Concept of Frequency Compensation

It can be noted that op-amp with single break / corner frequency is inherently stable. Consider a system with 3 break frequencies. Due to this an additional phase shift of -180º is present between the inverting input and output terminals. Hence the op-amp may behave oscillatory and become unstable. The phase margin becomes negative. The method of modifying loop gain frequency response of the op-amp so that it behaves like single break frequency response that provides sufficient positive phase margin is called Frequency compensation Technique. For hig gain op-amps the phase margin is more than +45º, though the op-amp is non-compensated. But for lower gain op-amps, the phase margin is smaller than +45º and there is chance of instability. Thus the op-amps with high closed loop gain are easy to compensate while op-amp with low closed loop gain are difficult to compensate to provide stability. Hence in practice compensation techniques are introduced both internally and externally.

1) External compensation 2) Internal compensation.

External Compensation Techniques

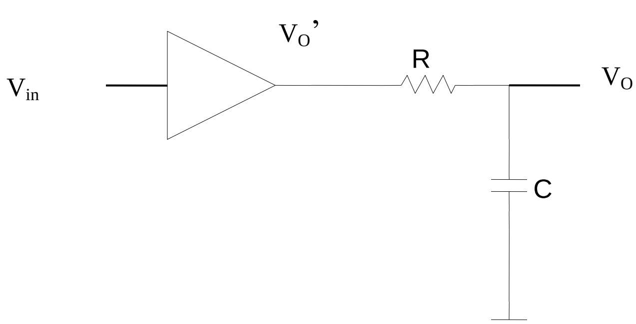
The compensation network is connected externally to alter the response as per requirements. The methods adopted are

1) Dominant Pole compensation 2) Pole-zero compensation.

Dominant Pole compensation: Consider an op-amp with 3 break frequencies**.** Its loop gain be A.

$$A = \frac{A_{OL}}{\left(1 + j\frac{f}{f_1}\right)\left(1 + j\frac{f}{f_2}\right)\left(1 + j\frac{f}{f_3}\right)}$$

Here the dominant pole is introduced by adding a compensating network. It is essentially an RC network as shown in figure.



The dominant pole means the pole with magnitude much smaller than the existing poles. Hence the break frequency of the compensating network is the smallest compared to the existing break frequencies. The transfer function of the compensating network is given as

Let A1 be the transfer function of the compensating network = V_o / V_o’

By voltage divider rule, $A_1 = \frac{V_O}{V_O\,'} = \frac{-jX_C}{R - jX_C}$

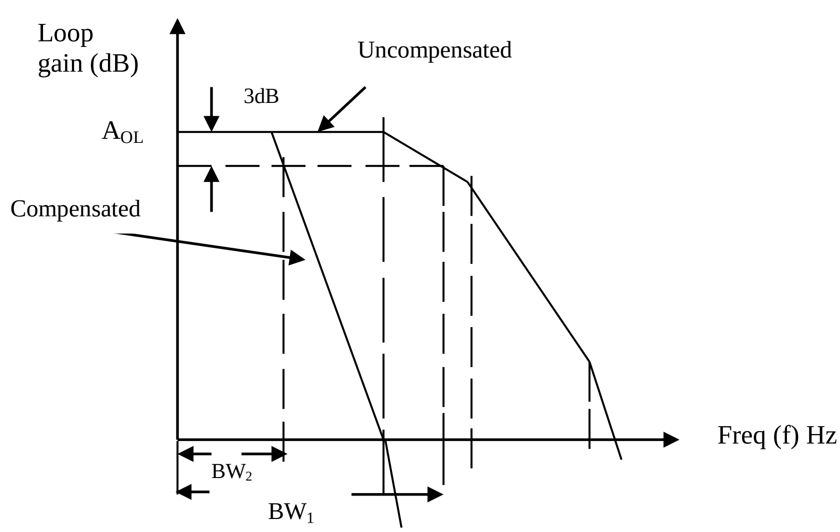
On simplification we get $A_1 = \frac{1}{1 + j2\pi fRC}$

Let $f_d = \frac{1}{2\pi RC}$ and $A_1 = \frac{1}{1 + j\left(\frac{f}{f_d}\right)}$

Where f_d is called the break frequency of the compensating network. Hence the compensated transfer function is given by

$$A' = \frac{A_{OL}}{\left(1 + j\frac{f}{f_d}\right)\left(1 + j\frac{f}{f_1}\right)\left(1 + j\frac{f}{f_2}\right)\left(1 + j\frac{f}{f_3}\right)}$$

The values of R and C are selected in such a way that the loop gain drops to 0 dB with a slope of -20 dB / decade and at a frequency where the poles of the uncompensated system contributes very small phase shift. This ensures that at gain cross over frequency the phase shift is greater than -180º and hence positive phase margin exist. Generally f_d is selected so that magnitude plot for A’ passes through 0 dB at the pole f_1 of A. The compensated and uncompensated plots are shown in figure 2.10



It can be seen that the 3 dB bandwidth for a non compensated system is BW_1 and that for compensated system is BW_2. Here the bandwidth reduces w.r.t. compensated system.

