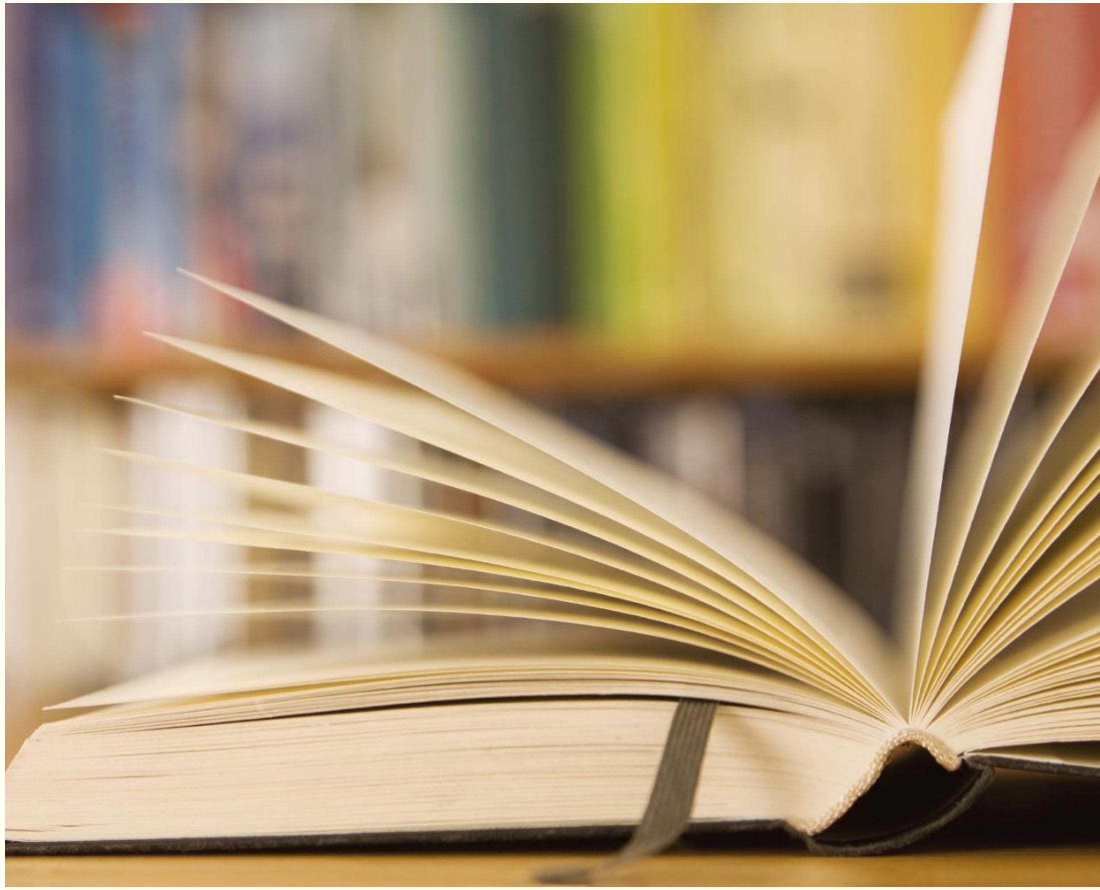
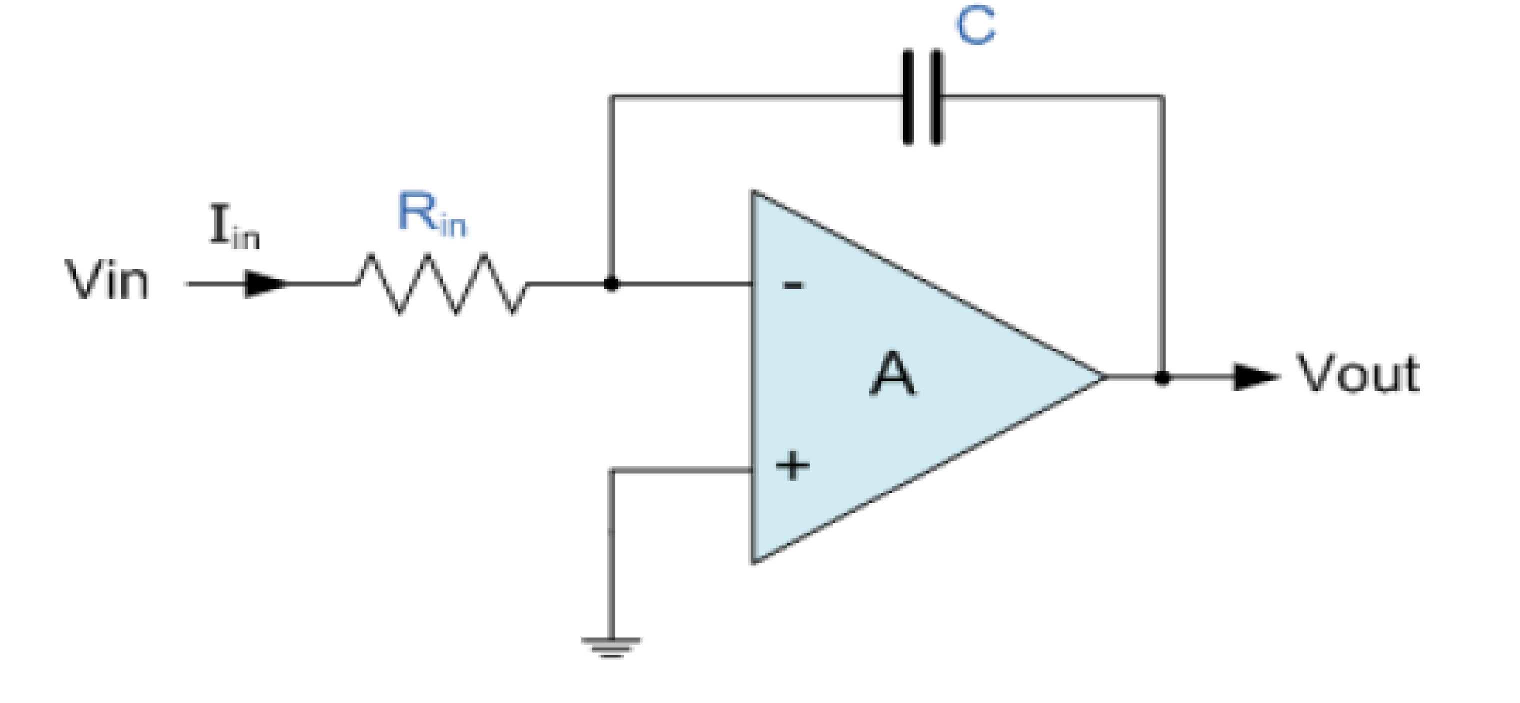
OP AMP APPLICATION CIRCUITS

