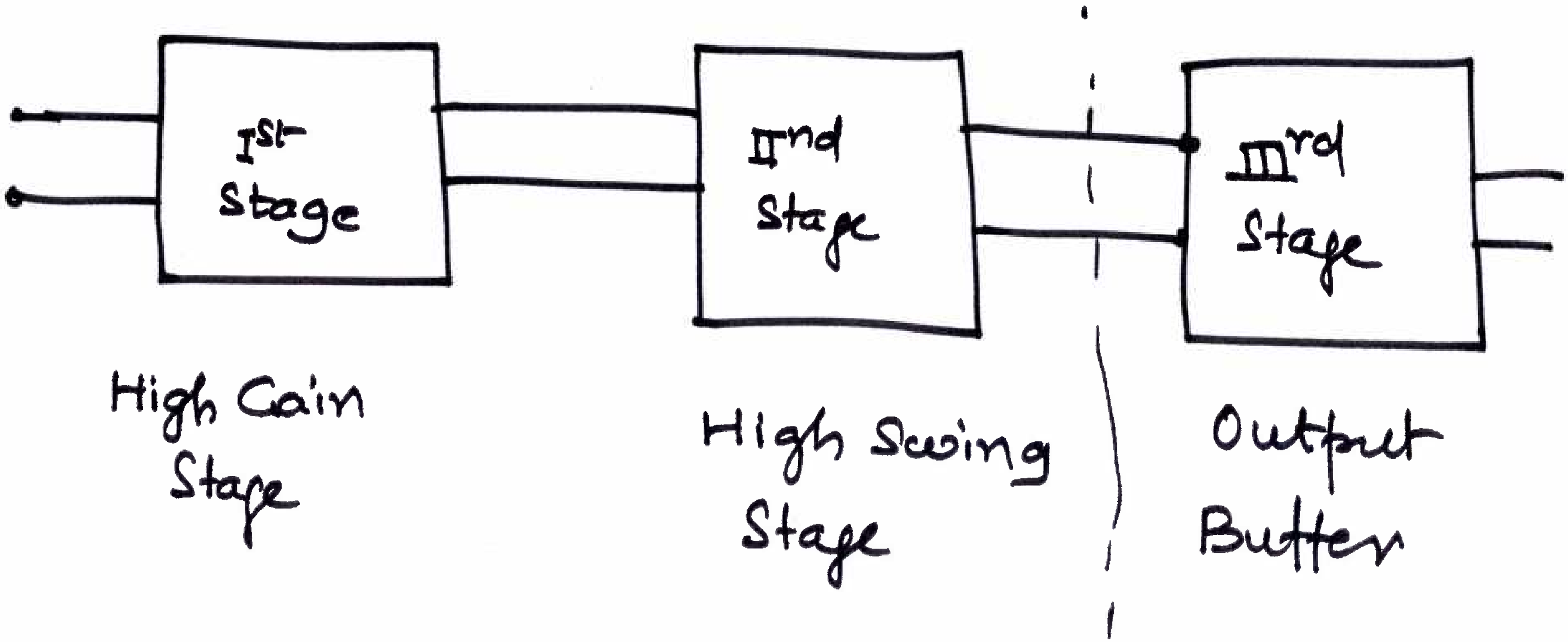
CMOS OPAMP : Two Stage OPAMP

Typically Double-ended CMOS uses Current Source biasing, while Single-ended OPAMP uses current Mirror Biasing



