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Stability studies using Bode's Frequency Plots.

For an Amplifier with feedback, we have

T. function: $A_{CL}(s) = \dfrac{A_o(s)}{1 + A_o(s)\beta(s)}$

We have defined $L(s)$ as Loop Gain $= A_o(s)\,\beta(s)$

or $L(jw) = A_o(jw)\,\beta(j\omega)$

$= |A(jw) \cdot \beta(jw)|\, e^{j\phi(\omega)}$ Phasor

$\phi(\omega)$ is the Phase angle

If $\phi(\omega_0) = 180^\circ$ Then $|A_o(j\omega_0)\,\beta(j\omega_0)| \cdot e^{j(180^\circ)}$

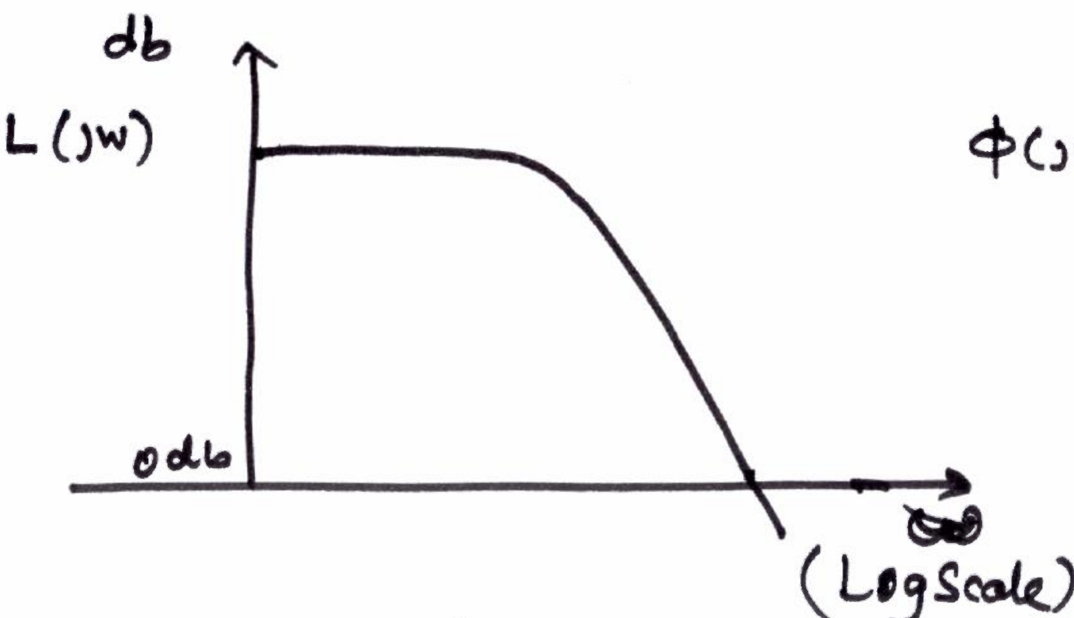
Which means $L(j\omega_0) = -$ <u>Real</u>

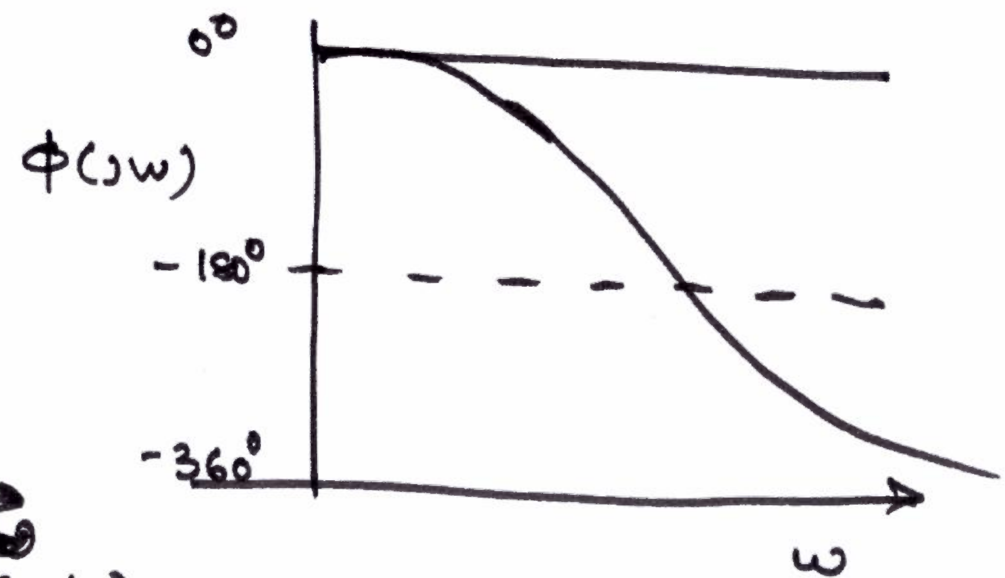
Thus we can say Positive feedback commences.

