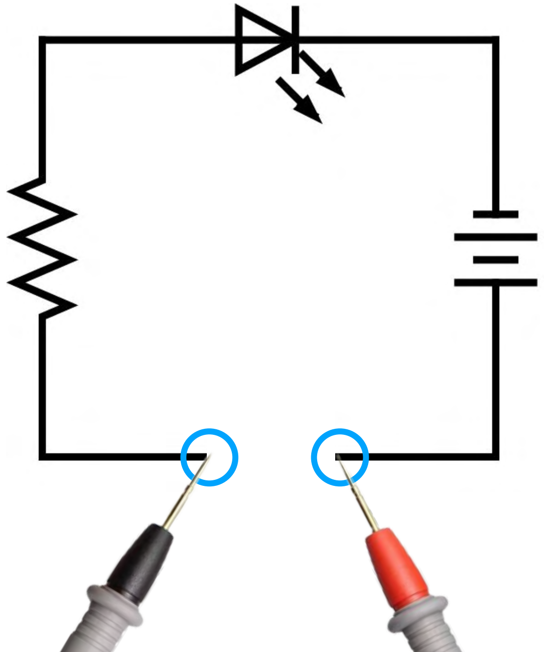
How to **measure DC current** with an auto-ranging multimeter:

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)

Measure the DC current across a simple LED circuit.

Calculate the expected current value and confirm it with the DMM



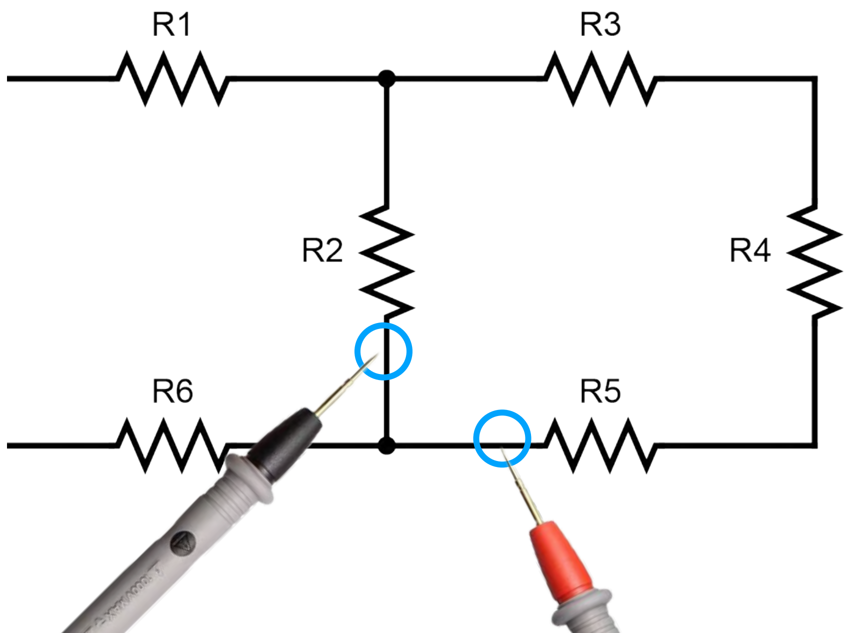
Testing Continuity

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:

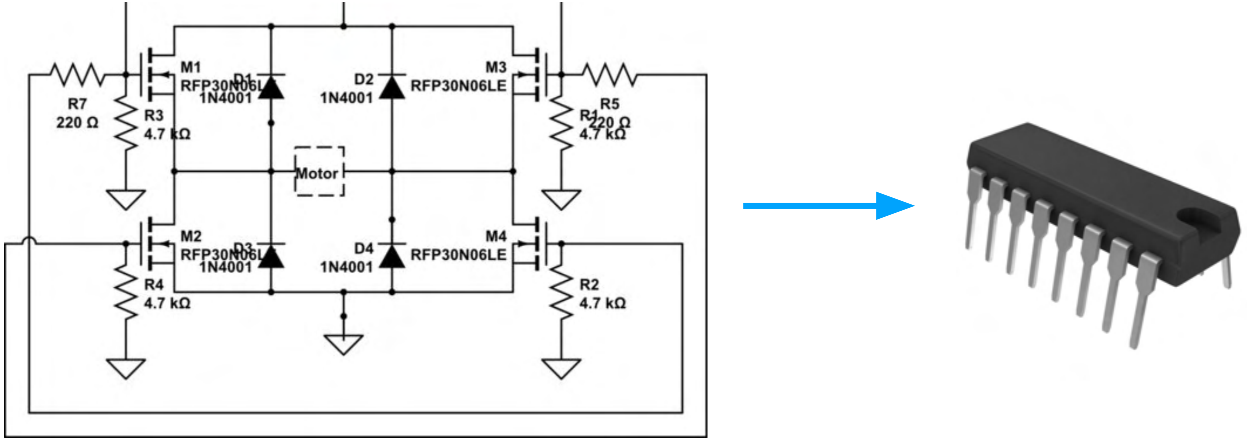
- Loose wire? Poor connection?
    1) Re-solder or replace connections as needed and test the circuit again
    2) If the circuit still fails, **test the connections again** with the multimeter. It’s possible to solder poorly on even the second or third try.

