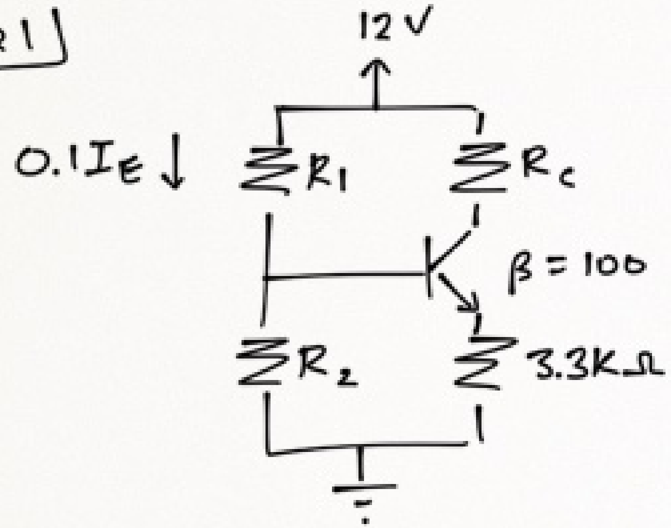
EECE 356 - CIRCUITS

Q1)



FIND R_1, R_2, R_c, r_π, g_m

$$V_B = \frac{1}{3} V_{cc} = 4V$$

$$V_c = \frac{2}{3} V_{cc} = 8V$$

$$I_E = \frac{V_E}{R_E} = \frac{\frac{1}{3}V_{cc} - 0.7}{R_E} = 1mA$$

$$I_1 = 0.1 I_E = 0.1mA$$

$$R_{B1} = \frac{2}{3} \frac{V_{cc}}{I_1} = \underline{80k\Omega}$$

$$R_{B2} = \frac{\frac{1}{3}V_{cc}}{\frac{I_E}{\sqrt{\beta}} - \frac{I_E}{\beta}} = \underline{44.4k\Omega}$$

$$I_B = I_1 - \frac{V_B}{R_{B2}} = 0.1mA - \frac{4V}{44.4k} = \underline{10\mu A}$$

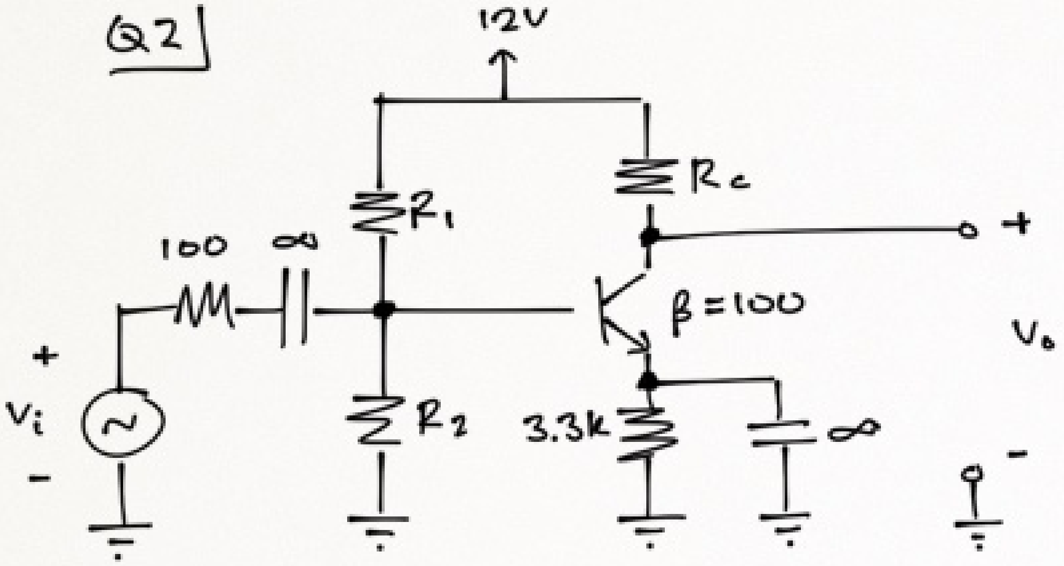
$$R_c = \frac{1}{3} \frac{V_{cc}}{I_c} = \frac{1}{3} \frac{V_{cc}}{\beta I_B} = \underline{4k\Omega}$$

$$g_m = \frac{I_c}{V_{th}} = \frac{\beta I_B}{V_{th}} = \frac{100 \cdot 10\mu A}{25.8mV} = \underline{38.76m\mho}$$

