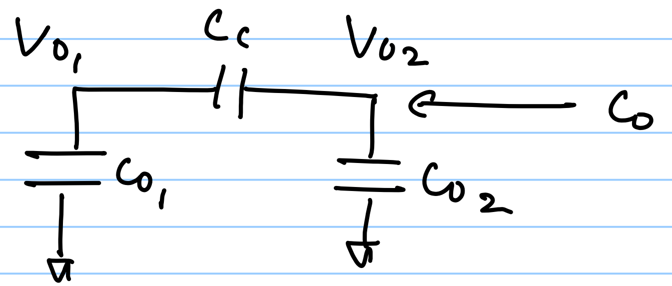
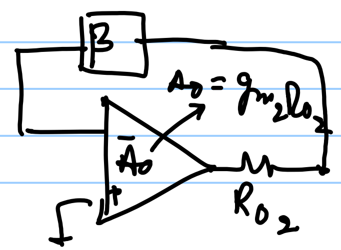
EE2019 Analog systems & lab

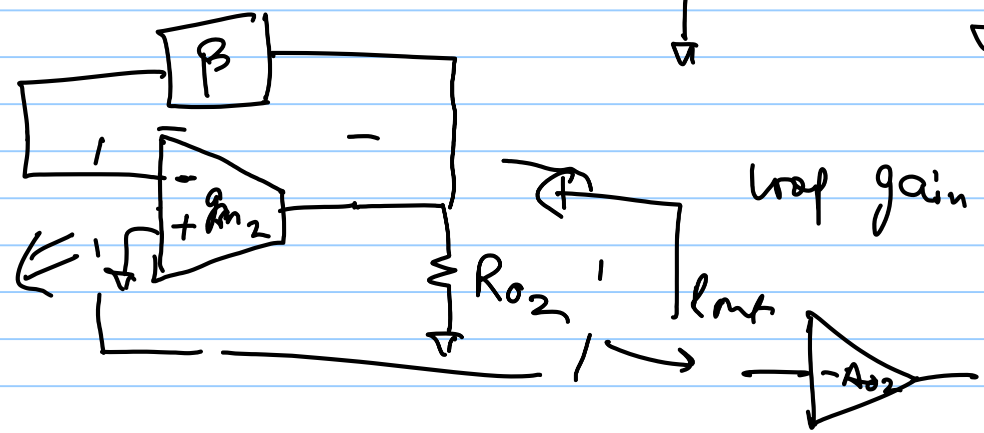
Note Title 3/13/2020

$$= \frac{C_c\, g_{m_2}}{C_{o_2}(C_{o_1}+C_c) + C_c C_{o_1}} = \frac{\overbrace{\frac{C_c}{C_{o_1}+C_c}}^{\beta}\, g_{m_2}}{C_{o_2} + \frac{C_c C_{o_1}}{C_{o_1}+C_c}} = \boxed{\frac{\beta\, g_{m_2}}{C_{o_2} + \frac{C_c C_{o_1}}{C_{o_1}+C_c}}}$$

$$C_o = C_{o_2} + \frac{C_c C_{o_1}}{C_{o_1}+C_c} \Rightarrow$$







loop gain $= -\beta\, g_{m_2} R_{o_2}$

$A_{o_2} = g_{m_2} R_{o_2}$

$$\text{effective } R_{out} = \frac{R_{o2}}{1 + A_0\beta} \approx \frac{R_{o2}}{A_0\beta} = \frac{\cancel{R_{o2}}}{g_{m_2} \cancel{R_{o2}} \cdot \beta} = \frac{1}{\beta g_{m_2}}$$

$$\omega_{p_2} = \frac{1}{R_{out} \times C_0}$$

$$C_0 = C_{o2} + \frac{C_c C_{o1}}{C_{o1} + C_c} \quad \& \quad R_{out} = \frac{1}{\beta g_{m_2}}$$

without compensation

$$\omega p_1 = \frac{1}{R_{o1} C_{o1}}$$

$$\omega p_2 = \frac{1}{R_{o2} C_{o2}}$$

with compensation

$$\omega p_1 = \frac{1}{R_{o1} (g_{m2} R_{o2}) C_c}$$

$$\omega p_2 = \frac{\frac{C_c}{C_{o1} + C_c} g_{m2}}{C_{o2} + \frac{C_{o1} C_c}{C_{o1} + C_c}}$$

assume, $C_c >> C_{o1}$

$$\omega p_2 = \frac{g_{m2}}{C_{o2} + C_{o1}}$$

Assume, $A_0 = 1000$; $g_{m_1} = 100\mu A/V$, $R_{o_1} = 1 M\Omega$, $g_{m_2} = 100\mu A/V$, $R_{o_2} = 100 k\Omega$