As then we observe that the Denomenator reduces $[1 - \{A(j\omega_0)\beta(j\omega_0)\}]$, and these

Then $A_{CL}(j\omega_0) > A_0(j\omega_0)$ A_0 = Openloop Gain.

This is the case of Positive feedback which will then make Amplifier Unstable.





Bode's Plot for Loop Gain

If this condition is met, the feedback system is said to be stable

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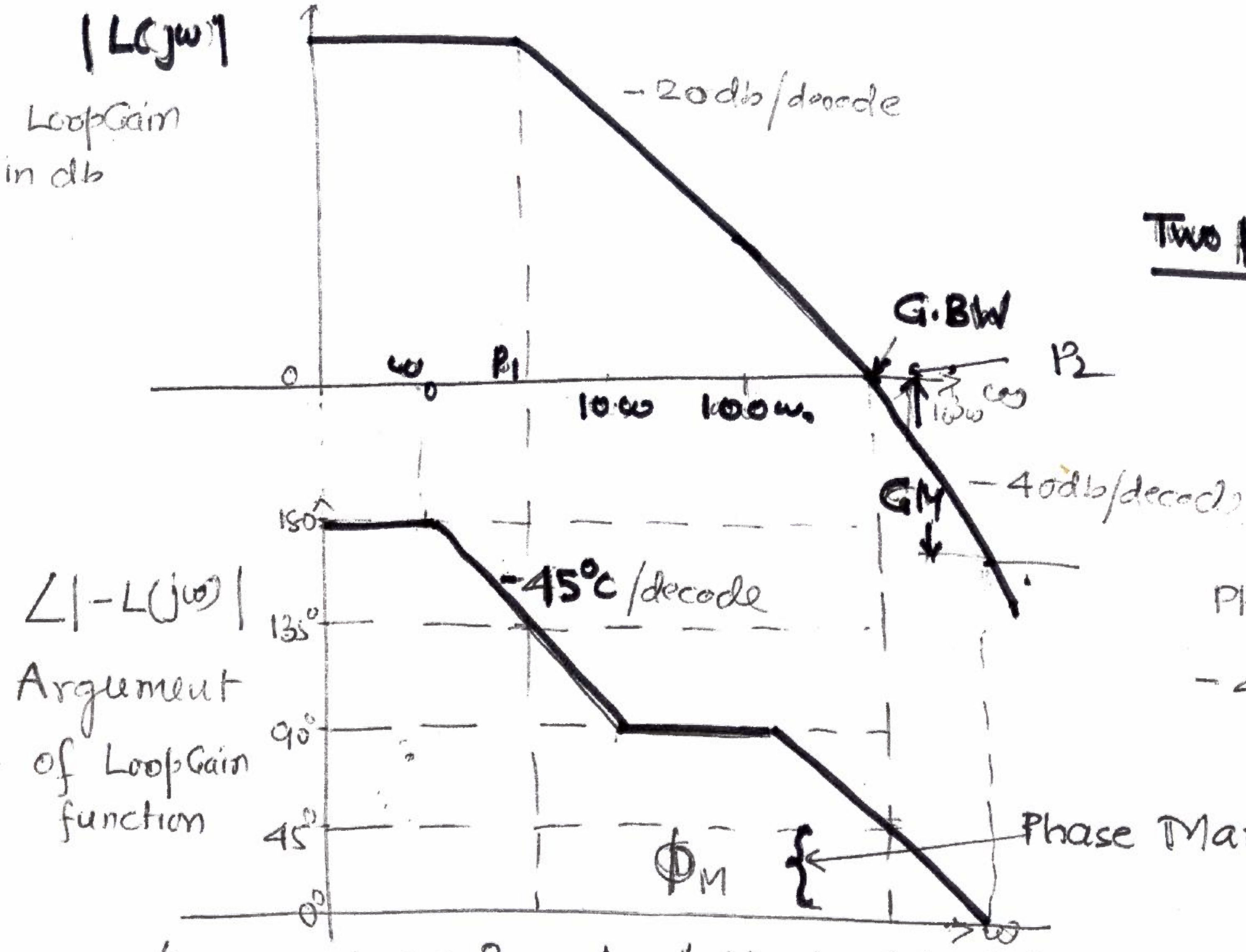
Two pole System

