Question :- To determine the cut off frequency of an op-amp having $B_1 = 1 MHz$. $A_{VD} = 200 V/mV$.

Solution :- Since; $f_1 = B_1 = 1 MHz$.

$$f_c = \frac{f_1}{A_{VD}} = \frac{1 MHz}{200 V/mV} = \frac{1 \times 10^6}{200 \times 10^3} = 5 Hz$$

Ans

2. Slew Rate :- Slew rate is defined as the maximum rate at which the amplifier output can change in volts per microsecond (v/μs).

$$SR = \frac{\Delta V_0}{\Delta t} \; V/\mu s$$

with t in μs.

If one tried to drive the o/p at a rate of voltage change greater than the slew rate, the output would not be able to change fast enough and would not vary over the full range expected resulting in signal clipping or distortion.

Question :- For an op-amp having a slew rate = 2v/μs what is the maximum closed loop voltage gain that can be used loop voltage gain that can be used when the input signal varies by .5v to 10μs?

Solution :- Since; $V_0 = A_{CL} V_i$

Or $$\frac{\Delta V_0}{\Delta V_t} = A_{CL} \frac{\Delta V_i}{\Delta t}$$

$$A_{CL} = \frac{\Delta V_0 / \Delta t}{\Delta V_i / \Delta t} = \frac{SR}{\Delta V_i / \Delta t}$$

$$A_{CL} = \frac{2V/\mu s}{.5V/10\mu s} = 40$$

Any closed loop voltage gain of magnitude greater than 40 would drive the output at a rate greater than the slew rate allows. So the maximum closed loop gain is 40.

3. Maximum Signal Frequency :-

The maximum frequency at which an op-amp may operate depends on both the bandwidth (BW) and the slew rate (SR) parameters of the op-amp. For a sinusoidal signal of general form :-

$$v_0 = k[\sin(2\pi f t)]$$

The maximum voltage rate of change can be shown to be :-

Signal maximum rate of change = $2\pi f k$ V/s

To prevent distortion at the output the rate of change must also be less than the slew rate i.e;

$$2\pi f k \leq SR$$

$$\omega \leq SR$$

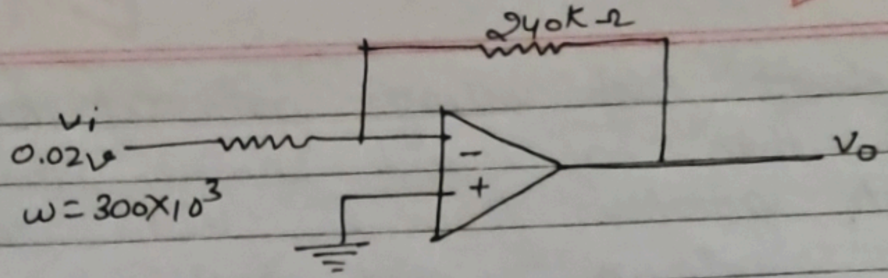
So that;

$$\boxed{f \leq \frac{SR}{2\pi k} \text{ Hz}}$$

$$\boxed{\omega \leq \frac{SR}{k} \text{ rad/s}}$$

Additionally the maximum frequency f in above eq^n is also limited by the unity gain band width.

Question-



For a signal and circuit, determines the maximum frequency that may be used op-amp $SR = 0.5V/\mu s$.

$$A_{CL} = \left|\frac{R_f}{R_1}\right| = \frac{240\,k\Omega}{10\,k\Omega} = 24$$

the output voltage provides

$$K = A_{CL} V_i = 24 \times (0.02V) = 0.48V$$

we know that;