$g_{m_1} R_{o_1} = 100$, $g_{m_2} R_{o_1} = 10$ $\longrightarrow$ $A_0 = 1000$

$C_{o_1} = 10pF$ & $C_{o_2} = 10pF$

$$\omega_{p_1} = \frac{1}{R_{o_1} C_{o_1}} = \frac{1}{10^6 \times 10^{-11}} = 10^5 \text{ rad/sec}$$

$$\omega_{p_2} = \frac{1}{R_{o_2} C_{o_2}} = \frac{1}{10^5 \times 10^{-11}} = 10^6 \text{ rad/sec}$$

After compensation

$$\omega_{p_2} = \frac{100\mu}{(10p + 10p)} = 5 \times 10^6 \text{ rad/sec}$$

ω_{ugb} for 60° phase margin

$$\omega_{ugb} = \frac{1}{\sqrt{3}}\,\omega p_2 = \frac{5}{1.7}\times 10^6 \text{ rad/sec} \simeq 3\times 10^6 \text{ rad/sec}$$

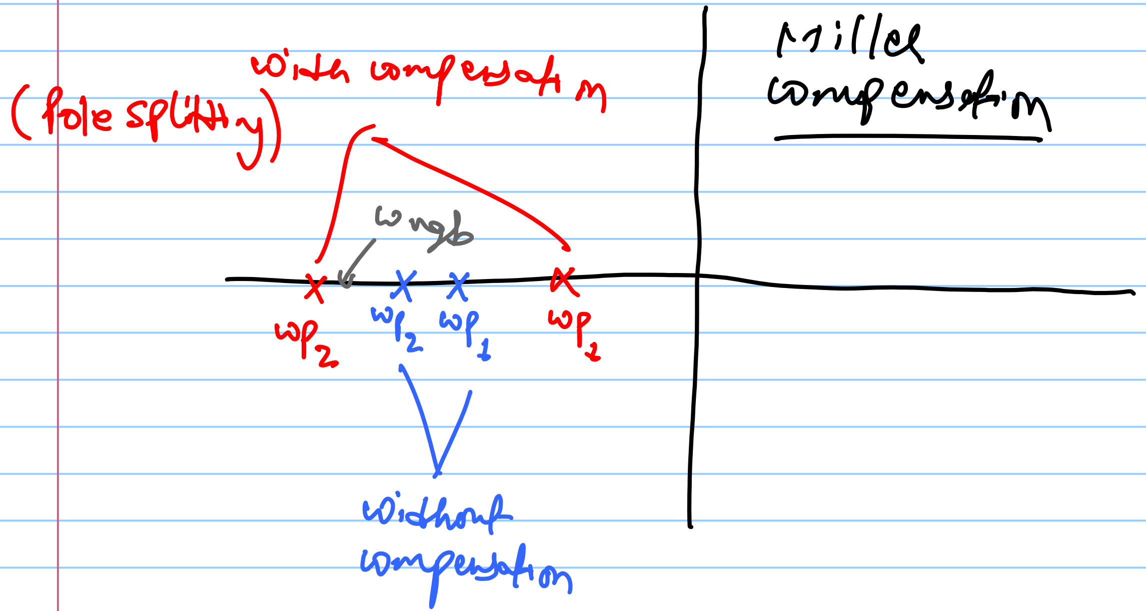
$$\omega p_1 = \frac{\omega_{ugb}}{A_0} = \frac{3\times 10^6 \text{ rad/sec}}{1000} = 3\times 10^3 \text{ rad/sec}$$