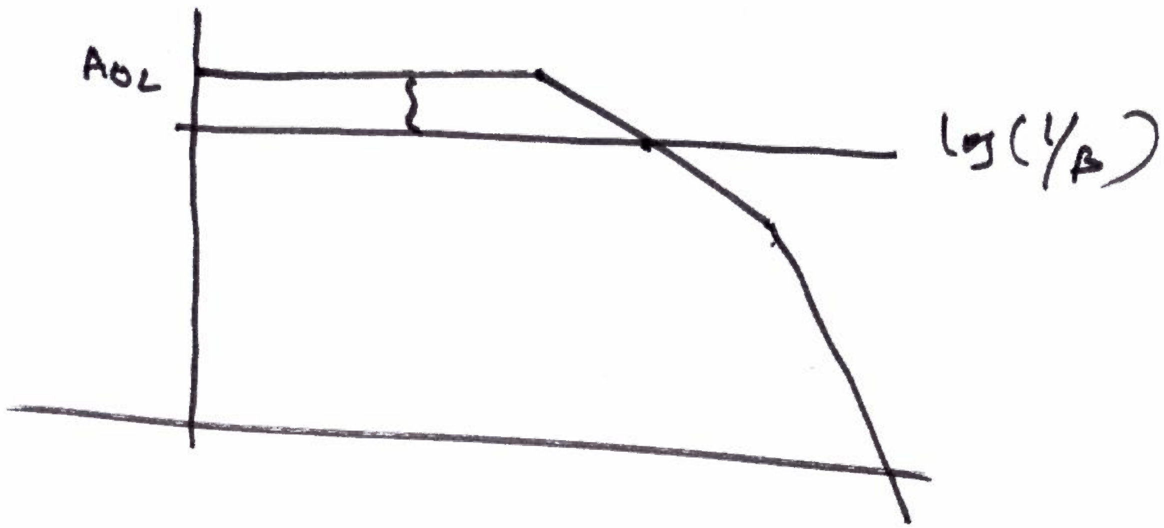


Phase goes as -45^0/decade

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

Stability looking from open-loop Bode plot

$$\log(A\beta) = \log A - \underline{\log(1/\beta)}$$



Time Response of Loop Gain with ϕ_M varying from 45^0 to 90^0 (Stability Requirement)

