Filters (Using Op Amp)

Filter (Electric filter):

A frequency selective electric circuit that passes electric signals of specific band of frequencies and attenuates the signals of frequencies outside the band is called an electric filter.

Category of Filter:

Filters can be placed in one of two categories:

1. **Passive filter:** Passive filters include only passive components—resistors, capacitors, and inductors.
2. **Active filter:** Active filters use active components, such as op-amps, in addition to resistors and capacitors, but not inductors.

Why active Filter is advantageous than passive? :

The simplest way to make a filter is by using passive components (Resistors, capacitors, inductors) This works well for high frequencies that is radio frequencies. However at audio frequencies inductors become problematic, as the inductors become large, heavy and expensive. so at low frequencies passive filter are not suitable.

Active filters overcome aforementioned problems of passive filters. they use op-Amp as the active element and resistors and capacitors as the passive

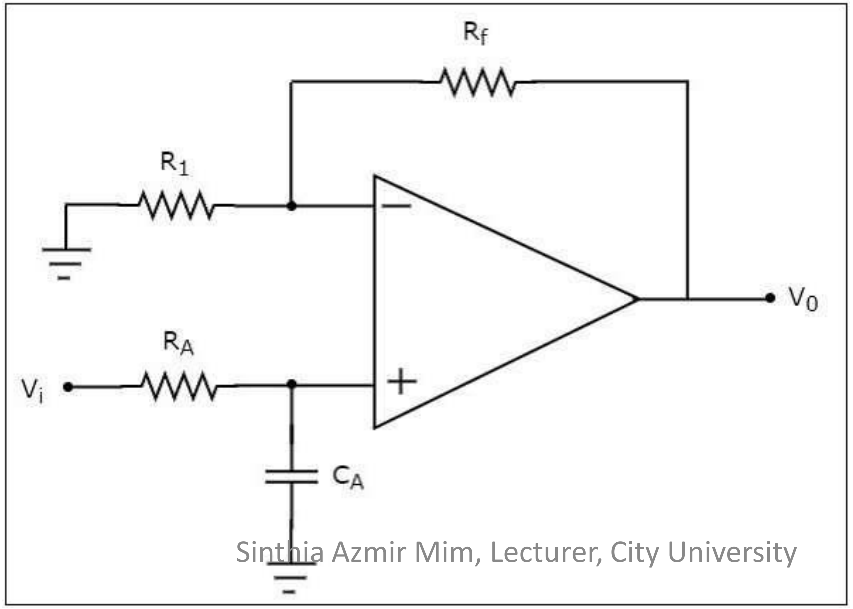
Types of Active Filters:

- Active Low Pass Filter
- Active High Pass Filter
- Active Band Pass Filter
- Active Band Stop Filter

Active Low Pass Filter:

If an active filter allows (passes) only low frequency components and rejects (blocks) all other high frequency components, then it is called as an active low pass filter.

The **circuit diagram** of an active low pass filter is shown in the following figure −



Active High Pass Filter:

