CAPACITORS

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Electrical Engineering – SS 2019 – Duke TIP

FARADAY CAGE

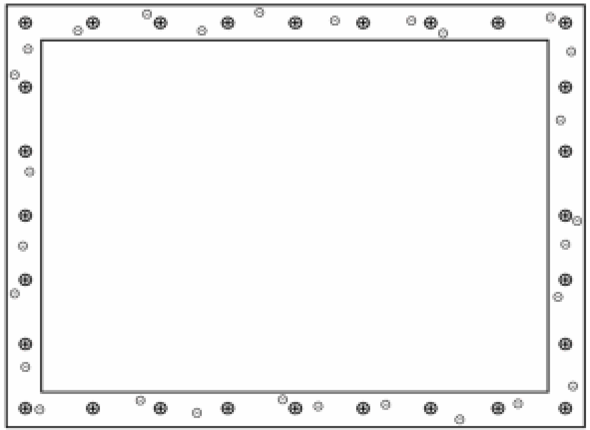
Faraday Cage

- https://youtu.be/pjw5gbkRTaY?t=65

- Why is he able to withstand these voltages?

Faraday Cage

- An enclosure used to block electromagnetic fields.
- Invented by Michael Faraday in 1836.
- A continuous covering



Faraday Cage

- It is essentially a hollow, continuous conductor.
- Externally or internally applied electromagnetic fields produce forces on the electrons within the conductor.
- The charges are redistributed to cancel electric field's effect within the cage.
- Can be used to keep charges out (cage) or charges in (microwave).

It also comes in a suit!

- https://www.youtube.com/watch?v=9YmFHAFYwmY

- But isn’t a bird safe sitting on a wire?
- The bird isn’t wearing a Faraday suit?
- Why does the line worker need a Faraday suit?

Capacitors?

- A Faraday cage rearranges the charge to cancel the electric field within an enclosure.
- A capacitor rearranges the charge to store energy in an electric field.
- In fact, capacitance is measure in Farads (F).

LEYDEN JAR

Leyden Jar

- Early water-filled Leyden jar, consisting of a bottle with a metal spike through its stopper to make contact with the water.
- An antique electrical component which stores a high-voltage electric charge between electrical conductors on the inside and outside of a glass jar.
- It typically consists of a glass jar with metal foil cemented to the inside and the outside surfaces, and a metal terminal projecting vertically through the jar lid to make contact with the inner water.