$$\omega \leq \frac{SR}{K} = \frac{.5V/\mu S}{.48V} = 1.1 \times 10^6\ rad/s.$$

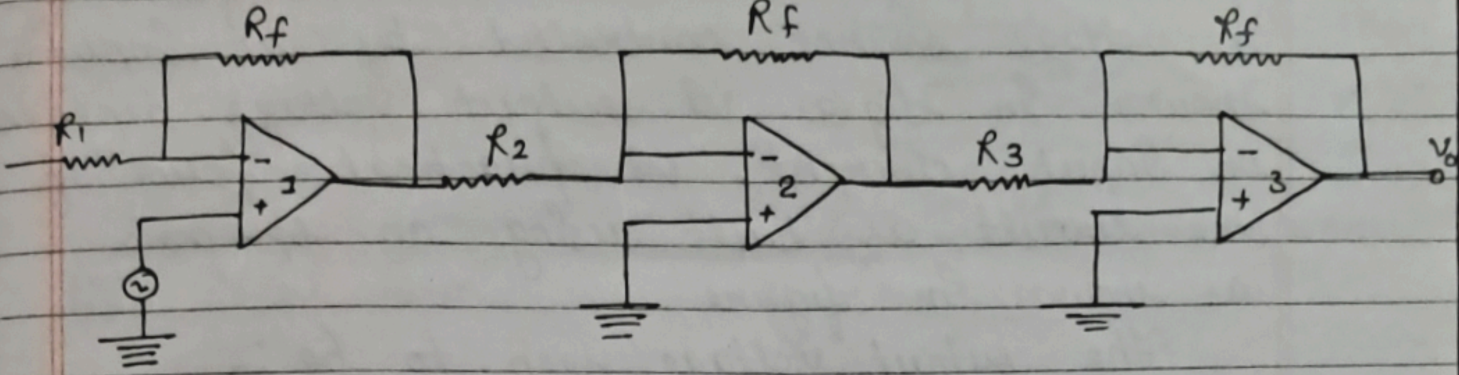
Since the signal frequency $\omega = 300 \times 10^3\ rad/s$ is less than the maximum value determines above. no output distortion will result.

Imperfection In Op-Amp Application:-

1. Multistage Gain:- when a number of stages are connected in series, the overall gain is the product of the individual stage gains. Fig. shows a connection of three stages. The first stage is connected to provide non inverting gain. The next two stages provides an inverting gain. The overall gain is the noninverting and is calculated by

$$A = A_1 A_2 A_3$$

where $A_1 = 1 + \frac{R_f}{R_1}$, $A_2 = -\frac{R_f}{R_2}$, $A_3 = -\frac{R_f}{R_3}$

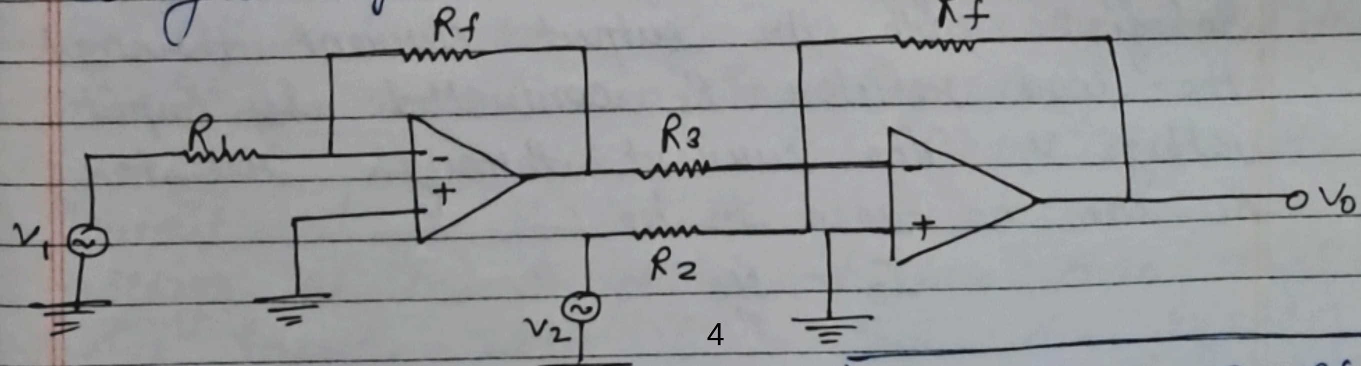


2. Voltage Summing :- Another popular use of an op-amp is as a summing amplifier. fig shows the connection with the output being the sum of three inputs, each multiplied by a different gain. The output voltage :-

$$V_0 = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right)$$

3. Voltage Subtraction :-

Two signals can be subtracted from one another in a number of ways. fig shows two op-amp stages are provides subtraction of input signals. The resulting output is given by :-