SECTION V

Integrated Circuits

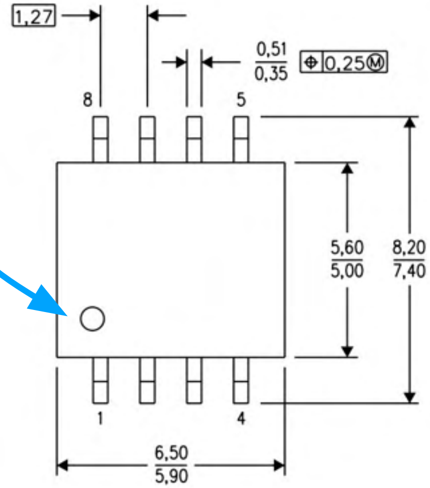
Integrated Circuits

- 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

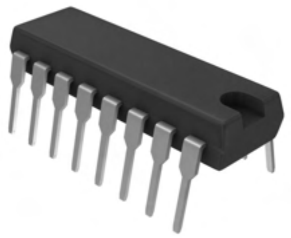
NAME	PIN NO. D, P, PS, PW, JG	PIN NO. FK	I/O	DESCRIPTION
CONT	5	12	I/O	Controls comparator thresholds, Outputs 2/3 VCC, allows bypass capacitor connection
DISCH	7	17	O	Open collector output to discharge timing capacitor
GND	1	2	–	Ground
NC		1, 3, 4, 6, 8, 9, 11, 13, 14, 16, 18, 19	–	No internal connection
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)

