EE 473/538
Homework 4
Kevin Egedy

P8.7 – skip the part of the problem that deals with calculating the input referred noise.
P8.10
P10.1
P10.2
P10.3
P10.11 – please do parts a, b, c and d, but skip e.

8.7 R_o [transimpedance] $= \dfrac{V_{out}}{\cancel{V_{in}}\, I_{in}}$

Given Ideal current source $\rightarrow$ $I_{out} = I_{in}$

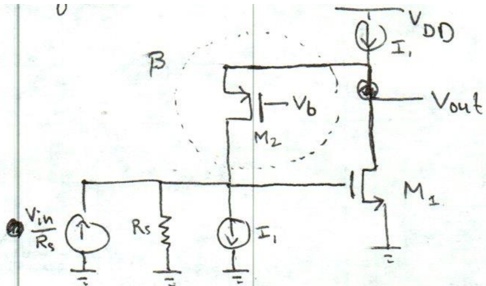
$A_{CL} = \dfrac{1}{\beta} = \dfrac{I_{out}}{I_{in}} = 1$

$V_{out} = -I_{out} R_{D2}$ $\quad | \quad I_{out} = I_{in}$

$V_{out} = -I_{in} R_{D2}$

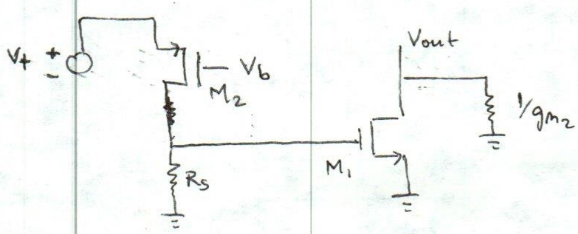
$R_o = \dfrac{V_{out}}{I_{in}} = -R_{D2}$

8.10



Break the loop and apply test voltage

Find the loop gain:



$$V_{out} = -g_{m2} \cdot (R_s // \underset{\infty}{r_{o2}}) \cdot \left(-g_{m1} \cdot \left(\frac{1}{g_{m2}} // \underset{\infty}{r_{o1}}\right)\right)$$

$$V_{out} = (-g_{m2} R_s)\left(-g_{m1} \frac{1}{g_{m2}}\right) = \cancel{g_{m2}} \rightarrow A \cdot \beta = g_{m1} \cdot R_s$$

Find Open-Loop Forward Gain

$$V_{out} = -\left(\frac{V_{in}}{R_s}\right) \cdot (R_s // r_{o2}) \cdot g_{m1} \cdot (1/g_{m2})$$

$$A_{closed} = \frac{-R_s \cdot g_{m1}/g_{m2}}{1 + g_{m1} R_s} = \frac{V_o}{V_{in}/R_s} \rightarrow \left.\frac{V_{out}}{V_{in}/R_s}\right|_{open} = \frac{-R_s \cdot g_{m1}}{g_{m2}}$$

$$\underset{\text{Transresistance}}{A_{v,closed}} = A_{v,closed} \cdot \frac{1}{R_s} = \frac{-1}{R_s} \cdot \frac{R_s\, g_{m1}/g_{m2}}{1 + g_{m1} R_s} = \frac{-g_{m1}}{g_{m2}(1 + g_{m1} R_s)}$$

Shunt-Shunt Feedback

$$R_{in,closed} = \frac{R_{in,open}}{1 + A\beta} \qquad R_{in,open} \approx R_s$$

