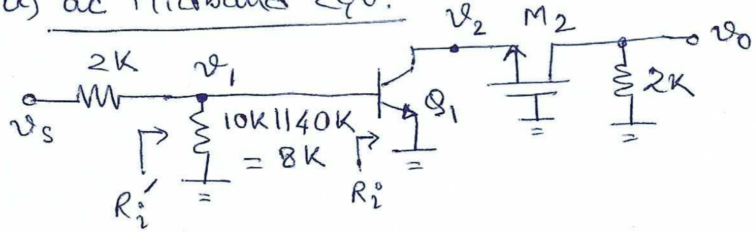
P1

a) ac Midband Equ.



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

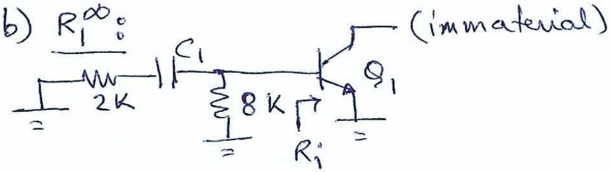
$$\frac{v_o}{v_2} = + g_{m_2} \times 2K = \underline{\underline{+4}}$$

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

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

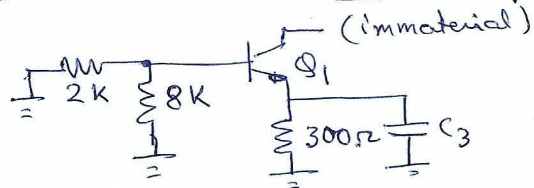
$$\Rightarrow \boxed{\frac{V_o}{V_s} = -38.46}$$

b) R_1^∞:

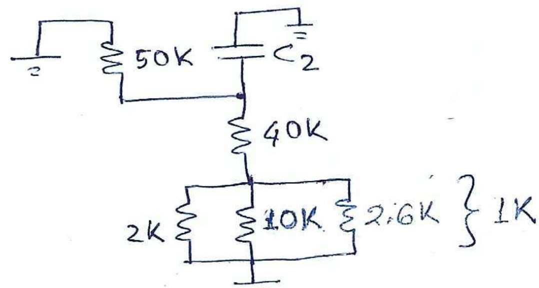


$R_1^\infty = 2K + 8K \| 2.6K = \underline{\underline{4K}}$

R_3^∞:



R_2^∞:



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

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

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

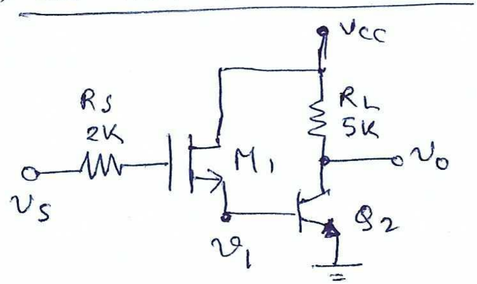
To make ΣC minimum, choose C_3 to contribute f_d, C_3 sees the least resistance $\Rightarrow$ & C_1 & C_2 each contribute $f_d/10$.

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

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

P2

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



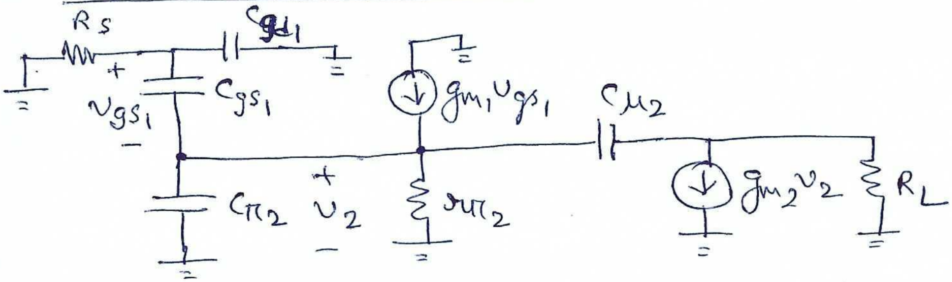
$r_{E2} = 26\Omega$, $r_{\pi 2} = 5.2K$, $g_{m1} = 200\mu A/V$

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

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

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

b) High-freq. equ. for ZVTC:



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

R^o_{gd1}: $R^o_{gd1} = R_s = \underline{2K} \Rightarrow \tau_2 = R^o_{gd1} C_{gd1} = \underline{2nS}$

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

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

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

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

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

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) $\boxed{V_o = \pm 4V}$ $\because$ 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) $P_L = \dfrac{V_{OM}^2}{2R_L} = 8mW$

$P_{supply} + P_{standby} = \dfrac{2V_{CC}V_{OM}}{\pi R_L} + 6.69mW = 19.4mW$

$\eta = \dfrac{P_L}{P_{supply} + P_{standby}} = \boxed{0.412 \text{ (or } 41.2\%)}$

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 $A_o = 50\,dB = 316.2$

$= \boxed{0.0775}$

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

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

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)

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

b) $f_Z = \underline{\underline{5\text{ MHz}}} = \dfrac{1}{2\pi R_2 C}$ ... ①

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

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

c) From <u>Asymptotic</u> Bode Plot:

$\phi\big|_{25\text{MHz}} = -90°\Big|_{f_P \text{ at } 791\text{Hz}} - 45°\Big|_{25\text{MHz pole}}$ (500 MHz pole won't contribute any ϕ here at 25 MHz)

$= \boxed{-135°}$

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

[<u>Exact</u> Value: $\phi = -90° - 45° - \tan^{-1}\dfrac{25\text{MHz}}{500\text{MHz}} = \underline{\underline{-138°}} \Rightarrow \boxed{PM = 42°}$]

d) <u>Short R_2</u> $\Rightarrow$ It will become an LPF with DPF at $\dfrac{1}{2\pi R_1 C}$.

———— × ————

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)

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

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

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

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

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