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Block Diagram of OPAMP

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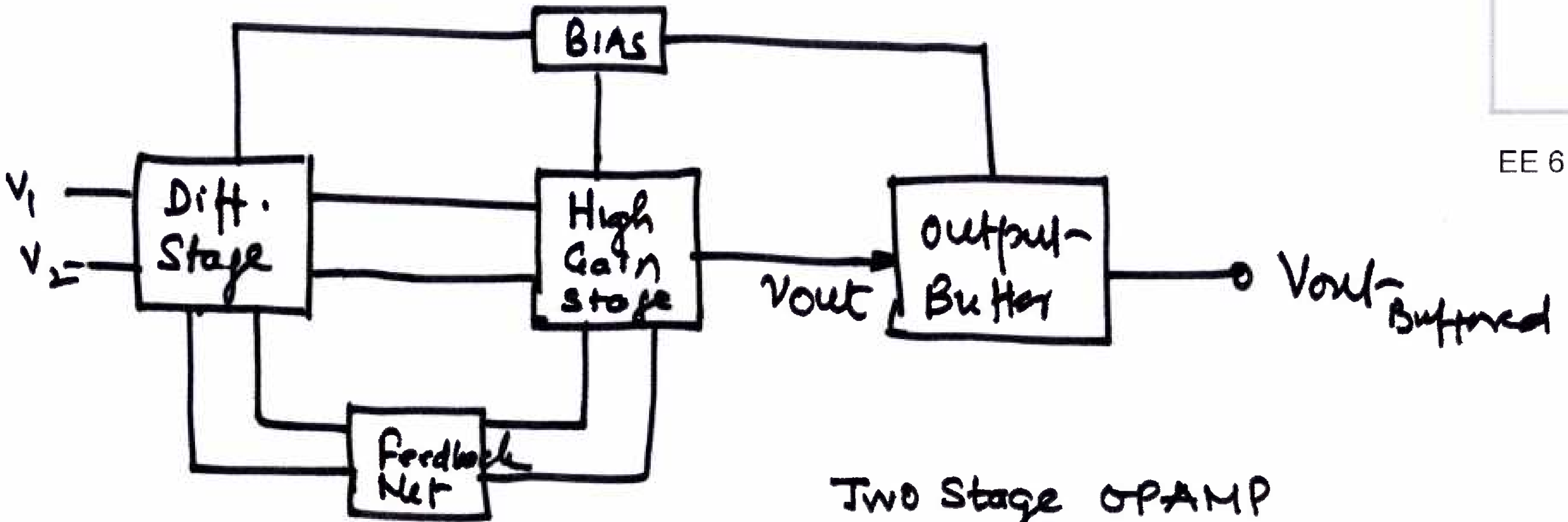
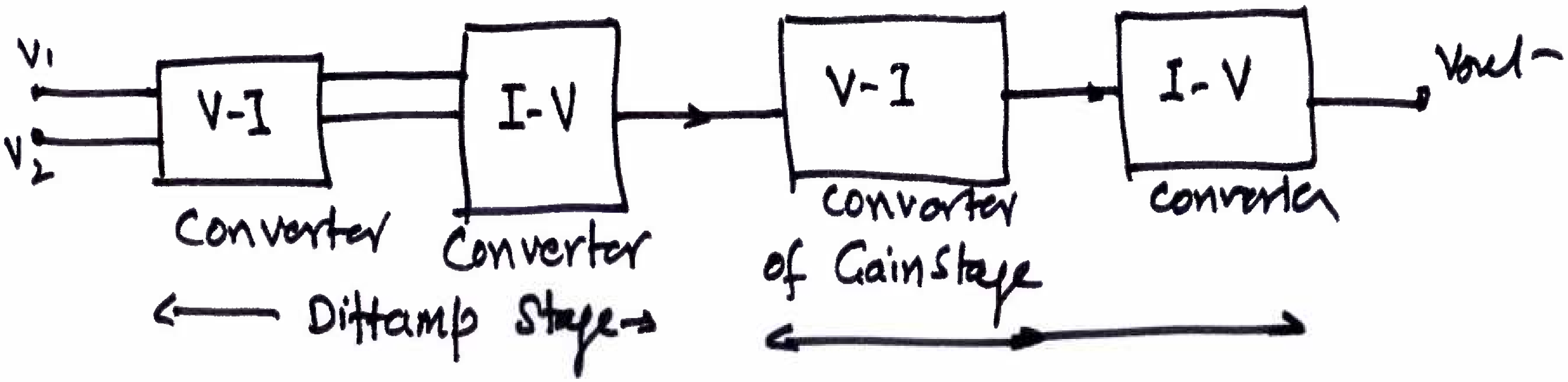


