AC Characteristics of op-amp :

→ The ac characteristic of op-amp are frequency response and slew rate.

Frequency response :

→ The manner in which gain of the op-amp respond to different frequencies is called frequency response.

→ A graph of the magnitude of gain (in dB) versus frequency is called frequency response.

→ Ideally, an op-amp should have infinite bandwidth i.e., gain of op-amp remains same for frequencies.

→ The practical op-amp gain decreases at higher frequencies (roll-off).

→ The reason for gain roll-off is due to capacitive component (capacitance) present in the equivalent circuit of op-amp.

→ The capacitance is due to the physical characteristics of the device (BJT or FET) used, and internal construction of op-amp.

→ For an op-amp with only one break frequency, all the capacitor effect can be represented by single capictor C.

→ There is one pole R_0C and one 20 dB/decade roll-off comes into effect.

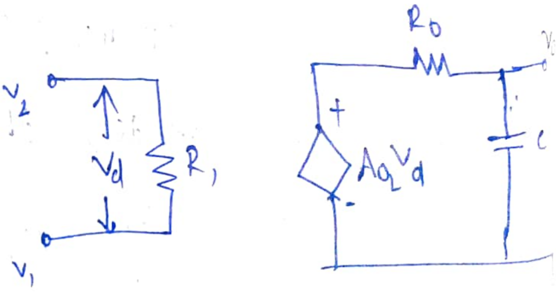
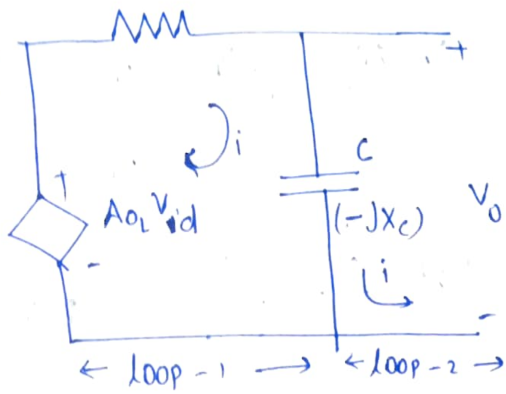


Fig. High frequency model of op-amp with single corner frequency.

Open loop voltage gain as a function of frequency :

→ The reactance value of capacitance = $\frac{1}{2\pi f c} = X_C$

→ The impedance value of capacitance is $-jX_C$.



Applying KVL in loop-1

$$-A_{OL}V_d + iR_0 - jX_c i = 0$$

$$\Rightarrow i(R_0 - jX_c) = A_{OL}V_d$$

$$\Rightarrow i = \frac{A_{OL}V_d}{R_0 - jX_c}$$

Applying KVL in loop-2

$$V_0 = -jX_c i \quad \text{— (1)}$$

puting value of i in above equation

$$\Rightarrow V_0 = -jX_c \cdot \frac{A_{OL}V_d}{R - jX_c} \quad \text{— (2)}$$

As we know, $X_c = \frac{1}{2\pi f c}$ $\Rightarrow -jX_c = \frac{1}{j2\pi f c}$

puting value of $-jX_c$ in eqn-(2)

$$V_0 = \frac{1}{j2\pi f c} \cdot \frac{A_{OL}V_d}{R_0 + \frac{1}{j2\pi f c}} = \frac{A_{OL}V_d}{R_0 \cdot j2\pi f c + 1}$$

$$\therefore V_o = \frac{A_{OL} V_d}{R_o \cdot j2\pi f C + 1}$$

$$\text{voltage gain} = \frac{V_o}{V_d} = A = \frac{A_{OL}}{1 + R_o j2\pi f C} \quad —③$$

Let $f_1 = \frac{1}{2\pi R_o C}$ putting this value in above equatio

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

Here $A(f)$ = open loop voltage gain as function of frequency

A_{OL} = gain of op-amp at 0Hz

f = operating frequency

f_1 = break frequency or corner frequency.

$$\text{Magnitude of open loop gain} = |A(f)| = \frac{A_{OL}}{\sqrt{1 + \left(\frac{f}{f_1}\right)^2}}$$

$$\text{phase angle of open loop gain} = \phi(f) = -\tan^{-1}\left(\frac{f}{f_1}\right)$$

$$|A(f)|\,dB = 20 \log |A(f)|$$

$$= 20 \log \left| \frac{A_{OL}}{\sqrt{1 + \left(\frac{f}{f_1}\right)^2}} \right|$$

$\therefore |A(f)|_{dB} = 20 \log (A_{OL}) - 20 \log \left(\sqrt{1 + \left(\frac{f}{f_1}\right)^2} \right)$

(i) When $f < f_1$ then $\left(\frac{f}{f_1}\right)^2 << 1$

So, $|A(f)|_{dB} = 20 \log (A_{OL})$

(ii) When $f = f_1$ then $\left(\frac{f}{f_1}\right)^2 = 1$,

So, $|A(f)|_{dB} = 20 \log (A_{OL}) - 20 \log (\sqrt{2})$

So, -3 dB decrease.

(iii) 20 dB decrease/decade after corner frequency. $(f > f_1)$

$\phi(f) = -\tan^{-1}\left(\frac{f}{f_1}\right)$

(i) If $f = 0 \Rightarrow \phi(f) = 0$

(ii) If $f = \infty \Rightarrow \phi(f) = -90°$

(iii) If $f = f_1 \Rightarrow \phi(f) = -45°$

→ The phase angle is zero at frequency $= f = 0$.

