1.7 AC CHARACTERISTICS

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

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 =∞ (i.e.) if its open loop gain in 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 figure 1.7.1 is a modified variation of the low frequency model with capacitor C at the output.

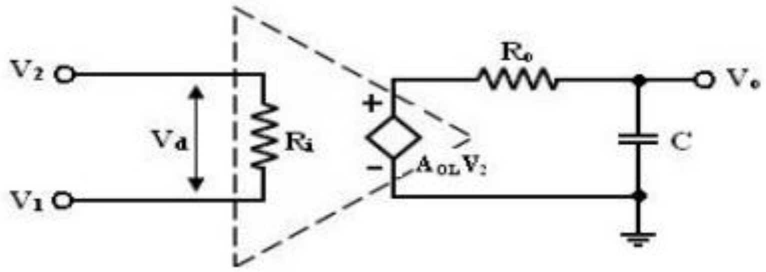

Figure1.7.1 High frequency model of an op-amp with single corner frequency

[source:"Linear Integrated Circuits"by D.Roy Choudhry, Shail Bala Jain, Page-125]

There is one pole due to R_0C and one -20dB/decade. The open loop voltage gain of an op-amp with only one corner frequency is obtained from above figure 1.7.1.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 volt gain are f1 of frequency can be written as, The magnitude and phase angle characteristics:

1. For frequency f<< f_1 the magnitude of the gain is 20 log AOL in db.
2. At frequency f = f_1 the gain in 3 dB down from the dc value of AOL in db. This

frequency f_1 is called corner frequency.

3. For f>> f_1 the fain roll-off at the rate off -20dB/decade or -6dB/decade. Figure 1.7.2.shows the open loop magnitude characteristics and phase characteristics for an op-amp with single break frequency

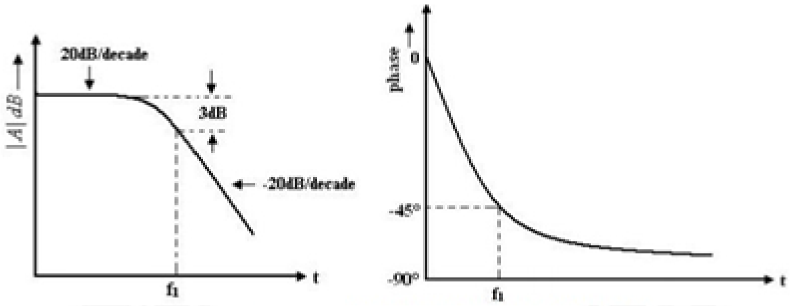

Figure 1.7.2 shows the open loop magnitude characteristics and phase characteristics for an op-amp with single break frequency

[source:"Linear Integrated Circuits"by D.Roy Choudhry, Shail Bala Jain, Page-126]

From the phase characteristics that the phase angle is zero at frequency f = 0. At the corner frequency f1 the phase angle is -45° (lagging and an infinite frequency the phase angle is -90 . It shows that a maximum of 90 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. Figure 1.7.3. Below shows the open loop gain vs frequency curve.

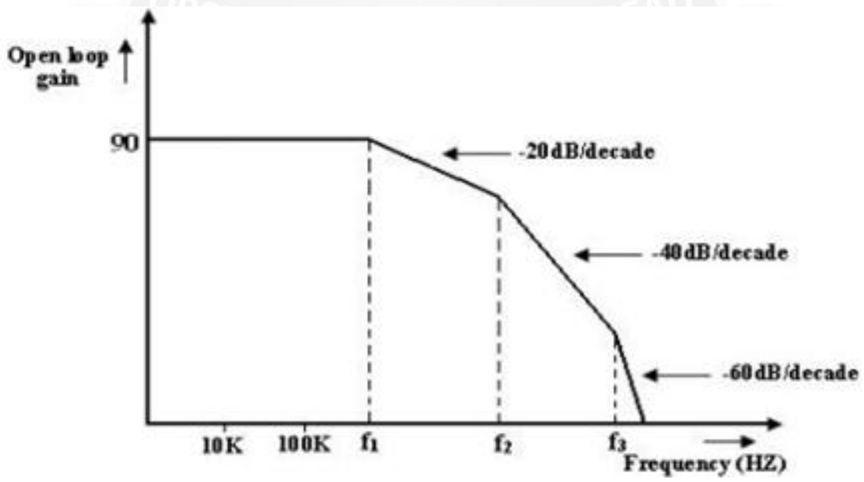

Figure 1.7.3 shows the open loop gain vs frequency curve

[source:"Linear Integrated Circuits"by D.Roy Choudhry, Shail Bala Jain, Page-127]

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 given 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 represented by the block diagram shown in figure 1.7.4 below.