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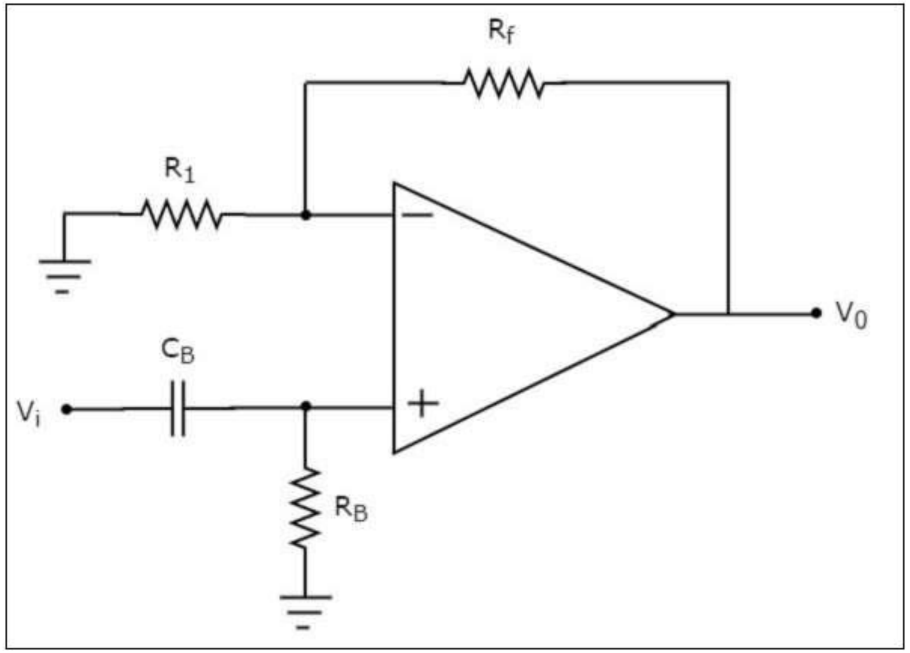
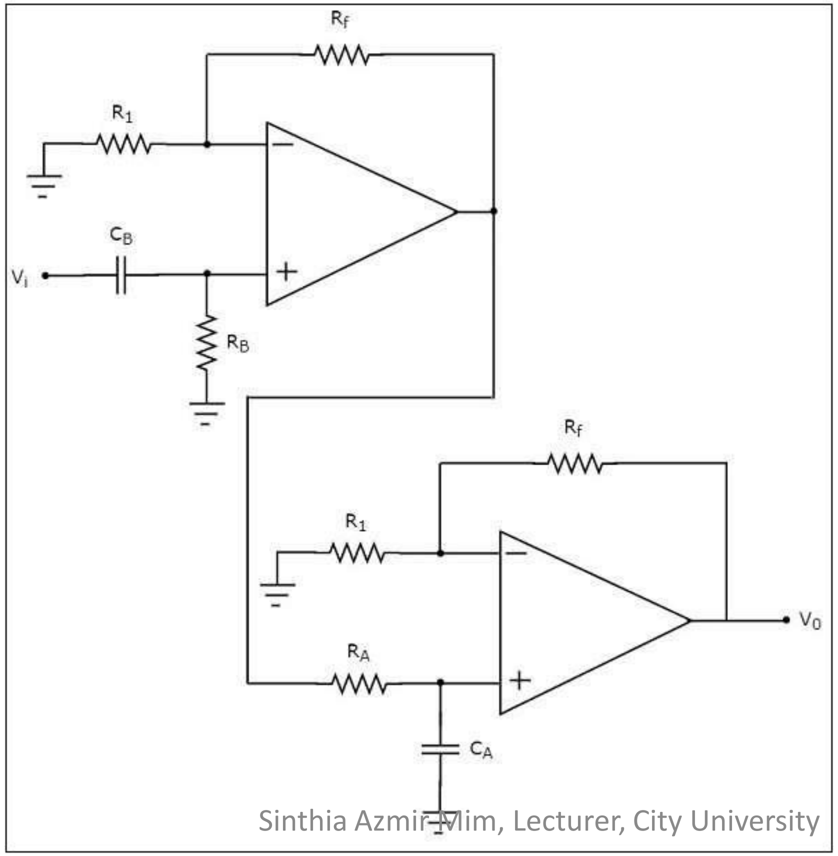


Active Band Pass Filter:

If an active filter allows (passes) only one band of frequencies, then it is called as an active band pass filter. In general, this frequency band lies between low frequency range and high frequency range. So, active band pass filter rejects (blocks) both low and high frequency components.