Integrator, Differentiator, Comparator



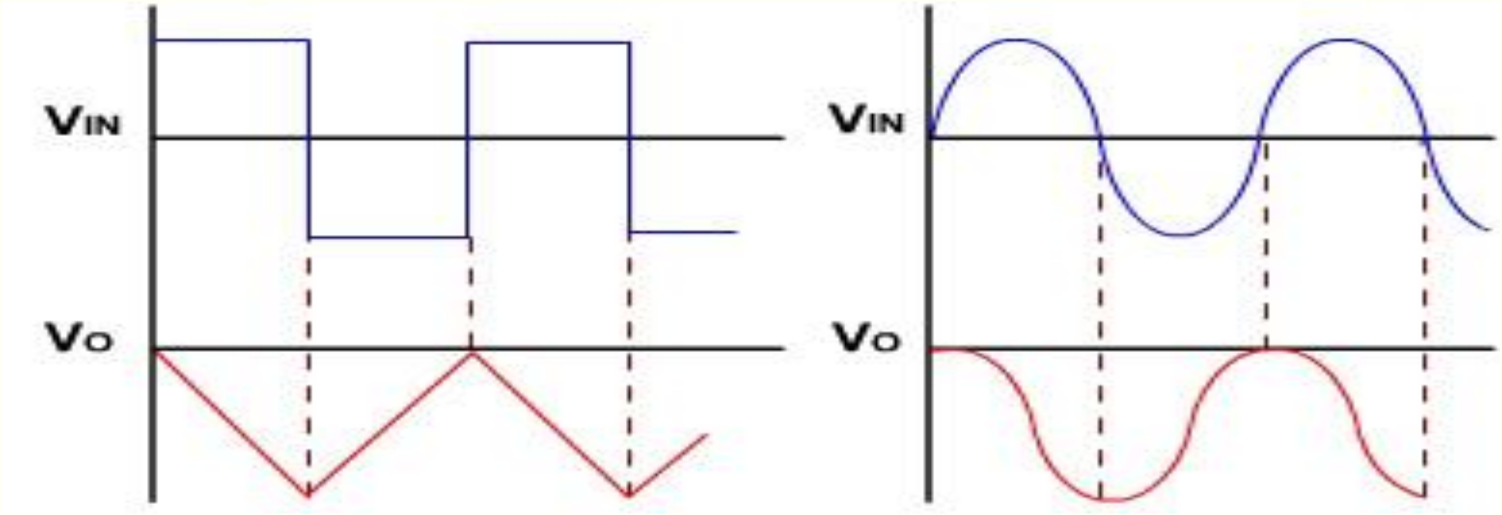
OP AMP as Integrator

- An integrator circuit is one whose output is the integral of the input.
- It is obtained by using a basic inverting amplifier configuration if the feedback resistor 'R_f' is replaced by a capacitor 'C_f'.



Contd..

- The integrator amplifier performs the mathematical operation of **integration**, that is, it can cause the output to respond to changes in the input voltage over time.
- The integrator amplifier produces a voltage output which is proportional to that of its input voltage with respect to time.
- The magnitude of the output signal is determined by the length of time a voltage is present at its input.



Mathematical analysis

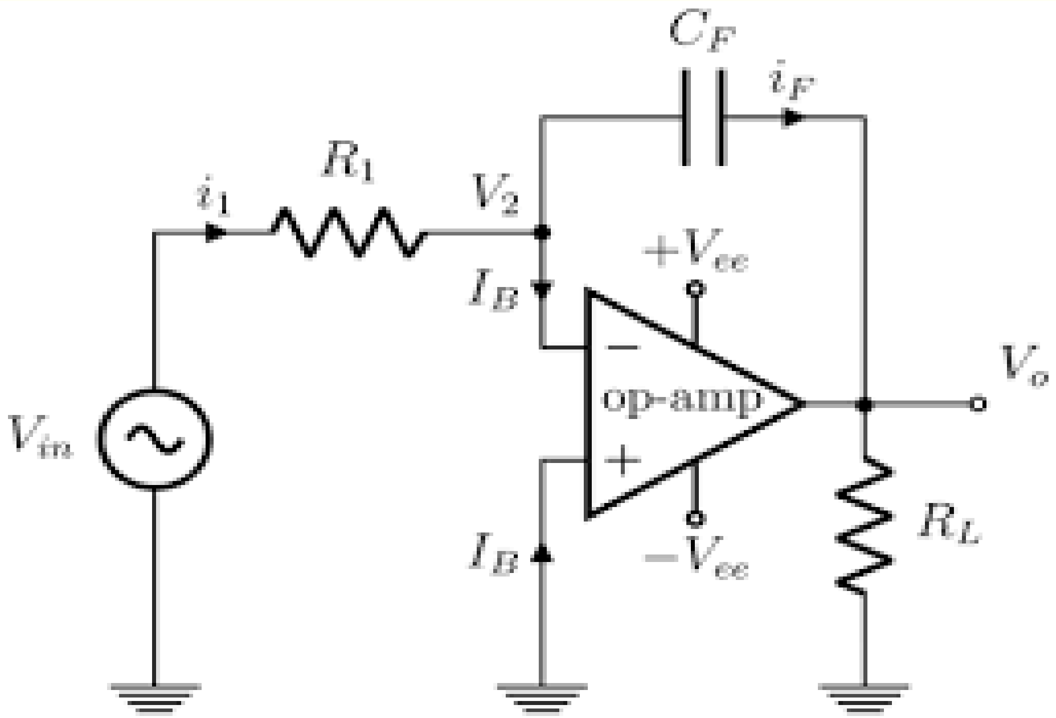
- The output voltage can be written as at node V_2 as

$$i_1 = I_b + i_F$$

- I_b is small, so $$i_1 = i_f$$
- So Current through capacitor is $$i_c = C\frac{dv_c}{dt}$$
- So $$\frac{V_{in} - V_2}{R_1} = C_F \frac{d}{dt}(V_2 - V_0)$$
- A is very large