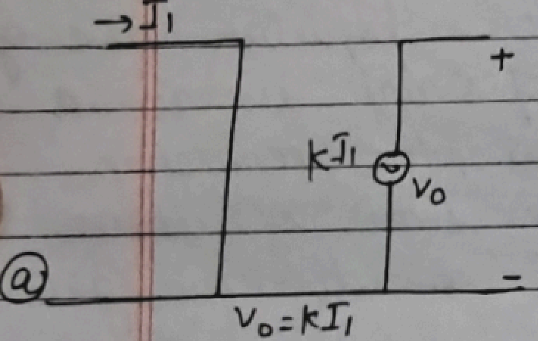
$$V_0 = -\left[\frac{R_f}{R_3}\left(-\frac{R_f}{R_1}V_1\right) + \frac{R_f}{R_2}(V_2)\right] \Rightarrow V_0 = -\left(\frac{R_f}{R_2}V_2 - \frac{R_f}{R_3}\frac{R_f}{R_1}V_1\right)$$

Current Controlled Voltage Source :-

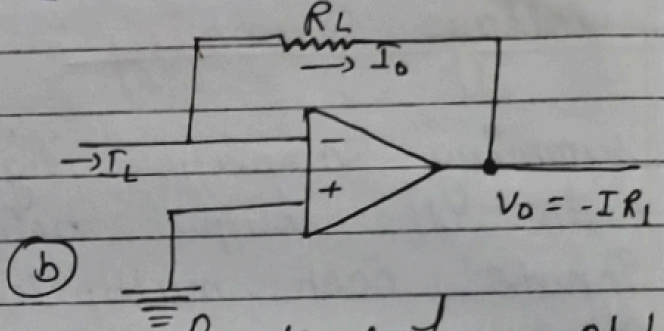
An ideal form of a voltage source controlled by an input is shown in fig (a). A output voltage depends on input current. A practical form of the circuit is built using an op-amp as shown in figure.

The output voltage seen to be :-

$$V_0 = -I_1 R_L = kI_1$$



Ideal current controlled voltage source.



Practical form of the current controlled voltage source.

Voltage Controlled Current Source:-

An ideal form of ckt providing an output current controlled by an input voltage is shown in fig 1. The output current is depend on input voltage. A practical circuit can be built as shown in fig 2. with the output current through the load resistor R_L controlled by input voltage V_1. The current through resistor R_L can be seen to be :-

$$I_0 = \frac{V_L}{R_1}$$

$$I_0 = kV_1$$

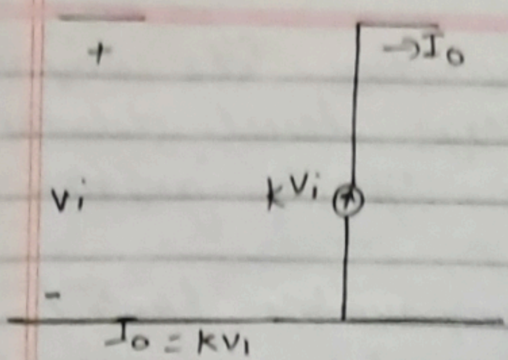


fig 1. Ideal form

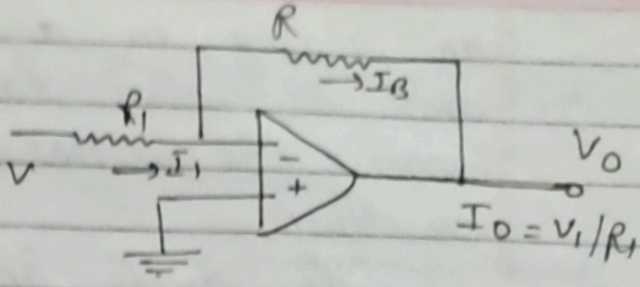


fig 2 :- Practical form.