Activity: Build a Leyden Jar

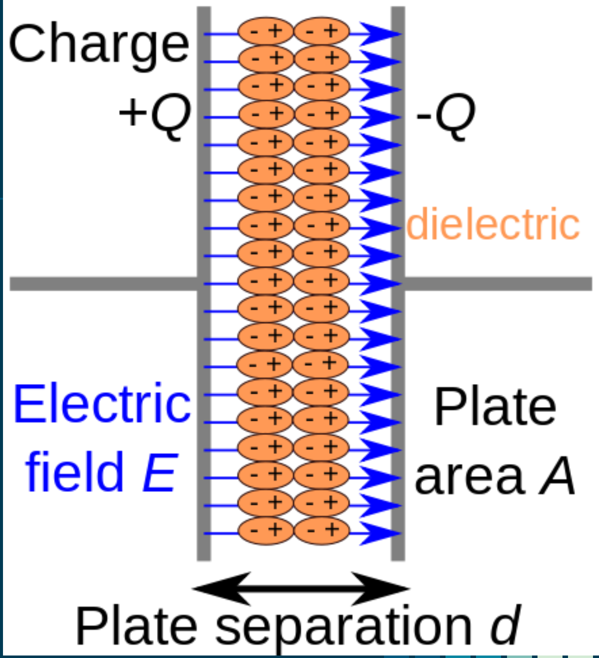
CAPACITORS

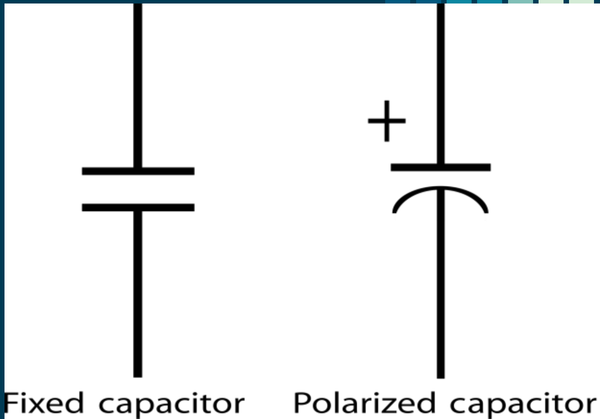
Capacitor

- A passive two-terminal electronic component that stores electrical energy in an electric field.
- Its capacitance (C) is measured in Farads (F).
- Capacitance – the ratio of the change in an electric charge in a system to the corresponding change in its electric potential.
- $C = \frac{Q}{V}$ meaning a 1 farad capacitor has a 1 volt difference between its plates when charged with 1 coulomb of electric charge.

Capacitors

- Two conductive plates with an insulator between called a dielectric.
- Dielectrics can be paper, plastic film, ceramic, glass, mica, or air.
- Cannot instantly change voltage value.
- Capacitor must be charged & discharged.
- Charging and discharging time depends upon the capacitance and resistances around the capacitor.
- Some capacitors have polarity!!



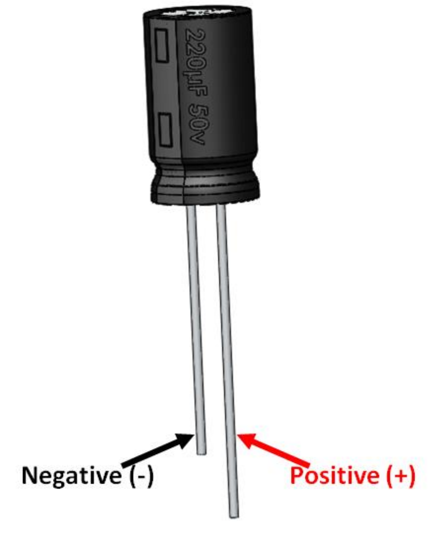


Important Capacitor Warning

- Many capacitors have polarity.
- All of them have a voltage rating.
- Because of the nature and construction of capacitors, they hold a lot of energy and tend blow up.
- We don’t want this!
- They let out a lot of smoke and can sometimes send particles flying.
- Never stick your face over a powered circuit!

Capacitor Polarities

- Electrolytic and tantalum capacitors have polarity.
- Most ceramic capacitors do not.
- Always double and triple check for polarity.



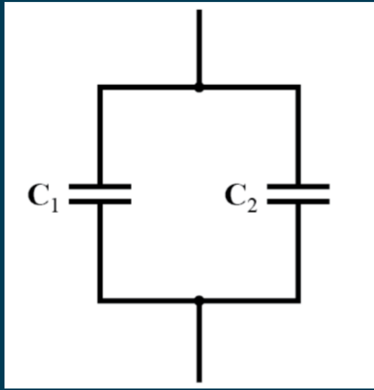
Ultracapacitor Demonstration

- Ultracap on MCU or LED

Series/Parallel Capacitances

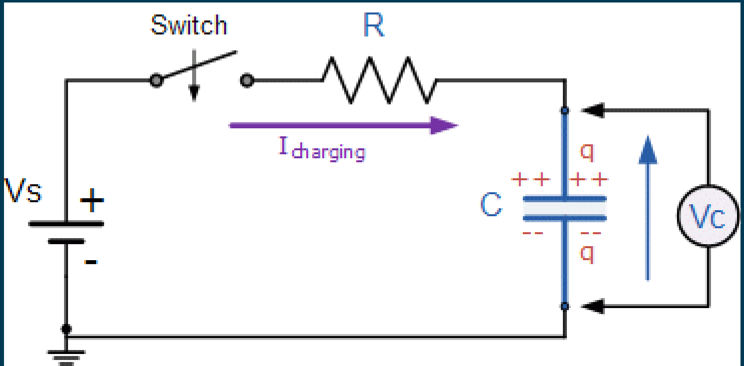
- Series Capacitors
  - Same as parallel resistors
  - $C_{eq} = \frac{1}{\frac{1}{C_1}+\frac{1}{C_2}}$