Two Stage OPAMP



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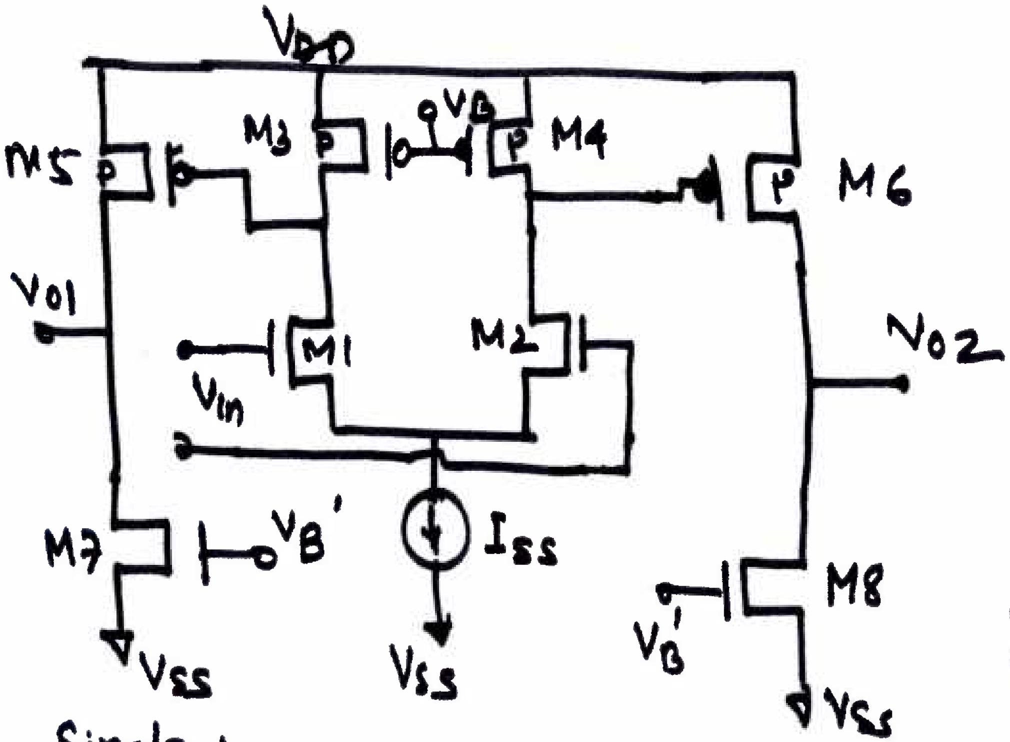
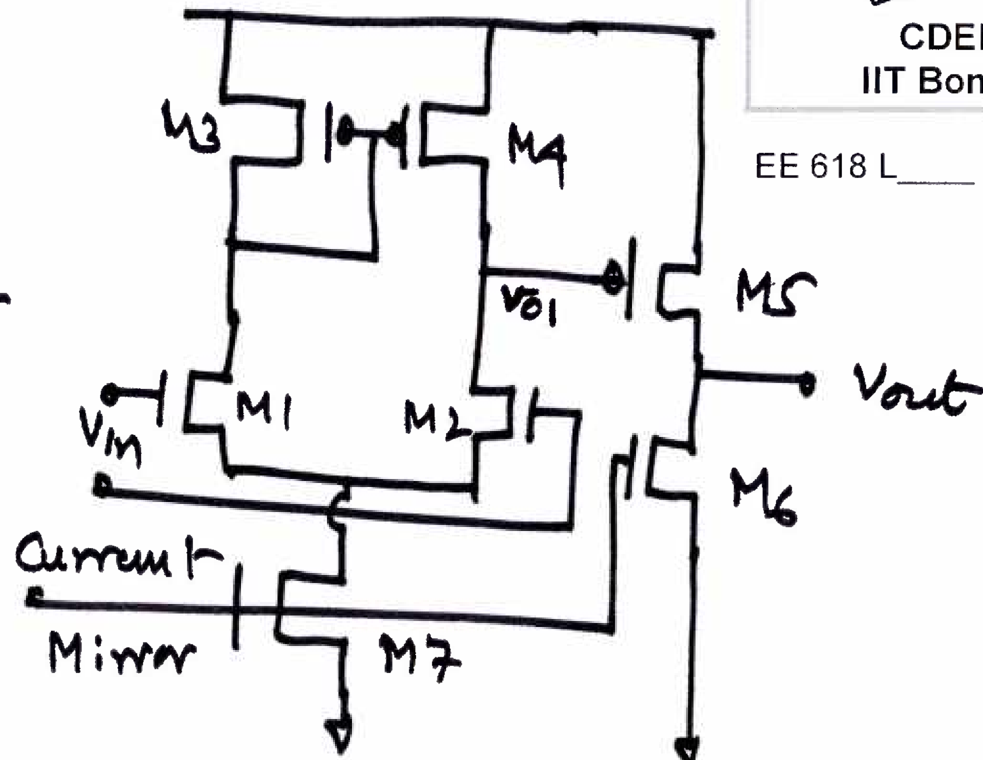
Two Stage Double-ended OPAMP