$$\frac{V_{in}}{R_1} = C_F \frac{d}{dt}(-V_0)$$

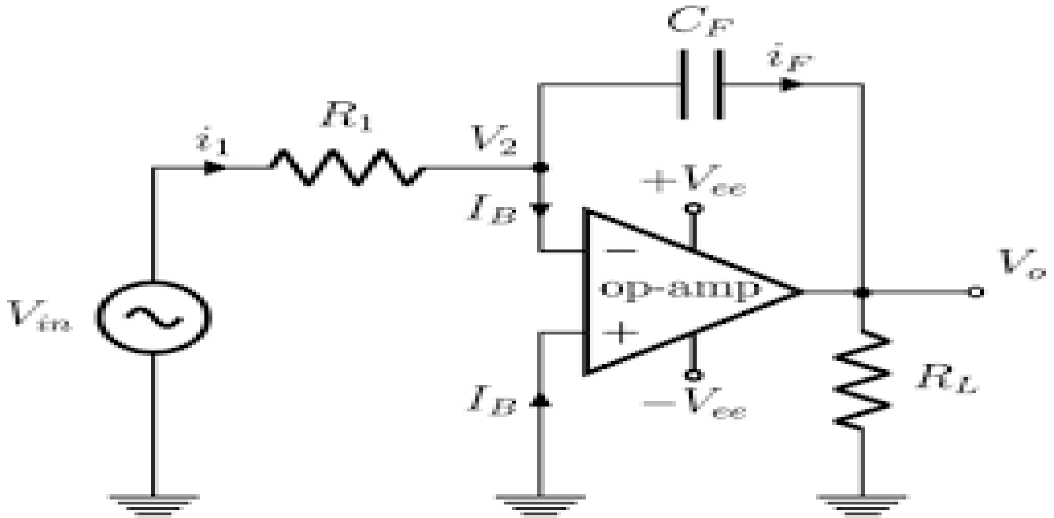
- As $$V_1 = V_2 \approx 0$$



Contd..

Integrate both sides

$$\int_0^t \frac{V_{in}}{R_1} dt = \int_0^t C_F \frac{d}{dt}(-V_0)dt = C_F(-V_0) + V_0\big|_{t=0}$$



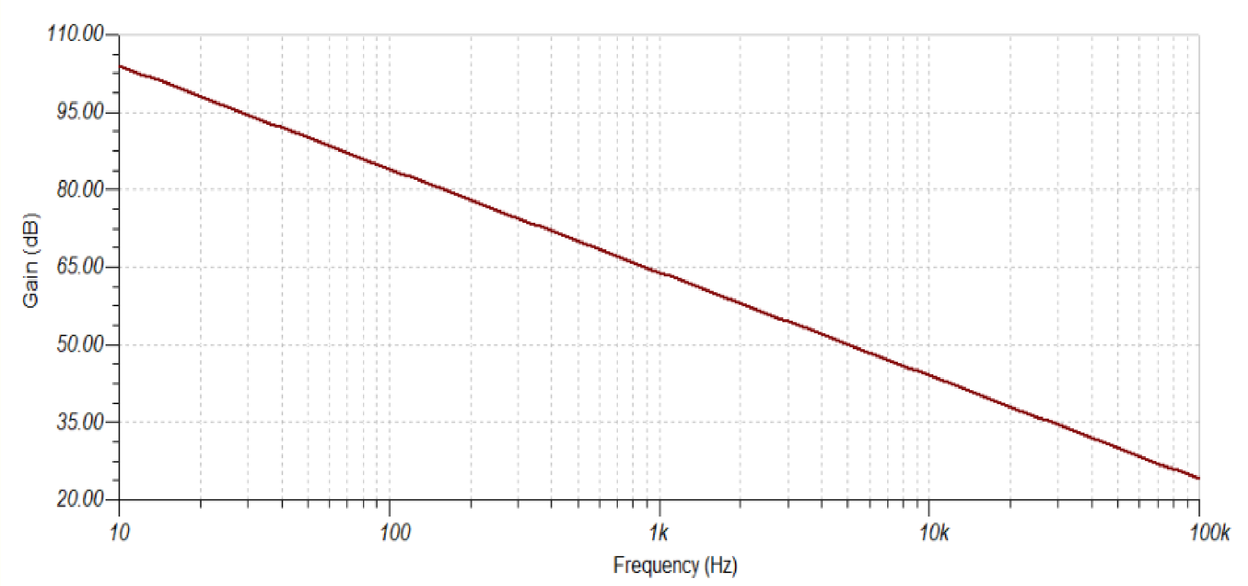
$$V_0 = \frac{-1}{R_1 C_F} \int_0^t V_{in} \; dt + C$$

- At DC value the gain is large due to capacitor works as open circuit.
- But as the frequency increases the capacitive reactance decrease, so the gain