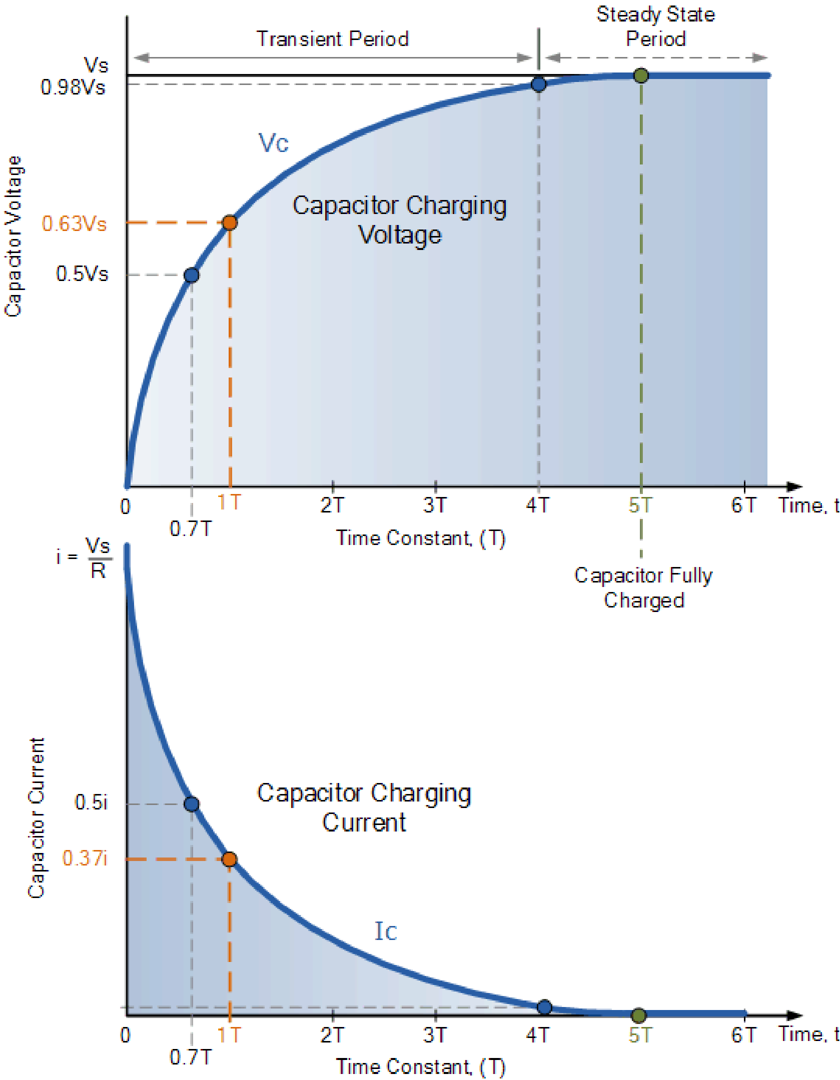
- Parallel Capacitors
  - Same as series resistors
  - $C_{eq} = C_1 + C_2$



Capacitor Charging

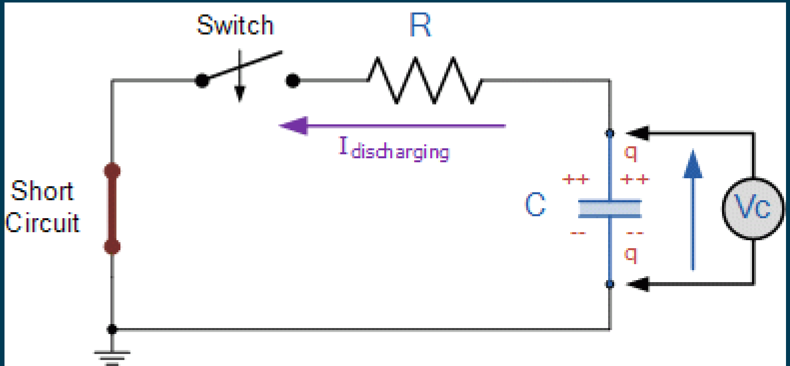
- Time constant τ. Units in seconds.
- $\tau = RC$
- $V_C = V_S \times (1 - e^{-t/\tau})$
- $I_C = \frac{V_S}{R} \times e^{-t/\tau}$

