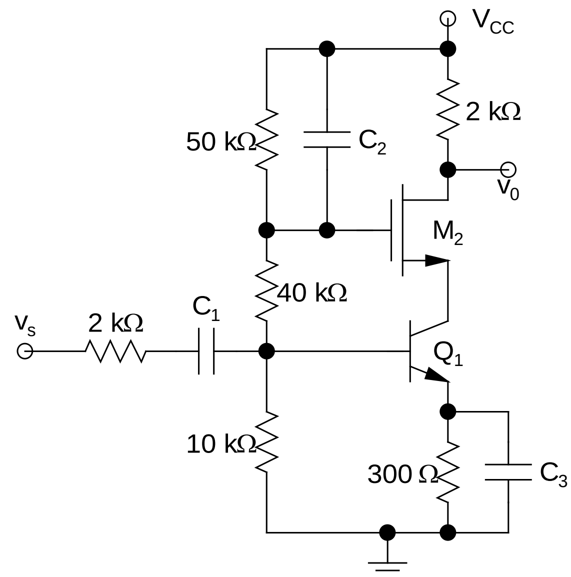
Department of Electrical Engineering
Indian Institute of Technology, Kanpur

EE 210 **END-SEM P1** **6.5.21**

Neglect base current, Early effect, body effect, CLM effect.
Data: For Q_1: $r_{E1} = 26\ \Omega$, $\beta_1 = 100$; for M_2: $g_{m2} = 2$ mA/V.

a) Determine the ac small-signal midband voltage gain (v_0/v_s). **2.5**

b) Using IVTC method, and the technique of total capacitance minimization, choose the values of C_1, C_2, and C_3, such that the tilt in the output v_0 for pulse excitation of frequency 1.57 kHz, does not exceed 2%. **9.5**



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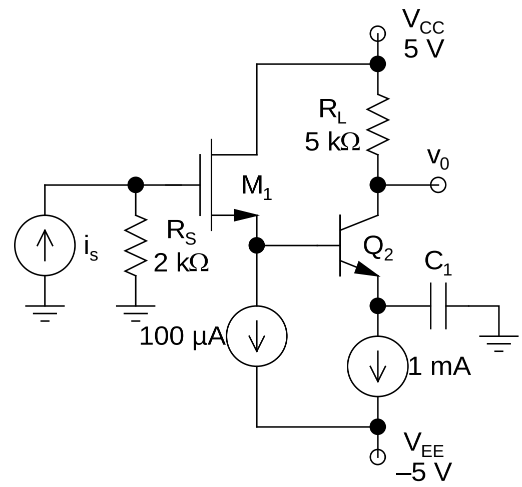
EE 210 **END-SEM P2** **6.5.21**

C_1 is an extremely large value capacitor. 100 μA and 1 mA current sources are ideal. Neglect base current, Early effect, body effect, and CLM effect. Other data: for M_1: g_{m1} = 200 μA/V, C_{gs1} = 10 pF, C_{gd1} = 1 pF, neglect C_{sb1} and C_{db1}; for Q_2: β_2 = 200, $C_{\pi 2}$ = 20 pF, $C_{\mu 2}$ = 2 pF.

a) Evaluate the ac small-signal midband transresistance (v_0/i_s). **3**

b) Using ZVTC method, evaluate the fall time of v_0 for pulse response. **8**

c) Which capacitor is primarily responsible for this performance? Justify. **1**



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EE 210 **END-SEM P3** **6.5.21**

$I_{S3} = I_{S4} = 2$ fA, $I_{S1} = I_{S2} = 10$ fA. I_{BIAS} is ideal. All transistors have $\beta = 200$ (neglect any drop in the value of β at low current levels).

