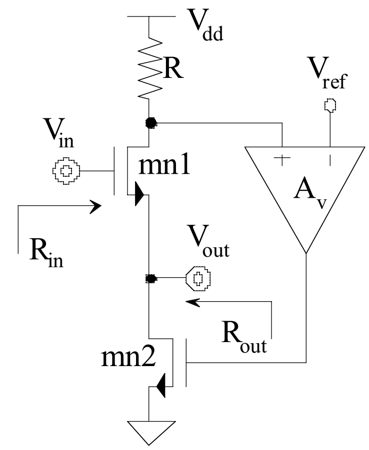
EXAMINATION NO. 3
(Average score = 74/100)

Problem 1 - (25 points)



Referring to the feedback circuit shown on the right, answer and/or fill in the blanks of the following questions:

a. What kind of mixing is being employed?

Series → (V_{in} – V_{out})

b. What kind of sampling is being employed?

Shunt → (V_{out} via mn1's CG gain stage))

c. What type of amplifier is the feedback circuit?

V_{out} / V_{in} → Voltage Amplifier

d. $R_{in} = R_{in\_open\_loop}$ * ***(1 + LoopGain)***

e. $R_{out} = R_{out\_open\_loop}$ * ***1 ÷ (1 + LoopGain)***

f. Calculate the loop gain of this circuit (assume $r_{ds} \rightarrow \infty$ and derive the relationship as a function of small-signal parameters, R, and A_v) –hint: break the loop somewhere and compute the transfer function–.

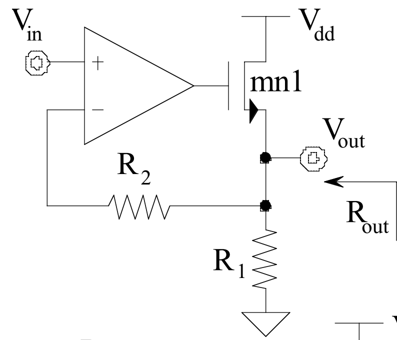
Opening the loop at the gate of mn2:

LG = $(v_{d2} / v_{g2}) (v_{d1} / v_{s1}) (v_{g2}' / v_{d1})$ = (CS gain) (CG gain) (A_v)

$= (-g_{m2}/g_{m1}) (g_{m1}R) (A_v) = -g_{m2}RA_v$

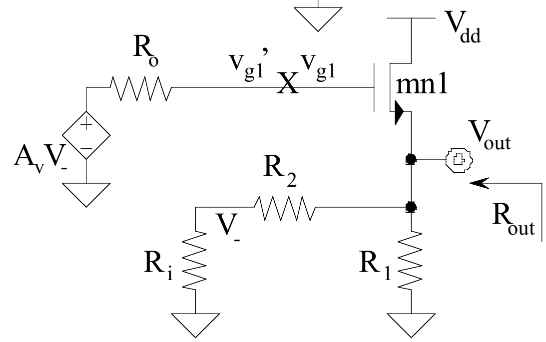
Problem 2 - (25 points)

Referring to the circuit shown, determine the closed-loop output resistance R_{out} using Return-Ratio (RR) and Blackman's formula:



$$R_{out} = \frac{R_{out\text{–(Controlled Source Gain=0)}} * (1 + RR_{output\ port\ shorted})}{(1 + RR_{output\ port\ open})} .$$

(Assume $r_{ds} \rightarrow \infty$, R_i, R_O, and A_v are the input resistance, the output resistance, and the gain of the differential amplifier. Derive the relationship as a function of small-signal parameters, R_1, R_2, and A_v.)