Op-Amp As A Comparator :-

Comparator :- A comparator as its name implies compares signal voltage on one input of an op-amp with a known voltage called reference voltage on other input. It is nothing more than an open loop gain op-amp with two analog inputs and a digital output, the output may be (+) or (−) saturation voltage, depending on which is larger.

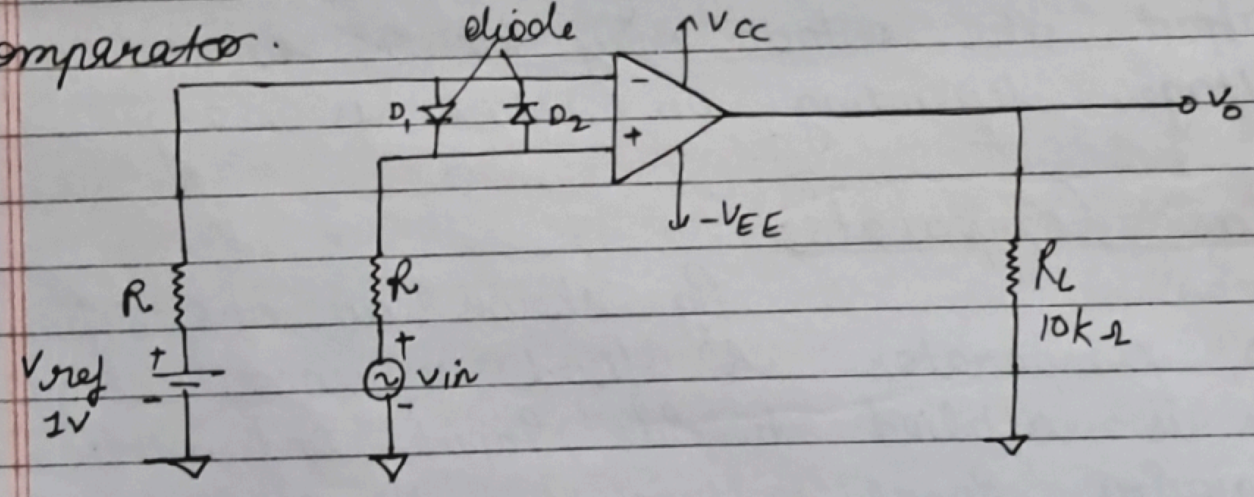
Basic Comparator :-

fig shows an op-amp used as a comparator. A fixed refrence voltage of 1v is applied to -ive input, and other time varying signal voltage Vin is applied to the (+) input. Because of this arrangement the circuit is called non-inverting comparator.

When Vin is less than Vref the output voltage V_0 is at $-V_{sat}$ because the voltage at (−) input is higher than that of +ive input. When Vin > Vref, the input becomes +ive with respect to -ive input the V_0 goes to $+V_{sat}$. Thus comparator is also an analog to digital converter. The comparator is also called voltage level detector because it detect whether Vin is greater or Vref.

The diode in a comparator protect the op-amp from damage due to excessive input voltage Vin. The resistance R in series with Vin is used to limit the current through D_1 and D_2. To reduce off set problem a resistance Rom is connected between -ive input & Vref for the switching action the amplitude of Vin must be large enough to pass through Vref.

Comparator.



Characteristics of Comparator :- The following characteristics of comparators are

1. Speed of operation
2. Accuracy
3. Compatibility of output.

Imp

Schmitt Trigger :-

A circuit which converts an irregular shaped wave form to a square wave or pulse. The circuit may is known as "Schmitt Trigger." Input wave form may be triangular, sine or distorted.