With R_L removed:

a) Perform a self-consistent analysis, and find the split of I_{BIAS} in Q_3 and Q_4. **3**

b) Evaluate V_{BIAS}. **2**

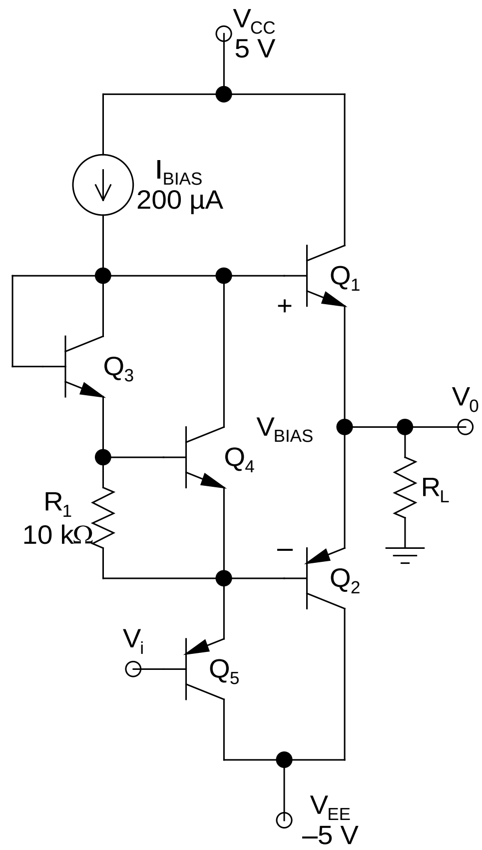
c) What should be the DC offset of V_i to ensure that the DC offset of V_0 is zero? **1**

d) If V_i is a ± 4 V sinuosid superimposed on the DC offset calculated in part c), what's the peak-to-peak swing of V_0? Justify your answer. **2**

e) What is the *total* standby power dissipation? **1**

With $R_L = 1$ kΩ:

f) Determine the power conversion efficiency. **3**



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EE 210 **END-SEM P4** **6.5.21**

a) A system has low-frequency gain of 50 dB, and two negative real poles, having pole frequencies at 1 Mrad/sec and 100 Mrad/sec.
   i) What is its unity-gain bandwidth? **2**
   ii) If it is used in a negative feedback configuration, determine the feedback factor (f), at which the poles would *just* start to have imaginary components. **2**
   iii) If f is increased beyond the value calculated in part ii), comment on the stability of the system, giving clear physical justification(s). **3**

b) Under unity negative feedback, the loop gain characteristic of a 3-pole (all negative and real) system is found to cross 0 dB at 2 MHz, with the total phase at this point equal to $-120°$.
   i) What is the phase margin of the system? **1**
   ii) Is the gain margin positive or negative? Justify. **1**
   iii) Based on the answers of parts i) and ii), comment on the stability of the system. **1**
   iv) If the locations of the second and third pole frequencies are 3 MHz and 5 MHz respectively, find the location of the first pole frequency. **2**

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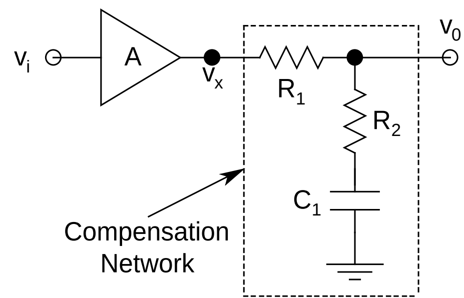
EE 210 **END-SEM P5** **6.5.21**



The amplifier block A has low-frequency gain $|v_x/v_i| = 90$ dB, and three negative real poles at frequencies 5 MHz, 25 MHz, and 500 MHz.

a) Derive the transfer function v_0/v_x, and show that the compensation network (within the dotted line) actually performs pole-zero compensation (PZC). What are the expressions for the pole and zero frequencies (in terms of R_1, R_2, and C_1)? **4**

b) Now, for unconditional stability, evaluate the required values of R_2 and C_1, if $R_1 = 10\ \text{k}\Omega$. **4**

c) What is the phase margin of the compensated system? **2**

d) What modification would you do to this compensation network, for it to perform dominant pole compensation (DPC) instead of PZC? Elaborate your answer. **2**