Single Stage CS |← Diffamp →| Single State CS

Two Stage Single-ended OPAMP



Bias Ckt |← Diffamp Stage →| Single Stage CS

For double ended case

$$V_{o1} = -g_{m1}(r_{o1} \| r_{o3})\, V_{in1}$$

$$V_{o2} = -g_{m2}(r_{o2} \| r_{o4})\,(-V_{o1})$$

$$V_{o2} = +g_1 g_{m5}(r_{o1} \| r_{o3})(r_{o2} \| r_{o4})\, V_{in}$$

$$\therefore\ A_{v1} = A_{v2} = \frac{V_{o1}}{V_{in}} = \frac{V_{o2}}{V_{in}} = g_{m1} g_{m5}(r_{o5} \| r_{o7})(r_{o1} \| r_{o3})$$

$$= g_{m2} g_{m6}(r_{o6} \| r_{o8})(r_{o2} \| r_{o4})$$

$$r_{o1} = \frac{1}{\lambda_1 \frac{I_{SS}}{2}} \quad \text{and} \quad r_{o3} = \frac{1}{\lambda_3 I_{SS}/2}, \quad r_{o5} = \frac{1}{\lambda_5 I_{DS7}}$$

$$r_{o2} = \frac{1}{\lambda_2 \frac{I_{SS}}{2}}, \quad r_{o4} = \frac{1}{\lambda_4 I_{SS}/2}; \quad r_{o6} = \frac{1}{\lambda_6 I_{DS8}}$$

Here for Single ended case

$$A_V = A_{V_1} \cdot A_{V_2}$$

$$A_{V_1} = \frac{V_{o1}}{V_{in}} = -g_{m1} \cdot (r_{o2} \| r_{o4})$$

However $V_{o1} = V_{in2}$ for CS Amplifier

$$\therefore A_{V_2} = \frac{V_{out}}{V_{o1}} = -g_{m5} \cdot (r_{o5} \| r_{o6})$$

$$\therefore A_V = +g_{m1} g_{m5} (r_{o2} \| r_{o4})(r_{o5} \| r_{o6})$$

$$g_{m1} = \sqrt{2\beta_1 I_{DS1}} = \sqrt{2\beta_2 I_{DS2}} = g_{m2}$$

$$I_{DS1} = I_{DS2} = \frac{I_{SS}}{2} \quad \therefore g_{m1} = \sqrt{\beta_1 I_{SS}} = g_{m2}$$

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If Bias current is chosen as 20 μA

$\therefore \; I_{SS} = 20\,\mu A \;, \quad \therefore \; \frac{I_{SS}}{2} = 10\,\mu A.$

$\therefore \; I_{DS1} = I_{DS3} = I_{DS2} = I_{DS4} = 10\,\mu A \; (\text{at } V_{id} = 0)$

$\therefore \; g_{m1} = \sqrt{2\beta_1 \frac{I_{SS}}{2}}$

We choose Technology of 5 μ.