$$V_{out} = -\frac{Xc}{R} V_{in}$$

$$A_v = -\frac{X_c}{R} = \frac{1}{2\pi R C_f \, f}$$

$$f_L = \frac{1}{2\pi R \, C_F}$$



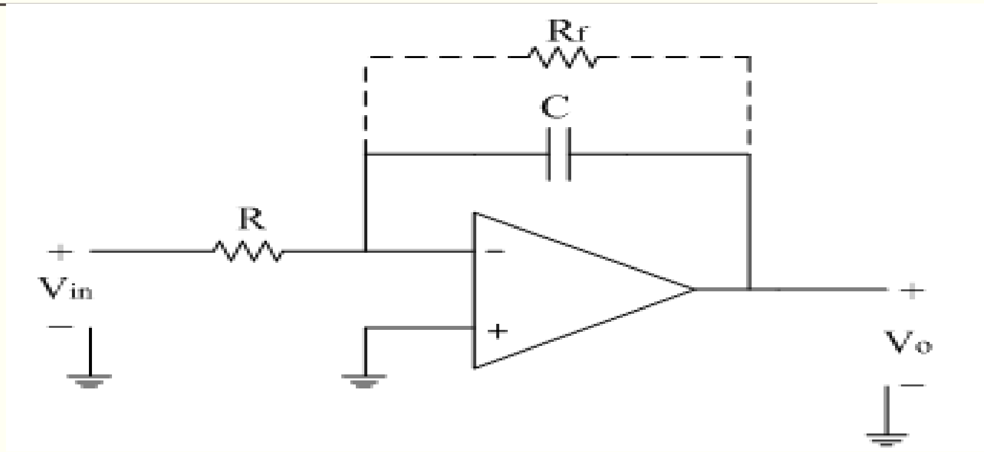
Practical Integrator

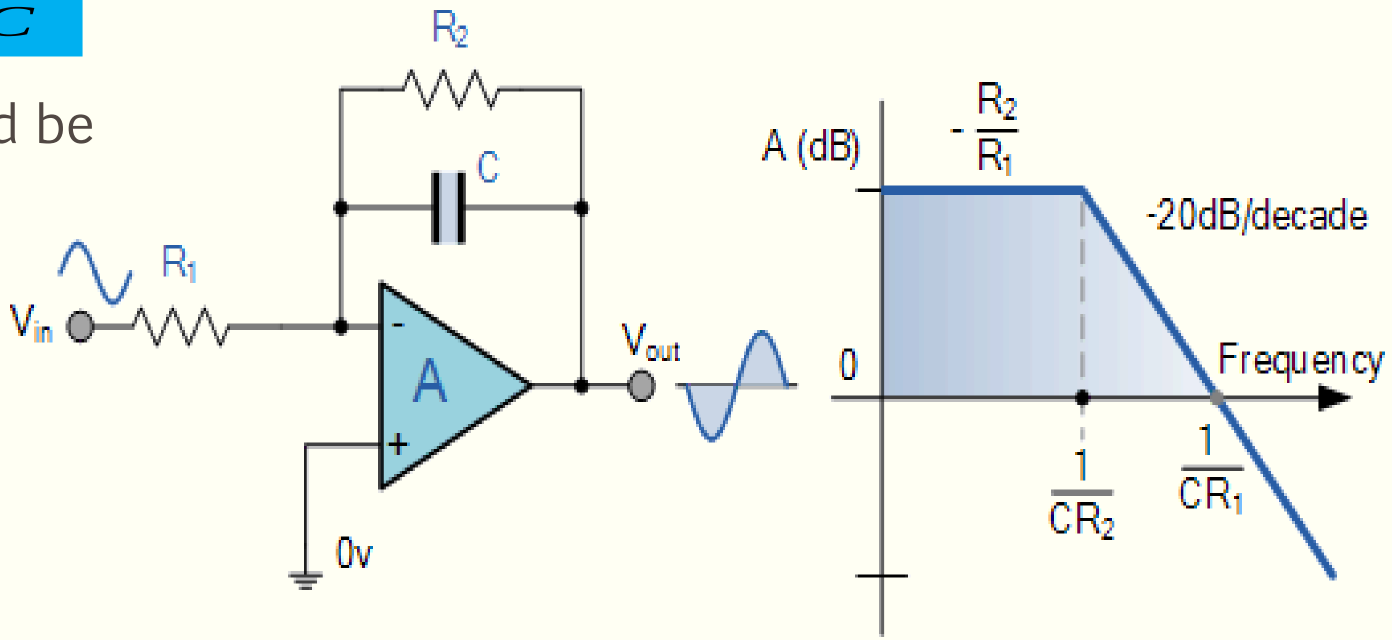
- The problem of saturation of Integrator at low frequency is resolved by using the resistor Rf parallel with Capacitor C.
- So the gain at lower frequency would be
- $A=-R_f/R1$

$$f_L = \frac{1}{2\pi R_2 C}$$

$$f_H = \frac{1}{2\pi R_1 C}$$

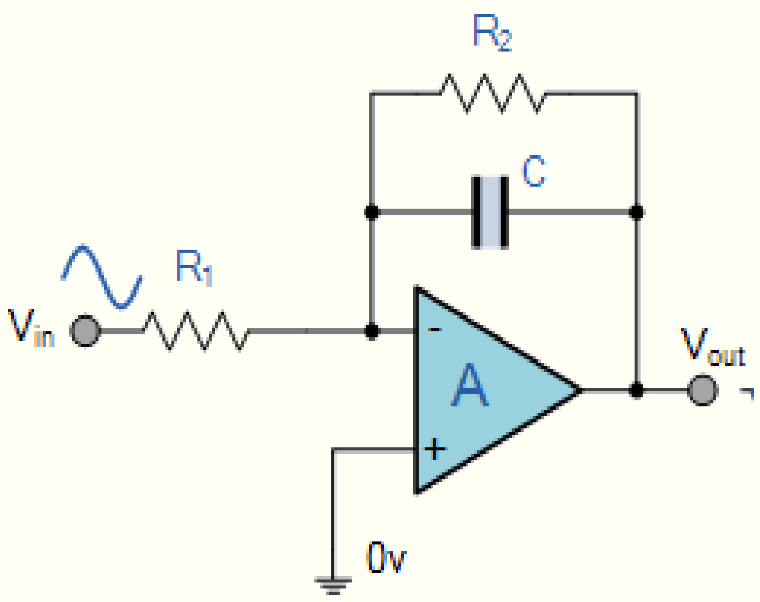
- So Input signal frequency should be
- $f_l < fs < f_h$
- i.e $f_s > 10 f_l$





Contd..

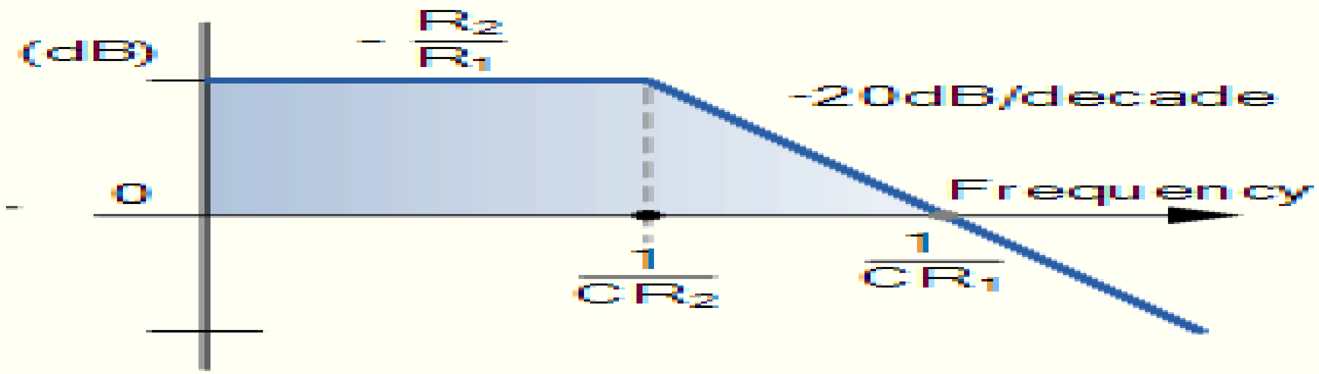
Q1 In the circuit shown, find the lower cut off frequency R1=1K, R2=100K, C=10nF of the integrator? Also find the f_H