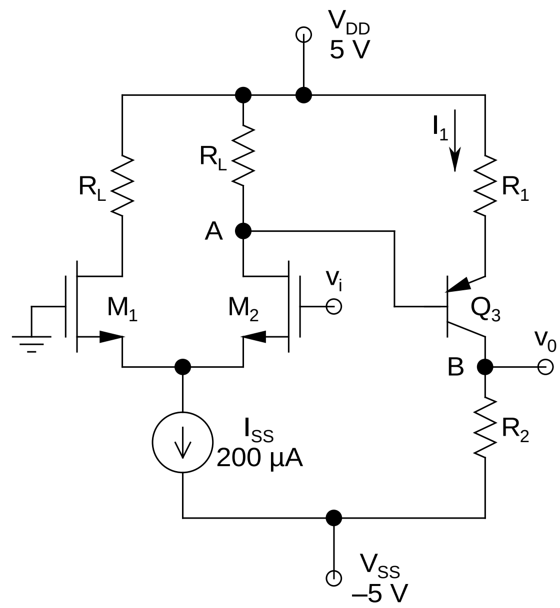
EE 210 **END-SEM P6** **6.5.21**

M_1-M_2 perfectly matched. I_{SS} ideal. Neglect base current, body effect, CLM effect, and Early effect. Other data: For M_1-M_2: $V_{TN0} = 1$ V, $k'_N = 40\ \mu A/V^2$, W/L = 80; for Q_3: $\beta = 100$.

a) Choose R_L, R_1, and R_2, such that the DC levels of the voltages at nodes A and B are 2.3 V and 0 V respectively, and $I_1 = 100\ \mu A$ (DC). **3**

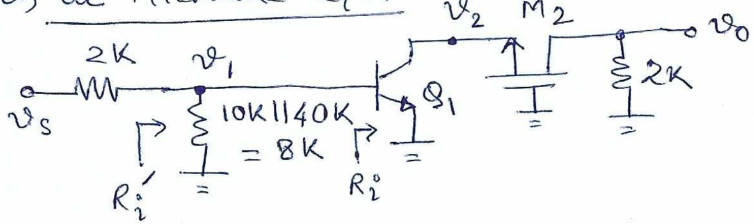
b) What is the voltage dropped across I_{SS}? **3**

c) Using the results of part a), find the ac small-signal midband voltage gain v_0/v_i. **6**



P1

a) ac Midband Equ.



$r_{E_1} = 26\Omega$, $r_{\pi_1} = 2.6K$, $g_{m_2} = 2mA/V$

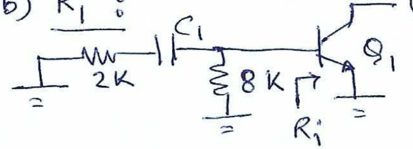
$$\frac{v_o}{v_2} = +g_{m_2} \times 2K = \underline{\underline{+4}}$$

$$\frac{v_2}{v_1} = -\frac{1/g_{m2}}{r_{E_1}} = \underline{\underline{-19.23}}$$

$R_i = r_{\pi_1} = \underline{\underline{2.6K}}$ $\quad R_i' = 8K||2.6K = \underline{\underline{2K}} \Rightarrow \dfrac{V_1}{V_s} = \dfrac{R_i'}{R_i'+2K} = \underline{\underline{0.5}}$

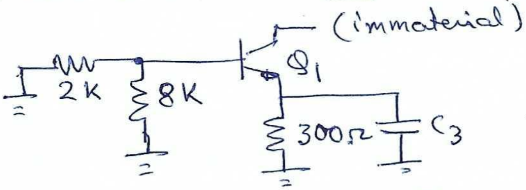
$$\Rightarrow \boxed{\frac{V_o}{V_s} = -38.46}$$

b) R_1^{∞}:

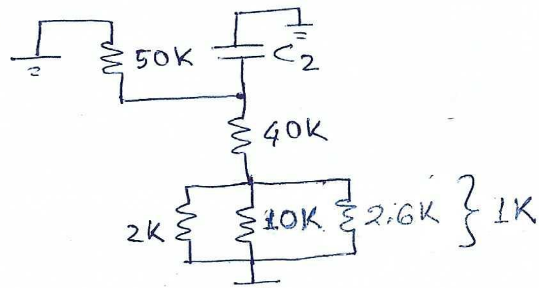


$R_1^{\infty} = 2K + 8K||2.6K = \underline{\underline{4K}}$

R_3^{∞}:



R_2^{∞}:



$R_2^{\infty} = 50K || 41K = \underline{\underline{22.5K}}$

$$R_3^{\infty} = 300 || \left[r_{E_1} + \frac{2K||8K}{\beta_1 + 1} \right] = \underline{\underline{36.7\Omega}}$$

$P = \dfrac{\pi f_L}{f} \times 100 = 2$ for $f = 1.57\ KHZ \Rightarrow f_L = \underline{\underline{10\ HZ}} = \sqrt{f_d^2 + 2\left(\frac{f_d}{10}\right)^2} \Rightarrow f_d = \underline{\underline{9.9\ HZ}}$

To make ΣC minimum, choose C_3 to contribute f_d, C_3 sees the least resistance $\Rightarrow$ To make ΣC minimum, choose C_3 to contribute f_d,

& C_1 & C_2 each contribute $f_d/10$.

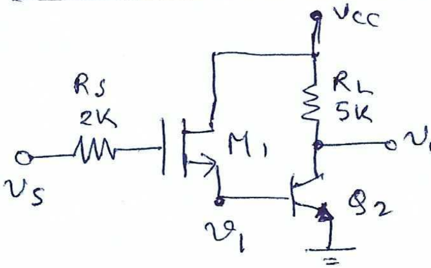
$$\Rightarrow C_1 = \frac{1}{2\pi (f_d/10) R_1^{\infty}} = \boxed{40.2\mu F} \qquad C_2 = \frac{1}{2\pi (f_d/10) R_2^{\infty}} = \boxed{7.15\mu F}$$

$$\& \quad C_3 = \frac{1}{2\pi f_d R_3^{\infty}} = \boxed{438\mu F}$$

×

P2

a) ac Midband Schematic: Convert the source i_s-R_s to its Thevenin equ. ($v_s = i_s R_s$)



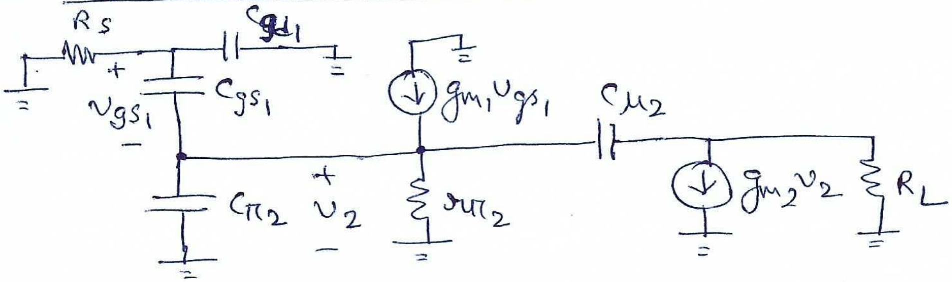
$r_{E2} = 26\Omega$, $r_{\pi 2} = 5.2K$, $g_{m1} = 200\,\mu A/V$

$$\frac{v_o}{v_1} = -\frac{R_L}{r_{E2}} = \underline{\underline{-192.3}}$$

$$\frac{v_1}{v_s} = \frac{r_{\pi 2}}{1/g_{m1} + r_{\pi 2}} = \underline{\underline{0.51}}$$

$$\Rightarrow \frac{v_o}{v_s} = \underline{\underline{-98.1}} \Rightarrow \frac{v_o}{i_s} = -1.96\times 10^{5}\,\Omega = \boxed{-196\,k\Omega}$$

b) High-freq. equ. for ZVTC:



$\underline{\underline{R^o_{gs1}}}$: $R^o_{gs1} = \frac{R_S + r_{\pi 2}}{1 + g_{m1} r_{\pi 2}} = \underline{\underline{3.53\,k\Omega}} \Rightarrow \tau_1 = C_{gs1} R^o_{gs1} = \underline{\underline{35.3\,ns}}$

$\underline{\underline{R^o_{gd1}}}$: $R^o_{gd1} = R_S = \underline{\underline{2K}} \Rightarrow \tau_2 = R^o_{gd1} C_{gd1} = \underline{\underline{2\,ns}}$