The input voltage V_{in} triggers the output V_0 every time It exceeds certain voltage levels called the upper threshold voltage V_{ut} and lower threshold voltage V_{lt}.

These threshold voltage are obtained by using the voltage divider R_1-R_2 where the voltage across R_1 is fedback to the (+) Input. The voltage across R_1 is a variable reference threshold voltage that depends on the value and polarity of output voltage V_0. When $V_0 = +V_{sat}$ the voltage across R_1 is called the upper threshold voltage. The Input voltage V_{in} must be slightly more +ive than V_{ut} In order to cause the output V_0 to switch from $+V_{sat}$ to $-V_{sat}$. As $V_{in} < V_{ut}$, V_0 is at $+V_{sat}$

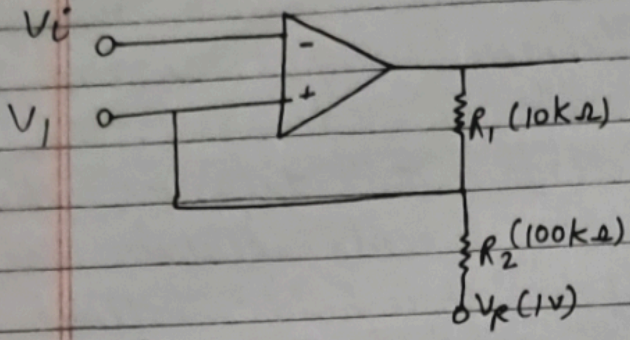
$$V_{ut} = \frac{R_1}{R_1+R_2}(+V_{sat})$$

when $V_0 = -V_{sat}$ the voltage across R_1 is referred to as the lower threshold voltage V_{lt}. V_{in} must be slightly more -ive than V_{lt} In order to cause V_0 to switch from $-V_{sat}$ to $+V_{sat}$

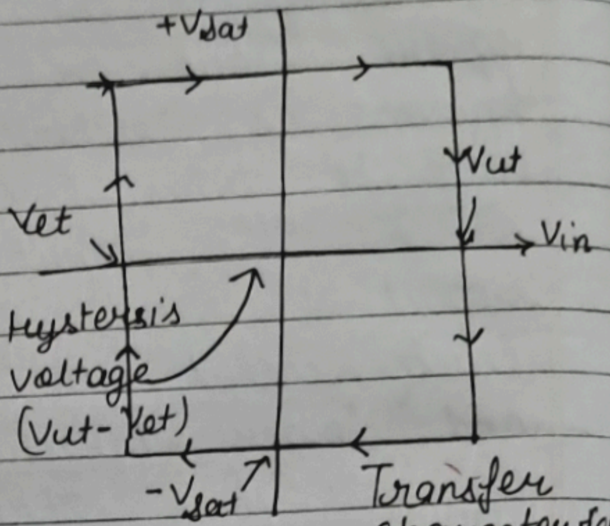
$$V_{lt} = \frac{R_1}{R_1+R_2}(-V_{sat})$$

The difference between the two threshold voltage V_{ut} and V_{lt} is known as "hysteresis" or "backlash"

$$V_{hy} = V_{ut} - V_{et}$$
$$= \frac{R}{R_1 + R_2}\left[+V_{sat} - (-V_{sat})\right]$$



Schmitt Trigger



Transfer characteristics

Filters:- An electric filter is often a frequency selective circuit that passes a specified band of frequencies and blocks or attenuates signals of frequencies outside this band.

Filters may be classified as :-

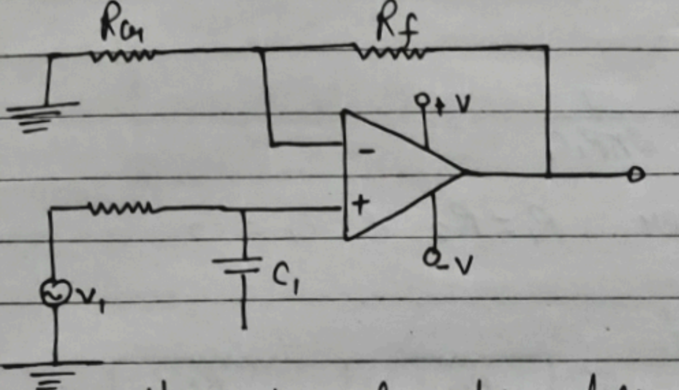
1. Analog or digital
2. Active
3. Audio frequency.