Solution

$$f_L = \frac{1}{2\pi R_2 C} = \frac{1}{2\pi 100 * 10} = 159Hz$$

$$fs > 10 f_l = 10 * 159 = 1590Hz$$

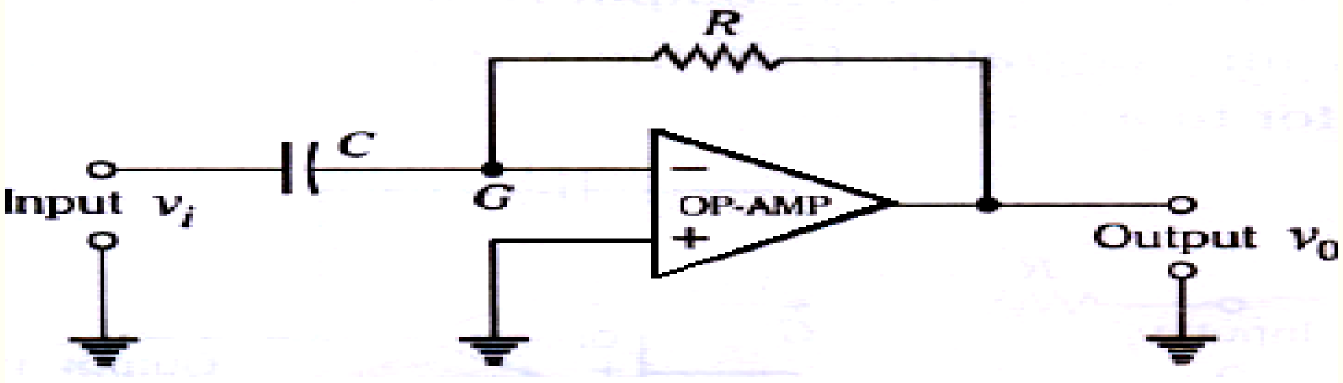


Points to remember

- An operational amplifier can be used to perform calculus operations such as differentiation and integration. Both these configurations use reactive components (usually capacitors than inductors) in the feedback part of the circuit.
- An integrating circuit performs the mathematical operation of integration with respect to time, on the input signal, i.e. the output voltage is proportional to the applied input voltage integrated over time.
- The output of an integrator is out of phase by 180^o with respect to the input, since the input is applied to the inverting input terminal of the op-amp.
- Integrating circuits are generally used to generate ramp wave from square wave input. Integrating amplifiers have frequency limitations while operating on sine wave signals.

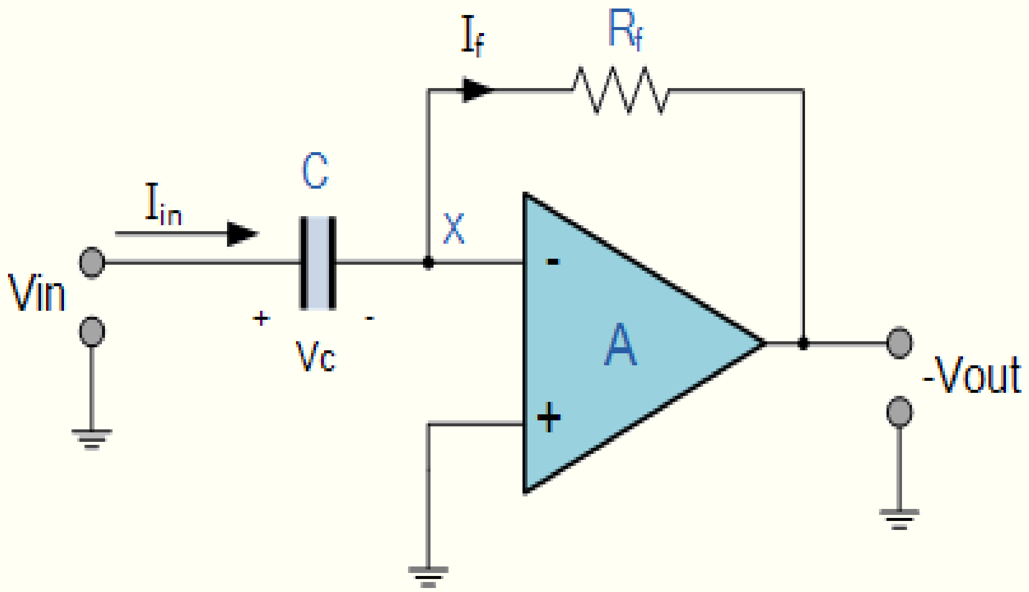
Differentiator

- A differentiator circuit is one whose output is the differential coefficient of the input.
- Figure shows a differentiator circuit using an Op-Amp. 'G' is the virtual ground



- The input voltage 'V_i' is applied to the inverting terminal of the Op- Amp through the capacitor. The non-inverting terminal is connected to the ground.
- This operational amplifier circuit performs the mathematical operation of **Differentiation**, that is it produces a voltage output which is directly proportional to the input voltage's rate-of-change with respect to time.
- In other words the faster or larger the change to the input voltage signal, the greater the input current, the greater will be the output voltage change in response, becoming more of a "spike" in shape.

Mathematical Analysis



$$I_{IN} = I_F \text{ and } I_F = -\frac{V_{OUT}}{R_F}$$

$$Q = C \times V_{IN}$$

$$\frac{dQ}{dt} = C\frac{dV_{IN}}{dt}$$

$$I_{IN} = C\frac{dV_{IN}}{dt} = I_F$$

$$\therefore -\frac{V_{OUT}}{R_F} = C\frac{dV_{IN}}{dt}$$

$$V_{OUT} = -R_F C\frac{dV_{IN}}{dt}$$

$$f_a = \frac{1}{2\pi R_F C}$$

Contd..

$$V_{OUT} = -R_F C \frac{dV_{IN}}{dt}$$

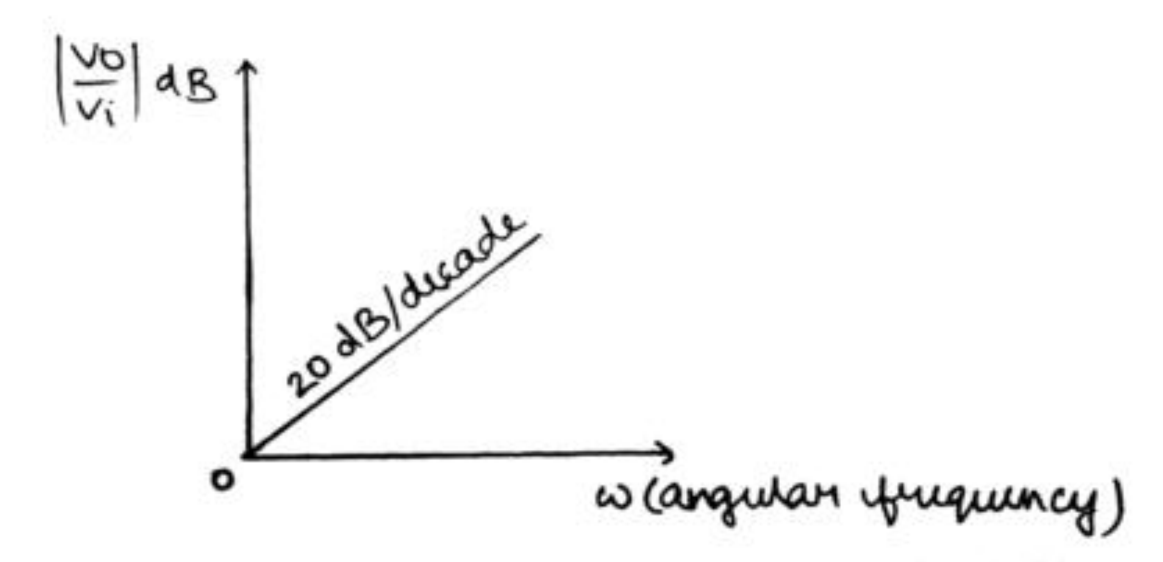
$$V_{out} = -\frac{R_f}{Xc} \times V_{in}$$

