1. Calculate the transfer function $v_{out}(s)/v_{in}(s)$ for the circuit shown in Fig. 1. The W/L of M1 is 2µm/0.8µm and the W/L of M2 is 4µm/4µm. Note that this is a small signal analysis and the input voltage has a dc value of 2 volts.

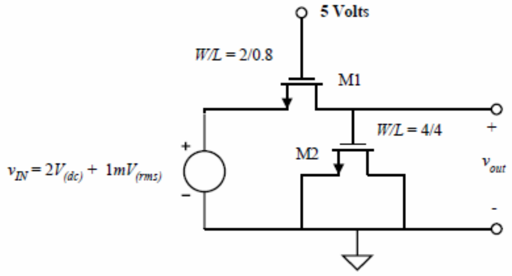


Figure 1(a)

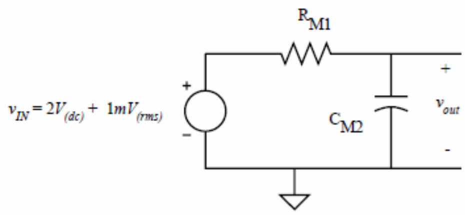


Figure 1(b)

$$\frac{v_{out}(s)}{v_{IN}(s)} = \frac{1/SC_{M2}}{R_{M1} + 1/SC_{M2}} = \frac{1}{SC_{M2}R_{M1} + 1}$$

$$V_{T1} = V_{T0} + \gamma[\sqrt{2|\phi_F| + v_{SB}} - \sqrt{2|\phi_F|}]$$

$$V_{T1} = 0.7 + 0.4\,[\sqrt{0.7 + 2.0} - \sqrt{0.7}] = 1.02$$

$$R_{M1} = \frac{1}{K'(W/L)_{M1}\,(v_{GS1} - V_{T1})} = 1.837\ \text{k}\Omega$$

$$C_{M2} = W_{M2} \times L_{M2} \times C_{ox} = 4 \times 10^{-6} \times 4 \times 10^{-6} \times 24.7 \times 10^{-4} = 39.52 \times 10^{-15}$$

$$R_{M1}C_{M2} = 1.837\ \text{k}\Omega \times 39.52 \times 10^{-15} = 72.6 \times 10^{-12}$$

$$\frac{v_{out}(s)}{v_{IN}(s)} == \frac{1}{\dfrac{S}{13.77 \times 10^{9}} + 1}$$

2. Figure 2 illustrates a source-degenerated current source. Using Table 1 model Parameters, calculate the output resistance at the given current bias.

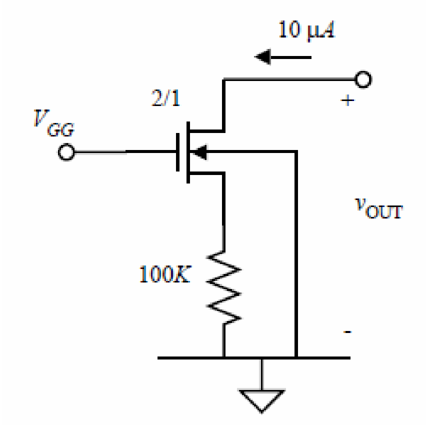


Figure 2

$I_D = 10\ \mu\text{A}$

$V_S = I_D \times \text{R} = 10 \times 10^{-6} \times 100 \times 10^{3} = 1\ \text{volt}$

$V_S = V_{SB}$

$$r_{\text{out}} = \frac{v_{\text{out}}}{i_{\text{out}}} = r + r_{ds} + [(g_m + g_{mbs})r_{ds}]r \cong (g_m r_{ds})r$$

$$g_m \cong \sqrt{(2K'W/L)|I_D|} = \sqrt{2\times 110\times10^{-6} \times 2/1 \times 10\times10^{-6}} = 66.3 \times10^{-6}$$

$$g_{mbs} = g_m \frac{\gamma}{2(2|\phi_F| + V_{SB})^{1/2}} = 66.3\times10^{-6}\frac{0.4}{2(0.7+1)^{1/2}} = 10.17\times10^{-6}$$

$$g_{ds} \cong I_D\,\lambda = 10\times10^{-6} \times 0.04 = 400\times10^{-9}$$

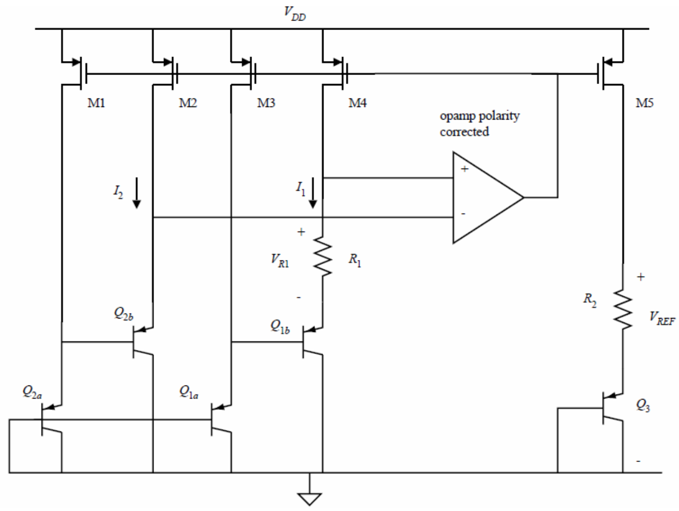
$$r_{ds} = \frac{1}{g_{ds}} = 2.5\times10^{6}$$

