Homework Assignment No. 11 Solutions

Problem 1 – (10 points)

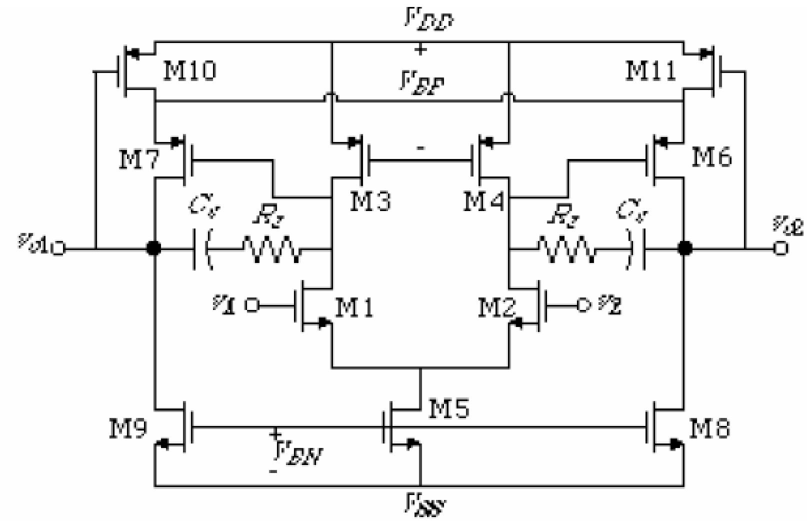


Figure 7.3-12 Two-stage, Miller, differential-in, differential-out op amp with common-mode stabilization.

The loop gain of the common-mode feedback loop is,

$$\text{CMFB Loop gain} \approx -\frac{g_{m10}}{g_{ds9}} = -g_{m10}r_{ds9} \quad \text{or} \quad -\frac{g_{m11}}{g_{ds8}} = -g_{m11}r_{ds8}$$

With $I_D = 50\mu\text{A}$ and $W/L = 10\mu\text{m}/1\mu\text{m}$, $g_{m10} = \sqrt{\dfrac{2K_P'WI_D}{L}} = \sqrt{2\cdot 50\cdot 10\cdot 50)} = 223.6\mu\text{S}$,

$$r_{dsN} = \frac{1}{\lambda_N I_D} = \frac{25}{50\mu\text{A}} = 0.5\text{M}\Omega \qquad \text{and} \qquad r_{dsP} = \frac{1}{\lambda_P I_D} = \frac{20}{50\mu\text{A}} = 0.4\text{M}\Omega$$

$\therefore$ $\boxed{\text{CMFB Loop gain} \approx -g_{m10}r_{ds9} = -223.6(0.5) = -111.8\text{V/V}}$

If the output is cascoded, the gain becomes,

$$\text{CMFB Loop gain with cascoding} \approx -\frac{g_{m10}}{g_{ds9}}\ g_m(\text{cascode})r_{ds}(\text{cascode})$$

$$= -g_{m10}\{[r_{ds9}\ g_m(\text{cascode})r_{ds}(\text{cascode})]||[g_{m7}r_{ds7}\ (r_{ds10}||r_{ds10}]\}$$

$$g_{mP} = \sqrt{\frac{2K_N'WI_D}{L}} = \sqrt{2\cdot 110\cdot 10\cdot 50)} = 331.67\mu\text{S}$$

$$= -(223.6)[(0.5\cdot 331.67\cdot 0.5)||(223.6)(0.4)(0.2)] = 223.6(14.7) = -3{,}290\text{ V/V}$$

$\therefore$ $\boxed{\text{CMFB Loop gain with cascoding} \approx -3.290\text{V/V}}$

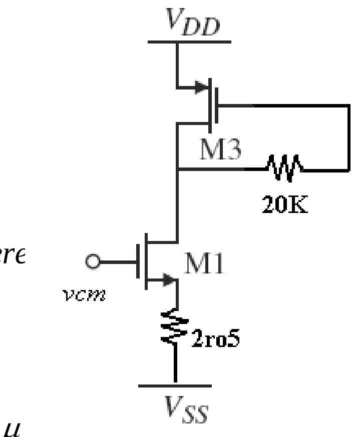
Problem 2 – (10 points)

Common mode half circuit:

$$V_{o1} = V_{o2} = V_{DD} - |V_{GS3}|$$

$$|V_{GS3}| = \sqrt{\frac{2I_D}{k_p' \frac{w}{L}}} + V_{TP} = |V_{ov}| + V_{TP} = 0.8V$$

$$\Rightarrow V_{o1} = V_{o2} = 2.5 - 0.8 = 1.7V$$



$$a_{dm} = -g_{m1}(r_{o1} \| r_{o3} \| 20K) = -1(100 \| 200 \| 20) = -15.38,\ where$$

$$g_{m1} = \sqrt{2k_n' \frac{w}{L} I_D} = k_n' \frac{w}{L} v_{ov} = 5000 \times 0.2 = 1mS$$