$$r_\pi = \frac{\beta}{g_m} = \underline{2.58k\Omega}$$

USING $\frac{1}{3}$rd RULE VERSION #1

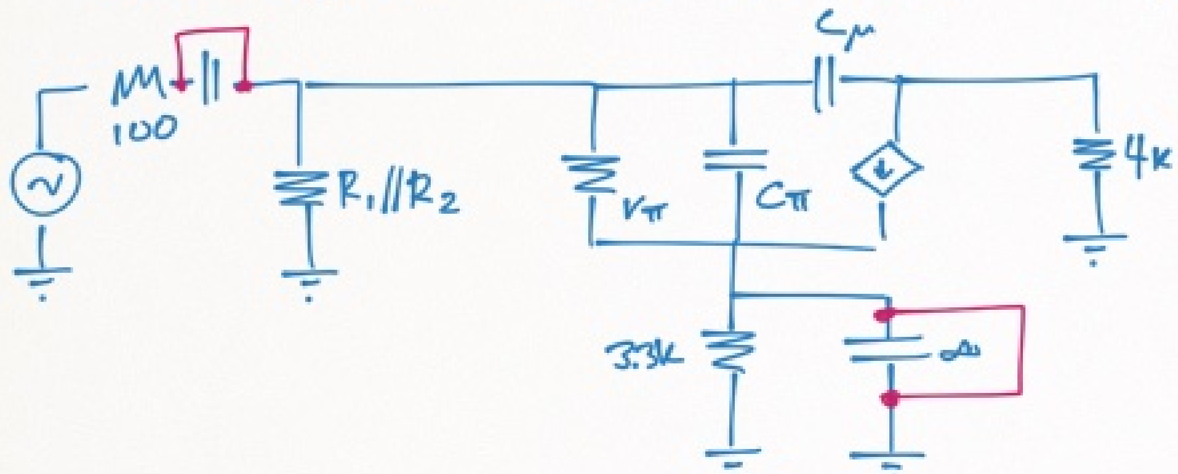
Q2



USING $R_1 = 80k\Omega$, $R_2 = 44.4k\Omega$, $R_C = 4k\Omega$, $r_\pi = 2.5K$

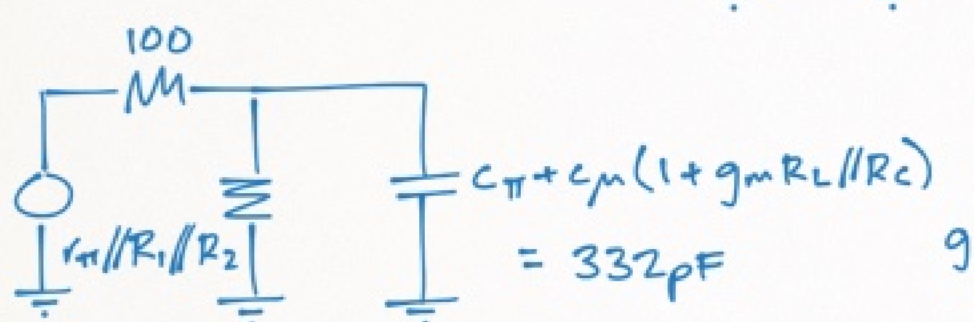
FIND UPPER CUTOFF FREQUENCY $C_\pi = 10pF$, $C_\mu = 2pF$

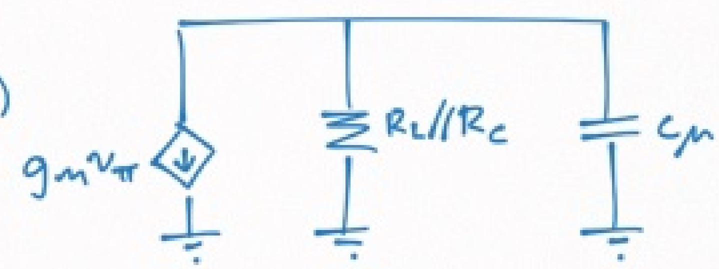
infinite capacitors are OC @ DC, SC @ AC, this is a common emitter amplifier



SMALL SIGNAL MODEL

HIGH FREQUENCY MODEL





$$\omega_{PH_1} = \left[100 // 80k // 44.4k // 2.5k \cdot 332pF\right]^{-1}$$

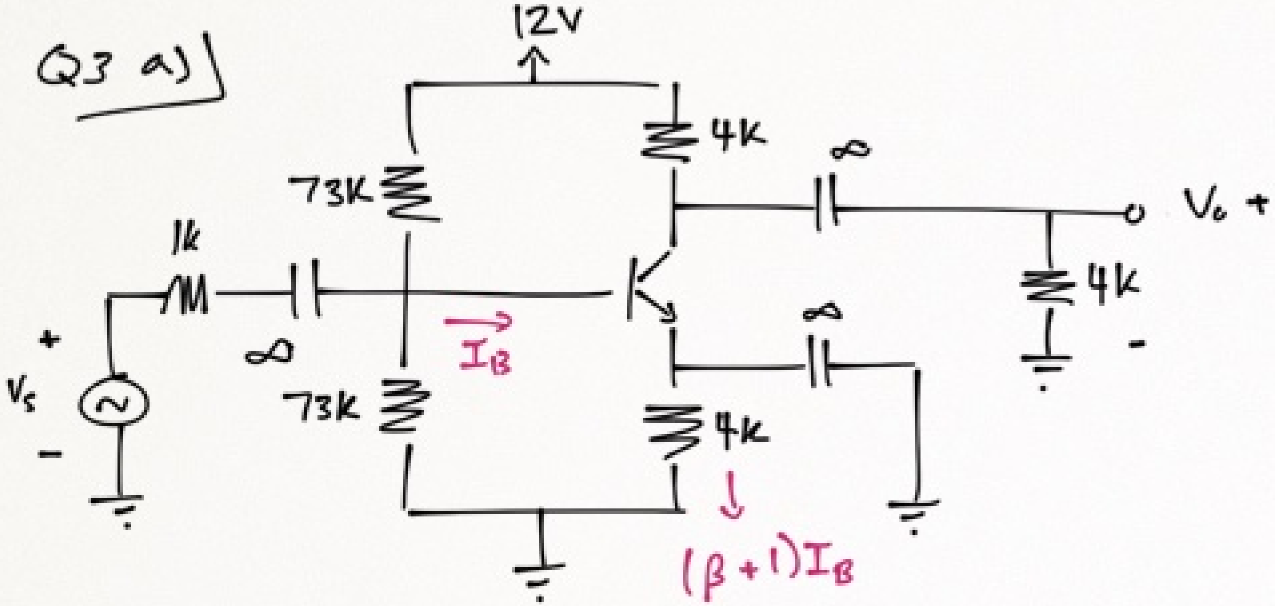
$$= \underline{31.43\ M\ \tfrac{rad}{s}}$$

$$\omega_{PH_2} = \left[4k \cdot 2pF\right]^{-1}$$

$$= \underline{125\ M\ \tfrac{rad}{s}}$$

ω_{PH_2} is about 2 octaves above ω_{HP_1} so we can approximate $\omega_{H3dB} = \underline{31.43\ M\ \tfrac{rad}{s}}$