$\beta_n' = 50\ \mu A/V^2 \qquad \lambda_1 = \lambda_2 = 0.06$

$\beta_p' = 16\ \mu A/V^2 \qquad \lambda_3 = \lambda_4 = 0.04/V$

$r_{o1} = r_{o2} = \cancel{\sqrt{\quad}} = \frac{1}{\lambda_2 I_{SS}/2}$

$r_{o4} = \frac{1}{\lambda_4 I_{SS}/2} \qquad \therefore \; r_{o2} \| r_{o4} = \frac{1}{(\lambda_2 + \lambda_4) I_{SS}/2}$

$\frac{I_{SS}}{2} = \frac{\beta_1}{2} \cdot (V_{GS1} - V_{Tn})^2 \quad \text{or} \quad \sqrt{I_{SS}} = \sqrt{\frac{\beta_1}{\cancel{2}}}\,(V_{GS1} - V_{Tn})$

Using Data from Boyce, Baker, Li's book,

For $V_{ov} = 0.37\,V$, $V_{Tn} = 0.83\,V$, $V_{TP} = -0.9\,V$

$V_{GS1} = V_{GS2} = 0.83 + 0.37\,V = 1.2\,V$

For $I_{SS} = 20\,\mu A$, or $I_{DS1} = I_{DS2} = +I_{SS}/2$

We get $\left(\frac{W}{L}\right)_n = \frac{15}{5}$ and $\left(\frac{W}{L}\right)_p = \frac{70}{5}$

Then Open loop Gain of Two Stage OPAMP can be found $= |A_{OL}|$

$$= \underbrace{\sqrt{2 \times 50 \times 10^{-6}\left(\frac{15}{5}\right) 10 \times 10^{-6}}}_{g_{m1}} \times \underbrace{\sqrt{2 \times 16 \times 10^{-6}\left(\frac{70}{5}\right) 10 \times 10^{-6}}}_{g_{m5}}$$

$$* \left[\frac{1}{\underbrace{(0.06 + 0.06) \times 10 \times 10^{-6}}_{(r_{o2} \| r_{o4})(r_{o5} \| r_{o6})}}\right]^2$$

Then $|A_{OL}| \simeq 2500$ V/V

It is obvious from A_{OL} expression that

$$A_{OL} \propto \frac{1}{I_{ss}}$$

Hence increase of I_{ss} may improve Bandwidth but decrease A_{OL}, or Vice-a-Versa.

In real life OPAMP, one wishes to improve the Stability of Gain against any variations.

So we wish to visit 'Feedback & Stability' issue in Brief, so that we can achieve desired Gain, Bandwidth and other specs, and also System is Stable.

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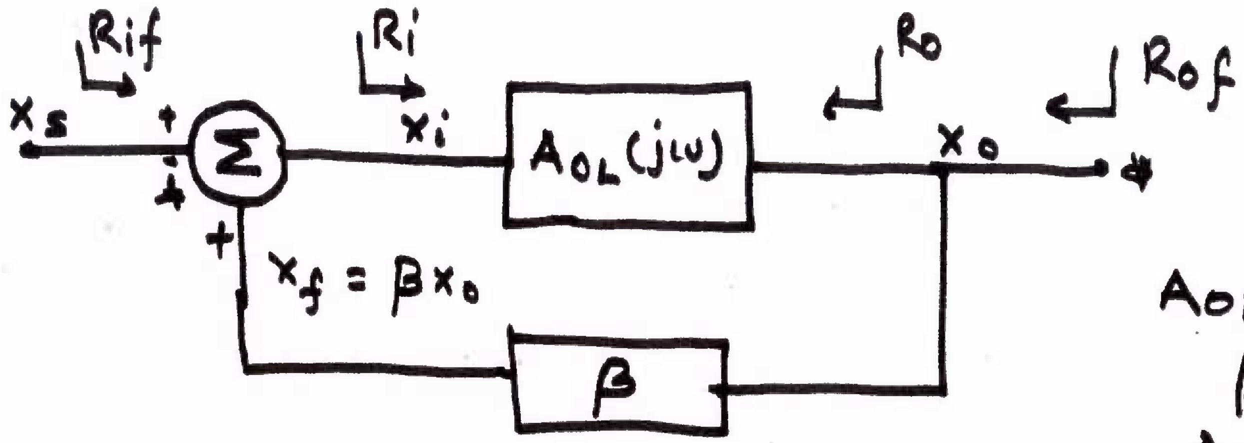
Feedback