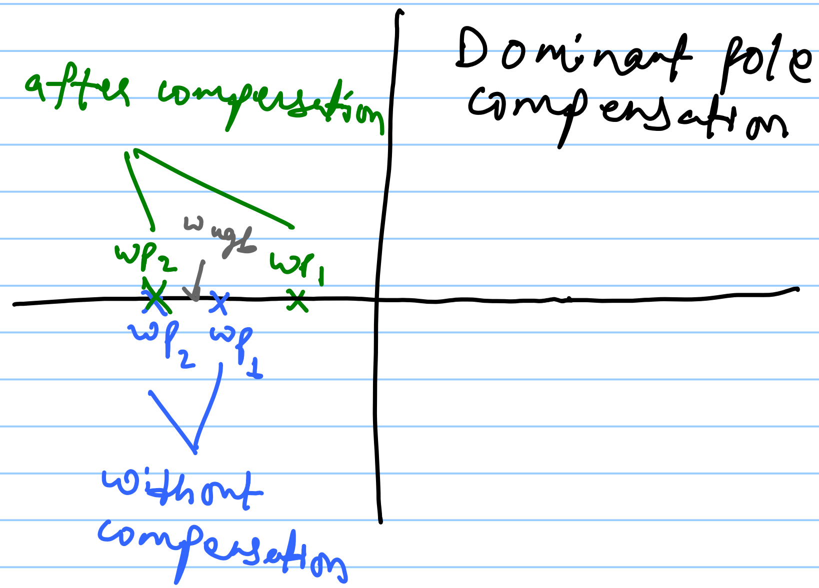
$$\omega p_1 = \frac{1}{R_{o1}(R_{o2}\,g_{m2})\,C_c} = 3\times 10^3 \text{ rad/sec}$$

$$C_c = \frac{1}{R_{o1}(R_{o2}g_{m2}) \times 3\times10^3} = \frac{1}{10^6 \times (10)(3\times10^3)}$$

$$= \frac{10^{-10}}{3} = 0.33 \times 10^{-10} \simeq \boxed{33\ pF}$$

S-plane


Miller compensation
with compensation
(pole splitting)
ωugb
ωp2
ωp2
ωp1
ωp1
without compensation

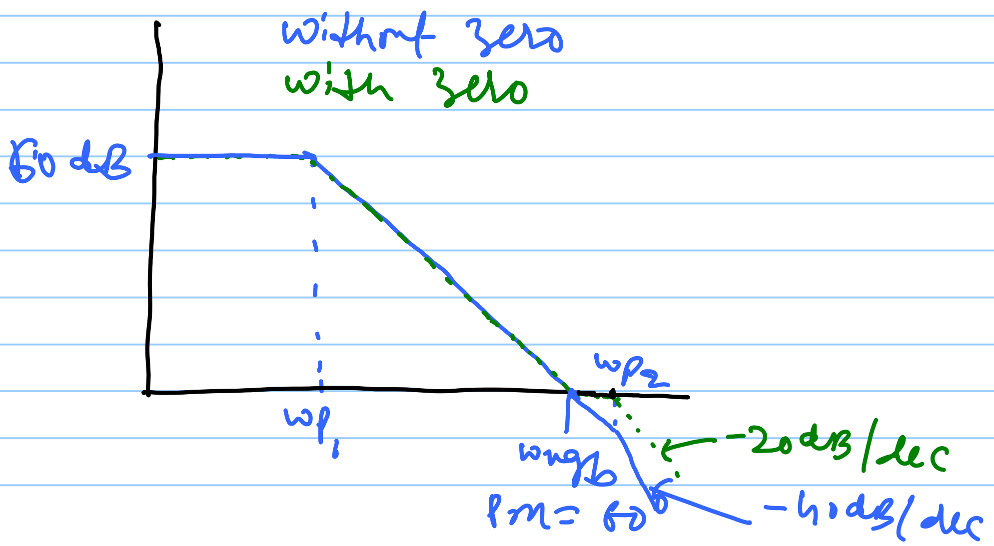

Dominant pole compensation
after compensation
ωugb
ωp2
ωp1
ωp2
ωp1
without compensation

So far we have ignored R.H.P. zero

$$\omega_z = \frac{g_{m_2}}{C_c} = \frac{100\,\mu}{33\,pF} = \frac{10^{-4}}{33\times10^{-12}} = \frac{100}{33}\times10^{6}$$

$$= 3.33\ \text{Mrad/sec}$$

$$\simeq \omega_{ugb}$$



PM without zero = 60°
PM with zero ≃ 15°

$$\omega_{p_1} = \frac{\omega_{ugb}}{A_0} \Rightarrow \omega_{ugb} = A_0\, \omega_{p_1} = g_{m_1} R_{o_1}\, \cancel{g_{m_2} R_{o_2}} \times \frac{1}{\cancel{R_{o_1}} (\cancel{g_{m_2} R_{o_2}}) C_c}$$