$$Xc = \frac{1}{2 \times pi \times fC}$$

$$V_{out} = -2 \times pi \times fCR_f \times V_{in}$$

$$Gain = A = \frac{V_{out}}{V_{in}} = -2 \times pi \times fCR_f$$

$$f_0 = \frac{1}{2 \times pi \times R_f C}$$

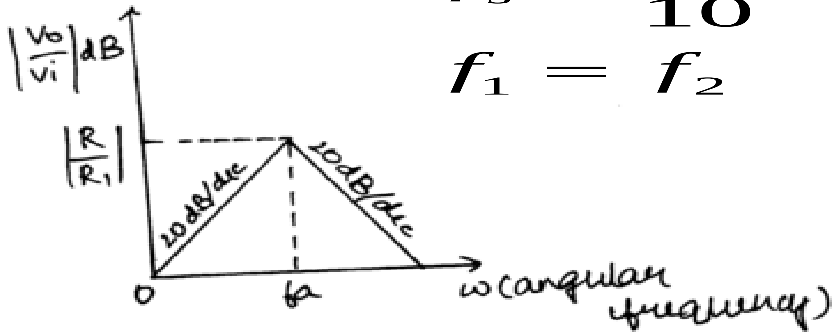


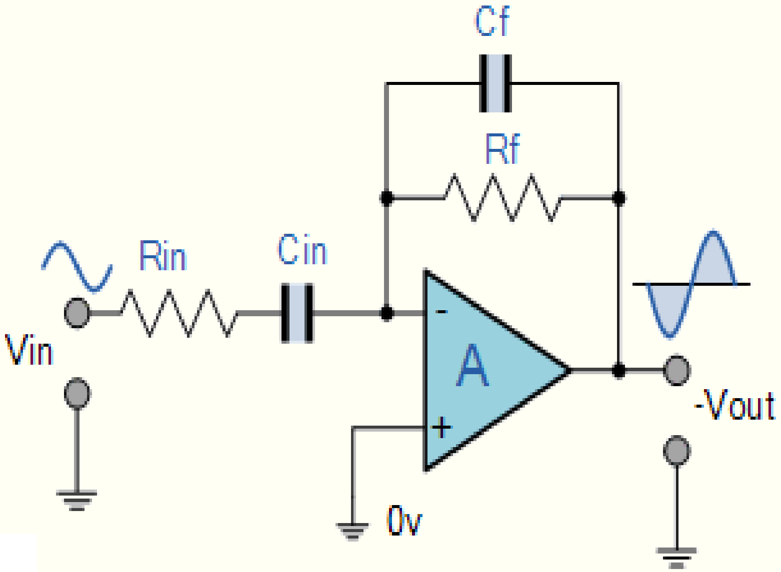
Note: As the Frequency increases, the reactance Xc decreases so a noise would be added if operated at higher frequencies.