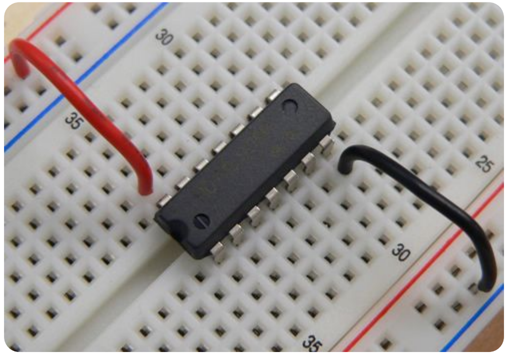
IC Packaging

- 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





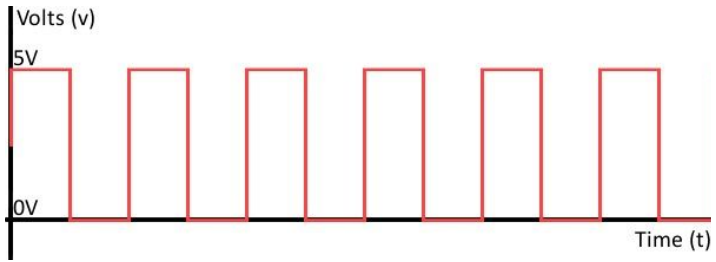
SECTION VI

555 Timer IC

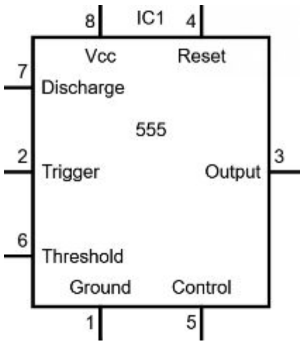
555 Timer IC

- 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



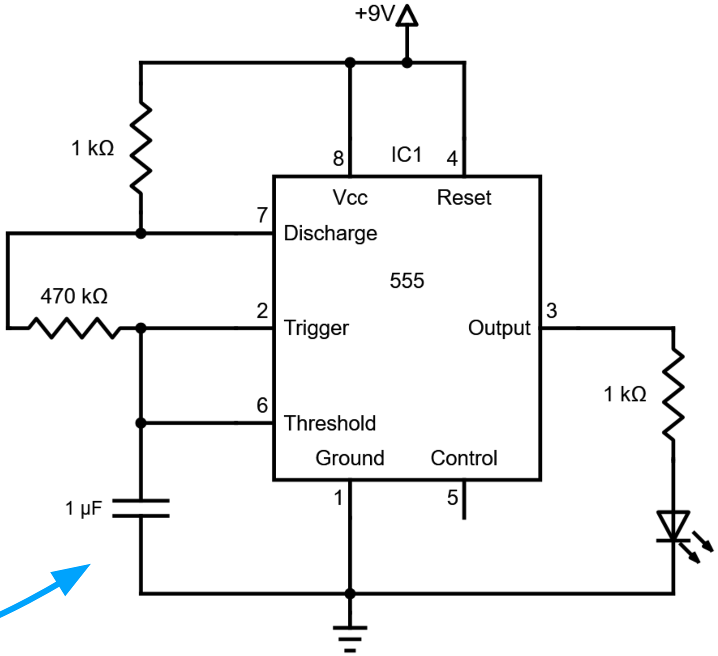
Oscillating Digital Waveform



555 Timer Schematic Symbol

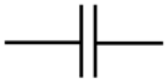
Blinking LED Circuit

- 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**



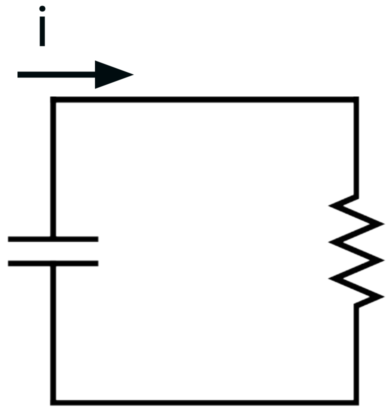
Capacitors

- 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

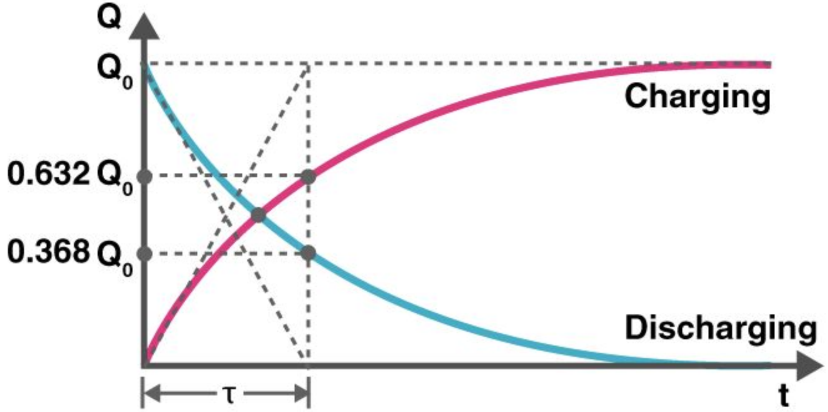
- Consider a simple circuit with a resistor and capacitor in series (a **resistor-capacitor** or **RC circuit**):
  - When the circuit is first closed, the fully-charged capacitor discharges its stored energy through the resistor
  - The values of the **capacitor** and **resistor** affect the time it 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)

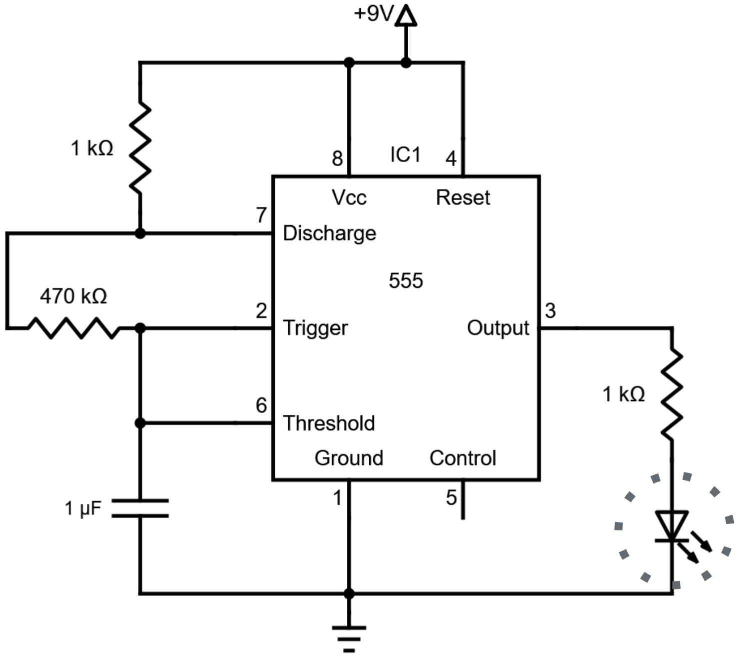
How It Works

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)