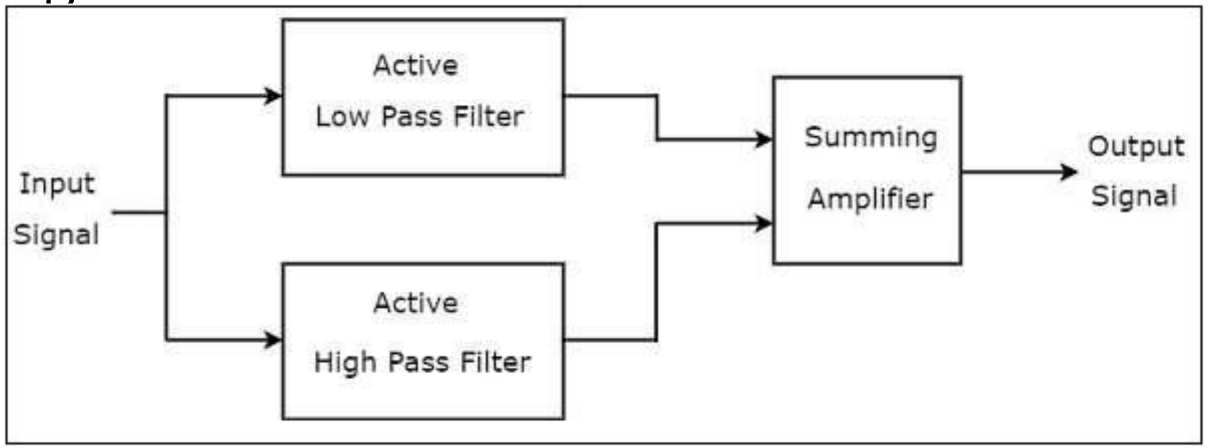
The **circuit diagram** of an active band pass filter is shown in the following figure

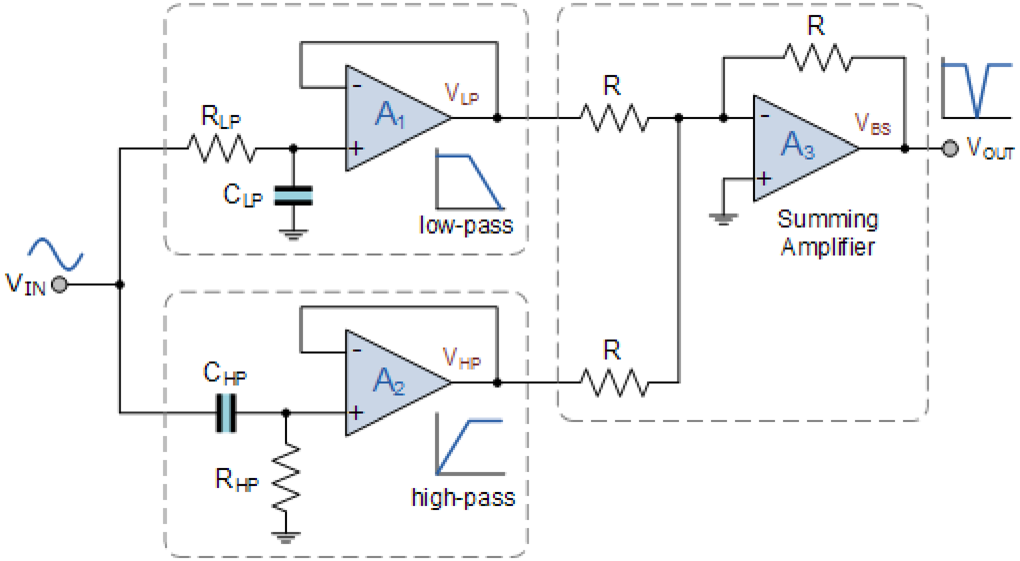


Active Band Stop Filter:

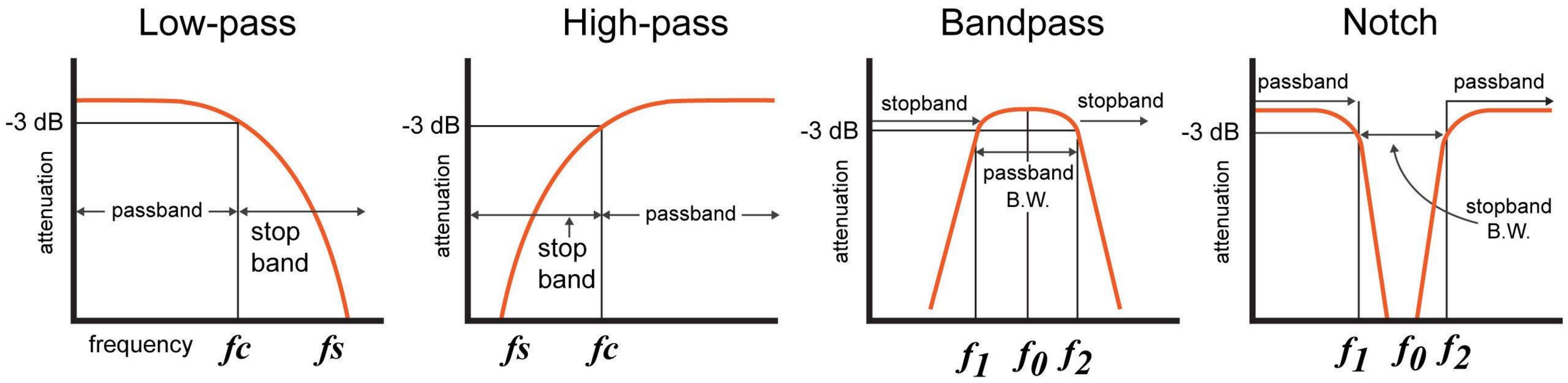
If an active filter rejects (blocks) a particular band of frequencies, then it is called as an active band stop filter. In general, this frequency band lies between low frequency range and high frequency range. So, active band stop filter allows (passes) both low and high frequency components.