thus

$$r_{\text{out}} = 100 \times 10^{3} + 2.5\times10^{6} + [(66.3 \times10^{-6} + 10.17\times10^{-6})\ 2.5\times10^{6}]\ 100 \times 10^{3} = 21.7\times10^{6}$$

$$r_{\text{out}} = 21.7\times10^{6}$$

3.



$$V_{\text{REF}}\Big|_{T=T0} = V_{G0} + V_{t0}\,(\gamma - \alpha) = 1.262 \text{ @ } 300\text{ K}$$

$$KV_{t0} = V_{G0} - V_{BE0} + V_{t0}\,(\gamma - \alpha)$$

$$K = \left(\frac{R_2}{R_1}\right)\ln(10) = \frac{V_{G0} - V_{BE0} + V_{t0}\,(\gamma - \alpha)}{V_{t0}}$$

$$V_{BE0} = \frac{kT}{q}\ln\left(\frac{I}{I_S}\right)$$

$$I = \frac{\Delta V_{BE}}{R_1} = 1\ \mu\text{A}$$

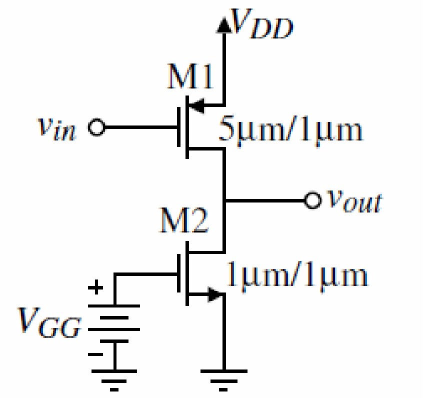
$$R_1 = \frac{0.0259\ \ln(10)}{1\ \mu\text{A}} = 59.64\text{ k}\Omega$$

$$K = \frac{1.205 - 0.53 + 0.0259(2.2)}{0.0259} = 28.26\text{ k}\Omega = \left(\frac{R_2}{R_1}\right)\ln(10)$$

$$R_2 = 732\text{ k}\Omega$$

Stacking bipolar transistors reduces sensitivity to amplifier offset.

4. .



a) $V_{GG} = V_{T2} + V_{dsat2}$

$$V_{GG} = V_{T2} + \sqrt{\frac{2I_{D2}}{K_N'(W/L)_2}} = \underline{\underline{2.05\ \text{V}}}$$

b) $V_{in} = V_{DD} - V_{T1} - \sqrt{\dfrac{2I_{D1}}{K_P'(W/L)_1}} = \underline{\underline{3.406\ \text{V}}}$

c) $A_v = \dfrac{v_{out}}{v_{in}} = -\dfrac{g_{m1}}{(g_{ds1} + g_{ds2})} = \underline{\underline{-24.85\ \text{V/V}}}$

d) $f_{-3dB} = \dfrac{(g_{ds1} + g_{ds2})}{2\pi\left(C_{gd1} + C_{gd2} + C_{bd1} + C_{bd2} + C_L\right)} = \underline{\underline{2.51\ \text{MHz}}}.$

5.

Referring to the figure

$$V_{GS1} = V_{T1} + V_{dsat1}$$

or, $$V_{GS1} = V_{T1} + \sqrt{\frac{2I_{D1}}{\beta_1}}$$

$$V_{GS2} = V_{T2} + V_{dsat2}$$

or, $$V_{GS2} = V_{T2} + \sqrt{\frac{2I_{D2}}{\beta_2}}$$

The input-offset voltage can de defined as

$$|V_{OS}| = |V_{GS1} - V_{GS2}|$$

or, $$|V_{OS}| = |V_{T1} - V_{T2}| + \left| \sqrt{\frac{2I_{D1}}{\beta_1}} - \sqrt{\frac{2I_{D1}}{\beta_2}} \right|$$

Considering the transistors M_3 and M_4, mismatches in these two transistors would cause an offset voltage between the output nodes. But, if it is assumed that this offset voltage between the output nodes is small as compared to the drain-to-source voltages of the transistors M_1 and M_2, then

$$V_{DS1} \cong V_{DS2}$$

Thus, it is assumed here that

$$I_{D1} = I_{D2} = I$$

So, the input-offset voltage becomes

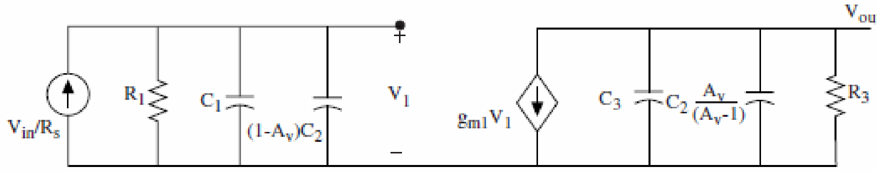
$$|V_{OS}| = |V_{T1} - V_{T2}| + \left| \sqrt{\frac{2I}{\beta_1}} - \sqrt{\frac{2I}{\beta_2}} \right|$$

Assuming $I = 50$ μA, the worst-case input offset voltage can be given by

$$|V_{os}| = (1.01 - 0.99) + \left[\sqrt{\frac{2(50\mu)}{0.95(10\mu)}} - \sqrt{\frac{2(50\mu)}{1.05(10\mu)}} \right]$$

or, $V_{OS}(\max) = \underline{0.18 \text{ V}}$

6.