Solution

For RR (Loop Gain), break the loop at the gate of mn1:

$RR_{output\ port\ shorted}$ = 0 (amplifier A_v amplifies a "0" signal)

$RR_{output\ port\ open} = (v_{s1} / v_{g1})\ (v_- / v_{s1})\ (v_{g1}' / v_-)$ = (CD gain) (Voltage divider) (A_v)

$$= \frac{g_{m1}(R_1 \| [R_i + R_2])}{1 + g_{m1}(R_1 \| [R_i + R_2])} \cdot \frac{R_i}{R_i + R_2} \cdot A_v$$

$R_{out\text{–(Controlled Source Gain=0)}} = (1/g_{m1}) \| R_1 \| (R_2 + R_I)$

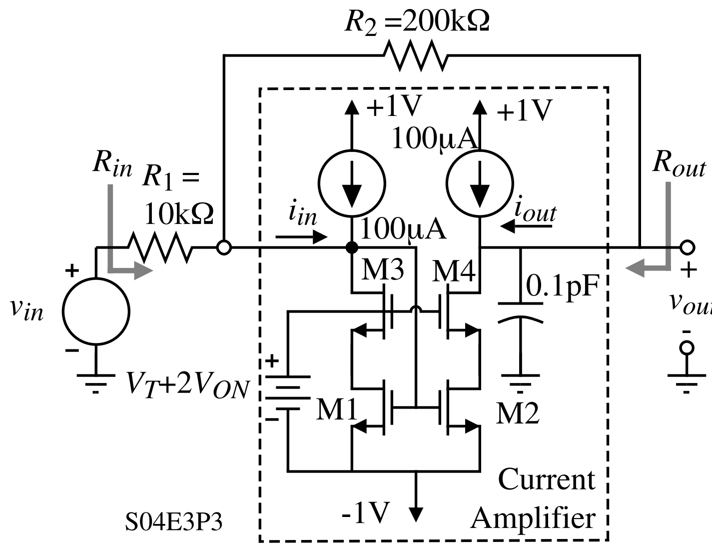
$= R_{out\_open\_loop}$ (open loop at gate of mn1)

Thus:

$$R_{out} = \frac{(1/g_{m1}) \| R_1 \| (R_i + R_2)}{\left[1 + \frac{g_{m1}(R_1 \| [R_i + R_2])}{1 + g_{m1}(R_1 \| [R_i + R_2])} \cdot \frac{R_i}{R_i + R_2} \cdot A_v\right]}$$

Problem 3 - (25 points)

A voltage amplifier using feedback around a current amplifier is shown. In this problem assume all of the NMOS transistors are identical. Assume that R_1 is greater than the transistor transconductance and find the input resistance, R_{in}, the output resistance, R_{out}, the voltage gain, v_{out}/v_{in}, and the gainbandwidth (GB) in Hz. Assume that the output resistance connected to this voltage amplifier is large.



Solution

$$R_{in} \approx R_1 = \underline{\underline{10\text{k}\Omega}}$$

$$R_{out} = \frac{v_t}{i_t}, \quad i_t = 2\frac{v_{out}}{R_2} = 2\frac{v_t}{R_2} \quad \rightarrow R_{out} = \frac{v_t}{i_t} = \frac{200\text{k}\Omega}{2} = \underline{\underline{100\text{k}\Omega}}$$

$$i_{in} \approx \frac{v_{in}}{R_1} + \frac{v_{out}}{R_2} \quad \text{and } i_{out} \approx -\frac{v_{out}}{R_2}$$

Since $i_{in} = i_{out}$, we get

$$\frac{v_{in}}{R_1} + \frac{v_{out}}{R_2} = -\frac{v_{out}}{R_2} \quad \rightarrow \quad \frac{v_{in}}{R_1} = -2\frac{v_{out}}{R_2} \quad \rightarrow \quad \frac{v_{out}}{v_{in}} = -\frac{R_2}{2R_1} = \underline{\underline{-10\text{V/V}}}$$

The dominant pole is found as,

$$p_{dominant} = \frac{1}{R_{out}C_{out}} = \frac{1}{100\text{k}\Omega\cdot 0.1\text{pF}} = 100\text{x}10^6 \text{ rads/sec.}$$

$\therefore \quad GB = 10\cdot 100\text{x}10^6$ rads/sec. $= 1000\text{x}10^6$ rads/sec. $\rightarrow \quad GB = \underline{\underline{159.15\text{MHz}}}$

Note: Many tried to work this problem as a feedback problem (which it is) so the results would be achieved from a shunt-shunt feedback network as follows.

