



# ROHINI

## COLLEGE OF ENGINEERING & TECHNOLOGY

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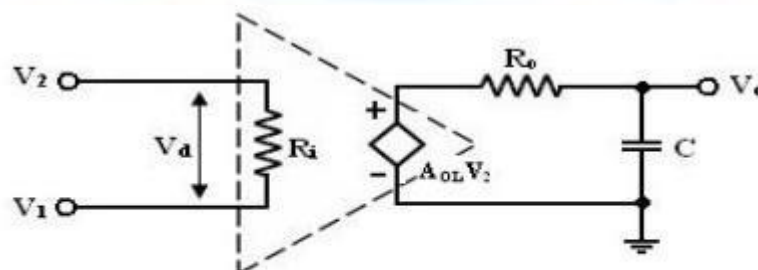
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### AC CHARACTERISTICS

For small signal sinusoidal (AC) application one has to know the ac characteristics such as frequency response and slew-rate.

#### 1. Frequency Response:

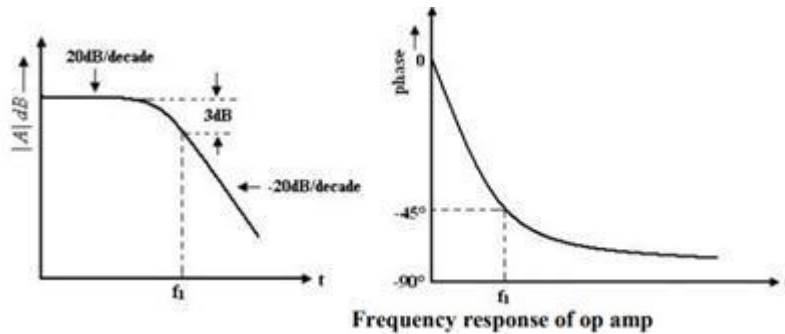
The variation in operating frequency will cause variations in gain magnitude and its phase angle. The manner in which the gain of the op-amp responds to different frequencies is called the frequency response. Op-amp should have an infinite bandwidth  $BW = \infty$  (i.e.) if its open loop gain is 90dB with dc signal its gain should remain the same 90 dB through audio and onto high radio frequency. The op-amp gain decreases (roll-off) at higher frequency what reasons to decrease gain after a certain frequency reached. There must be a capacitive component in the equivalent circuit of the op-amp. For an op-amp with only one break (corner) frequency all the capacitors effects can be represented by a single capacitor C. Below fig is a modified variation of the low frequency model with capacitor C at the output.



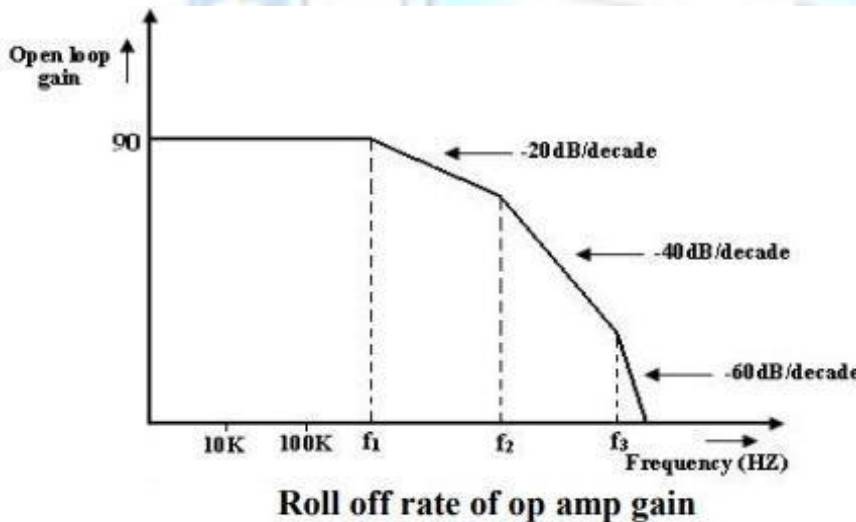
Equivalent circuit of practical circuit

There is one pole due to  $R_o C$  and one  $-20\text{dB/decade}$ . The open loop voltage gain of an op-amp with only one corner frequency is obtained from above fig.  $f_1$  is the corner frequency or the upper 3 dB frequency of the op-amp. The magnitude and phase angle of the open loop voltage gain are  $f_1$  of frequency can be written as, The magnitude and phase angle characteristics:

- 1 For frequency  $f \ll f_1$  the magnitude of the gain is  $20 \log A_{OL}$  in db.
- 2 At frequency  $f = f_1$  the gain is 3 dB down from the dc value of  $A_{OL}$  in db. This frequency  $f_1$  is called corner frequency.
- 3 For  $f \gg f_1$  the gain roll-off at the rate of  $-20\text{dB/decade}$  or  $-6\text{dB/decade}$ .