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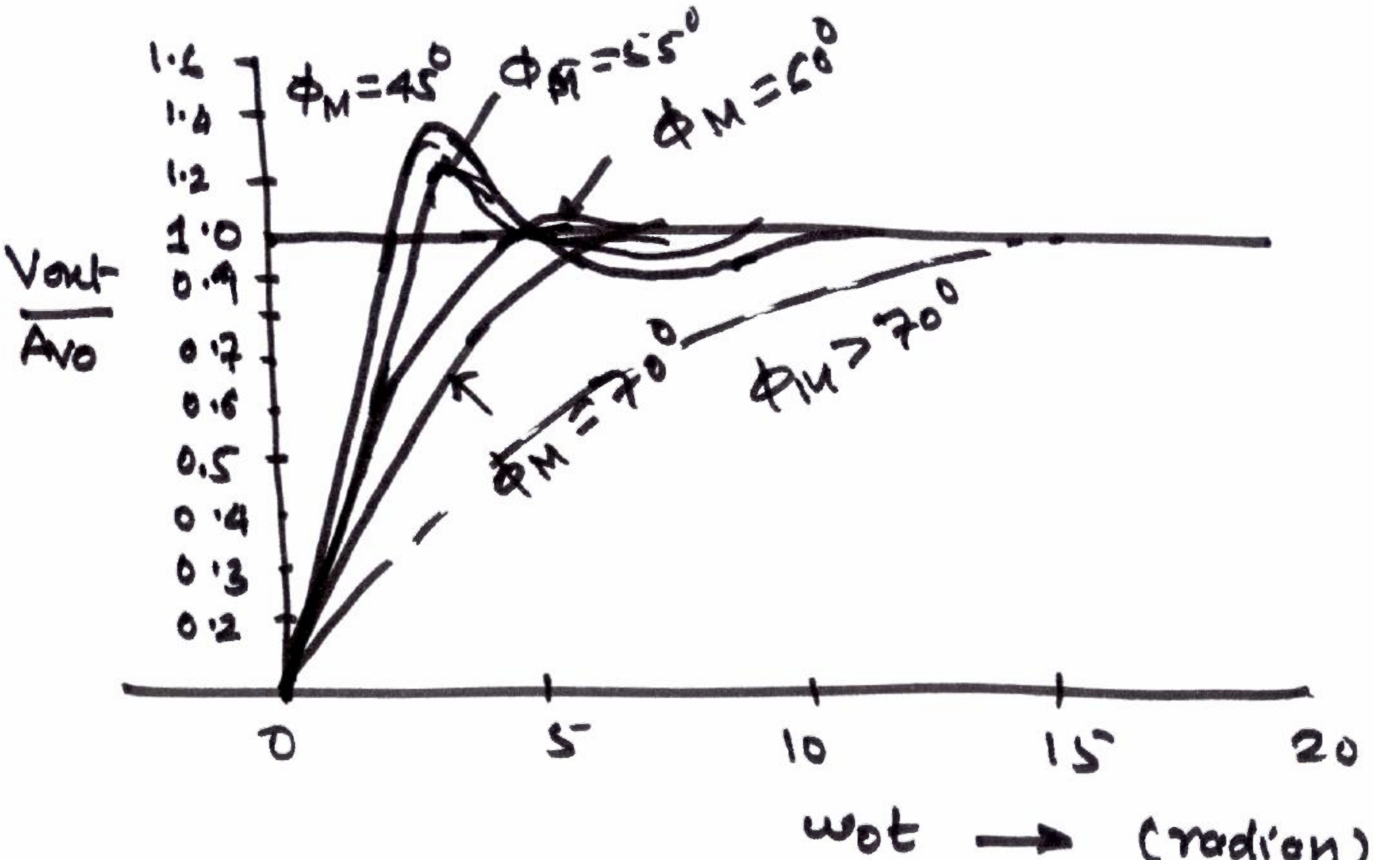
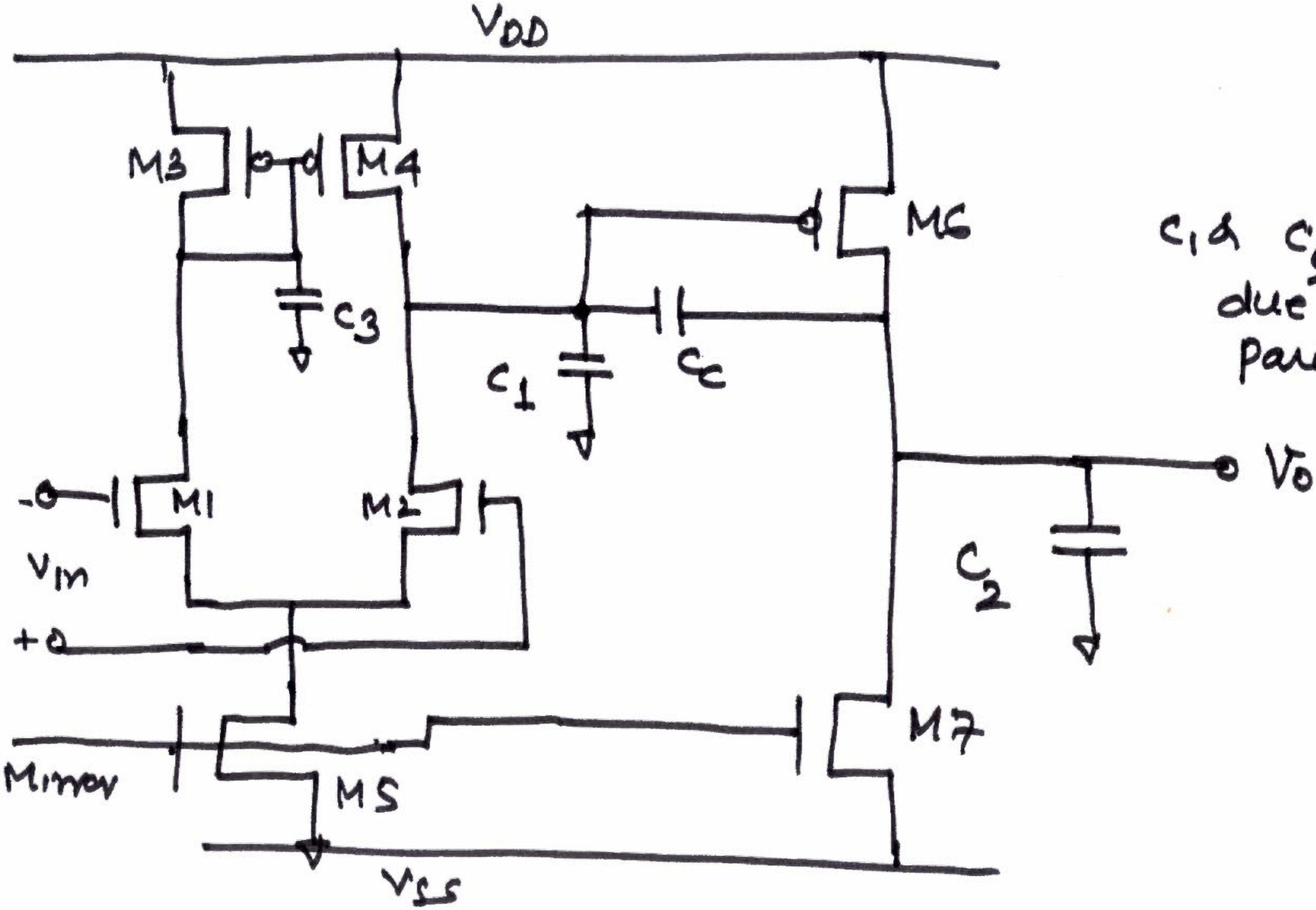