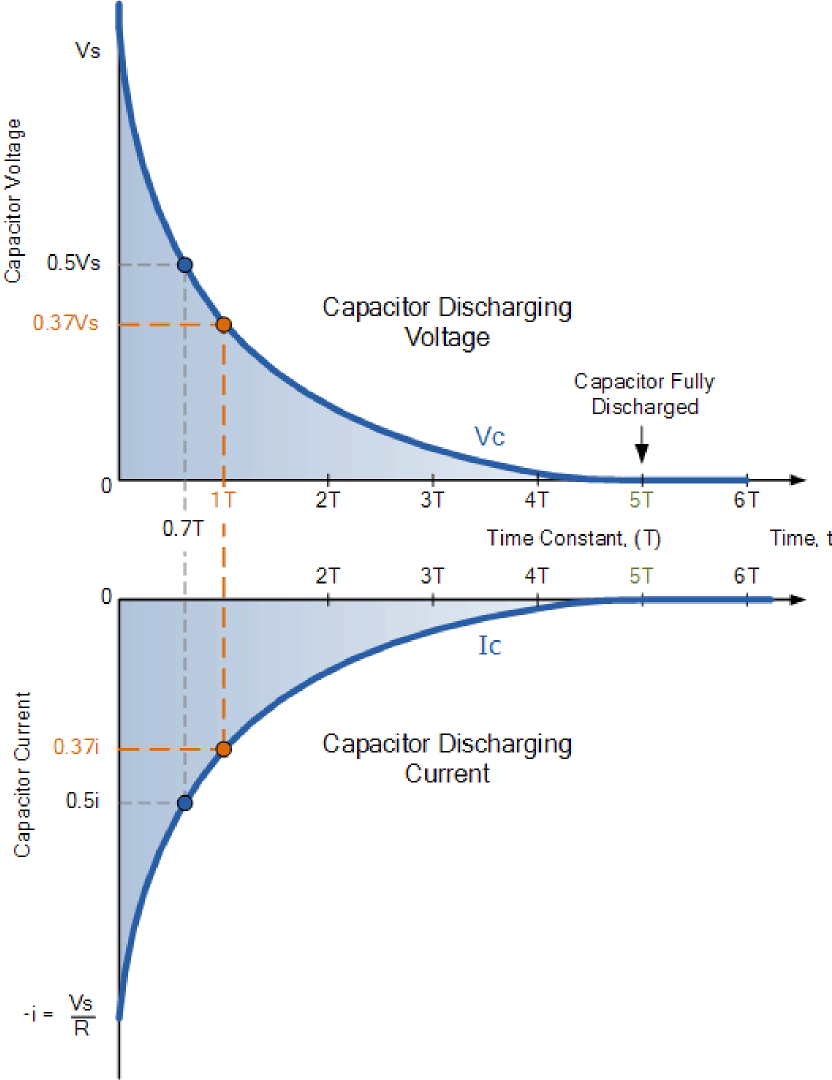




Capacitor Discharging

- Time constant τ. Units in seconds.
- $\tau = RC$
- $V_C = V_S \times e^{-t/\tau}$
- $I_C = -\frac{V_S}{R} \times e^{-t/\tau}$





Capacitor Properties

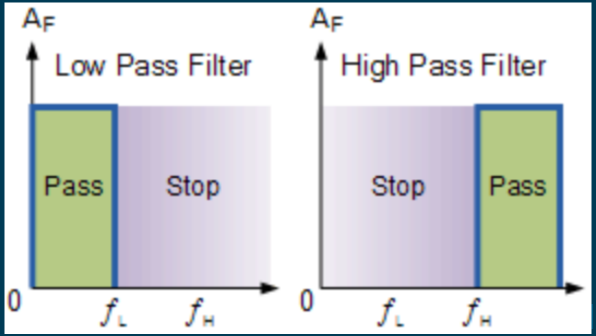
- When a capacitor is fully discharged, it acts like a short.
  - It wants charge to build up the electric field.
  - So it pulls a lot of current.
- When a capacitor is fully charged, it acts like an open.
  - It has all the charge it wants.
  - It pulls no current so it is happy.
- High frequency AC signals do not allow the capacitor enough time to charge or discharge to the appropriate levels.
  - Therefore, the capacitor acts like a short.
  - It is still trying to draw current to build up the electric field.