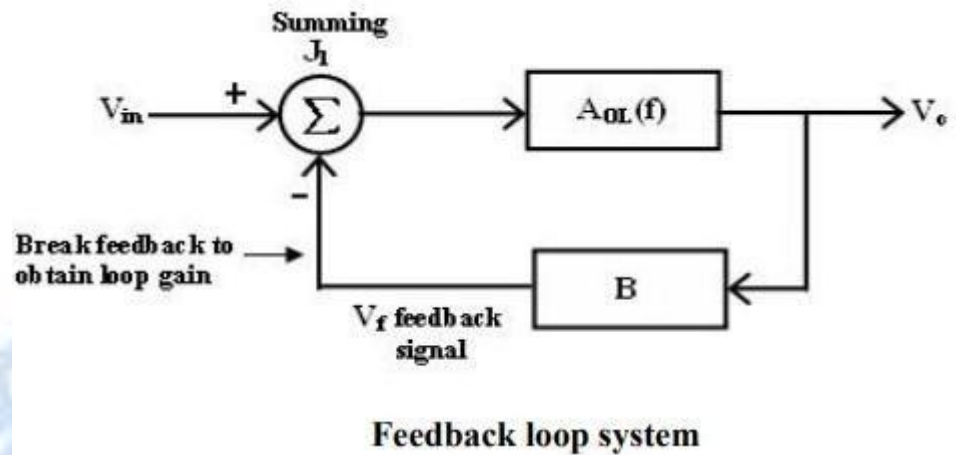
From the phase characteristics that the phase angle is zero at frequency  $f = 0$ . At the corner frequency  $f_1$  the phase angle is  $-45^\circ$  (lagging) and at an infinite frequency the phase angle is  $-90^\circ$ . It shows that a maximum of  $90^\circ$  phase change can occur in an op-amp with a single capacitor  $C$ . Zero frequency is taken as the decade below the corner frequency and infinite frequency is one decade above the corner frequency.



## 2. Circuit Stability:

A circuit or a group of circuit connected together as a system is said to be stable, if its o/p reaches a fixed value in a finite time. A system is said to be unstable, if its o/p increases with time instead of achieving a fixed value. In fact the o/p of an unstable sys keeps on increasing until the system break down. The unstable system is impractical and need be made stable. The criterion gn for stability is used when the system is to be tested practically. In theoretically, always used to test system for stability, ex: Bode plots.

Bode plots are compared of magnitude Vs Frequency and phase angle Vs frequency. Any system whose stability is to be determined can be represented by the block diagram.



The block between the output and input is referred to as forward block and the block between the output signal and f/b signal is referred to as feedback block. The content of each block is referred to as transfer frequency. From fig. we represented it by  $A_{OL}(f)$  which is given by  $A_{OL}(f) = V_o/V_{in}$  if  $V_f = 0$  ----- (1) where  $A_{OL}(f)$  = open loop volt gain.

The closed loop gain  $A_f$  is given by  $A_f = V_o/V_{in}$   
 $= A_{OL} / (1 + (A_{OL})(B))$  -----(2)  $B$  = gain of feedback circuit.

$B$  is a constant if the feedback circuit uses only resistive components.

Once the magnitude Vs frequency and phase angle Vs frequency plots are drawn, system stability may be determined as follows **Case 1:**

Determine the phase angle when the magnitude of  $(A_{OL})(B)$  is 0dB (or) 1.

If phase angle is  $> -180$ , the system is stable. However, in some systems the magnitude may never be 0, in that case method 2, must be used.

#### **Case 2:**

Determine the phase angle when the magnitude of  $(A_{OL})(B)$  is 0dB (or) 1.

If phase angle is  $> -180$ , If the magnitude is -ve decibels then the system is stable. However, in some systems the phase angle of a system may reach  $-180$ , under such conditions method 1 must be used to determine the system stability. **Stability Specifications:**

**Gain cross over frequency:** The frequency at which the loop gain magnitude  $|A_{OL}(f)\beta|$  is unity i.e.,  $20 \log|A_{OL}(f)\beta| = 0$  is called gain cross over frequency.

**Phase cross over frequency:** The frequency at which the phase shift introduced by the loop gain is  $-180^\circ$  or

$n\pi$  radians is called phase cross over frequency.