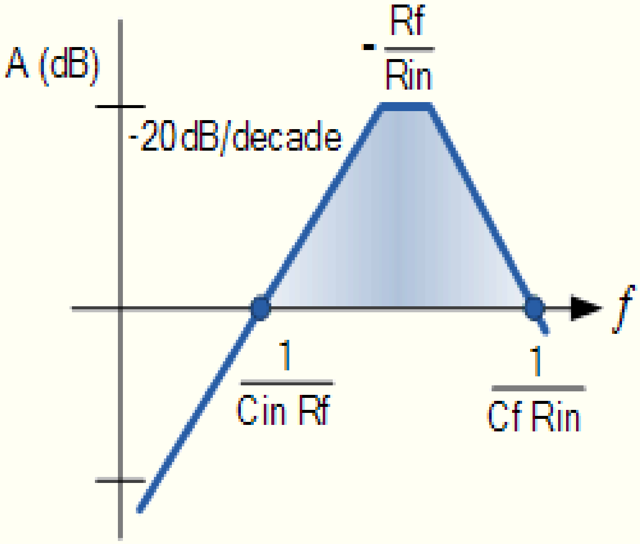
Practical Differentiator circuit

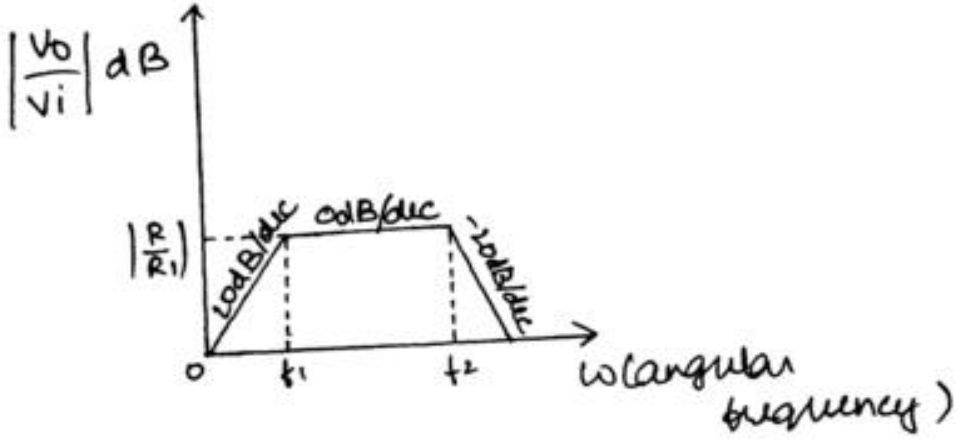
$$f_s = \frac{f_1}{10}$$

$$f_1 = f_2$$





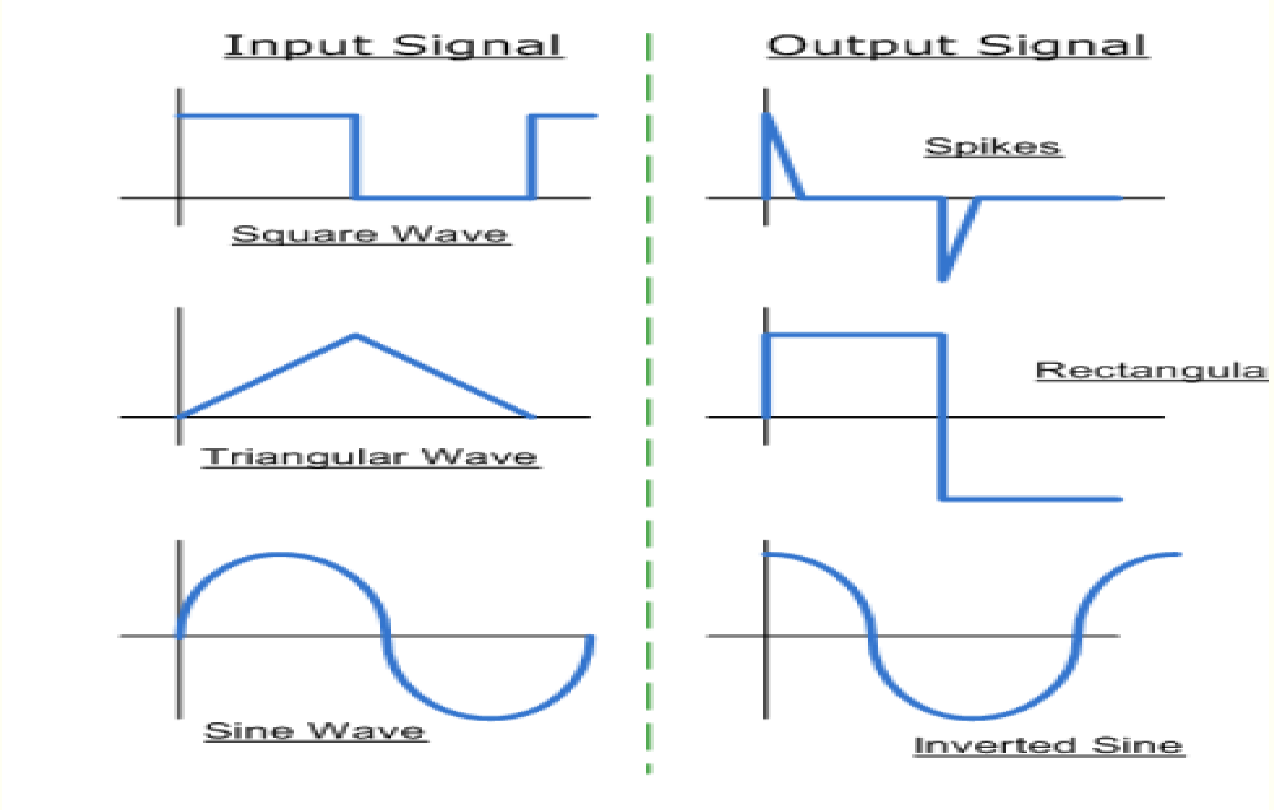




Note: When $f<f_1$ act as differentiator, When $f>f_2$ act as Integrator

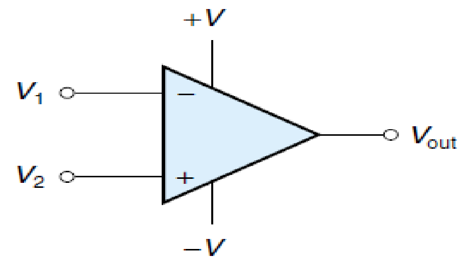
Differentiator Waveforms

- If we apply a constantly changing signal such as a Square-wave, Triangular or Sine-wave type signal to the input of a differentiator amplifier circuit the resultant output signal will be changed and whose final shape is dependent upon the RC time constant of the Resistor/Capacitor combination.

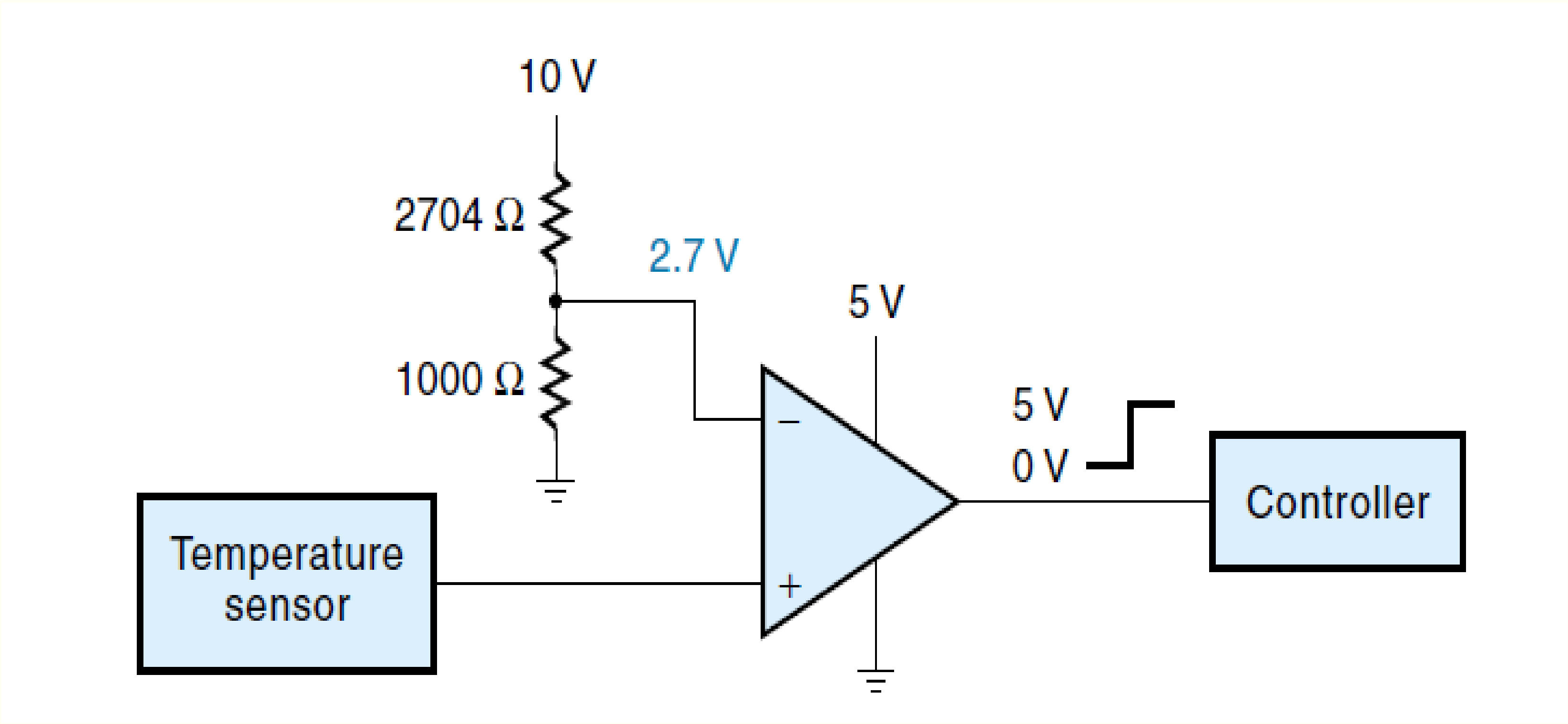


Comparator

- A typical application of OP amp is a slow-moving analog signal from a sensor being used to trigger some event.
- Such an interface that will switch from off to on when a specified input voltage level is reached.
- Comparators are usually operated open-loop so that if V_2 is even slightly more positive than V_1, the tremendous gain will amplify the small difference and drive the output into positive saturation (close to +V).
- On the other hand, if V_1 is slightly more positive than V_2, the output will go to negative saturation (–V).
- The output is essentially digital in nature—either on or off depending on a very small change in the inputs. This requires a threshold detector circuit.