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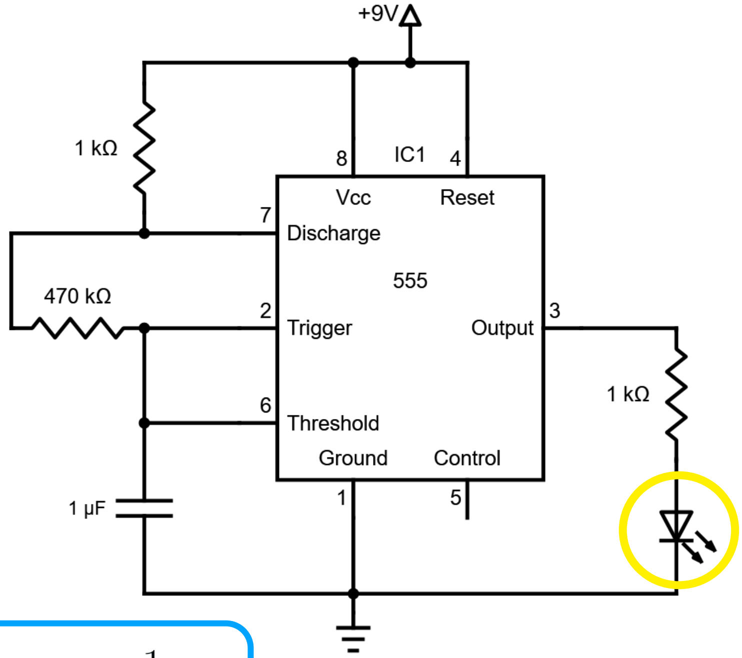

$$V_{cap} < \frac{1}{3}V_{cc}$$

Blinking LED Circuit (Cont'd)

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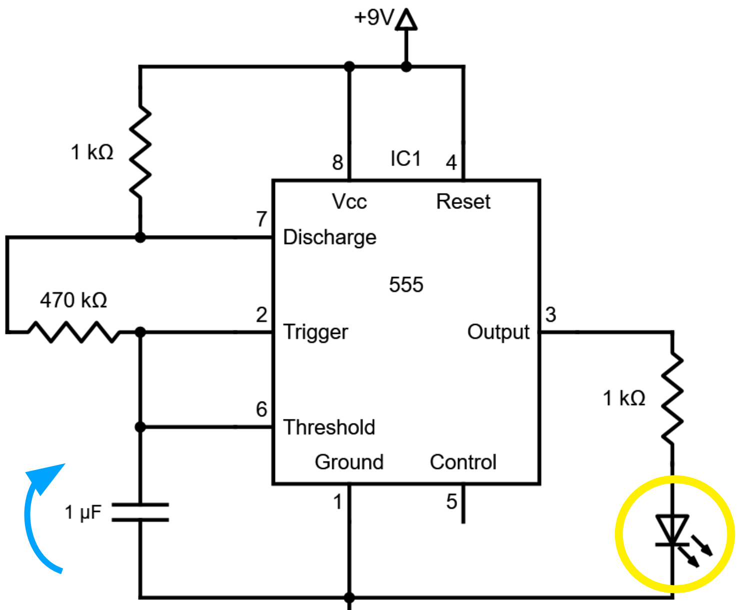

$$\frac{1}{3}V_{cc} \leq V_{cap} \leq \frac{2}{3}V_{cc}$$

Blinking LED Circuit (Cont'd)