$$\boxed{\omega_{ugb} = \frac{g_{m_1}}{C_c}} \quad \text{L.H.P}$$

$$\omega_z = \frac{g_{m_2}}{C_c} \quad \text{R.H.P.}$$

Phase Margin after miller compensation

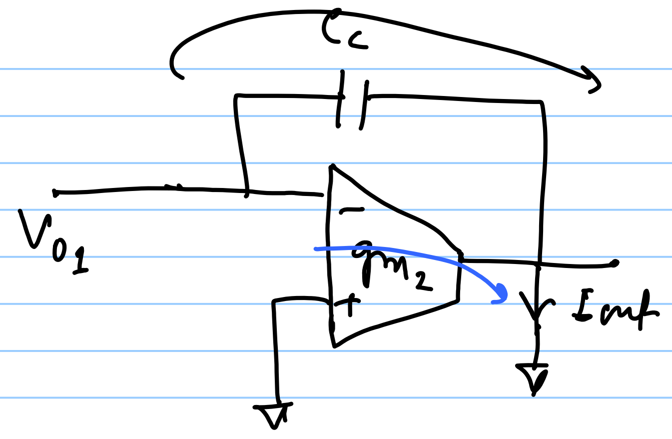
$$PM = \underbrace{90^0 - \tan^{-1}\frac{\omega_{ugb}}{\omega_{p_2}}}_{\tan^{-1} \omega_{p_2}/\omega_{ugb}} - \tan^{-1}\frac{\omega_{ugb}}{\omega_z}$$

$$= \tan^{-1}\frac{\omega_{P_2}}{\omega_{ugb}} - \tan^{-1}\frac{\omega_{ugb}}{\omega_2} = \tan^{-1}\frac{g_{m_2}/(C_{O_1}+C_{O_2})}{g_{m_1}/C_c} - \tan^{-1}\frac{g_{m_1}/\cancel{C_c}}{g_{m_2}/\cancel{C_c}}$$

$$= \tan^{-1}\frac{g_{m_2}}{g_{m_1}}\left(\frac{C_c}{C_{O_1}+C_{O_2}}\right) - \tan^{-1}\frac{g_{m_1}}{g_{m_2}}$$

this should be minized to increase the P.M

$$\frac{g_{m_1}}{g_{m_2}} << \qquad g_{m_2} \geq 10 \times g_{m_1}$$



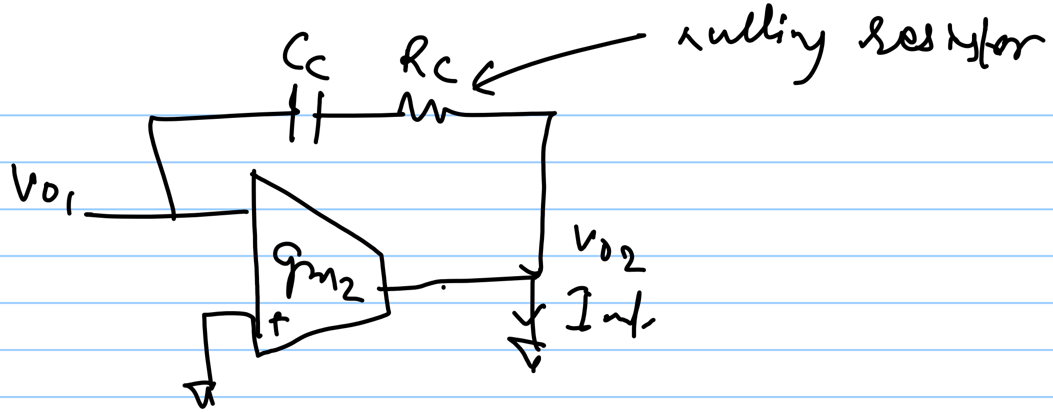
Without C_c

$I_{out} = -g_{m_2} V_{o_1}$

With C_c

$I_{out} = -g_{m_2} V_{o_1} + V_{o_1} C_c s$

in order order to maintain -ve feedback, current through C_c should be less than current from g_{m_2}



R_c will limit the current through C_c

current in R_c should be less than current through g_{m2}

$$R_c > \frac{1}{g_{m2}}$$

$$\boxed{\omega_z = -\frac{1}{\left(R_c - \frac{1}{g_{m2}}\right)C_c}}$$

(L.H.P if $R_c > \frac{1}{g_{m2}}$ $\qquad \rightarrow \infty$
R.H.P if $R_c < \frac{1}{g_{m2}}$ $\qquad$ if $R_c = \frac{1}{g_{m2}}$

if $R_c > \frac{1}{g_{m2}}$

$\omega_z = \omega p_2$ $\longrightarrow$ ωp_2 is cancelled out & system becomes 1st order

pole-zero cancellation.

always stable

U.G.B can be extended at much higher frequency