$$v_{ov} = \sqrt{\frac{2I_{D3}}{k_p' \left(\frac{w}{L}\right)_3}} \Rightarrow 0.2 = \sqrt{\frac{2 \times 100\mu}{k_p' \left(\frac{w}{L}\right)_3}} \Rightarrow \begin{cases} k_p' \left(\frac{w}{L}\right)_3 = 5000\mu \\ k_n' \left(\frac{w}{L}\right)_1 = 5000\mu \end{cases}$$

$$r_{o1} = 100K,\ r_{o3} = 200K$$

$$a_{cm} = -\frac{g_{m1}}{1 + 2g_{m1}r_{o5}}(r_{o1}(1 + 2g_{m1}r_{o5}) \| r_{o3} \| \frac{1}{g_{m3}}) = \frac{1}{1 + 2m \times 50K} = 0.01,\ where:$$

$$g_{m3} = 5000 \times 0.2 = 1mS$$

$$r_{o5} = 50K$$

Because of adding the 20Kresistors, the a_{dm} becomes smaller but a_{cm} becomes much smaller. The effective impedance of M_3 and M_4 is now $1/g_m$, which is much smaller than r_o→ a_{dm}/a_{cm}=1538 which is much higher than 100 in 12.4.1

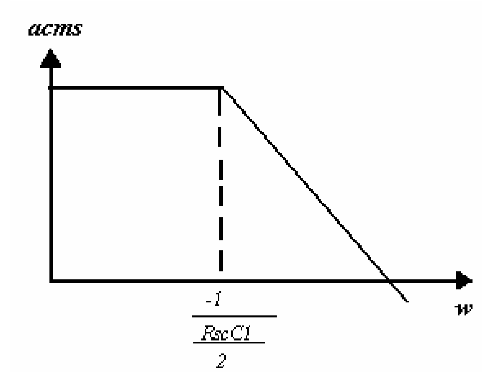
Problem 3 – (10 points)

Without C_{cs}:

$$v_{cms} = (v_{ov1} + v_{ov2}) \frac{(R_{cs} \| \frac{1}{C_1 s})}{(R_{cs} \| \frac{1}{C_1 s}) + R_{cs}}$$

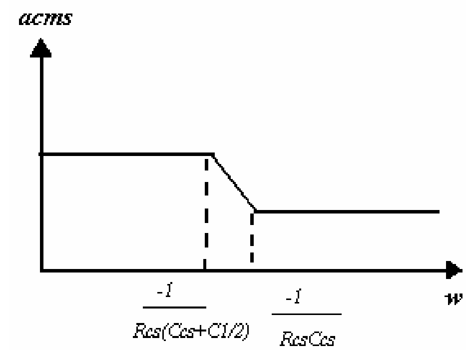
$$v_{oc} = \frac{v_{ov1} + v_{ov2}}{2}$$

$$\frac{v_{cms}}{v_{oc}} = 2\frac{R_{cs}}{R_{cs} + R_{cs}(R_{cs}C_1 s + 1)} \Rightarrow a_{cms} = \frac{1}{1 + \frac{R_{cs}C_1 s}{2}}$$



Gain starts to drop at frequencies higher than the pole. In Other words the CM detector cannot follow the signal at the same rate.

With C_{cs}:



$$v_{cms} = (v_{ov1} + v_{ov2}) \frac{(R_{cs} \left\| \frac{1}{(C_{cs}+C_1)s} \right.)}{(R_{cs} \left\| \frac{1}{(C_{cs}+C_1)s} \right.) + (R_{cs} \left\| \frac{1}{C_{cs}s} \right.)}$$

$$v_{oc} = \frac{v_{ov1} + v_{ov2}}{2}$$

$$\frac{v_{cms}}{v_{oc}} = 2\frac{R_{cs}C_{cs}s+1}{R_{cs}C_{cs}s+1+1+R_{cs}(C_1 s + C_{cs}s)} \Rightarrow a_{cms} = \frac{1+R_{cs}C_{cs}s}{1+R_{cs}(C_{cs}+\frac{C_1}{2})s}$$

If $C_{cs} >> \frac{C_1}{2}$ → gain stays constant over the entire frequency range.