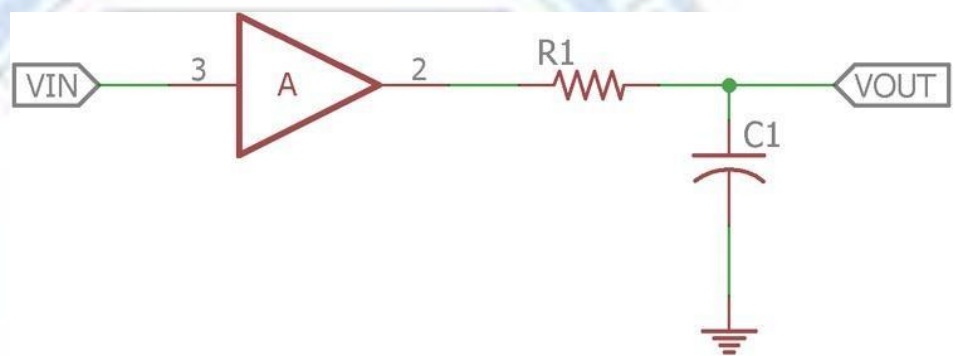
### **3. Frequency compensation:**

In applications where one desires large bandwidth and lower closed loop gain suitable compensation techniques are used. Two types of compensating techniques are used

1. External compensation
2. Internal compensation **External frequency compensation:**

Some types of op-amp are made to be used with externally connected compensating components specially if they are to be used for relatively low closed loop gain. The compensating network alters the open loop gain so that the roll-off rate is -20 dB/decade over a wide range of frequency. The common methods for accomplishing this are:

Dominant-pole compensation Pole-zero (lag) compensation **Dominant-pole compensation:**



**Fig . Dominant-pole compensation**

Suppose A is the uncompensated transfer function of the op-amp in open-loop condition as given by

$$A = \frac{A_{OL} \cdot \omega_1 \cdot \omega_2 \cdot \omega_3}{(s + \omega_1)(s + \omega_2)(s + \omega_3)}$$

Introduce a dominant pole by adding RC-network in series with op-amp as in fig.or by connecting a capacitor C from a suitable high resistance point to ground. The compensated transfer function A' becomes

$$\begin{aligned} A' &= \frac{V_o}{V_i} \\ &= A \cdot \frac{-j}{\omega C} = \frac{A}{R - \frac{j}{\omega C}} = \frac{A}{1 + j \frac{f}{f_d}} \end{aligned}$$

$$\text{where, } f_d = \frac{1}{2\pi RC}$$

$$\text{using equation } A = \frac{A_{OL}}{(i + j \frac{f}{f_1})(i + j \frac{f}{f_2})(i + j \frac{f}{f_3})} : 0 < f_1 < f_2 < f_3$$

$$\text{We get, } A' = \frac{A_{OL}}{(i + j \frac{f}{f_d})(i + j \frac{f}{f_1})(i + j \frac{f}{f_2})(i + j \frac{f}{f_3})}, f_d < f_1 < f_2 < f_3$$

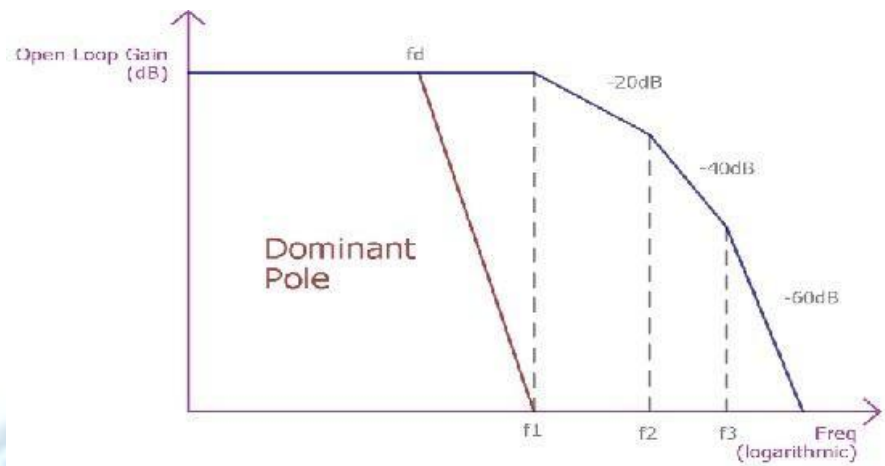


Fig: Gain vs Frequency curve for dominant pole compensation Disadvantages :

It reduces the open –loop bandwidth drastically. But the noise immunity of the system is improved since the noise frequency components outside the bandwidth are eliminated.