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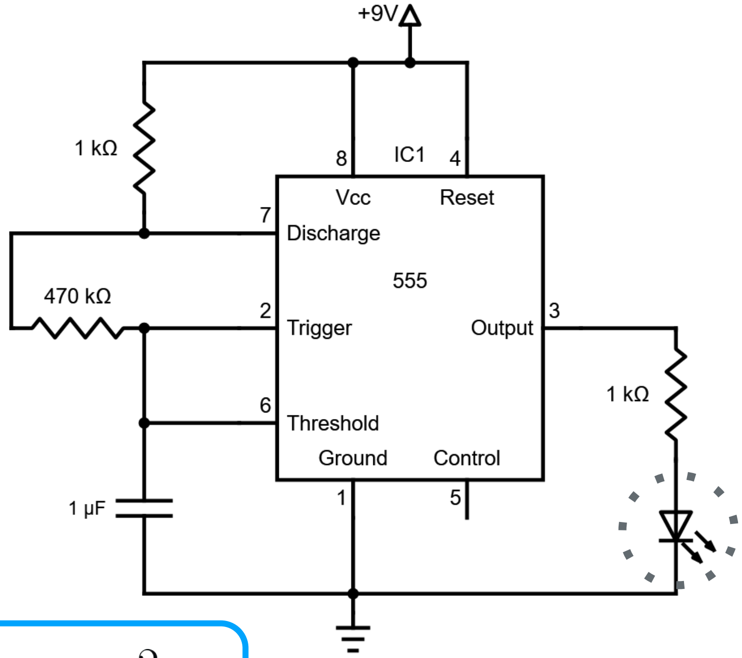

$$V_{cap} > \frac{2}{3} V_{cc}$$

Blinking LED Circuit (Cont'd)

How It Works

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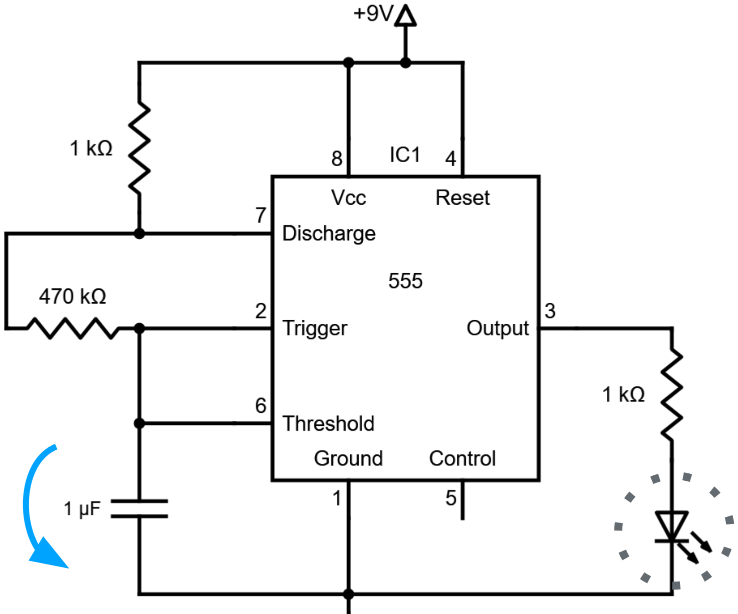

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Blinking LED Circuit (Cont'd)

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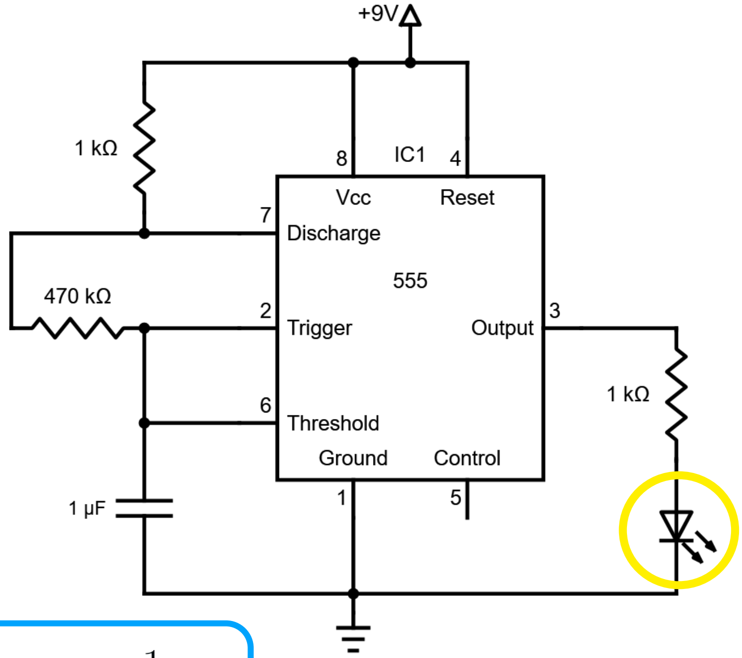