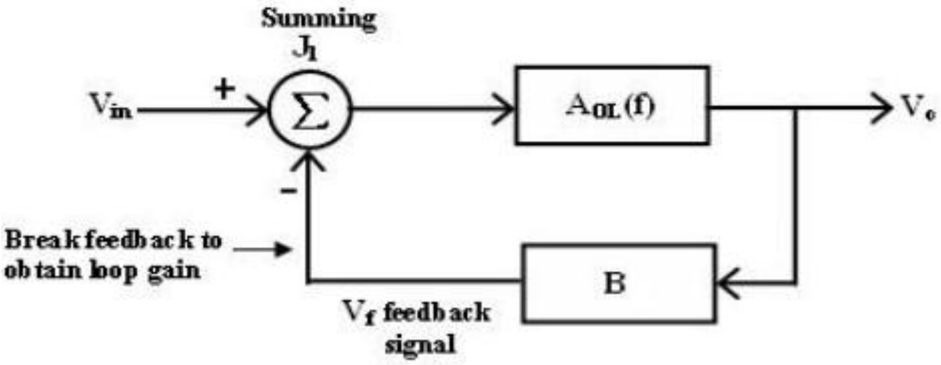

Figure 1.7.4 feedback loop system

[source: https://www.brainkart.com/subject/Linear-Integrated-Circuits_220/]

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 as transfer frequency. From fig. we represented it by AOL (f) which is given by

$$A_{OL}\ (f) = V_0/V_{in} \text{ if } V_f = 0 \text{ ----- (1)}$$

where A_{OL} (f) = open loop volt gain.

The closed loop gain A_f is given by $A_F = V_0/V_{in}$

$$= A_{OL} / (1+(A_{OL})\ (B) \text{ ----(2)}$$

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 (AOL) (B) is 0dB (or) 1.If phase angle is >-180 , the system is stable. However, the some systems the magnitude may never be 0, in that cases method 2, must be used.

Case 2:

Determine the phase angle when the magnitude of (AOL) (B) is 0dB (or) 1.If phase angle is > - 180 , If the magnitude is –ve decibels then the system is stable. However, the some systems the phase angle of a system may reach -1800, 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 ie,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° or nπ radians is called phase cross over frequency.

FREQUENCY COMPENSATION

In applications where one desires large bandwidth and lower closed loop gain satiable 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

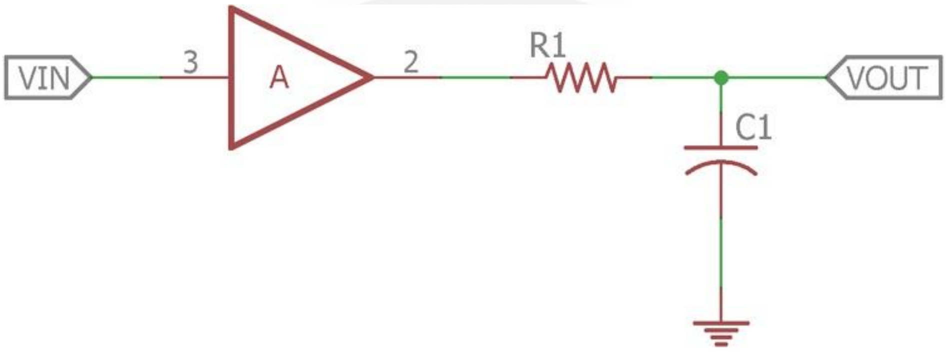

Figure 1.7.5 Dominant-pole compensation

[source: https://circuitdigest.com/tutorial/frequency-compensation-of-op-amp]

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

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

Introduce a dominant pole by adding RC-network in series with op-amp as in fig 5.or by connecting a capacitor C from a suitable high resistance point to ground. Gain vs Frequency curve for dominant pole compensation is shown in figure1.7.6. The compensated transfer function A' becomes

$$A' = \frac{V_o}{V_i}$$

$$= A.\frac{\frac{-j}{\omega C}}{R - \frac{j}{\omega C}} = \frac{A}{1 + j\frac{f}{f_d}}$$