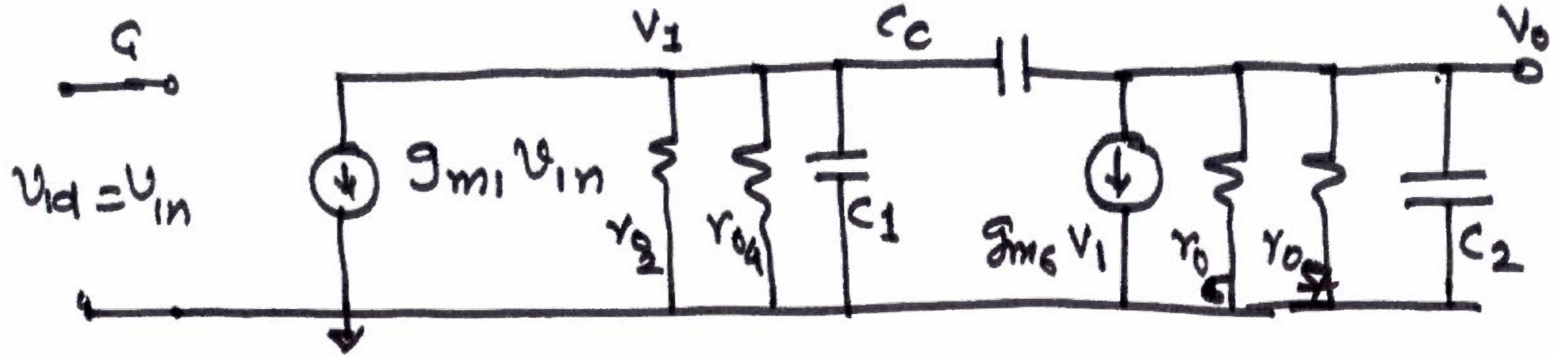
$\therefore$ ϕ_M is normally chosen from 55^0 to 70^0

Two stage Single-ended OPAMP with Parasitics.



C_1 & C_2 could be due to C_{gds} & other parasitics.

Poles and Zeros of Two Stage OPAMP



Take $R_1 = r_{o2} \| r_{o4}$; $R_2 = r_{o7} \| r_{o6}$

$$C_1 = C_{gs5} + C_{gd5}(1+|A_{v20}|) + C_{db4} + C_{gd4} + C_{bd2} + C_{gd2}$$

(C_{gd6}) (C_{db6})

$$C_2 = C_{gd5}\left(1 + \frac{1}{|A_{v20}|}\right) + C_{db5} + C_{db7} + C_{ext}$$

We use nodal analysis to solve this Network

$$g_{m1} V_{in} + \frac{V_1}{R_1} + sC_1 V_1 + sC_c (V_1 - V_0) = 0 \quad -①$$

$$g_{m6} V_1 + \frac{V_0}{R_2} + sC_2 V_0 + sC_c (V_0 - V_1) = 0 \quad -②$$

From ①

$$V_1 = \frac{(V_0 sC_c - g_{m1} V_{in}) R_1}{[1 + R_1 s (C_1 + C_c)]} \quad -③$$

Substituting ③ in ②

$$g_{m6} \left[\frac{(V_0 sC_c - g_{m1} V_{in}) R_1}{\{1 + R_1 s (C_1 + C_c)\}} \right] + V_0 \left[\frac{1}{R_2} + sC_2 + sC_c \right] - sC_c \left[\frac{R_1 (V_0 sC_c - g_{m1} V_{in})}{\{1 + R_1 s (C_1 + C_c)\}} \right] = 0 \quad -④$$

From ④, we get

$$\frac{V_o(s)}{V_{in}(s)} = \frac{R_1 R_2 g_{m1} g_{m6} - g_{m1} R_1 R_2 s C_c}{g_{m6} R_1 R_2 s C_c + \left[(1 + R_1 s (C_1 + C_c)\right]\left[1 + R_2 s (C_2 + C_c)\right] - R_1 R_2 s^2 C_c^2}$$