General Feedback System

$A_{OL}(j\omega)$ = Open Loop Gain

β = Feedback Factor

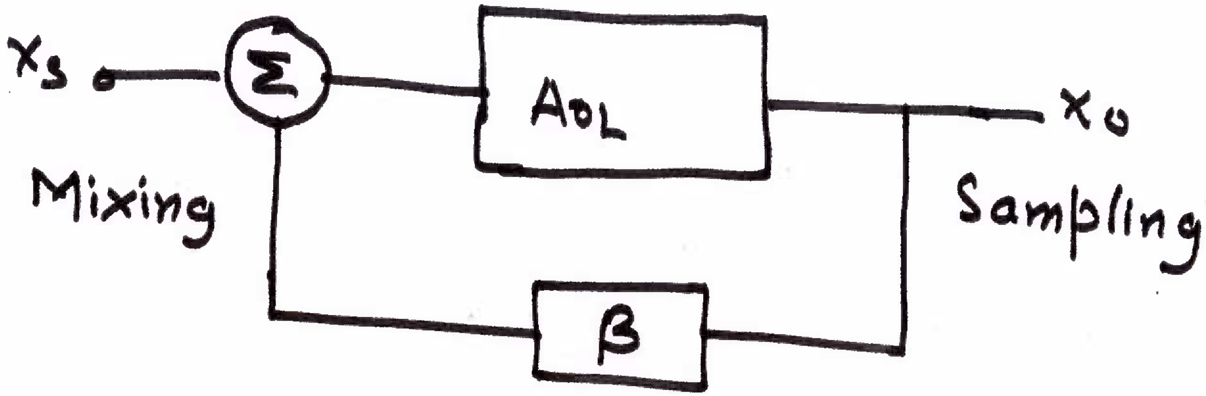
$A_{CL}(j\omega)$ = Closed Loop Gain

$$x_o = A_{OL}(j\omega)\cdot x_i = A_{OL}(j\omega)\,[x_s - x_f]$$

Here $x_i = x_s - x_f$ And $x_f = \beta x_o$

$$\therefore\ x_o = A_{OL}x_s - A_{OL}\beta x_o \qquad \therefore\ A_{CL}(j\omega) = \frac{x_o}{x_s} = \frac{A_{OL}}{1 + A_{OL}\beta}$$

Definitions



$A_{OL} = A_o$ = Gain without feedback

A_{CL} = Closed Loop Gain

$A_{OL}\beta$ = Loop Gain

$1 + A_o\beta$ = Amount of Feedback

$A_o\beta$ = Loop Gain = Return Ratio

If $A_o\beta >> 1$

Then $A_{CL} \cong \frac{A_o}{A_o\beta} = \frac{1}{\beta}$

This means that Gain of Feedback Amplifier (A_{CL}) is only decided by Passive Feedback network gain β.

As $\beta < 1$ $\quad A_{CL} > 1$

However $A_{CL} = \frac{A_o}{1+A_o\beta}$ can change with β & value & sign of A_o

(i) Negative Feedback (ii) Positive Feedback

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Properties of Negative Feedback

[1] Gain Desensitivity

We have $A_{CL} = \dfrac{A_0}{1+A_0\beta}$

or $dA_{CL} = dA_0 \left[\dfrac{1}{1+A_0\beta} - \dfrac{A_0\beta}{(1+A_0\beta)^2} \right]$

$x_i = x_s + x_f$

or $dA_{CL} = \dfrac{dA_0}{(1+A_0\beta)^2}$

$\therefore \dfrac{dA_{CL}}{A_{CL}} = \dfrac{dA_0}{(1+A_0\beta)^2} \cdot \dfrac{(1+A_0\beta)}{A_0} = \dfrac{1}{(1+A_0\beta)} \cdot \dfrac{dA_0}{A_0}$

Clearly % change in A_{CL} is Always Less than % change in A_0

$\therefore$ $(1+A_0\beta)$ is also called Desensitivity factor

[2] Bandwidth Enhancement

$$A_{OL}(s) = \frac{A_{Midband}}{1 + S/\omega_0} = \frac{A_M}{1 + S/\omega_0} = A_0$$