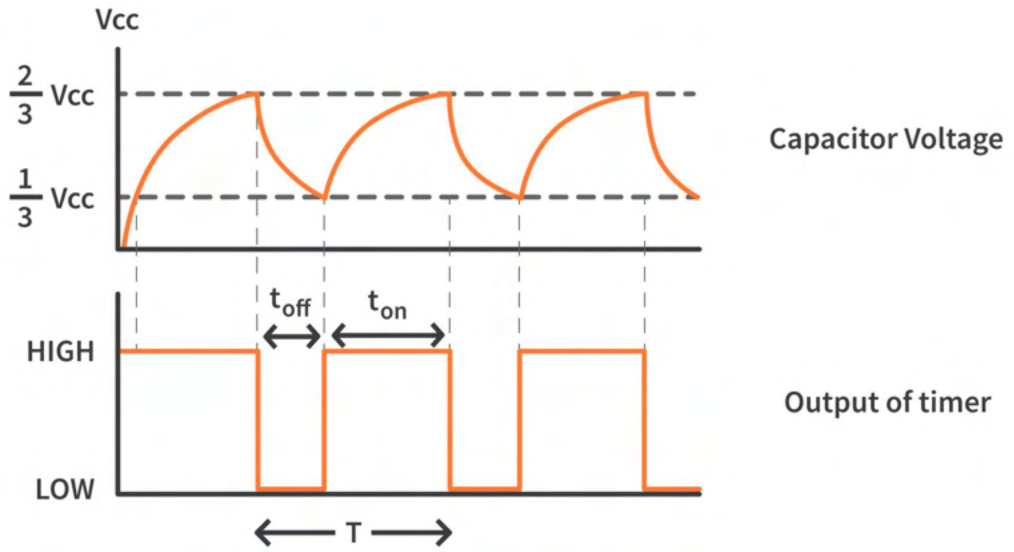
$$V_{cap} < \frac{1}{3} V_{cc}$$

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

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

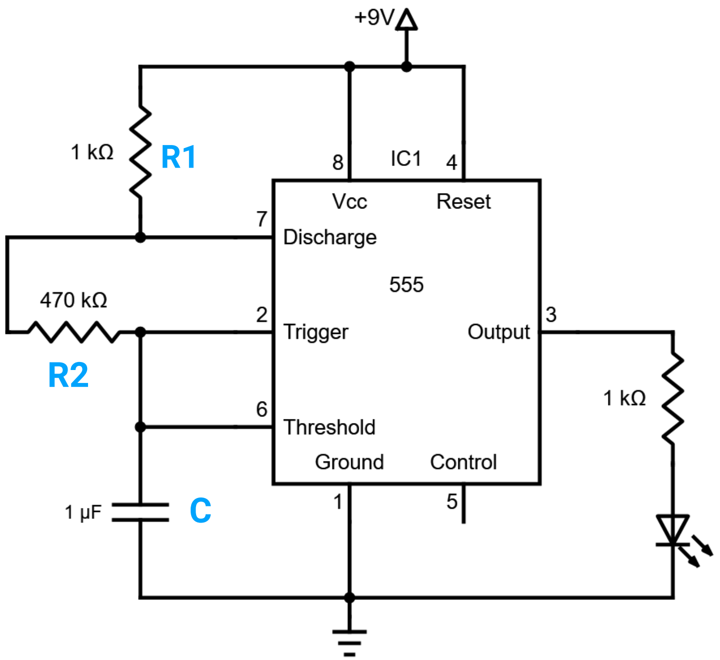
t_{on} : Length of high output pulse in seconds

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 $Farads$

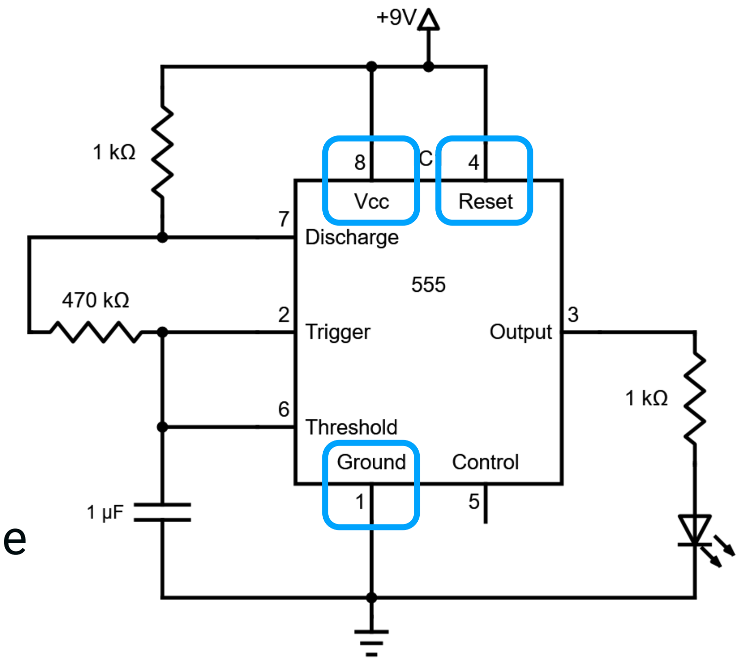


Blinking LED Circuit (Cont'd)