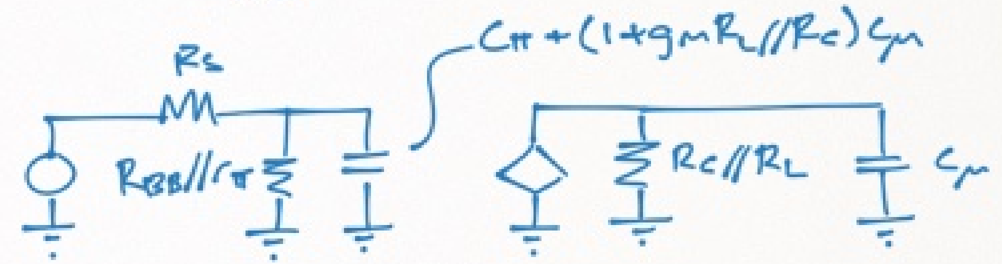
Q3 a)



calculate midband gain & location of dominant high frequency pole

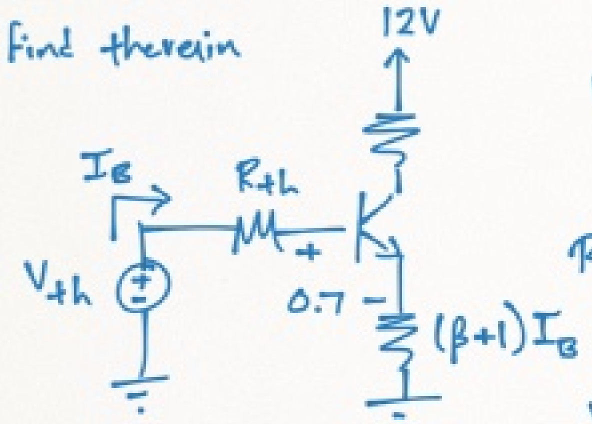
$\beta = 400,\ V_T = 25mV,\ C_\pi = 10pF,\ C_\mu = 1pF$

$r_\pi = \frac{25mV}{I_B} = 7.7399k\Omega$



in order to bias, we must calculate I_c

find thevenin



$V_{th} = V_{cc}\frac{R_{B2}}{R_{B1}+R_{B2}} = 6V$

$R_{th} = R_{B1}//R_{B2} = 36.5k\Omega$

$V_{th} = I_B R_{th} + 0.7V + (\beta+1)I_B(4k)$

$6V = I_B(36.5k) + 0.7 + I_B(401.4k)$

$\hookrightarrow I_B = 3.23\mu A$

$\beta = \frac{I_c}{I_B} \longrightarrow I_c = 1.29mA$

$V_c = V_{cc} - I_c(4k) = 6.84V$

$V_E = (\beta+1)I_B(4k) = 5.18V$

$V_B = V_E + 0.7 = 5.88V$

$\omega_{PH1} = \left[R_s//R_{BB}//r_\pi \cdot \left[C_\mu(1+g_m R_L//R_c) + C_\pi\right]\right]^{-1}$

$= 10.12(10^6)\frac{rad}{s}$

$\omega_{PH2} = \left[R_c//R_L \cdot C_\mu\right]^{-1}$

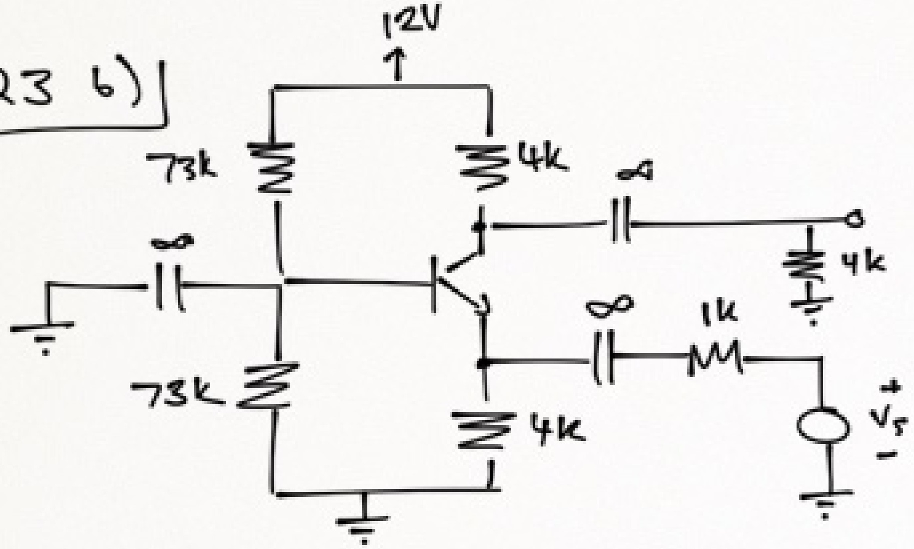
$= 500(10^6)\frac{rad}{s}$

dominant pole

$A_M = \frac{-\beta}{r_\pi} R_c//R_L \frac{R_{B1}//R_{B2}//r_\pi}{R_{B1}//R_{B2}//r_\pi + R_s}$