$\underline{\underline{R^o_{\pi 2}}}$: $R^o_{\pi 2} = r_{\pi 2} \,||\, \frac{1}{g_{m1}} = \underline{\underline{2.55\,k}} \Rightarrow \tau_3 = R^o_{\pi 2} C_{\pi 2} = \underline{\underline{51\,ns}}$

$\underline{\underline{R^o_{\mu 2}}}$: $R^o_{\mu 2} = R^o_{\pi 2} + R_L + g_{m2} R^o_{\pi 2} R_L = \underline{\underline{498\,K}} \Rightarrow \tau_4 = C_{\mu 2} R^o_{\mu 2} = \underline{\underline{1\,\mu s}}$

$\Rightarrow \tau_{net} = \underline{\underline{1.0883\,\mu s}} \Rightarrow f_H = \frac{1}{2\pi \tau_{net}} = \underline{\underline{146.2\,kHz}} \Rightarrow t_f = \frac{0.35}{f_H} = \boxed{2.4\,\mu s}$

c) $C_{\mu 2}$, ∵ it produces the largest time constant.

———— × ————

P3

a) Assume $V_{BE4} = \underline{0.7V} \Rightarrow I_{C3} \simeq I_{R_1} = \underline{70\mu A} \Rightarrow I_{C4} = I_{BIAS} - I_{C3} = \underline{130\mu A}$

Self-consistent analysis:

$$I_{C3} = \frac{I_{C4}}{\beta 4} + \frac{V_T \ln I_{C4}/I_{S4}}{R_1} = \boxed{65,4\mu A} \Rightarrow \boxed{I_{C4} = 134.6\mu A}$$

Another iteration would change these values very little.

b) $I_{C_1} = I_{C_2} = \sqrt{I_{C3} I_{C4}} \times \sqrt{\dfrac{I_{S_1} I_{S_2}}{I_{S_3} I_{S_4}}} = \boxed{469\mu A}$

$\Rightarrow V_{BIAS} = V_T \ln \dfrac{I_{C_1} I_{C2}}{I_{S_1} I_{S_2}} = V_T \ln \dfrac{I_{C3} I_{C4}}{I_{S_3} I_{S4}} = \boxed{1.28V}$

c) DC offset of V_i to make DC offset of $V_o = 0$:

$V_I = -V_{BIAS} = \boxed{-1,28V}$

d) $\boxed{V_o = \pm 4V}$ ∵ V_o would follow V_i, due to Q_5 & Q_1-Q_2 being emitter followers with gain ~ 1.

e) $P_{standby} = (V_{CC} + |V_{EE}|) \times (I_{BIAS} + I_{C_1}) = \boxed{6,69mW}$

f) $P_L = \dfrac{V_{OM}^2}{2R_L} = \underline{8mW}$

$P_{supply} + P_{standby} = \dfrac{2V_{CC}V_{OM}}{\pi R_L} + 6,69mW = \underline{19.4mW}$

$\eta = \dfrac{P_L}{P_{supply} + P_{standby}} = \boxed{0,412 \text{ (or } 41,2\%)}$

P4

a) i) At 100 Mrad/s, Gain = 10 dB

$\Rightarrow 10 = 40 \log_{10}\left(\frac{\omega_T}{100}\right) \Rightarrow \boxed{\omega_T = 177.8 \text{ Mrad/s}}$

ii) $f = \left[\frac{(\omega_{P_1} + \omega_{P_2})^2}{4\,\omega_{P_1}\,\omega_{P_2}} - 1\right]\frac{1}{A_o}$ with $A_o = 50\,\text{dB} = 316.2$

$= \boxed{0.0775}$

iii) Will remain stable, ∵ poles will be complex conjugate with constant real part & will remain in the LHP.

b) i) $PM = 180° - |\varphi|_{L=0\,dB} = 60°$

ii) with +ve PM, GM got to be $\boxed{-ve}$

iii) with +ve PM & −ve GM, the system is of course $\boxed{\text{stable.}}$

iv) $-120° = -\tan^{-1}\frac{2\,MHz}{f_1} - \tan^{-1}\frac{2\,MHz}{3\,MHz} - \tan^{-1}\frac{2\,MHz}{5\,MHz}$