555 Timer Pin Layout

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

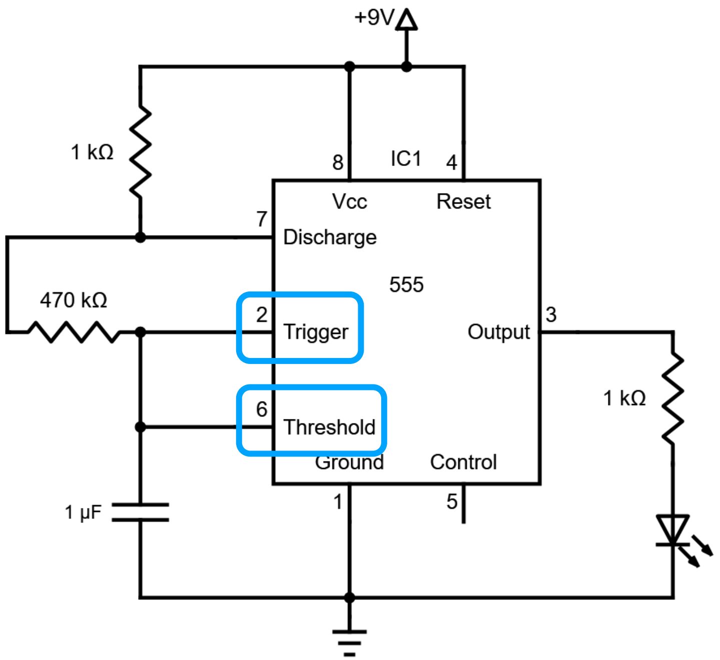
- Pin 4: **Reset (RST)**
  - Restarts the timer when at a LOW voltage
  - We connect the pin to the 9V source so that it never restarts



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

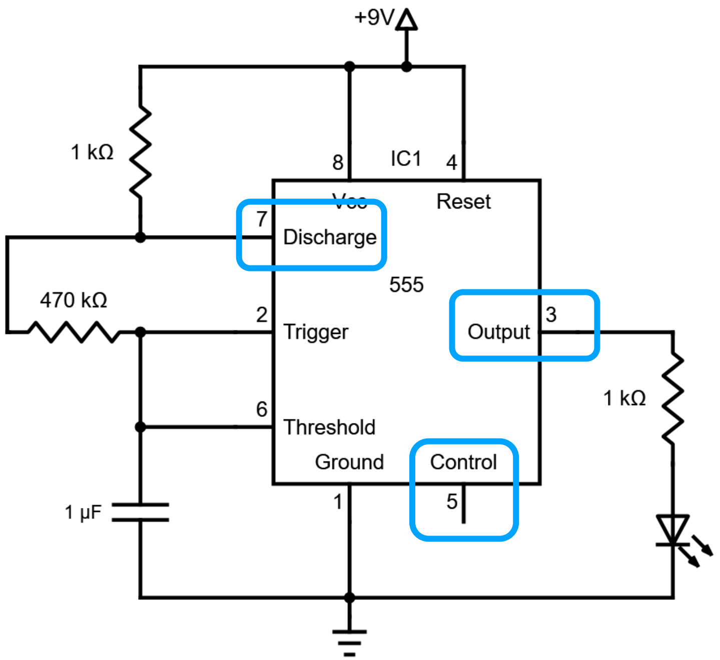


The **Trigger** and **Threshold** pins are at the same node

Blinking LED Circuit (Cont'd)