ω_0 is Dominant Pole

Then with Negative Feedback

$$A_{CL}(s) = \frac{A_{OL}(s)}{1 + A_{OL}(s)\,\beta} = \frac{A_M / (1 + S/\omega_0)}{1 + \frac{A_M}{1 + S/\omega_0} \cdot \beta}$$

$$= \frac{A_M / (1 + A_M \beta)}{S / (1 + A_M \beta)\omega_0 + 1}$$

$$A_{CLO} = \frac{A_M}{1 + A_M \beta}$$

$$= \frac{A_{CLO}}{1 + S / [(1 + A_M \beta)]\omega_0}$$

Clearly Gain (CL) $= \dfrac{A_M}{1+A_M\beta}$

& New Pole $= \omega_o(1+A_M\beta) = \omega_f$

As $A_M\beta > 1$

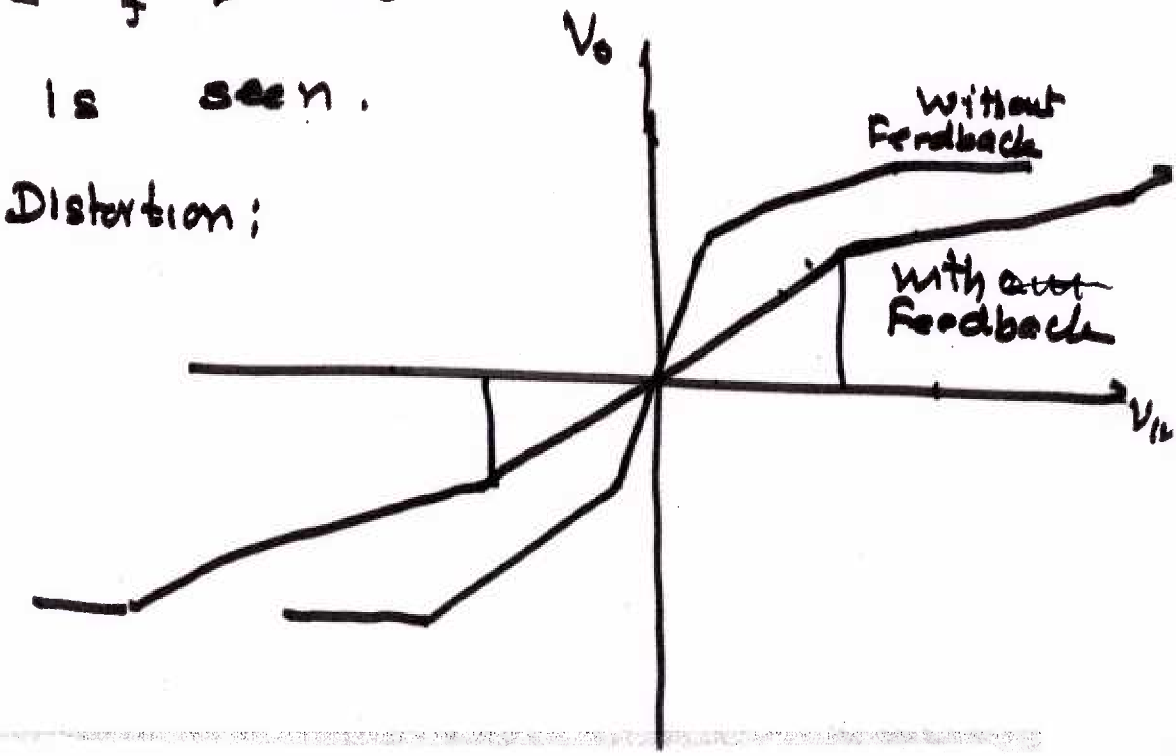
$\therefore \quad \omega_o(1+A_M\beta) = \omega_f > \omega_o$

$\therefore$ Bandwidth extension is seen.

[3] Reduction in Non-Linear Distortion:

:→ <u>Linearization</u> ?

Reduced Feedback Gain $\left(\dfrac{dV_o}{dV_{in}}\right)$ increases 'linearity' for larger V_{in} range.