$= -89.26\ \frac{V}{V}$

Q3 b)



Calculate midband gain & location of dominant pole

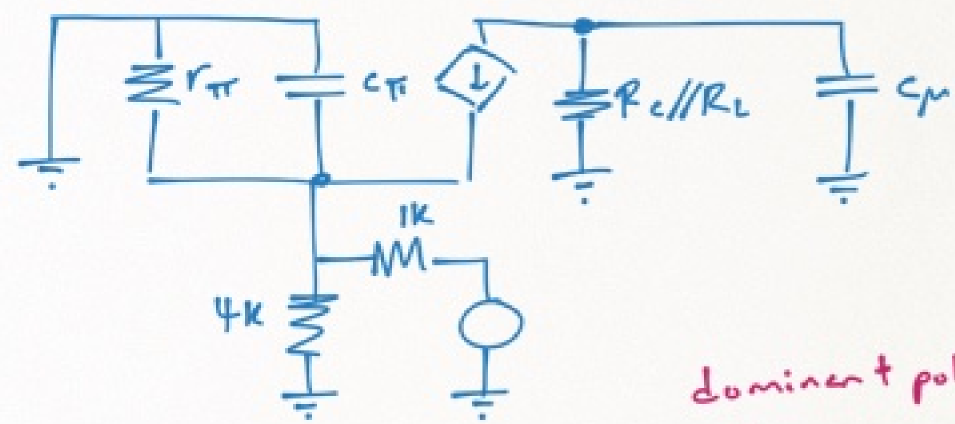
$\beta = 400, \ V_T = 25mV, \ C_\pi = 10pF, \ C_\mu = 1pF$

~~@ High frequency~~ $\cancel{V_B = \varnothing, \ I_1 = \frac{12-0V}{73k\Omega} = 164.38\mu A}$

$\cancel{I_1 = \frac{I_E}{\sqrt{\beta}} \rightarrow I_E = 3.288 mA}$

$\cancel{I_E = (1+\beta) I_B}$

don't need to rederive r_π



dominant pole

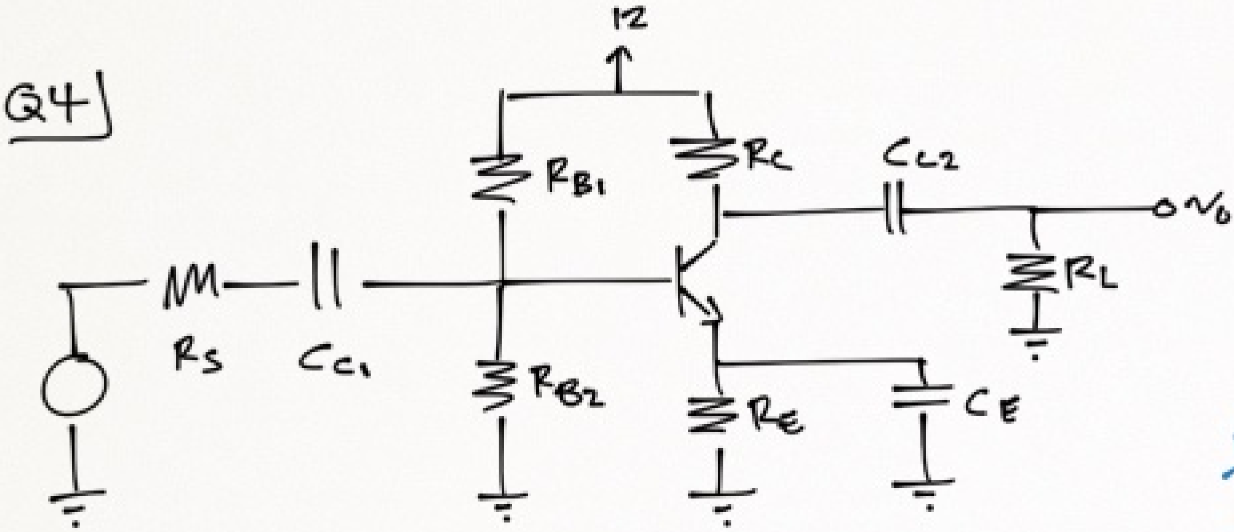
↓

$$\omega_{HP1} = \left[R_C // R_L \cdot C_\mu \right]^{-1} = \underline{500(10^6)\ \frac{rad}{s}}$$

$$\omega_{HP2} = \left[R_E // R_S // \frac{r_\pi}{1+\beta} C_\pi \right]^{-1} = \underline{5.3(10^9)\ \frac{rad}{s}}$$

$$\boxed{A_M = \frac{-\beta}{r_\pi} (R_C // R_L) \frac{-\frac{r_\pi}{1+\beta} // R_E}{\frac{r_\pi}{1+\beta} // R_E + R_S}} = \underline{1.94 \ \frac{V}{V}}$$

Q4)



Find R_{B1}, R_{B2}, R_C, R_E, A_m, dominant low frequency pole, dominant high frequency pole