Capacitor Uses

- Power supply filter – cleans up rectified output to make a filtered DC voltage output.
- Sag remover – removes temporary voltage sags by holding up voltage.
- AC-DC selective filter or DC blocker – a series capacitor will pass the fluctuations but completely block the DC level.
- RC (Resistor Capacitor) circuits have many different uses that we will discuss coming up!
- And many more uses.

RC Filters

- There are two basic types of RC filters:
  - Low Pass Filters (LPF)
  - High Pass Filters (HPF)
- Important characteristics of RC filters:
  - Time constant (τ)
    - Given in seconds (s)
    - $\tau = RC$
  - Cutoff frequency (f_c) (also known as corner frequency)
    - Given in hertz (Hz)
    - Frequency at which 70.71% power is allowed through.
    - $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi\tau}$



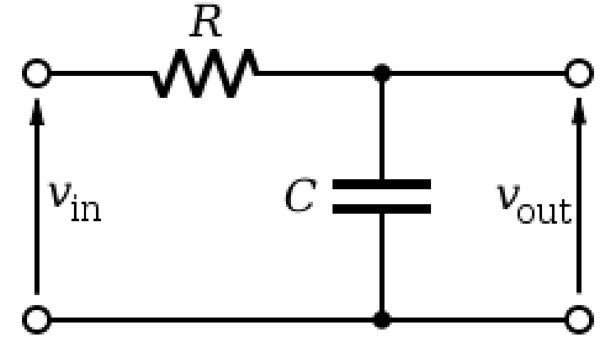
Low Pass Filter (LPF)

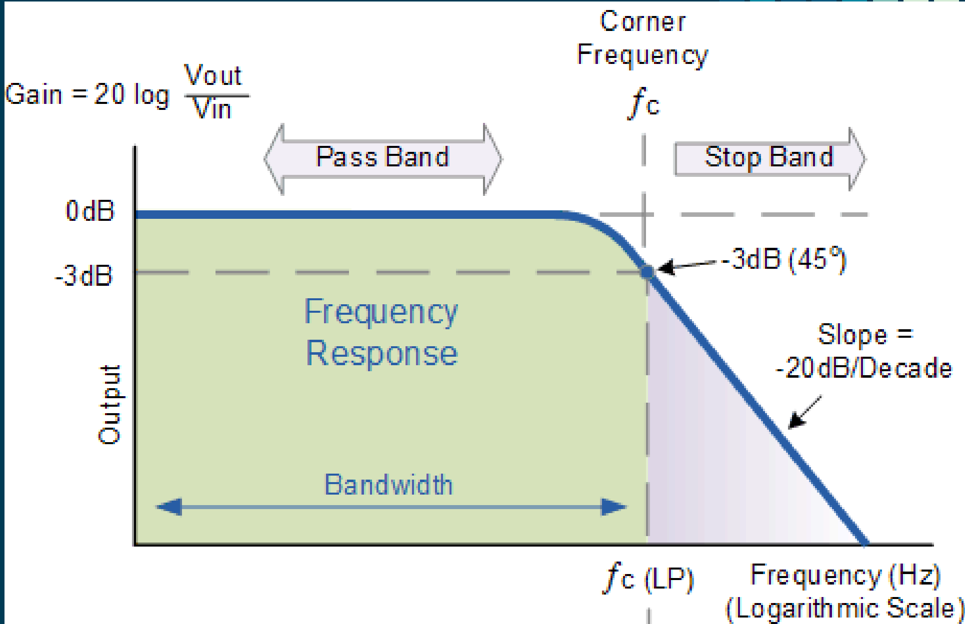
- LPF – means that low frequency signals can pass through while high frequency signals are stopped.

- Frequencies higher than the cutoff frequency are attenuated.