$\Rightarrow \boxed{f_1 = 954\ KHz}$

a) $\dfrac{v_o}{v_x} = \dfrac{R_2 + 1/sC}{R_1+R_2+1/sC} = \dfrac{1+sR_2C}{1+s(R_1+R_2)C} = \dfrac{1+j\,\omega/\omega_Z}{1+j\,\omega/\omega_P}$ (PZC form)

$\omega_Z = \dfrac{1}{R_2C}$ $\omega_P = \dfrac{1}{(R_1+R_2)C}$

b) $f_Z = \underline{\underline{5\,MHz}} = \dfrac{1}{2\pi R_2C}$ ... (1)

$A_0 = 90\,dB = 3.16\times10^4 \Rightarrow f_P = \dfrac{25\,MHz}{3.16\times10^4} = \underline{\underline{791\,Hz}} = \dfrac{1}{2\pi(R_1+R_2)C}$ ... (2)

$\Rightarrow \boxed{R_2 = 1.58\,\Omega}$ $\boxed{C = 20.15\,nF}$ (from (1) & (2))

c) From Asymptotic Bode Plot:

$\phi\big|_{25\,MHz} = -90^\circ\big|_{f_p \text{ at } 791\,Hz} - 45^\circ\big|_{25\,MHz \text{ pole}}$ (500 MHz pole won't contribute any phase at 25 MHz)

$= \boxed{-135^\circ}$

$\Rightarrow PM = 180^\circ - |\phi| = \boxed{45^\circ}$

[Exact Value: $\phi = -90^\circ - 45^\circ - \tan^{-1}\dfrac{25\,MHz}{500\,MHz} = \underline{\underline{-138^\circ}} \Rightarrow \boxed{PM = 42^\circ}$]

d) Short R_2 $\Rightarrow$ It will become an LPF with DPF at $\dfrac{1}{2\pi R_1C}$.

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a) $R_L = \frac{V_{DD} - V_A}{I_{D2}} = \boxed{27\,k\Omega}$

$V_{E3} = V_A + V_{EB3} = \underline{\underline{3V}} \Rightarrow R_1 = \frac{V_{DD} - V_{E3}}{I_1} = \boxed{20\,k\Omega}$

$R_2 = \frac{V_o - V_{SS}}{I_1} = \boxed{50\,k\Omega}$

b) $I_{D2} = \frac{k_N'}{2}\left(\frac{W}{L}\right)_2 (V_{GS2} - V_{TN2})^2 \Rightarrow V_{GS2} = \underline{\underline{1.25V}} \Rightarrow V_{S2} = \underline{\underline{-1.25V}}$

Drop across $I_{SS} = V_{S2} - V_{SS} = \boxed{3.75\,V}$

c) $g_{m2} = K_N V_{GT2} = \sqrt{2 K_n I_{D2}} = \underline{8 \times 10^{-4}\,\mho}$

A_{dm} (NMOS DA) $= -g_{m2} R_L = \underline{\underline{-21.6}}$

$v_A = v_{o2}$ (for DA) $= -\frac{A_{dm}}{2} v_{id}$ ($\because A_{cm} = 0$ due to I_{SS} being ideal)

& $v_{id} = -v_i \Rightarrow \frac{v_A}{v_i} = \frac{A_{dm}}{2} = \boxed{-10.8}$

$r_{E3} = \underline{\underline{260\,\Omega}}$ $\quad r_{\pi 3} = \underline{\underline{26\,k\Omega}} \Rightarrow R_{i3} = r_{\pi 3} + (\beta+1) R_1 = \underline{\underline{2.05\,M\Omega}}$

[$R_{i3} \gg R_L \Rightarrow$ It does not load the DA]

$\frac{v_o}{v_A} = -\frac{R_2}{r_{E3} + R_1} = \boxed{-2.47}$

$\Rightarrow \frac{v_o}{v_i} = \boxed{+26.7}$