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

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

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

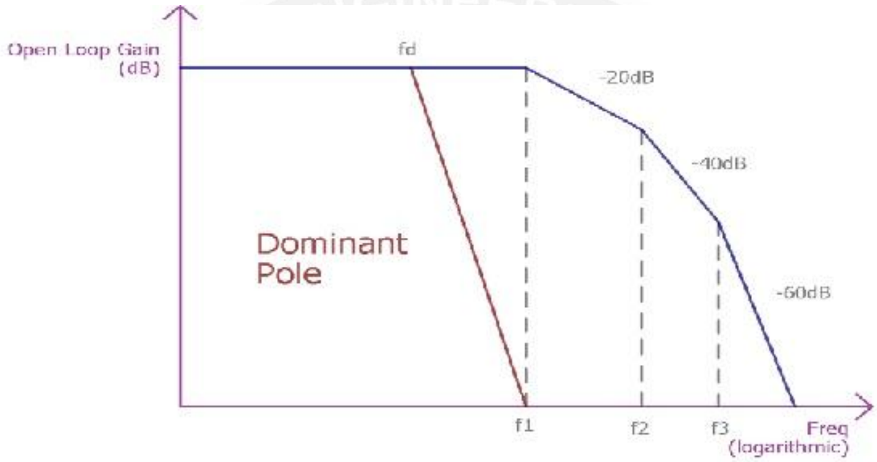

Figure 1.7.6 Gain vs Frequency curve for dominant pole compensation

[source:"Linear Integrated Circuits"by D.Roy Choudhry, Shail Bala Jain, Page-133]

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

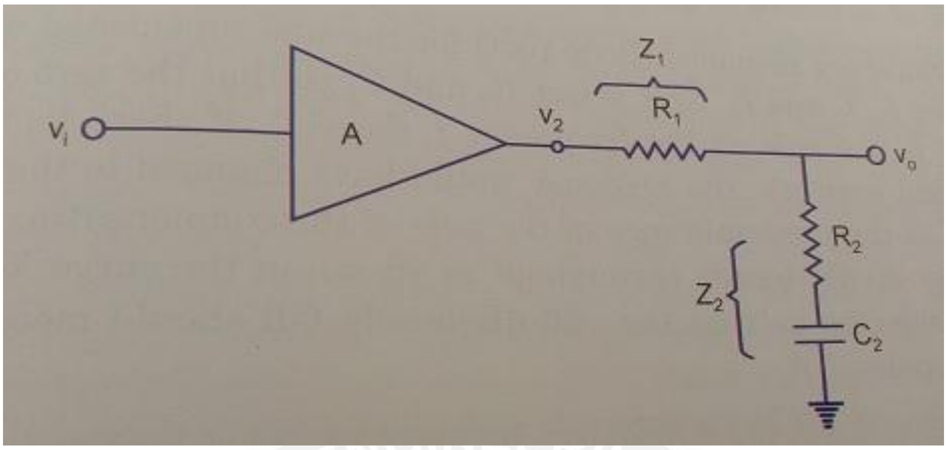

Figure 1.7.7 pole-zero compensation

[source:"Linear Integrated Circuits"by D.Roy Choudhry, Shail Bala Jain, Page-133]

Here the uncompensated transfer function A is altered by adding both pole and a zero as shown in figure1.7.7.The zero should be at higher frequency than pole.The transfer function of the compensating network alone is ,

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

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

The compensating network is designed to produce a zero at the first corner frequency f_1 of the uncompensated transfer function A. Figure 1.7.8.shown below is the open loop gain vs frequency for Pole-zero compensation.

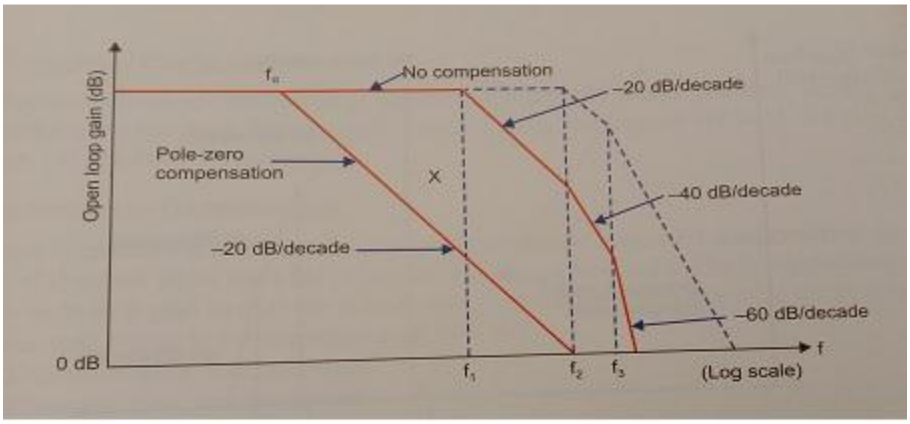

Figure1.7.8.open loop gain vs frequency for Pole-zero compensation

[source:“Linear Integrated Circuits”by D.Roy Choudhry, Shail Bala Jain, Page-135]

The compensated transfer function is given as

$$A^{'} = \frac{V_o}{V_i} = \frac{V_O}{V_2}.\frac{V_2}{V_I} = A.\frac{R_2}{R_1 + R_2}\frac{1 + j\frac{f}{f_1}}{1 + j\frac{f}{f_o}}$$

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

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

$$\boldsymbol{with}\ 0 < f_o < f_1 < f_2 < f_3$$

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.

SLEW RATE

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

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