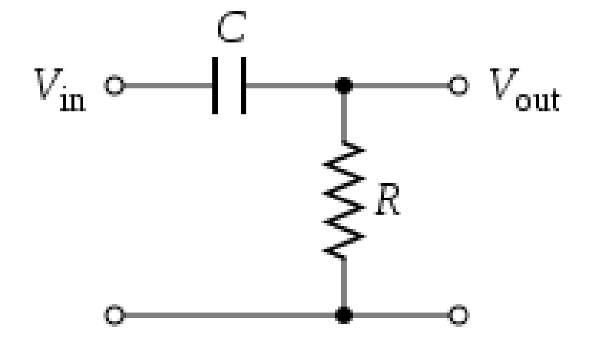
- $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi\tau}$

- A first-order LPF can also act like a passive integrator.





High Pass Filter (HPF)

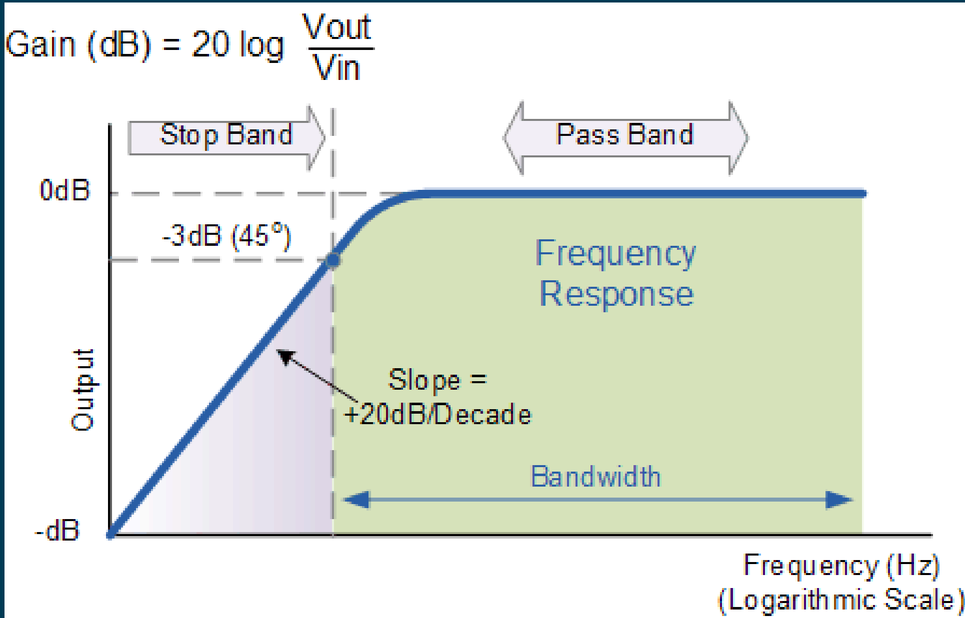


- HPF – means that high frequency signals can pass through while low frequency signals are stopped.

- Frequencies lower than the cutoff frequency are attenuated.

- $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi\tau}$

- A first-order HPF can also act like a passive differentiator.



Visualization

- LPF and HPF simulations in LTSpice.

Activity: Build Low Pass Filter

- Build a low pass filter that will block notes higher than middle C.
- Use waveform generator as source.
  - Use 5 Vpp sine wave.
  - Filter output should go to a passive buzzer.
- $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi\tau}$
- Resistor value should be 100 Ω.
- Use oscilloscope to monitor output waveform.
  - What does LPF do to the sine wave?

Activity: Build High Pass Filter

- Build a high pass filter that will block notes lower than middle C.
- Use waveform generator as source.
  - Use 5 Vpp sine wave.
  - Filter output should go to a passive buzzer.
- $f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi\tau}$
- Resistor value should be 10 Ω.
- Use oscilloscope to monitor output waveform.
  - What does HPF do to the sine wave?