$I_E = 2mA$, $R_s = 50\,\Omega$, $C_{C1} = C_E = 50\mu F$, $C_{C2} = 1\mu F$

$C_\pi = 10pF$, $C_\mu = 1pF$, $R_L = 1k\Omega$

$\frac{1}{3}$ rule $\quad V_B = \frac{1}{3}V_{CC} = 4V \quad V_E = 3.3V$

$V_C = \frac{2}{3}V_{CC} = 8V$

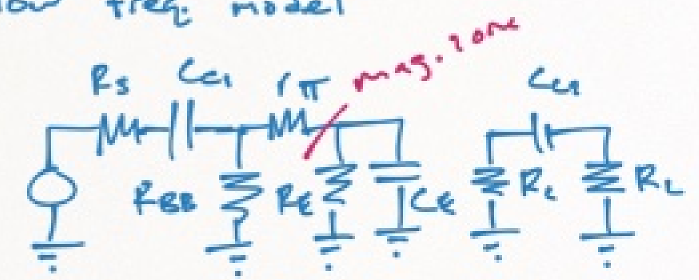
$I_E = \frac{V_E}{R_E} \rightarrow R_E = \frac{3.3V}{2mA} = 1.65k\Omega$

$I_1 = \frac{I_E}{\sqrt{\beta}} = 0.2mA = \frac{V_{CC}-V_B}{R_{B1}} \rightarrow R_{B1} = 40k\Omega$

$R_{B2} = \frac{1}{3}\frac{V_{CC}}{I_1 - I_B} = \frac{1}{3}\frac{V_{CC}}{\frac{I_E}{\sqrt{\beta}} - \frac{I_E}{\beta}} = 22.2k\Omega$

$R_C = \frac{1}{3}\frac{V_{CC}}{I_B \cdot \beta} = \frac{4}{I_E} = 2k\Omega$

low freq. model



$$A_m = \frac{-\beta}{r_\pi} R_C // R_L \frac{R_{B1}//R_{B2}//r_\pi}{R_{B1}//R_{B2}//r_\pi + R_s} = -51.11$$

dominant low frequency pole

ASSUMING C_{C1} IS SC

$$\omega_{P1L} = \left[C_E\left(\frac{R_S//R_{BB} + r_\pi}{\beta+1} // R_E\right)\right]^{-1} = 1.566(10^3)\ \frac{rad}{s}$$

ASSUMING C_{C1} IS OC

$$\omega_{P1L} = \left[C_E\left(\frac{R_{BB} + r_\pi}{\beta+1} // R_E\right)\right]^{-1} = 142.14\ \frac{rad}{s}$$

$$\omega_{PL3} = \left[C_{C2}(R_C + R_L)\right]^{-1} = 1\mu F(3k) = 333\ \frac{rad}{s}$$

ASSUMING CE IS SC

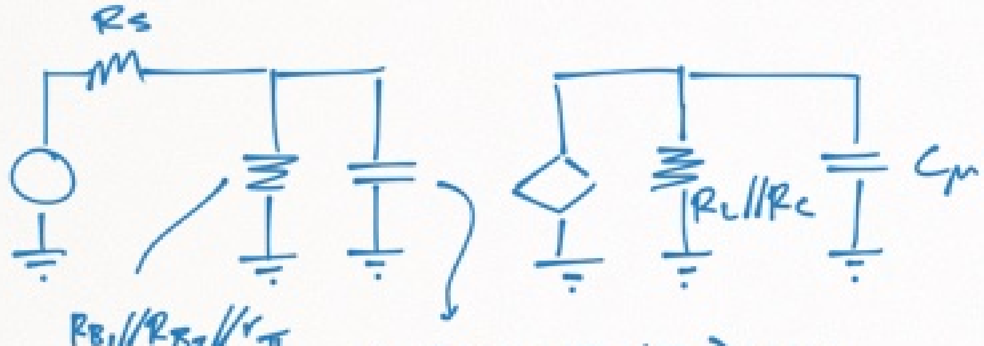
$$\omega_{P2L} = \left[C_{C1}(R_s + R_{B1}//R_{B2}//r_\pi)\right]^{-1} = 16.675\ \frac{rad}{s}$$

ASSUMING CE IS OC

$$\omega_{P2L} = \left[C_{C1}(R_s + R_{B1}//R_{B2}//(r_\pi + R_E(\beta+1))\right]^{-1} = 1.5134\ \frac{rad}{s}$$

Q4 cont'd

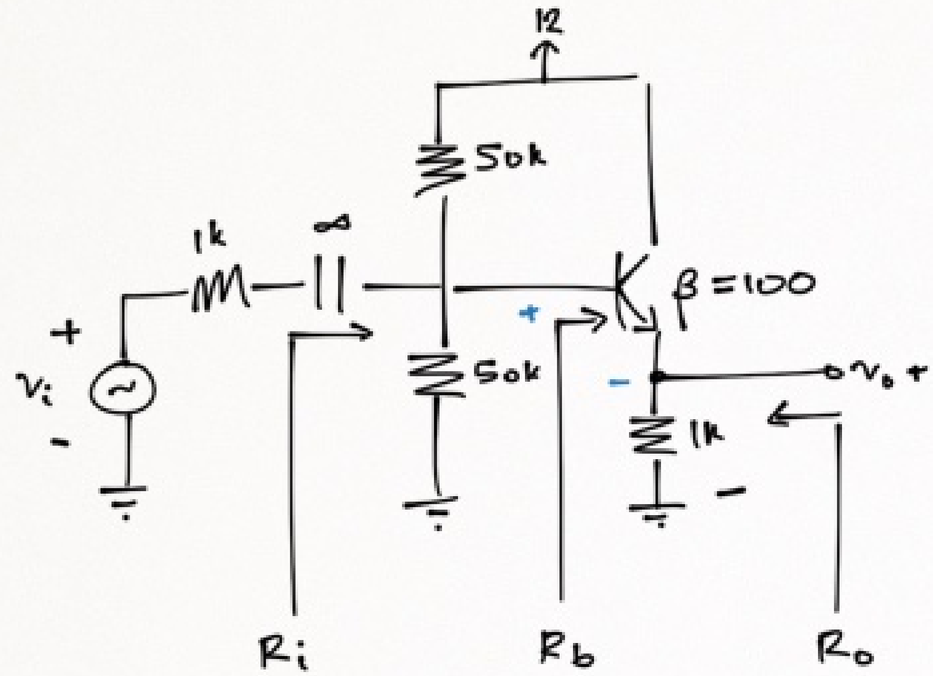
high frequency model.