→ At corner frequency the phase angle is $-45°$ & infinite frequency the phase angle is $-90°$

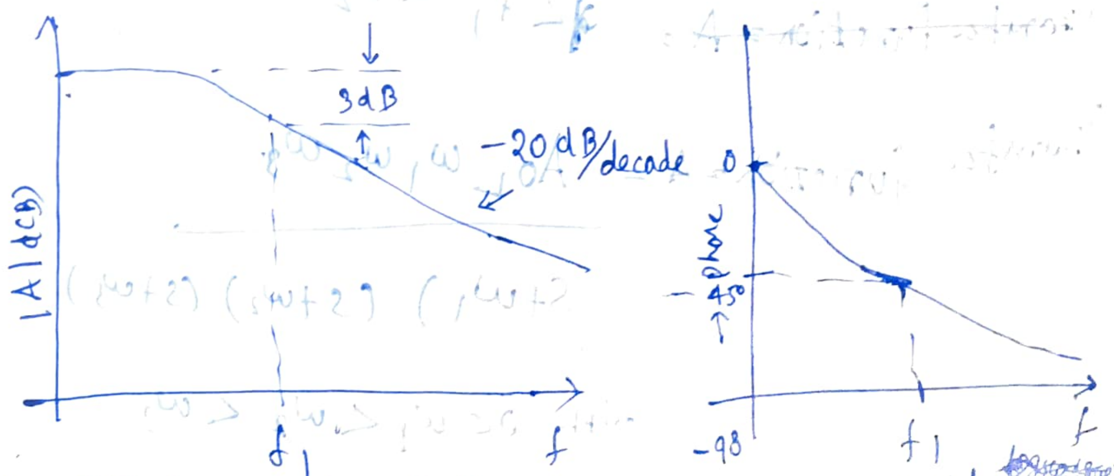


Fig. open loop magnitude & phase characteristics for an op-amp with single break frequency

$$A(f) = \frac{A_{OL}}{1 + j\left(\frac{f}{f_1}\right)} = \frac{A_{OL}}{1 + j\left(\frac{\omega}{\omega_1}\right)}$$

→ The voltage transfer function in s-domain can be written as:

$$A(f) = \frac{A_{OL}\,\omega_1}{\omega_1 + j\omega} \qquad \text{as } j\omega = s$$

$$A(f) = \frac{A_{OL}\,\omega_1}{\omega_1 + s}$$

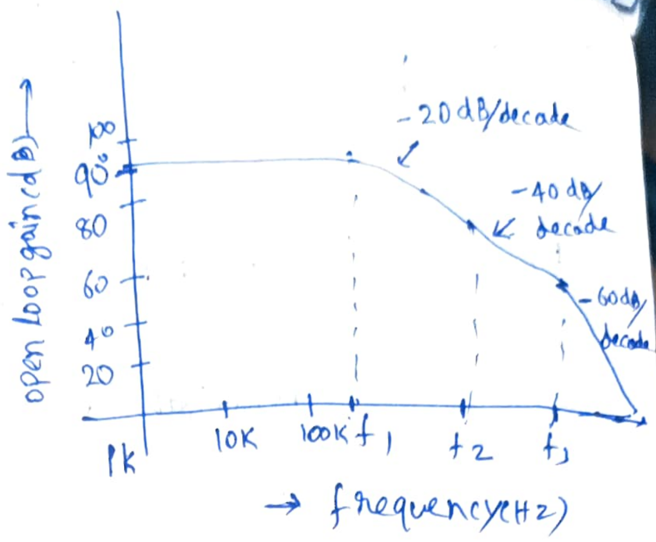
→ A practical op-amp has number of stages and each stage produces a capacitive component. Thus there will be different frequencies due to number of RC pole pairs. The transfer function of an op-amp with 3 break frequencies

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

~~Transfer function = A =~~ $0 < f_1 < f_2 < f_3$

$$\text{Transfer function} = A = \frac{A_{OL}\,\omega_1\,\omega_2\,\omega_3}{(s + \omega_1)(s + \omega_2)(s + \omega_3)}$$

with $0 < \omega_1 < \omega_2 < \omega_3$



~~Band~~ Unity gain bandwidth

The frequency where op-amp gain equal to unity is called unity gain bandwidth.

$$\text{unity gain bandwidth} = B = \frac{0.35}{\text{rise time}}$$

$$\text{open loop gain at } f = \frac{\text{bandwidth at unity gain}}{\text{input signal frequency } f}$$

bandwidth of inverting or non-inverting

$$\text{amplifier} = f_H = \frac{B}{(R_f + R_i)/R_1}$$

where B = unit gain bandwidth

R_f = feedback resistance

R_i = input resistance

14Q: (a) A 741 op-amp has a rise time of 0.35 μsec. Find the small-signal or unity gain bandwidth.

(b) What is the open loop voltage gain of op-amp at 1MHz?

(c) What is open-loop voltage gain at 100 kHz.

Ans : Given rise time = 0.35 μsec

(a) $B = \frac{0.35}{\text{rise time}} = \frac{0.35}{0.35\ \mu\text{sec}} = 1\ \text{MHz}$

(b) Open loop gain at 1 MHz = $\frac{1\ \text{MHz}}{1\ \text{MHz}} = 1$

$= \frac{\text{bandwidth at unity gain}}{\text{input signal frequency}}$

(c) Open loop gain at 100 KHz = $\frac{1\ \text{MHz}}{100\ \text{KHz}} = 10$