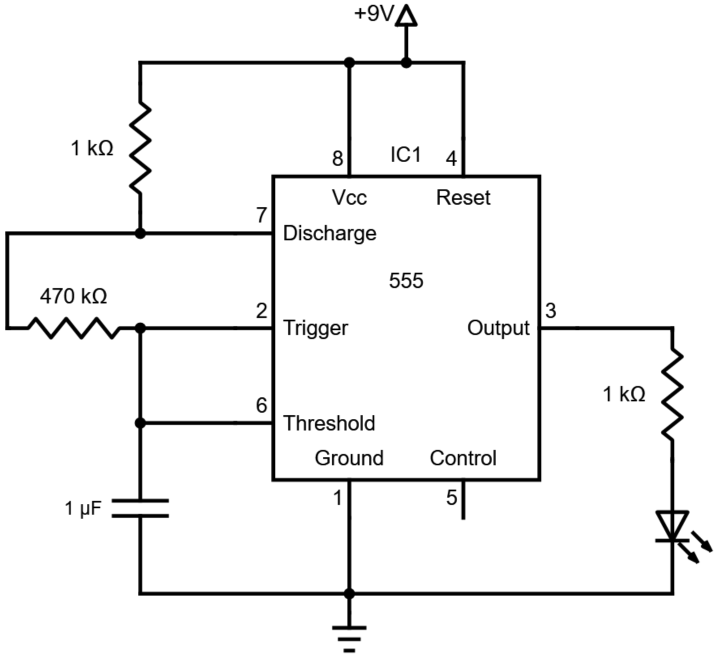
555 Timer Pin Layout

- 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)

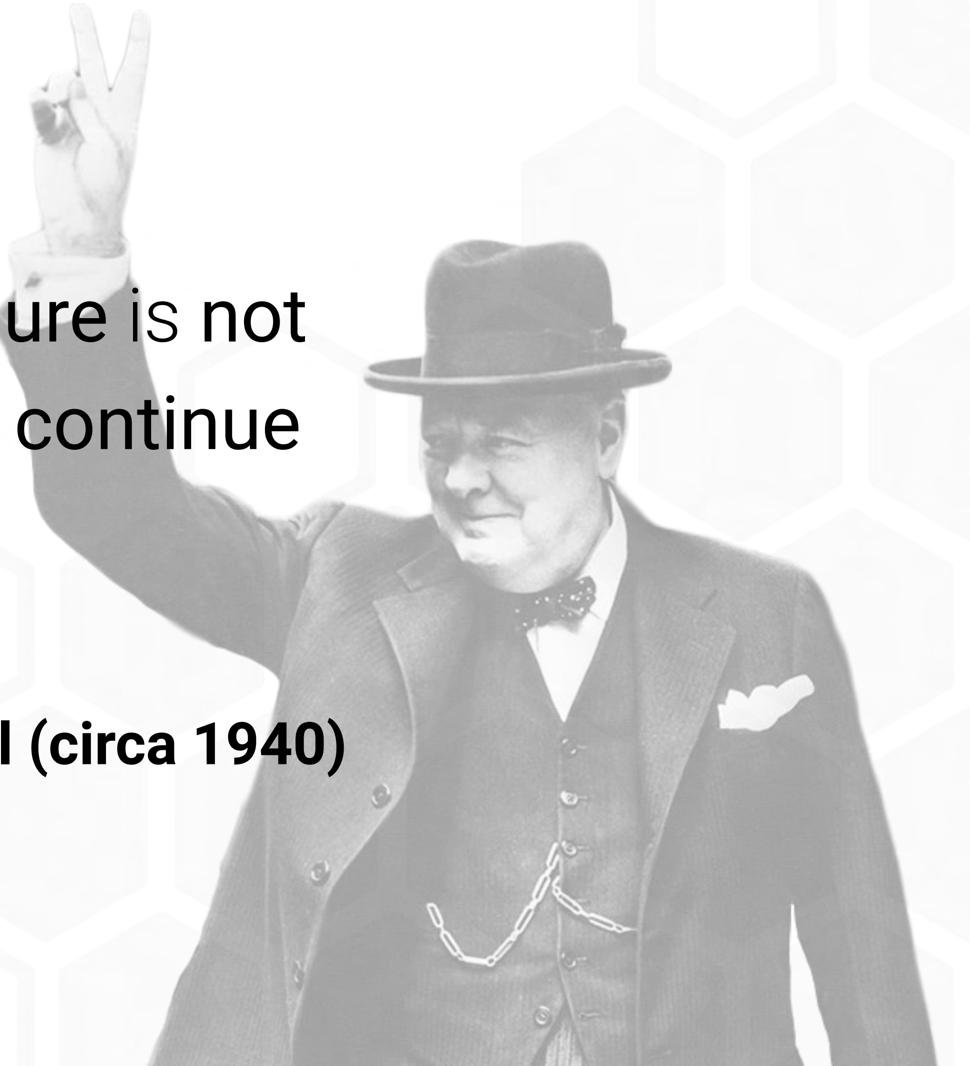
- It is absolutely normal if you don’t understand the circuit just yet
- **Review the slides** again and **begin the accompanying project** to solidify your understanding



"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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