$$\omega_{PH1} = \left[C_\mu \cdot R_L /\!/ R_c\right]^{-1} = 1.5(10^9)\ \frac{rad}{s}$$

$$\omega_{PH2} = \left[(R_S /\!/ R_{B1} /\!/ R_{B2} /\!/ r_\pi)(C_\mu(1+g_m R_L /\!/ R_c)+C_\pi)\right]^{-1} = 313(10^6)\ \frac{rad}{s}$$

Q5



Find I_c, g_m, A_M, R_i, R_b, R_o

use thevenin equivalent to find I_c

$$V_{th} = V_{cc}\frac{R_{B1}}{R_{B1}+R_{B2}} = 12\,\frac{50k}{100k} = 6V$$

$$R_{th} = R_{B1} /\!/ R_{B2} = 25k\Omega$$

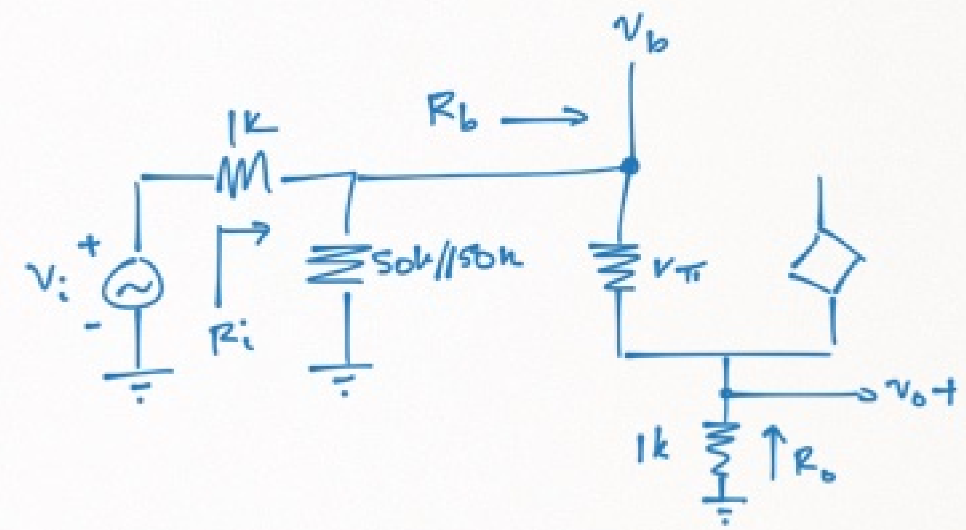
$$6V - I_B(R_{th}) - 0.7 - I_E R_E = \emptyset$$

$$6 - I_B(25k) - 0.7 - (\beta+1)I_B = \emptyset \longrightarrow I_B = 42\mu A$$

$$I_c = \beta I_B = \underline{4.2mA}$$

$$g_m = \frac{I_c}{V_T} = \frac{4.2mA}{25mV} = \underline{168\,m℧}$$

$$r_\pi = \frac{\beta}{g_m} = 595\Omega$$



$$R_o = 1k /\!/ \frac{r_\pi + 50k/\!/50k/\!/1k}{1+\beta} = \underline{15.2\,\Omega}$$