The feedback factor would be $f = -1/R_2$ and the amplifier gain would be

$$a = \frac{v_{out}}{i_{in}} = -R_2 \quad \text{(loop gain is 1)}$$

Therefore the closed loop gain would be

$$\frac{v_{out}}{i_{in}} = \frac{a}{1+af} = \frac{-R_2}{2}$$

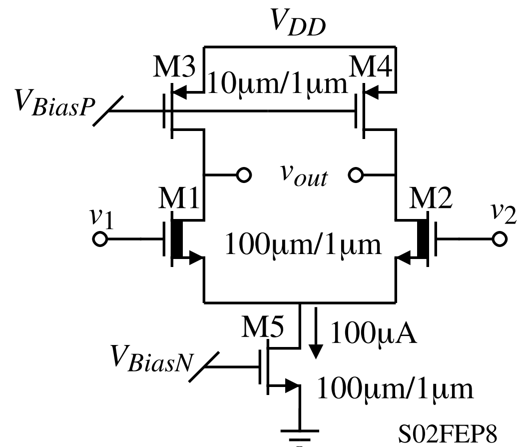
The desired voltage gain would be

$$\frac{v_{out}}{v_{in}} = \frac{v_{out}}{i_{in}}\frac{1}{R_{in}} = -\frac{R_2}{2R_1} = \underline{\underline{-10\text{V/V}}}$$

The input resistance of the current amplifier is approximately zero, so feedback would give the correct input and output resistances calculated above.

Problem 4 - (25 points)

A differential CMOS amplifier using depletion mode input devices is shown. Assume that the normal MOSFETs parameters are $K_N' = 110\text{V}/\mu\text{A}^2$, $V_{TN} = 0.7\text{V}$, $\lambda_N = 0.04\text{V}^{-1}$ and for the PMOS transistors are $K_P' = 110\text{V}/\mu\text{A}^2$, $V_{TP} = 0.7\text{V}$, $\lambda_P = 0.04\text{V}^{-1}$. For the depletion mode NMOS transistors, the parameters are the same as the normal NMOS except that $V_{TN} = -0.5\text{V}$. (a.) What is the maximum input common-mode voltage, $V_{icm}^+(\text{max})$? (b.) What is the minimum input common-mode voltage, $V_{icm}^-(\text{min})$? (c.) What value of V_{DD} gives an $ICMR = 0.5V_{DD}$?



Solution

(a.) $V_{icm}^+(\text{max}) = V_{DD} - V_{SD3}(\text{sat}) - V_{DS1}(\text{sat}) + V_{GS1}(50\mu\text{A})$

$$i_D = \frac{\beta}{2}(V_{GS1} - V_{T1})^2 \rightarrow \qquad V_{GS1} = \sqrt{\frac{2i_D}{\beta}} + V_{T1} = V_{DS1}(\text{sat}) + V_{T1}$$

$\therefore$ $$V_{icm}^+(\text{max}) = V_{DD} - V_{SD3}(\text{sat}) + V_{T1} = V_{DD} - \sqrt{\frac{2I_{D3}}{\beta_3}} + V_{T1}$$

$$V_{icm}^+(\text{max}) = V_{DD} - 0.3015 - 0.5 = \underline{\underline{V_{DD} - 0.8015}}$$

(b.) $V_{icm}^-(\text{min}) = V_{DS5}(\text{sat}) + V_{GS1}(50\mu\text{A}) = V_{DS5}(\text{sat}) + V_{DS1}(\text{sat}) + V_{T1}$

$$V_{icm}^-(\text{min}) = \sqrt{\frac{2I_{D5}}{\beta_5}} + \sqrt{\frac{2I_{D1}}{\beta_1}} + V_{T1} = 0.1348 + 0.0953 - 0.5 = \underline{\underline{-0.2698\text{V}}}$$

(c.) $ICMR = V_{icm}^+(\text{max}) - V_{icm}^-(\text{min}) = V_{DD} - 0.8015 + 0.2698 = V_{DD} - 0.5317$

$\therefore$ $V_{DD} - 0.5317 = 0.5V_{DD} \qquad \rightarrow \qquad V_{DD} = 2(0.5317) = \underline{\underline{1.063\text{V}}}$