The **block diagram & Circuit diagram** of an active band stop filter is shown in the following figure –

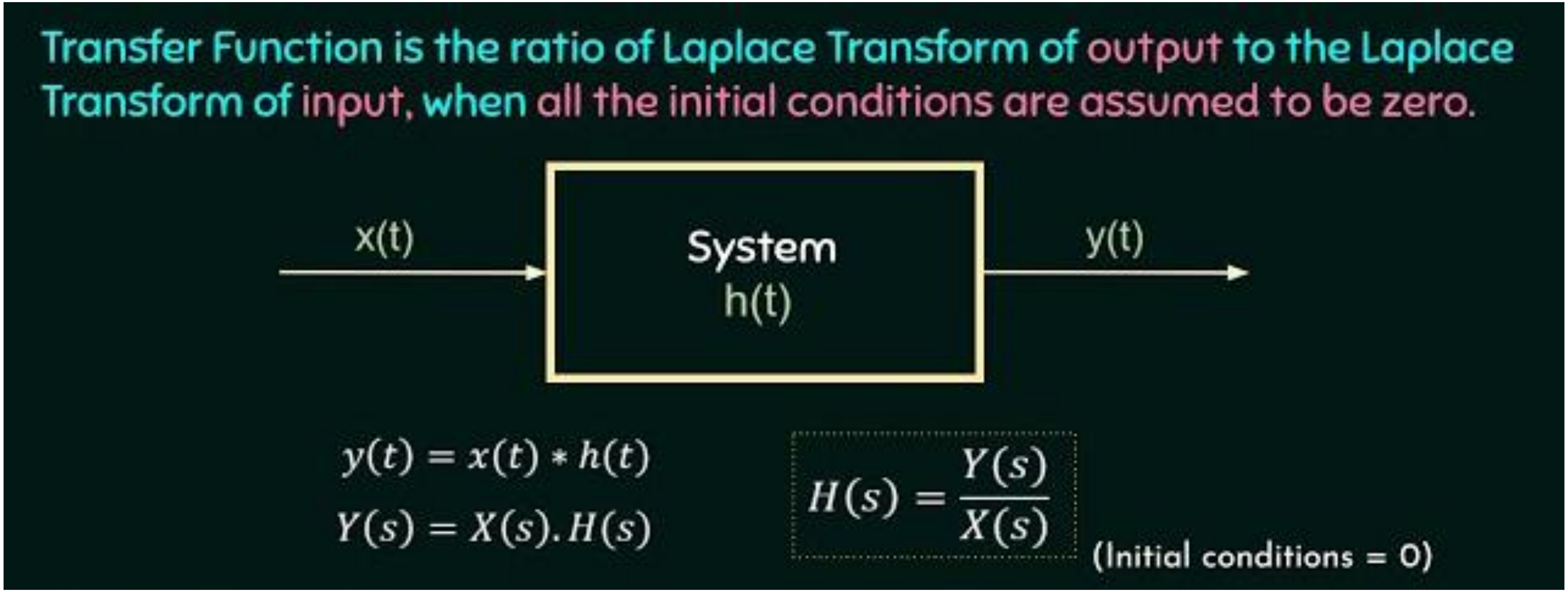




Response curves for the four major filter types:

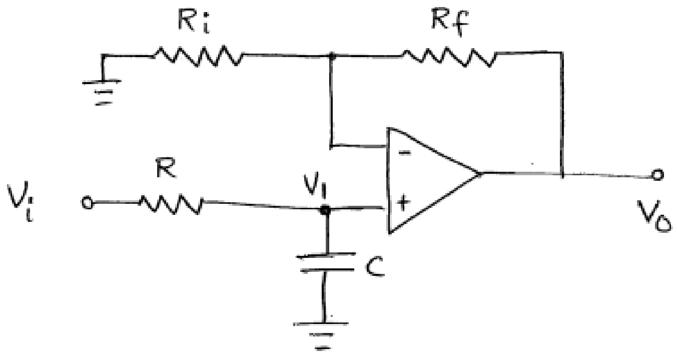


Transfer Function



Transfer Function of First Order Active Low Pass Filter:

A first order filter consists of a single RC network connected to the (+) input terminal of a non-inverting op-Amp amplifier and is shown in figure below. Resistors R_i and R_f determine the gain of the Filter in the pass band.



The closed loop gain A_0 of the op-Amp is

$$A_0 = \frac{V_0(s)}{V_1(s)} = 1 + \frac{R_f}{R_i} \longrightarrow (1)$$

$$V_1(s) = V_i(s) \times \frac{\frac{1}{sC}}{R + \frac{1}{sC}}$$

$$\Rightarrow \frac{V_1(s)}{V_i(s)} = \frac{1}{1 + sRC} \longrightarrow (2)$$

$$\therefore \quad H(s) = \frac{V_o(s)}{V_i(s)} = \frac{V_o(s)}{V_1(s)} \times \frac{V_1(s)}{V_i(s)}$$

$$H(s) = \left[1 + \frac{R_f}{R_i}\right] \frac{1}{1+SRC} \qquad \left[\text{From } 1 \wedge 2\right]$$

$$H(s) = \frac{A_0}{1+SRC} \longrightarrow 3$$

$$H(s) = \frac{A_0}{1+\frac{s}{\omega_h}} \quad \text{where} \quad \omega_h = \frac{1}{RC}$$

$$H(j\omega) = \frac{A_0}{1+j\left(\frac{\omega}{\omega_h}\right)} = \frac{A_0}{1+j\left(\frac{f}{f_h}\right)}$$

Here $\omega_h = \frac{1}{RC} \Rightarrow f_h = \frac{1}{2\pi RC}$

where f_h = upper cut-off frequency.

$$H(j\omega) = \frac{A_0}{1+j\left(\frac{f}{f_h}\right)}$$

$$\Rightarrow \left|H(j\omega)\right| = \frac{A_0}{\sqrt{1+\left(\frac{f}{f_h}\right)^2}}$$

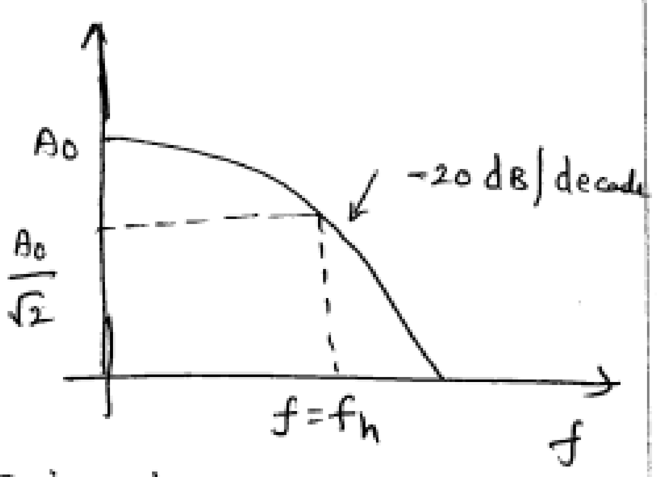
If $f << f_h \rightarrow \frac{f}{f_h}$ is neglegible, $|H(j\omega)| = A_0$