If this condition is met, the Feedback System is said to be Stable

Two pole System

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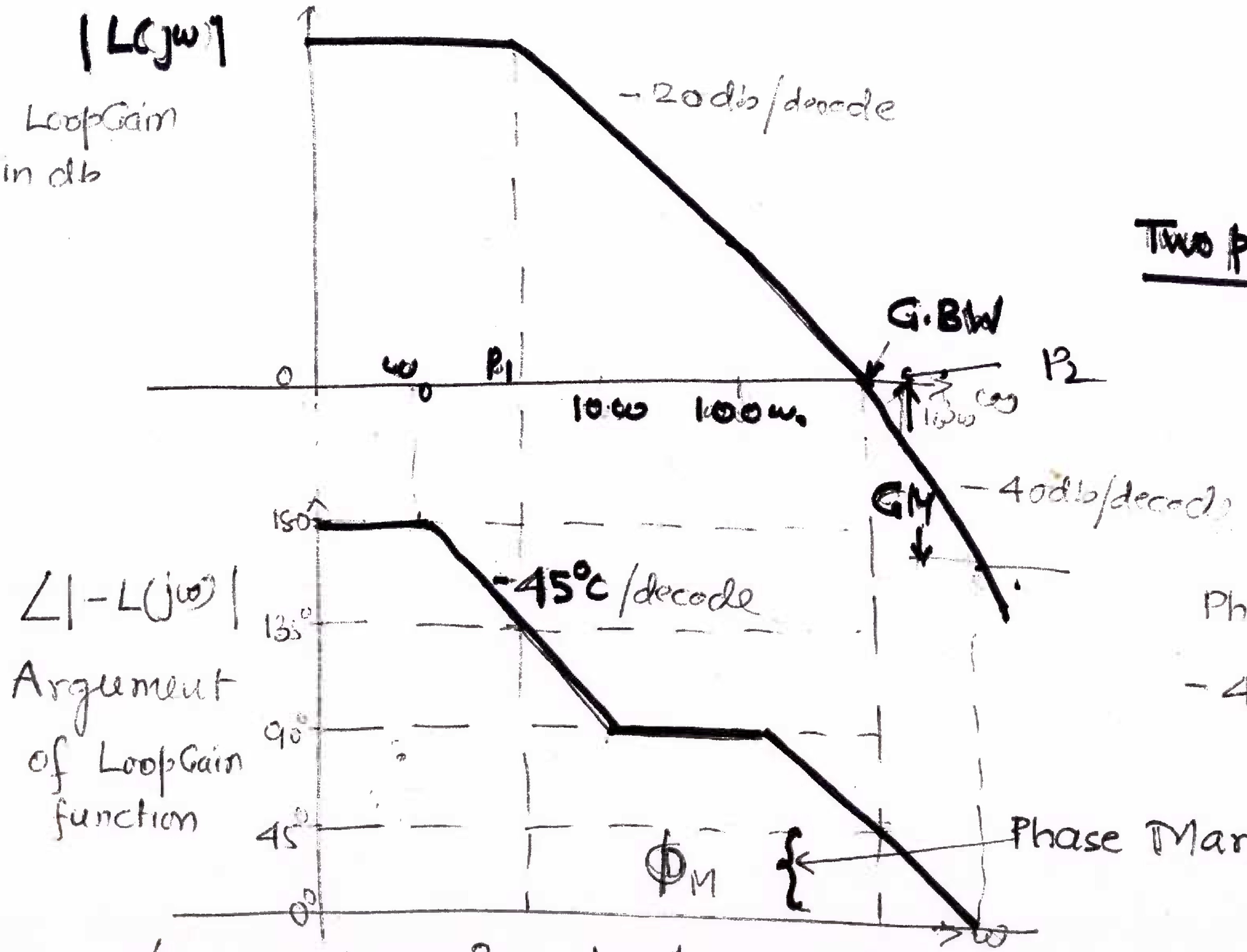

Phase goes as -45^0/decade

$$\phi_M = \pm 180^0 - \mathrm{Arg}\,|A(j\omega)\cdot\beta(j\omega)|$$