If we define $m = g_{m1} g_{m6} R_1 R_2$

$$n = R_2 (C_2 + C_c) + R_1 (C_1 + C_c) + g_{m6} R_1 R_2 C_c$$

&

$$Q = R_1 R_2 (C_1 C_2 + C_1 C_c + C_2 C_c)$$

Then Gain Transfer function $A_v(s)$ can be written as

$$A_v(s) = m(1 - sC_c/g_{m6}) / [1 + ns + Qs^2]$$

We have Denomenator of $A_v(s)$ as

$$= 1 + ns + Qs^2$$

$$\rightarrow D = \left(1 - \frac{s}{p_1}\right)\left(1 - \frac{s}{p_2}\right)$$

$$= 1 - \left(\frac{s}{p_1} + \frac{s}{p_2}\right) + \frac{s^2}{p_1 p_2}$$

If we assume that $|p_1| >> |p_2|$

Then $D = 1 - \frac{s}{p_1} + \frac{s^2}{p_1 p_2}$

$\therefore \quad p_1 = -\frac{1}{n}$ and $\frac{1}{p_1 p_2} = Q$

or $p_2 = \frac{1}{p_1 Q} = -\frac{n}{Q}$

$$\therefore |p_1| = \frac{1}{R_2(C_2+C_c) + R_1(C_1+C_c) + g_{m6} R_1 R_2 C_c}$$

$$D_n = (g_{m6} R_1 R_2 + R_2 + R_1) C_c + R_2 C_2 + R_1 C_1$$

For typical Amplifier

$$(g_{m6} R_1 R_2 + R_1 + R_2) C_c >> R_1 C_1 + R_2 C_2$$

& Further $g_{m6} R_1 R_2 >> (R_1 + R_2)$

$$\therefore |p_1| = \frac{1}{g_{m6} R_1 R_2 C_c} \quad \text{or} \quad p_1 = \frac{-1}{g_{m6} C_c R_1 R_2}$$

now $p_2 = -\frac{n}{Q} = +\frac{1}{p_1 Q}$

$$p_2 = \frac{-g_{m6} R_1 R_2 C_c}{R_1 R_2 (C_1 C_2 + C_1 C_c + C_2 C_c)}$$

or $$p_2 = \frac{-g_{m6} C_c}{(C_1 C_2 + C_1 C_c + C_2 C_c)}$$

If $C_2 \gg C_1$ & $C_c > C_1$

Then $$p_2 = \frac{-g_{m6} C_c}{C_2 C_c} = -\frac{g_{m6}}{C_2}$$

Further a zero $z_1 = \dfrac{g_{m6}}{C_c}$ exist as at this frequency, Numerator of $A_v(s)$ becomes zero.

$$A_v(s) = \frac{m\left(1 - \frac{sC_c}{g_{m6}}\right)}{1 + ns + Qs^2}$$

Clearly this is Second Order system which has One Zero and Two Poles.

$$P_1 = \frac{-1}{g_{m6} R_1 R_2 C_c}$$

$$P_2 = \frac{-g_{m6} \cdot C_c}{C_1 C_2 + C_2 C_c + C_1 C_c}$$

$$= -\frac{g_{m6}}{C_2}$$ if $C_2 >> \text{both } C_1 \,\&\, C_c$

$\&\ C_c >> C_1$

And $z_1 = \frac{g_{m6}}{C_c}$

The coupling capacitor C_c is called Compensating Capacitor and is used in improving Stability.

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With TWO POLES p_1, p_2 and a zero z_1

$$\phi_M = 180 - \tan^{-1}\left(\frac{\omega}{|p_1|}\right) - \tan^{-1}\left(\frac{\omega}{|p_2|}\right) - \tan^{-1}\left(\frac{\omega}{|z_1|}\right)$$

At $\omega = GBW$

{ Generally $z_1 >> GB$ is attempted

$$\phi_M = 180 - \tan^{-1}\left(\frac{GBW}{|p_1|}\right) - \tan^{-1}\left(\frac{GBW}{|p_2|}\right) - \tan^{-1}\left(\frac{GB}{z_1}\right)$$