### Poe-Zero compensation:

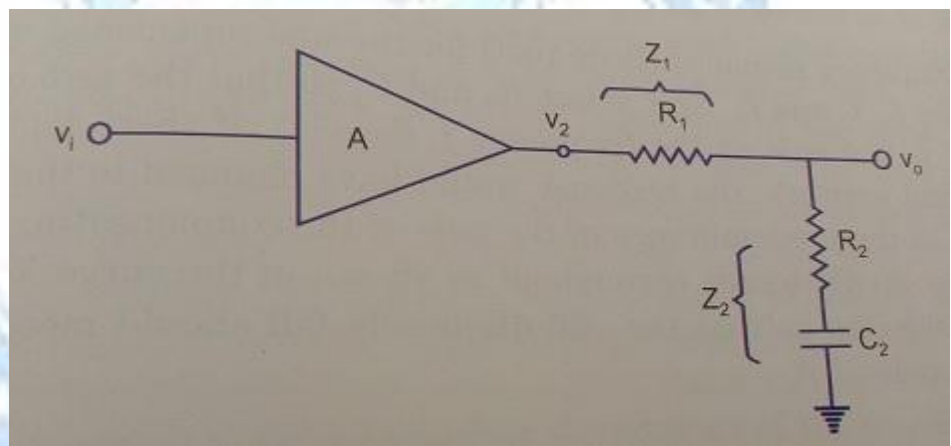


Fig: pole-zero compensation

Here the uncompensated transfer function  $A$  is altered by adding both pole and a zero as shown in fig. The zero should be at higher frequency than pole. The transfer function of the compensating network alone is ,

$$\frac{V_o}{V_i} = \frac{Z_2}{Z_1 + Z_2} = \frac{R_2}{R_1 + R_2} \frac{1 + j\frac{f}{f_1}}{1 + j\frac{f}{f_0}}$$

$$\text{where, } Z_1 = R_1, Z_2 = R_2 + \frac{1}{j\omega C_2}, f_1 = \frac{1}{2\pi R_2 C_2}, f_0 = \frac{1}{2\pi(R_1 + R_2)C_2}$$

The compensating network is designed to produce a zero at the first corner frequency  $f_1$  of the uncompensated transfer function  $A$ .

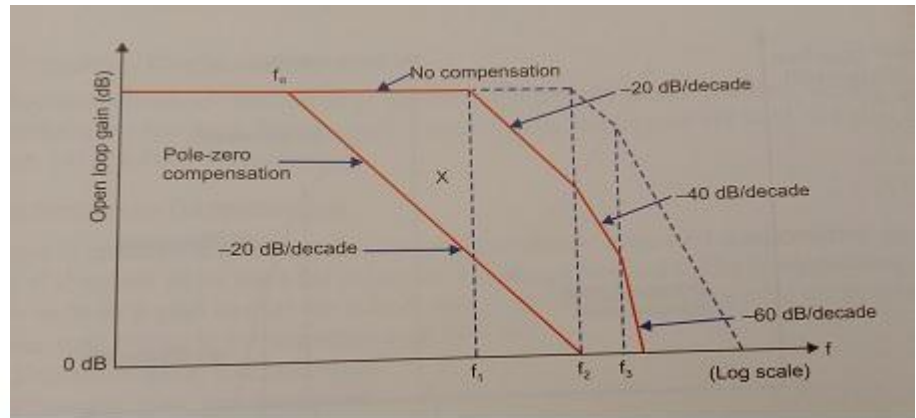


Fig: open loop gain vs frequency for Pole-zero compensation. The compensated transfer function is given as

$$A' = \frac{V_o}{V_i} = \frac{V_o}{V_2} \cdot \frac{V_2}{V_1} = A \cdot \frac{R_2}{R_1 + R_2} \frac{1 + j\frac{f}{f_1}}{1 + j\frac{f}{f_0}}$$

$$= \frac{A_{OL}}{(i + j\frac{f}{f_1})(i + j\frac{f}{f_2})(i + j\frac{f}{f_3})} \cdot \frac{R_2}{R_1 + R_2} \frac{1 + j\frac{f}{f_1}}{1 + j\frac{f}{f_0}}$$

$$= \frac{A_{OL}}{(i + j\frac{f}{f_0})(i + j\frac{f}{f_2})(i + j\frac{f}{f_3})}$$

$$\text{with } 0 < f_0 < f_1 < f_2 < f_3$$

#### Internal compensation:

In this case we are not using any compensation techniques. During the fabrication of IC we are compensating and designing the IC. Capacitor is fabricated internally and miller effect compensation is used.

#### 4. Slew Rate:

The rate of change of output voltage with respect to time is called slew rate. It can be represented as V/μsec

$$SR = \frac{dV_o}{dt} / \max \text{ or } SR = \frac{I_{\max}}{C}$$