At $f = f_h \Rightarrow |H(j\omega)| = \frac{A_0}{\sqrt{2}}$

If $f >> f_h \Rightarrow |H(j\omega)| = 0$

Here $H(s) = \dfrac{A_0}{1 + \frac{s}{\omega_h}}$

$\Rightarrow H(s) = \dfrac{A_0 \omega_h}{s + \omega_h}$



Here the gain decreases at a rate of -20 dB/decade

Problem 1 : Design a first order low pass filter so that cut-off frequency by 2KHz and pass band gain 1

Solution:

$$f_h = \frac{1}{2\pi RC} \Rightarrow 2 \times 10^3 = \frac{1}{2\pi R C}$$

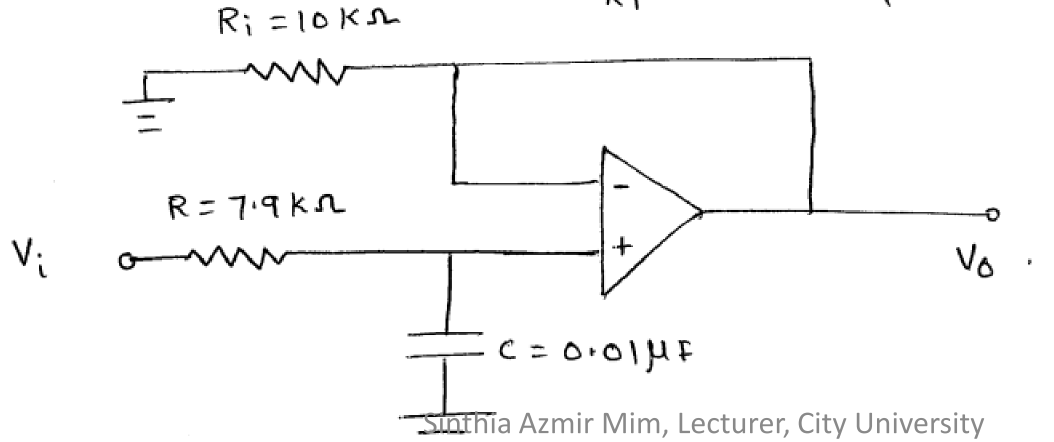
choose $C = 0.01\,\mu F$, $R = 7.9\,k\Omega$

pass band gain = 1

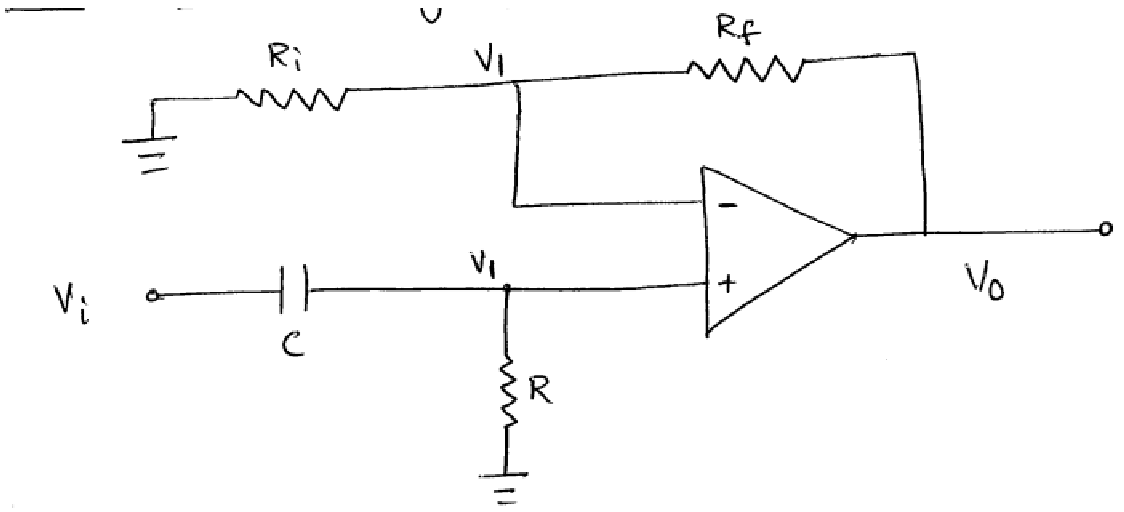
$$A_0 = 1 \Rightarrow A_0 = 1 + \frac{R_f}{R_i}$$

$$1 = 1 + \frac{R_f}{R_i}$$

$$\Rightarrow \frac{R_f}{R_i} = 0 \quad \left(\text{If} \quad R_f = 0\,\Omega,\ R_i = 10\,k\Omega \right)$$