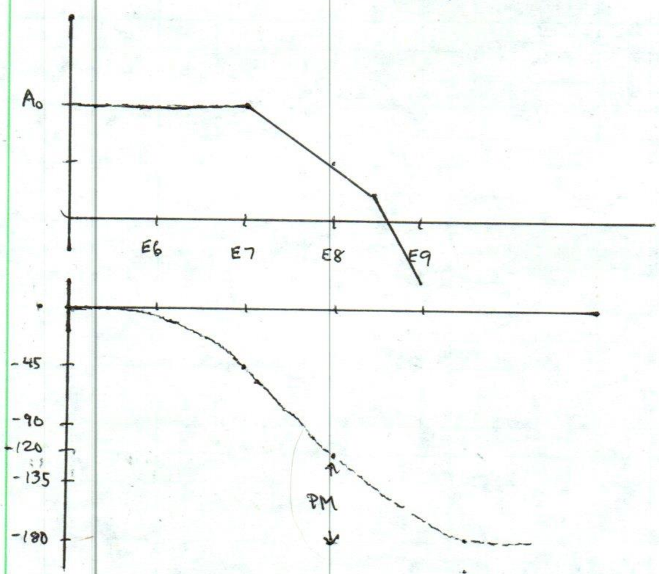
$$R_{in,closed} = \frac{R_s}{1 + \underbrace{g_m R_s}_{\text{loop-gain}}}$$

$$R_{out,closed} = \frac{R_{out,open}}{(1 + A\beta)}$$

10.1 $f_1 = 10\,\text{MHz}$, $f_2 = 500\,\text{MHz}$, $PM = 60^\circ$

Need $\angle \beta H = -120^\circ$

$$\frac{Y}{X}(s) = H(s) = \frac{A_0}{\left(1+\frac{s}{\omega_{p1}}\right)\left(1+\frac{s}{\omega_{p2}}\right)+\beta A_0}$$



gain crossover is after ω_{p1}

$$\angle \beta H = \underbrace{-\tan^{-1}\left(\frac{\omega}{\omega_1}\right)}_{-90^\circ} - \tan^{-1}\left(\frac{\omega}{\omega_2}\right) = -120^\circ$$

$$-\tan^{-1}\left(\frac{\omega}{\omega_2}\right) = -30^\circ$$

$$\tan^{-1}\left(\frac{\omega}{\omega_2}\right) = 30^\circ$$

$$\tan[\quad] = \tan\left(30^\circ \cdot \frac{\pi}{180^\circ}\right)$$

$$\frac{\omega}{\omega_2} = \tan\left(\frac{\pi}{6}\right)$$

~~$\omega = f$~~

$$\frac{f}{f_2} = \tan\left(\frac{\pi}{6}\right) \rightarrow \quad f = f_2 \tan\left(\frac{\pi}{6}\right) = \cancel{2.65}\ 2.89\text{ E8 Hz}$$

$f = 2.89$ E8 Hz [gain crossover]

Find A_0:

$$A_0 - 20\log_{10}\left(\frac{\omega}{\omega_1}\right) - 20\log_{10}\left(\frac{\omega}{\omega_2}\right) = 0$$

$$A_0 - 20\log_{10}\left(\frac{f}{f_1}\right) - 20\log_{10}\left(\frac{f}{f_2}\right) = 0$$

$$A_0 - 20\left[\log_{10}\left(\frac{f}{f_1}\right) + \log_{10}\left(\frac{f}{f_2}\right)\right] = 0 \qquad x$$

$$A_0 = 20\left[\log_{10}\left(\frac{f}{f_1}\right) + \underbrace{\log_{10}\left(\frac{f}{f_2}\right)}_{0}\right] \quad \Big| \quad f = \cancel{2.65}\ \cancel{2.89\text{ E8 Hz}} \quad 2.89\text{ E8 Hz}$$

$$A_0 = 20\log_{10}\left(\frac{f}{f_1}\right)$$

$$A_0 = 29.2\text{ dB}$$

10.2

$\beta = 1 \qquad H(s) = \dfrac{A_0}{\left(1+\frac{s}{\omega_p}\right)\left(1+\frac{s}{\omega_p}\right) + \beta A_0}$

$A_0 - 40\log_{10}\left(\frac{\omega}{\omega_p}\right) = 0 \qquad \omega_p = 1\text{ MHz}$