<u>Problem 4 – (10 points)</u>

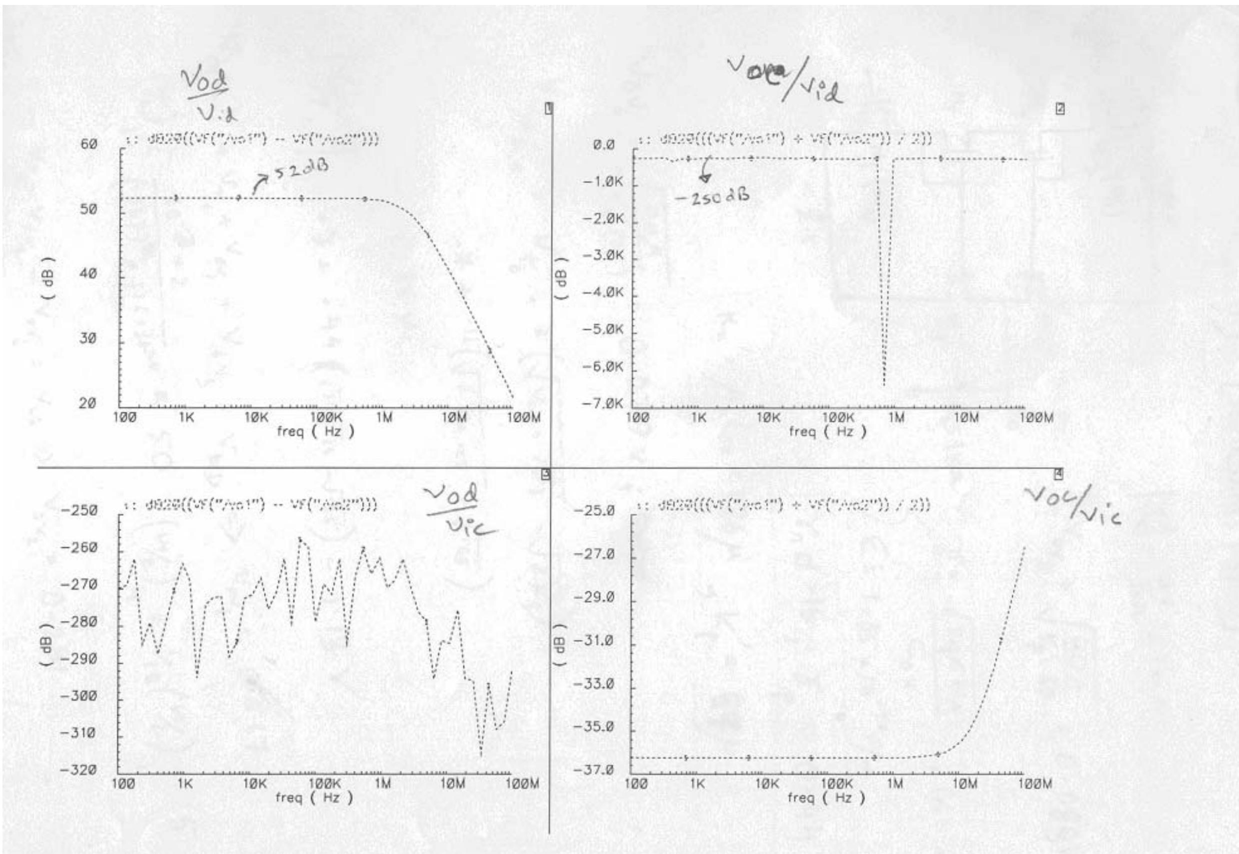
$$\frac{(\frac{w}{L})_{12}}{(\frac{w}{L})_{11}} = \frac{20}{100} \Rightarrow (\frac{w}{L})_{12} = 19.2 \Rightarrow w_{12} = 19.2\mu m$$

$$I_{D51} = 120\mu$$

$$\frac{(\frac{w}{L})_{51}}{(\frac{w}{L})_{14}} = \frac{120}{100} \Rightarrow (\frac{w}{L})_{51} = 1.2 \times \frac{16}{0.8} \times 0.8 = 19.2 \Rightarrow w_{51} = 19.2\mu m$$

$$SR = \frac{100\mu A}{4pF} = 25 \, V/\mu\,\text{sec}$$

$$v_{o1\,\min} = \max(-1.65 + v_{ov51} + v_{ov1} + v_{ov1C},\, v_i - v_t + v_{ov1C})$$
$$v_{o1\,\max} = 1.65 - v_{ov27} - v_{gs24}$$


Vod / Vid
52dB
(dB)
freq (Hz)
Voc/Vid
-250dB
Vod / Vic
Voc/Vic
100
1K
10K
100K
1M
10M
100M

Problem 5 – (10 points)

$$v^+_o = v_{DD} - v_{ds3} - v_{gs1}$$

$$v^-_o = v_{DD} - v_{ds6} - v_{gs2}$$

$$k_n' = \mu_n C_{ox} = 126,\ k_p' = \mu_p C_{ox} = 57$$

$$v_{ov6} = \sqrt{\frac{20\mu}{k_n'(25)}} = 0.079V$$

$$v_{ov3} = \sqrt{\frac{20\mu}{k_p'(50)}} = 0.083V$$

$$V_{tn} = V_{t0} + 0.16(\sqrt{3.5+0.65} - \sqrt{0.65}) = 0.897V$$

$$\Rightarrow v_{gs1} = 2.5 - 1 - 0.083 = 1.41V$$

$$\Rightarrow \left(\frac{w}{L}\right)_1 = \frac{2\times 1mA}{126\mu\times(1.41-0.897)^2} = 60,\ \left(\frac{w}{L}\right)_4 = 0.1\times 60 = 6$$

$$V_{tp} = V_{t0} - 0.44(\sqrt{3.5+0.65} - \sqrt{0.65}) = -1.242V$$

$$\Rightarrow v_{gs2} = -2.5 + 1 + 0.079 = 1.421V$$

$$\Rightarrow \left(\frac{w}{L}\right)_2 = \frac{2\times 1mA}{57\mu\times(1.421-1.242)^2} = 1095,\ \left(\frac{w}{L}\right)_4 = 0.1\times 1095 = 109.5$$