Transfer Function of First Order Active High Pass Filter:



Here $A_o = \frac{V_o}{V_1} = 1 + \frac{R_f}{R_i} \longrightarrow (1)$

$$V_1(s) = V_i(s)\,\frac{R}{R + \frac{1}{sC}} \longrightarrow (2)$$

$$\frac{V_1(s)}{V_i(s)} = \frac{R}{R + \frac{1}{sC}} = \frac{1}{1 + \frac{1}{sRC}} \longrightarrow (3)$$

$$H(s) = \frac{V_o(s)}{V_i(s)} = \frac{V_o(s)}{V_1(s)} \times \frac{V_1(s)}{V_i(s)}$$

$$H(s) = A_0 \times \frac{1}{1 + \frac{1}{sRC}}$$

$$H(j\omega) = \frac{A_0}{1 + \frac{1}{j\omega RC}}$$

$$H(j\omega) = \frac{A_0}{1 - j\frac{\omega_L}{\omega}} \quad \text{where} \quad \omega_L = \frac{1}{RC}$$

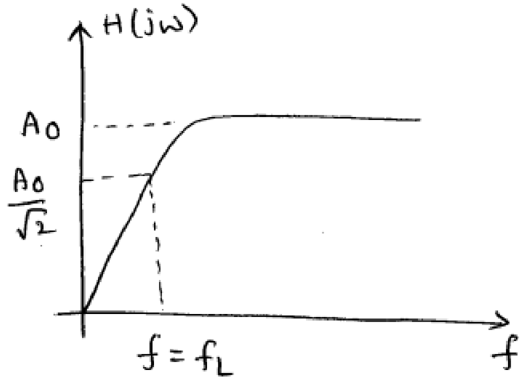
$$|H(j\omega)| = \frac{A_0}{\sqrt{1 + \left(\frac{\omega_L}{\omega}\right)^2}} = \frac{A_0}{\sqrt{1 + \left(\frac{f_L}{f}\right)^2}}$$

where $f_L = \frac{1}{2\pi RC}$ = Lower cut-off frequency

$f << f_L \Rightarrow |H(j\omega)| = 0$

$f = f_L \Rightarrow |H(j\omega)| = \frac{A_0}{\sqrt{2}}$

$f >> f_L \Rightarrow |H(j\omega)| = A_0$



Problem 4: Design a first order highpass filter so that lower cut-off frequency by 1KHz and pass band gain of 2.

Solution: Here $f_L = \frac{1}{2\pi RC}$

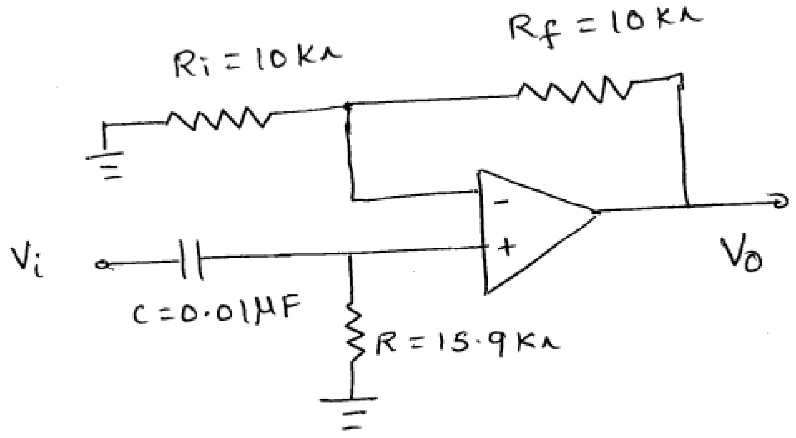
$f_L = 1\times10^3$, choose $C = 0.01\,\mu F$

then $R = 15.9\,K\Omega$

pass band gain = 2

$2 = 1 + \frac{R_f}{R_i}$

then $R_f = R_i = 10\,K\Omega$




Thank you