1. Active Filter :- A filter circuit can be constructed using passive components resistor and capacitors. An active filter employ transistor or op-amp in addition to resistors and the capacitors.

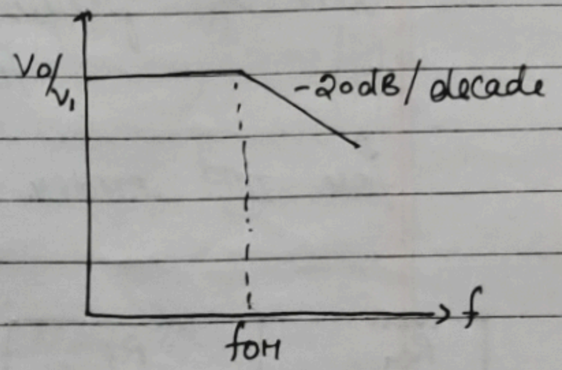
(a) Low Pass Active Filter :- A filter that provides a constant output from dc up to a cutoff frequency for and then passes no signal above the frequency is called an ideal low pass filter.

A first order low pass filter using a single resistor and capacitor is shown in figure. The voltage gain below the cut off frequency is constant at

$$A_V = 1 + \frac{R_f}{R_G} \qquad f_{OH} = \frac{1}{2\pi R_1 C_1}$$

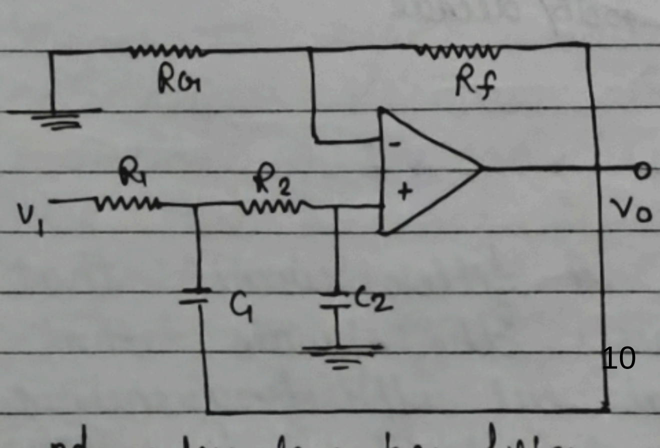


I st order low pass filter

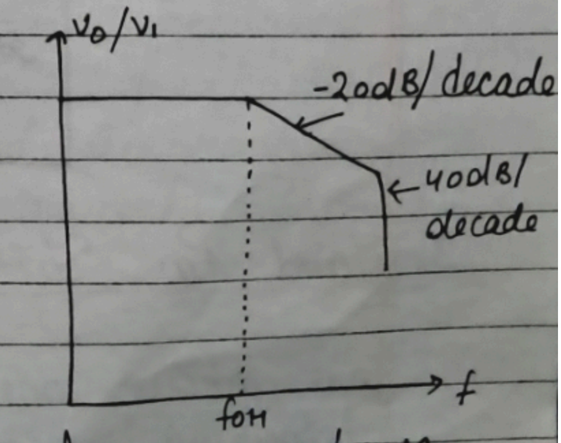


Frequency response.

connecting two sections of filter as in figure results in a II nd order low pass filter with cut off -40dB per decade. The circuit gain & cut off frequency are the same for I st order filter, except that the filter response drops at a faster rate for II nd order filter circuit.



II nd order low pass filter.



frequency response.