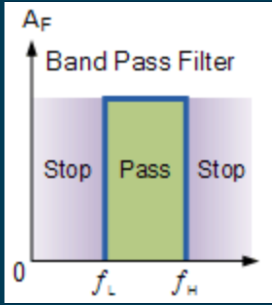
Harmonics

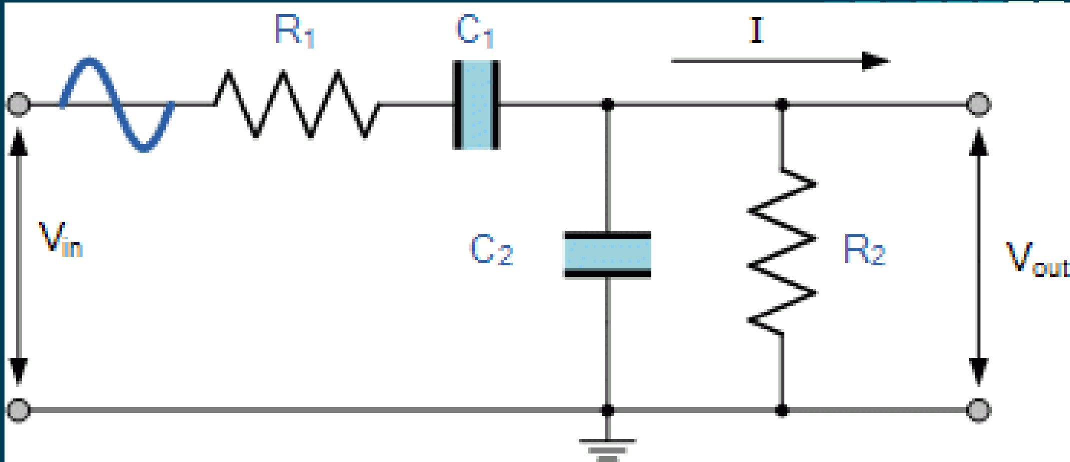
- *A* note is 440 Hz.
- *A* note an octave up is 880 Hz.
- An octave up from that is 1760 Hz. etc.

MORE ACTIVITIES

Activity: Build a Band Pass Filter

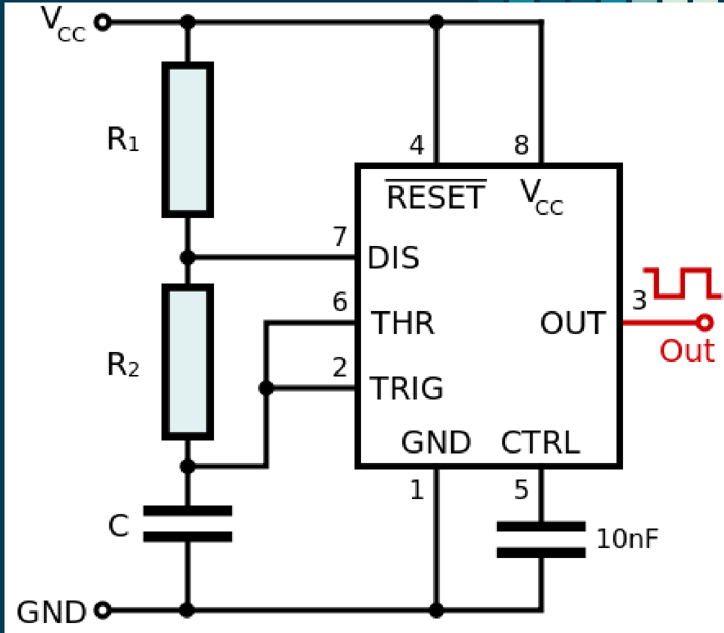
- High pass filter stage
  - $f_l = \dfrac{1}{2\pi RC_1} = \dfrac{1}{2\pi\tau}$
- Low pass filter stage
  - $f_h = \dfrac{1}{2\pi RC_2} = \dfrac{1}{2\pi\tau}$





Activity: 555 Timer LED Flasher

- Change the RC circuit to adjust the pulse.
- Can you make it flash once a second? Twice a second?
- Puts out a continuous stream of rectangular pulses having a specific frequency determined by R1, R2, C.
- Output high when trigger less than 1/3 Vcc, low when threshold greater than 2/3 Vcc.
- $f = \frac{1}{0.693 \times C \times (R_1 + 2R_2)}$



Activity: Sine Wave RC Integrator

Sine Wave RC Integrator