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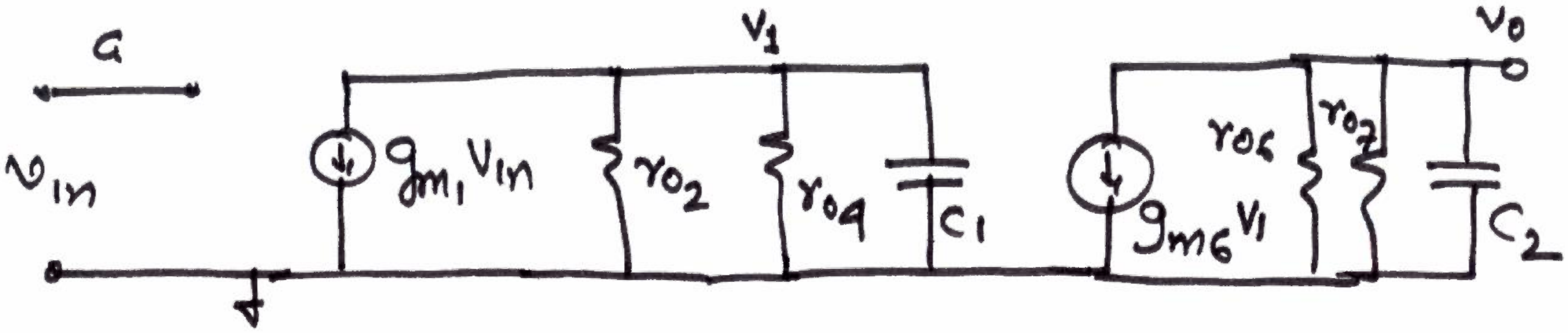
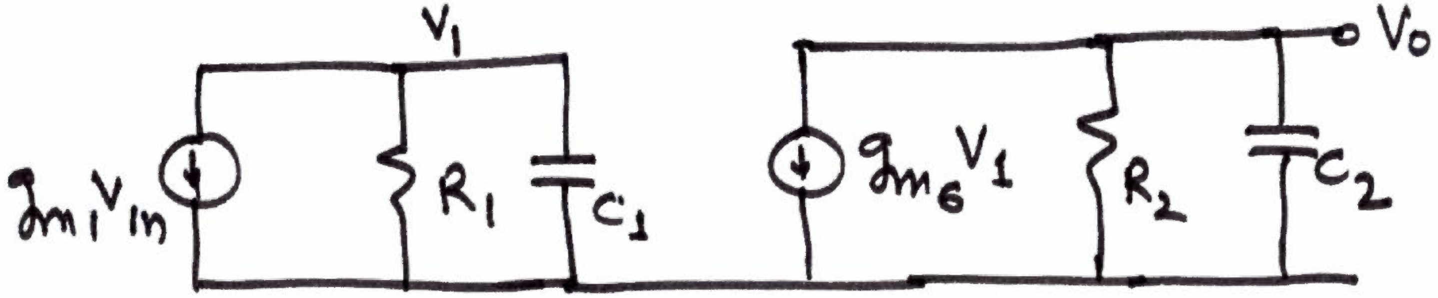
If Miller capacitor C_c is not present then the circuit equivalent looks like :