$$R_i = 50k/\!/50k/\!/(r_\pi + 1k(101)) = \underline{20.06\Omega}$$

$$R_b = r_\pi + 1k(101) = \underline{101.6k\Omega}$$

REVIEW

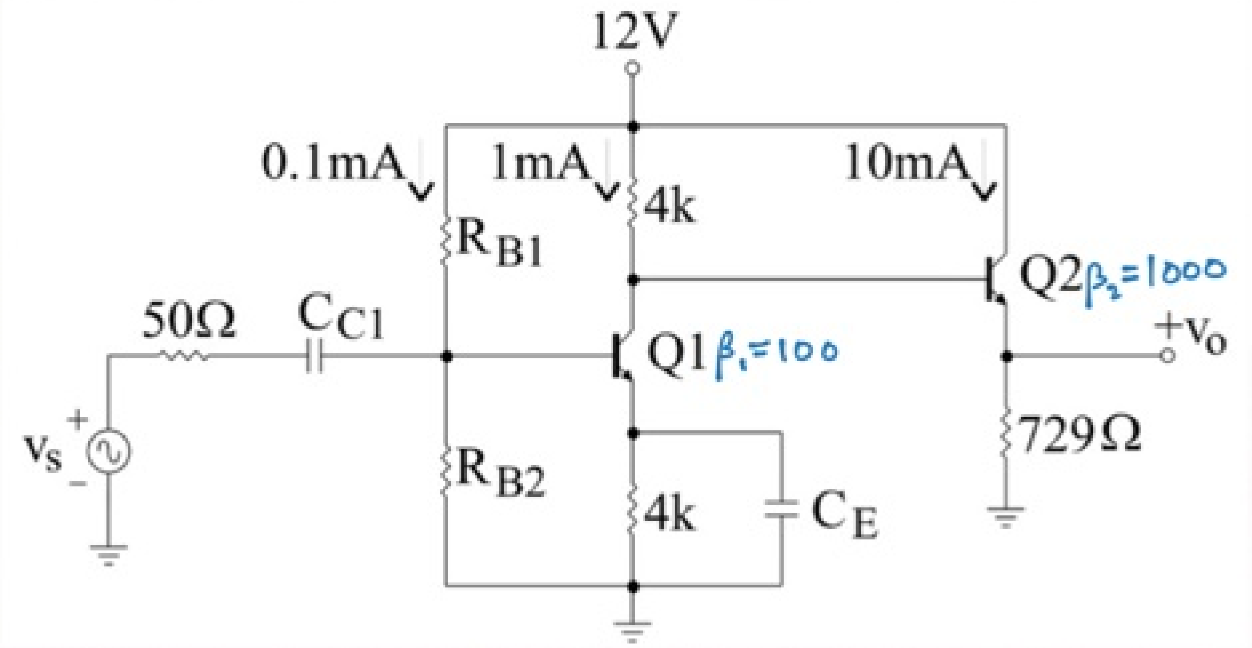
$$A_M = \frac{v_o}{v_i}$$

$$v_o = v_b\,\frac{1k(\beta+1)}{r_\pi + 1k(\beta+1)} = v_b(0.994)$$

$$v_b = v_i\,\frac{50k/\!/50k/\!/(r_\pi + (\beta+1)1k)}{50k/\!/50k/\!/(r_\pi + (\beta+1)1k) + 1k} = v_i(0.953)$$

$$A_M = \frac{v_o}{v_i} = 0.947$$

Q6)



The designers of the circuit have used a 1/3 rule to bias the amplifier shown. They have also used "pole-zero cancellation" to give the amplifier the low frequency amplitude response of a single time-constant circuit and have put $\omega_{L\text{-}3dB}$ at 1000/s. Assume that $\beta_1 = 100$ and that $\beta_2 = 1000$. What are the values of C_E and C_{C1}?

REVISIT

First find R_{B1} & R_{B2}

$$I_{B2} = \frac{I_{C2}}{\beta_2} = \frac{10mA}{1000} = 10\mu A$$

$$I_{C1} = 1mA - I_{B2} = 0.99mA$$

$$I_{E1} = (\beta_1+1) I_{B1} = 101 \frac{0.99mA}{100} = 999.9\mu A$$

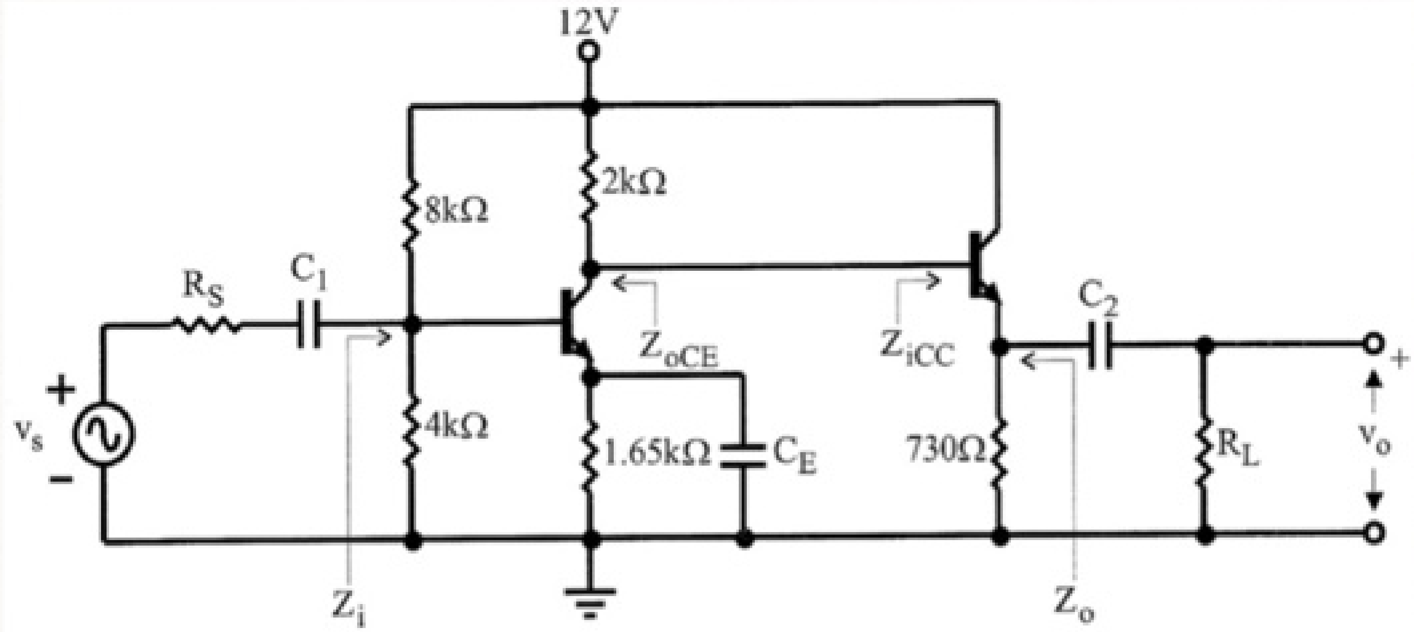
$$V_{E1} = R_E I_{E1} = 4k(999.9\mu A) \simeq 4V$$

$$V_{B1} = V_{E1} + 0.7 = 4.7V$$

$$R_{B1} = \frac{12-4.7}{0.1mA} = 73k\Omega$$

$$R_{B2} = \frac{V_{B1}}{I_{C1} - I_{B1}} = \frac{4.7}{0.1m - \frac{0.99mA}{100}} = 52.16k\Omega$$