$sC_2 << R_3$

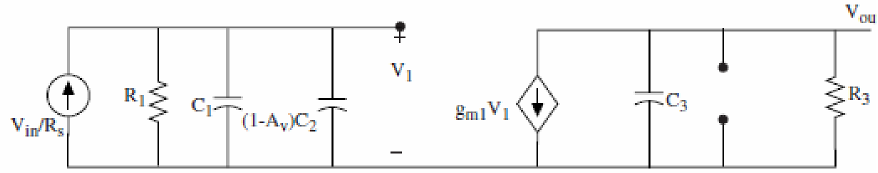


Fig. S5.3-09

__Solution__

Given that in the frequency of interest, the reactance of C_2 is greater than $1/R_3$

or, $2\pi f C_2 >> \frac{1}{R_3}$

Referring to the figure

$$V_1(s) = \frac{V_{in}(s)}{R_S\left[\frac{1}{R_1} + s\left(C_1 + \left(1 + A_v\right)C_2\right)\right]} \tag{1}$$

where, $A_v = g_{m1}R_3$

Also, $V_o(s) = \dfrac{-g_{m1}V_1(s)}{\left(\frac{1}{R_3} + sC_3\right)} \cong \dfrac{-g_{m1}V_1(s)}{sC_3}$

or, $$V_o(s) = \frac{-g_{m1}}{\left(\frac{1}{R_3} + sC_3\right)} \frac{V_{in}(s)}{R_S\left[\frac{1}{R_1} + s\left(C_1 + \left(1 + A_v\right)C_2\right)\right]} \tag{2}$$

The dominant pole in Eq. (2) can be expressed as

$$p_1 = \frac{-1}{R_1\left(A_v C_2 + C_1\right)} \cong \frac{-1}{R_1\left(A_v C_2\right)}$$

or, $$\boxed{p_1 = \frac{-1}{g_{m1}R_1R_3C_2}}$$

7. A two-stage, Miller-compensated CMOS op amp has a RHP zero at 20*GB*, a dominant pole due to the Miller compensation, a second pole at p_2 and a mirror pole at -3*GB*. (a) If *GB* is 1MHz, find the location of p_2 corresponding to a 45° phase margin. (b) Assume that in part (a) that $|p_2|$ = 2*GB* and a nulling resistor is used to cancel p_2. What is the new phase margin assuming that *GB* = 1MHz? (c) Using the conditions of (b), what is the phase margin if C_L is increased by a factor of 4?

a.) Since the magnitude of the op amp is unity at GB, then let ω = GB to evaluate the phase.

$$\text{Phase margin= PM} = 180° - \tan^{-1}\left(\frac{GB}{|p_1|}\right) - \tan^{-1}\left(\frac{GB}{|p_2|}\right) - \tan^{-1}\left(\frac{GB}{|p_3|}\right) - \tan^{-1}\left(\frac{GB}{|z_1|}\right)$$

But, $p_1 = GB/A_o$, $p_3 = -3GB$ and $z_1 = -20GB$ which gives

$$PM = 45° = 180° - \tan^{-1}(A_o) - \tan^{-1}\left(\frac{GB}{|p_2|}\right) - \tan^{-1}(0.33) - \tan^{-1}(0.05)$$

$$45° \approx 90° - \tan^{-1}\left(\frac{GB}{|p_2|}\right) - \tan^{-1}(0.33) - \tan^{-1}(0.05) = 90° - \tan^{-1}\left(\frac{GB}{|p_2|}\right) - 18.26° - 2.86°$$

$$\therefore \tan^{-1}\left(\frac{GB}{|p_2|}\right) = 45° - 18.26° - 2.86° = 23.48° \rightarrow \frac{GB}{|p_2|} = \tan(23.84°) = 0.442$$

$$\boxed{p_2 = -2.26 \cdot GB = -14.2\text{x}10^6 \text{ rads/sec}}$$

b.) The only roots now are p_1 and p_3. Thus,

$$\boxed{PM = 180° - 90° - \tan^{-1}(0.33) = 90° - 18.3° = 71.7°}$$

c.) In this case, z_1 is at -2GB and p_2 moves to -0.5GB. Thus the phase margin is now,

$$\boxed{PM = 90° - \tan^{-1}(2) + \tan^{-1}(0.5) - \tan^{-1}(0.33) = 90°-63.43°+26.57°-18.3° = 34.4°}$$