2. High Pass Filter :-

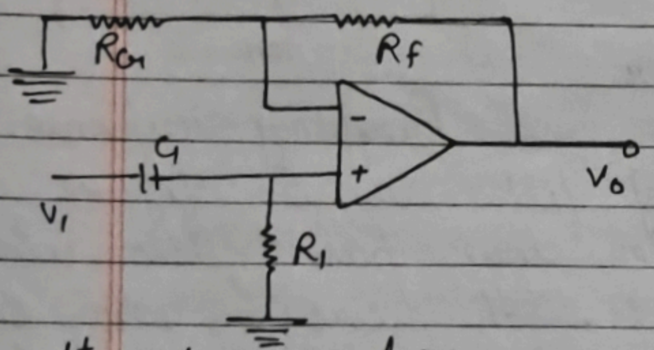
A filter that provides or passes signal above a cut off frequency f_{OL} is a high pass filter.
A first and IInd order high pass filter can be built as shown in figure. The amplifier gain can be calculated as

$$A_V = 1 + \frac{R_f}{R_G}$$

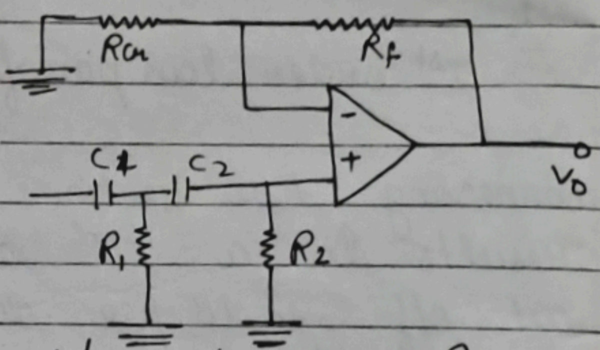
cut off frequency :-

$$f_{OL} = \frac{1}{2\pi R_1 C_1}$$

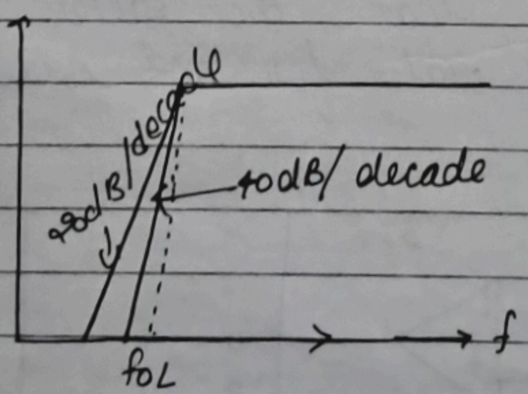
for IInd order filter $R_1 = R_2$ & $C_1 = C_2$.



Ist order H.P filter.



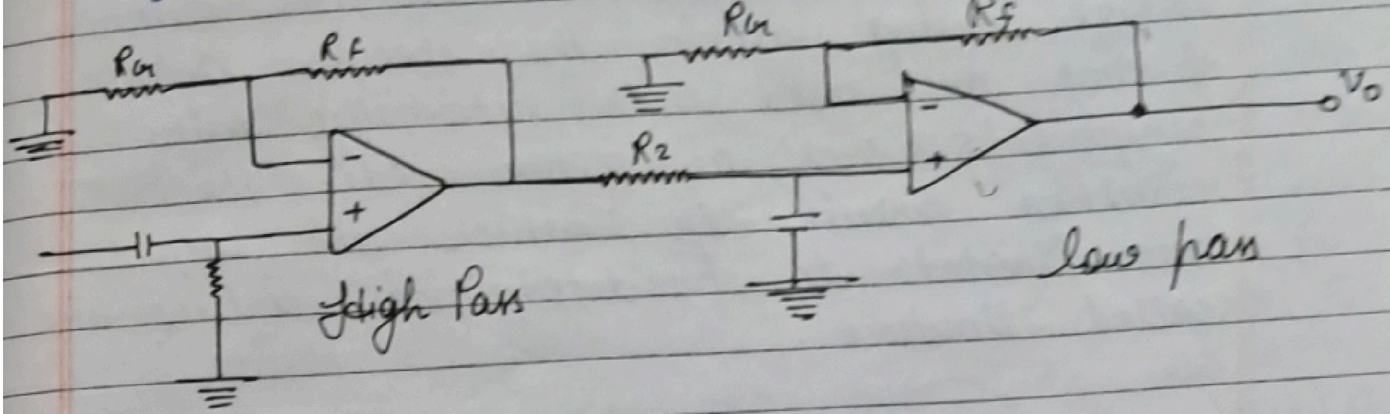
IInd order H.P Filter.