Merits: 1) Excellent noise immunity system as the bandwidth is small.
2) By adjusting f_d, adequate phase margin and stability of the system is assured.

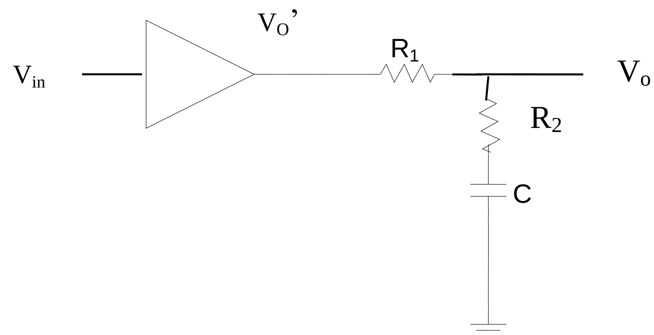
Demerits: The Bandwidth is drastically reduced for a compensated system.

Pole Zero compensation:

Consider an op-amp with 3 break frequencies**.** Its loop gain be A.

$$A = \frac{A_{OL}}{\left(1 + j\frac{f}{f_1}\right)\left(1 + j\frac{f}{f_2}\right)\left(1 + j\frac{f}{f_3}\right)}$$

Here the transfer function A is modified by adding a pole and zero with the help of compensating network. The zero added is at HF while the pole is at LF. Such a network is shown in figure 2.11



Let A_1 be the transfer function of the compensating network = V_o / V_o'

Let $Z_1=R_1$ & $Z_2 = R_2 - jX_{C2}$

By Voltage Divider rule, $A_1 = \dfrac{Z_2}{Z_1 + Z_2}$

$$\therefore A_1 = \frac{R_2 - jX_{C2}}{R_1 + R_2 - jX_{C2}}$$

On simplification, $\therefore A_1 = \dfrac{1 + j2\pi fR_2C_2}{1 + j2\pi f\left(R_1 + R_2\right)C_2}$

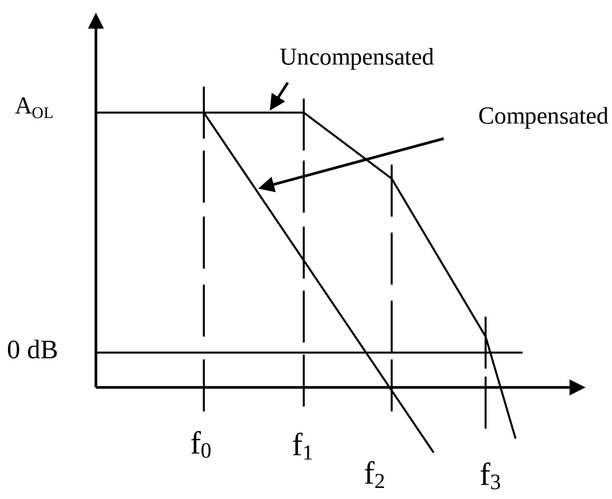
Now let $f_1 = \dfrac{1}{2\pi R_2 C_2}$ and $f_o = \dfrac{1}{2\pi(R_1 + R_2)C_2}$

$$\therefore A_1 = \frac{1 + j\left(\dfrac{f}{f_1}\right)}{1 + j\left(\dfrac{f}{f_o}\right)}$$

The values of Resistors and Capacitors are so selected that the break frequency for zero matches with the first corner frequency f1 of the uncompensated system while the pole of the compensating network at f_o passes through 0 dB at the second corner frequency f_2 of the uncompensated system. The loop gain becomes A' = AA_1.

$$A_1 = \frac{A_{OL}\left(1 + j\dfrac{f}{f_1}\right)}{\left(1 + j\dfrac{f}{f_0}\right)\left(1 + j\dfrac{f}{f_1}\right)\left(1 + j\dfrac{f}{f_2}\right)\left(1 + j\dfrac{f}{f_3}\right)}$$

Where $0<f_0<f_1<f_2<f_3$. The first corner frequency is now $f_{o,}$ and the gain starts rolling off at -20 dB / decade at f_o. At $f = f_{1,}$ there is pole zero cancellation and rolling rate continues as -20 dB / decade. The values of Resistors and Capacitors are so selected that plot passes through 0 dB at f_2. The response is shown in figure



As compared to the dominant pole compensation there is an improvement in bandwidth**.**

Internal Compensation Techniques

In recently developed op-amps like IC741, the compensation is built internally. A capacitor ranging from 10-30pF is fabricated between input and output stage to achieve the required compensation**.** This type of compensation is called Miller effect compensation. The demerit of dominant pole compensation techniques are overcome in this type. Here the capacitor is connected in the feedback path of the Darlington pair used in the output stage of the op-amp. These op-amps have single break frequency and are stable in nature. Some internally compensated op-amps are µA741, LM 107, LM 741, LM 112 and MC 1858.