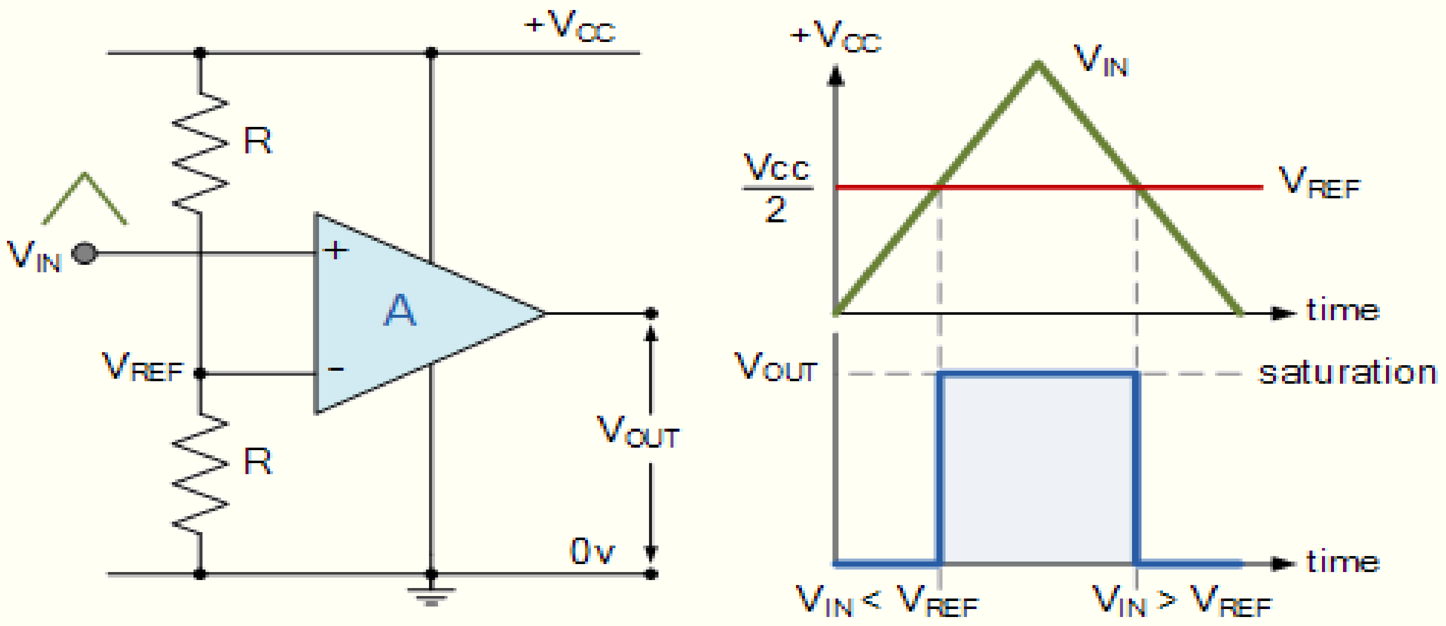


Comparator circuit



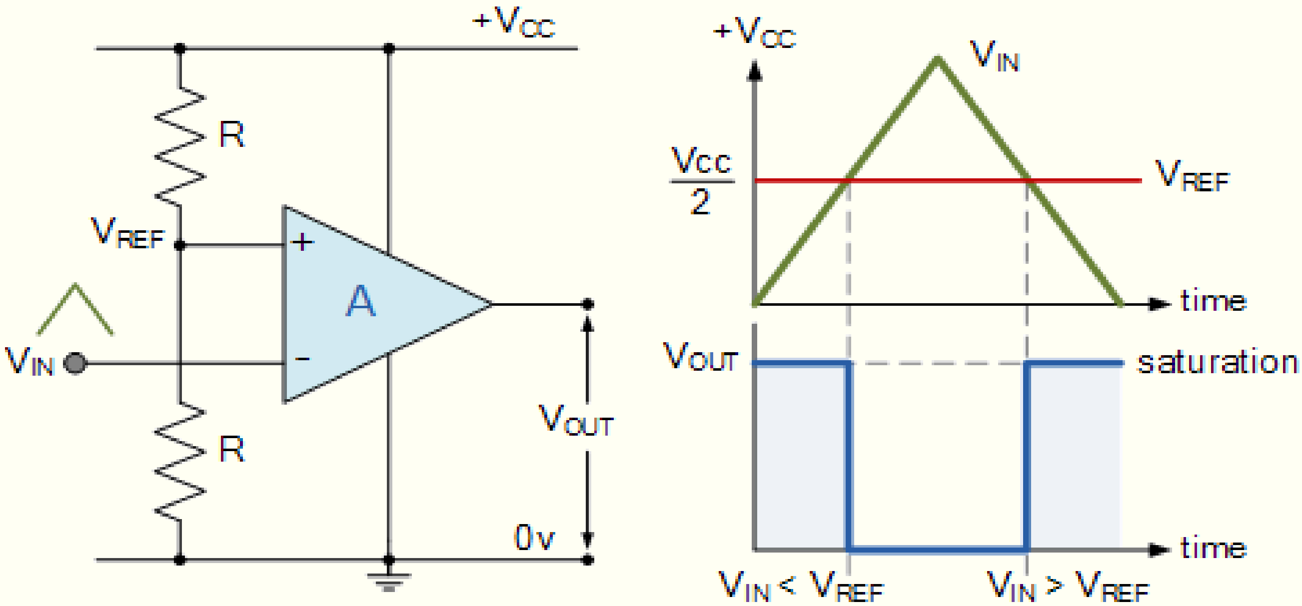
Positive Voltage Comparator

- The basic configuration for the positive voltage comparator, also known as a non-inverting comparator circuit detects when the input signal, V_{IN} is ABOVE or more positive than the reference voltage, V_{REF} producing an output at V_{OUT} which is HIGH



Negative Voltage Comparator

- The basic configuration for the negative voltage comparator, also known as an inverting comparator circuit detects when the input signal, V_{IN} is BELOW or more negative than the reference voltage, V_{REF} producing an output at V_{OUT} which is HIGH .



References

❖ *Coughlin, R.F., Operational Amplifiers and Linear Integrated Circuits, Pearson Education (2006).*

❖ *Gayakwad, R.A., Op-Amp and Linear Integrated Circuits, Pearson Education (2002).*

❖ Franco, S., Design with Operational Amplifier and Analog Integrated circuit, McGraw Hill (2016).

❖ *Terrell, D., Op Amps Design Application and Troubleshooting, Newness (1996).*