Poles P_1 & P_2 are then given by

$$|P_1| = \frac{1}{R_1 C_1} \quad \text{and} \quad |P_2| = \frac{1}{R_2 C_2}$$

With C_c we found, the poles are

$$|P_1'| = \frac{1}{g_{m6} R_2 (R_1 C_1) \frac{C_c}{C_1}}$$

$$|P_2'| = \frac{g_{m6}}{C_2}$$

We know

$$g_{m6} > \frac{1}{R_2} = (r_{o6} \parallel r_{o7})^{-1}$$

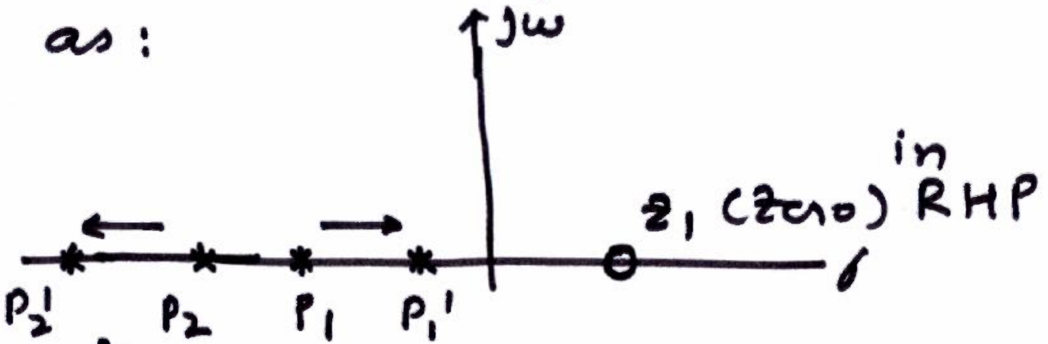
Clearly $|P_1| > |P_1'|$

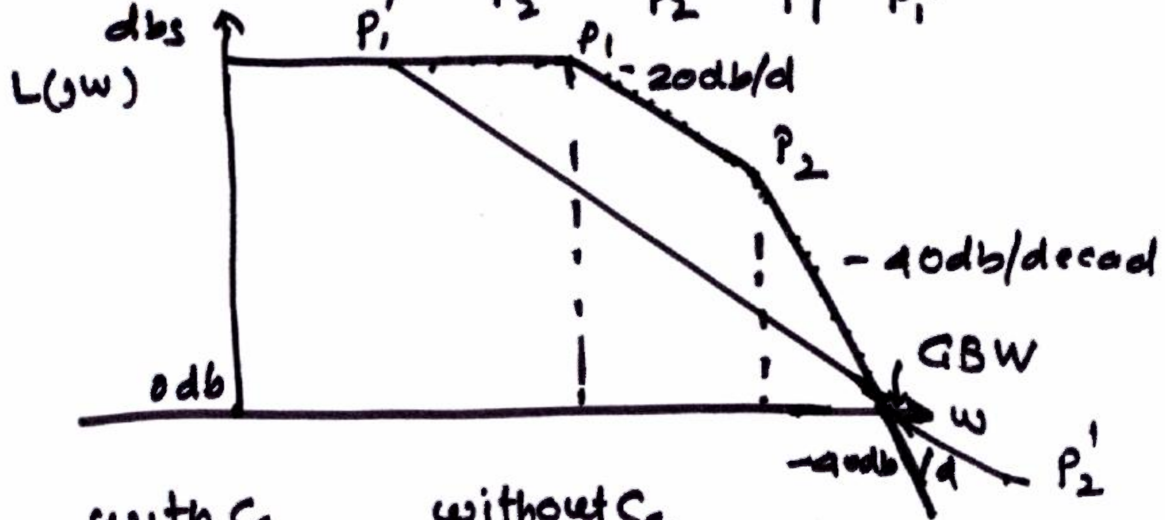
Further with $g_{m6} > \frac{1}{R_2}$

Then $|P_2'| > |P_2|$

This shows that Miller Capacitance C_c in Circuit allows 'Pole-Splitting'

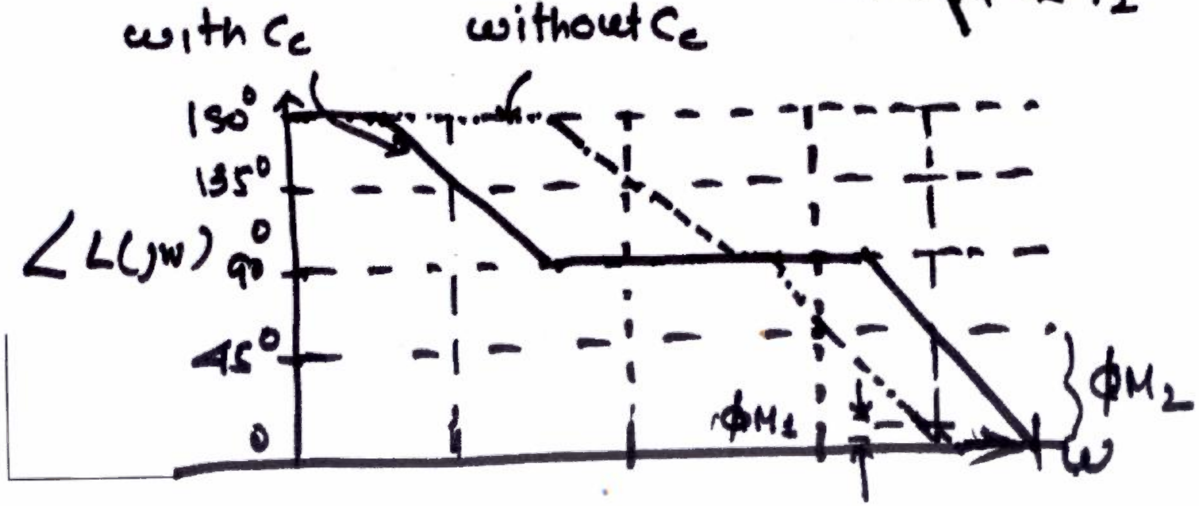
Root Locus Plot of Loop Gain then looks like as:





C_c causes splitting of old poles. Case $P_2' = GBW$

Result :- ① Bandwidth Reduction



ϕ_{M1} due to absence of C_c

ϕ_{m_2} due to Presence of C_c

Clearly $\phi_{m_2} > \phi_{M1}$

$\therefore$ Stability Improves

In this case we chose position of new second pole p_2' placed at GBW point (0db loop gain)

Without C_c, $GBW = \dfrac{g_{m1}}{C_1 + C_c} \simeq \dfrac{g_{m1}}{C_c}$

And $|p_2'| = \dfrac{g_{m6}}{C_2}$

$\therefore$ For this case $\boxed{\dfrac{g_{m1}}{g_{m6}} = \dfrac{C_c}{C_2}}$

For further improvement in ϕ_M

we can increase C_c, but we may loose Bandwidth.

Hence to avoid reduction of Bandwidth, but to improve ϕ_M for Stability, we can control RHP 'zero' to bring it towards LHP. A Series Resistance to C_c may do that.