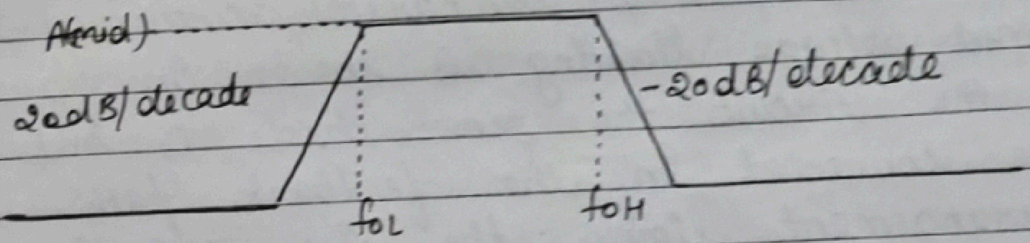


3. Band Pass Filter :-

A filter circuit that passes the signals that are above one ideal cut off frequency & below a second cut off frequency. It is

called "band Pass filter".
Fig. Shows a bandpass filter using two stages the first a high pass filter and second a low pass filter, the combined operation being a desired band pass response.





Frequency Response Curve.

Limitation of Op-Amp As A Comparator :-

A general purpose of op-amp can be used in relatively less critical comparator which speed and accuracy are not major factors, with true feedback, the switching speed can be ~~speed~~ improved and false transition due to noise can be eliminated. In addition an off set voltage compensating network and offset minimize register can be used to minimize the offset problems. The voltage swing of an op-amp is relatively very

very large because it is designed primarily as an amplifier. In words the output of a comparator is not compatible with a particular logic family such as TTL, which requires input voltage approximately +5V or 0V. Therefore to keep the output voltage swing within the specific limits op-amp are used with externally wire components such as zener diode. The resulting circuit in which the output are limited to predetermined values are called limitors.

Limitors:- The op-amp comparator circuit with output voltage limiting is shown in figure. In the circuit the zener diode D_1 and D_2 are connected in the feedback path. this arrangement limits the +ve and -ve output voltage V_o, when the input voltage V_{in} across the zero volt and increases in the +ve direction and the output voltage V_o increases in the -ve direction until the diode D_1 is forward bias and D_2 goes into the avalanche condition. Therefore the maximum -ve ~~volto~~ value of V_o is equal to $(V_2 + V_{D1})$ where V_2 is zener voltage and V_{D1} is voltage drop across the zener diode D_1. If the input voltage V_{in} crosses the 0V and increase in the -ve direction the output voltage increases in +ve direction. Therefore the maximum +Ve V_o is equal to $(V_2 + V_{D2})$.

$(D_2 = 0.7V)$. Thus the output voltage swings limited to $(V_2 + 0.7V)$ and $-(V_Z + 0.7)V$.

Since the output terminal of the op-amp is virtual ground, the input voltage V_{in} appears across R and V_0 appears across D_1 and D_2. The resistance Rom is connected to reduce off set problem.

If there is a need to limit the swing of output only in the true direction a combination of zener and rectifier are used. If only a single zener is used in the feedback path the output voltage is limited between $+V_2$ and $-V_0$. The exact opposite result can be obtained by reversing the direction of zener diode i.e; V_0 will be limited to $-V_2$ to $+V_D$.