Need $\measuredangle \beta H = -120$ for 60° phase margin

$-\cancel{2}\tan^{-1}\left(\frac{\omega}{\omega_p}\right) - \tan^{-1}\left(\frac{\omega}{\omega_p}\right) = -120^\circ$

$-2\tan^{-1}\left(\frac{\omega}{\omega_p}\right) = \cancel{1}20^\circ$

$\tan^{-1}\left(\frac{\omega}{\omega_p}\right) = 60^\circ$

$\frac{f}{f_p} = \tan\left(\frac{\pi}{3}\right)$

$f = 1.73\text{ MHz}$

$A_0 - 40\log_{10}\left(\frac{1.73\text{ MHz}}{1\text{ MHz}}\right) = 0$

$\underline{A_0 = 9.52\text{ dB}}$

$\frac{1}{\beta} = 4 \rightarrow \qquad A_0' = A_0 \cdot \left|\frac{1}{\beta}\right|$

$A_0' = A_0[\text{dB}] + 20\log_{10}\left(\frac{1}{\beta}\right)$

$A_0' = 9.52\text{dB} + 20\log_{10}(4)$

$A_0' = 21.56\text{ dB}$

10.3 $\omega_p = 1\,MHz$

$\omega_{p_2} = 2\omega_{p_1}$

$1000 = 60dB$

$$A_o - 20\log\left(\frac{\omega}{\omega_c}\right) - 20\log\left(\frac{\omega}{\omega_{c_2}}\right) = 0 \quad [\log = \log_{10}]$$

$$A_o - 20\log\left(\frac{f}{f_1}\right) - 20\log\left(\frac{f}{2f_1}\right) = 0 \quad [\log = \log_{10}]$$

$$60 - 20\left[\log\left(\frac{f}{f_1}\right) + \log\left(\frac{f}{2f_1}\right)\right] = 0 \quad [\log = \log_{10}]$$

$$60 - 20\log_{10}\left(\frac{f^2}{2f_1^2}\right) = 0$$

$$60 - \cancel{2}\,40\log_{10}\left(\frac{f}{\sqrt{2}f_1}\right) = 0$$

$$\log_{10}\left(\frac{f}{\sqrt{2}f_1}\right) = \frac{3}{2}$$

$$\frac{\log(f) - \log(f_1) - \log(2)}{\log(10)} = \frac{3}{2} \quad [\log = \ln]$$

$$\log(f) = \frac{3}{2}\log(10) + \log(f_1) + \frac{\log(2)}{2} \quad [\log = \ln]$$

$$\log(f) = 17.62$$

$$f = e^{17.62} = 44.7\ MHz$$

$$\measuredangle = -\tan^{-1}\left(\frac{44.7\ MHz}{1\ MHz}\right) - \tan^{-1}\left(\frac{44.7\ MHz}{2\ MHz}\right)$$

$$= -3.07 \cdot \frac{180}{\pi}$$

$$= -176.16^\circ$$

$$PM = 180 - 176.16^\circ$$

$$= \underline{3.84^\circ}$$

$w_{p_2} = 4 w_{p_1}$

$$\frac{\log(f) - \log(f_1) - \log(2)}{\log(10)} = \frac{3}{2}$$

$$\log(f) = \frac{3}{2}\log(10) + \log(f_1) + \log(2)$$

$$\log(f) = 17.96$$

$$f = 63.2 \text{ MHz}$$

$$\measuredangle = -\tan^{-1}\left(\frac{63.2 \text{ MHz}}{1 \text{ MHz}}\right) - \tan^{-1}\left(\frac{63.2 \text{ MHz}}{4 \text{ MHz}}\right)$$

$$\measuredangle = -3.06 \cdot \frac{180}{\pi} = -175.47^\circ$$

$$PM = 180 - 175.47 = \underline{4.53^\circ}$$