Q7



Calculate input impedance of amp
output impedance of amp
output impedance of CE
input impedance of CC
gain at midband

$\beta = 200, \; V_T = 25mV, \; R_S = 100, \; R_L = 730$

$$V_{B1} \simeq V_{cc}\frac{R_{B2}}{R_{B1}+R_{B2}} = 12\,\frac{4k}{12k} = 4V$$

$$V_{E1} \simeq 4V - 0.7V = 3.3V$$

$$I_{E1} \simeq \frac{3.3V}{1.65k} = 2mA$$

$$I_{C1} \simeq I_{E1} = 2mA$$

$$I_{B1} \simeq \frac{I_{C1}}{200} = 0.01\ mA$$

$$r_{\pi_1} = \frac{V_T}{I_B} = \frac{25mV}{0.01mA} = 2.5k$$

@ MIDBAND $\quad C_E = C_1 = C_2 =$ SHORTS
$\quad C_\pi = C_\mu =$ BREAKS

$$Z_i = R_{B1} /\!/ R_{B2} /\!/ r_\pi = 4k /\!/ 8k /\!/ 2.5k = \underline{1.3k\Omega}$$

$$\underline{Z_{oCE} = 2k}$$

$$V_{B2} = V_{c1} = V_{cc} - I_{c1}R_c = 12 - 2mA \cdot 2k = 8V$$

$$V_{E2} = V_{B2} - 0.7 = 7.3V$$

$$I_{E2} = \frac{V_{E2}}{730} = 10mA \simeq I_{c2}$$

$$I_{B2} = \frac{I_{c1}}{\beta} = \frac{10mA}{200} = 50\mu A$$

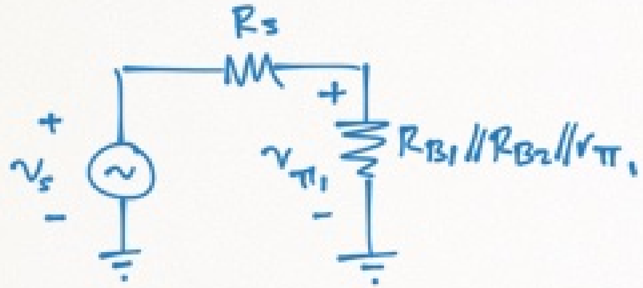
$$r_{\pi_2} = \frac{V_T}{I_{B2}} = \frac{25mV}{50\mu A} = 500\,\Omega$$

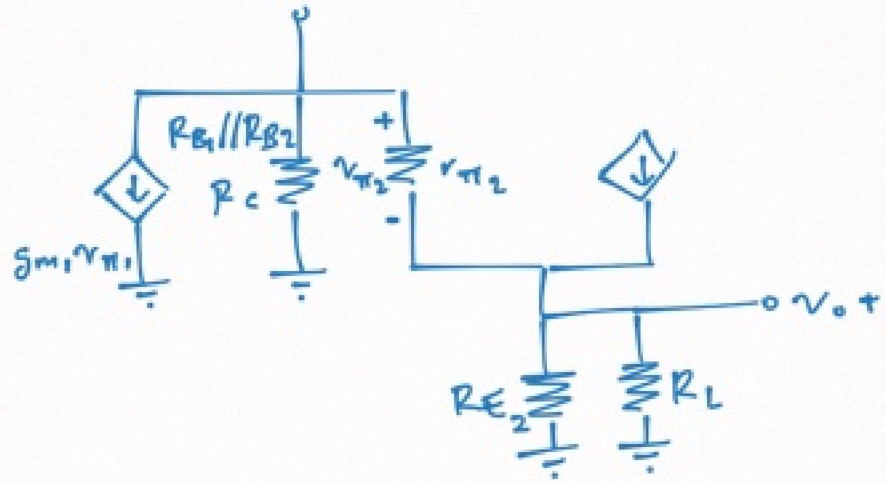
$$Z_{icc} = r_{\pi 2} + (1+\beta)R_E /\!/ R_L = 500 + 101\,\frac{730}{2} = \underline{73.5k\Omega}$$

$$Z_o = R_E /\!/ \frac{r_{\pi 2} + R_c}{1+\beta} = 730 /\!/ \frac{2.5k}{201} \simeq \underline{12.5\Omega}$$

Q7 cont'd | finding midband gain

MIDBAND SMALL SIGNAL MODEL





$$A_M = \frac{v_o}{v_s} = \frac{v_o}{v_{B2}} \cdot \frac{v_{B2}}{v_{\pi_1}} \cdot \frac{v_{\pi_1}}{v_s}$$

$$v_o = v_{B2} \frac{R_{E2}//R_L}{R_{E2}//R_L + \frac{r_{\pi 2}}{\beta+1}} = v_{B2} \frac{730//730}{730//730 + \frac{500}{201}} \simeq \underline{1\, v_{B2}}$$

$$v_{\pi_1} = v_s \frac{R_{B1}//R_{B2}//r_{\pi_1}}{R_s + R_{B1}//R_{B2}//r_{\pi_1}} = v_s \frac{1.3K}{1.35K} = \underline{0.96 v_s}$$

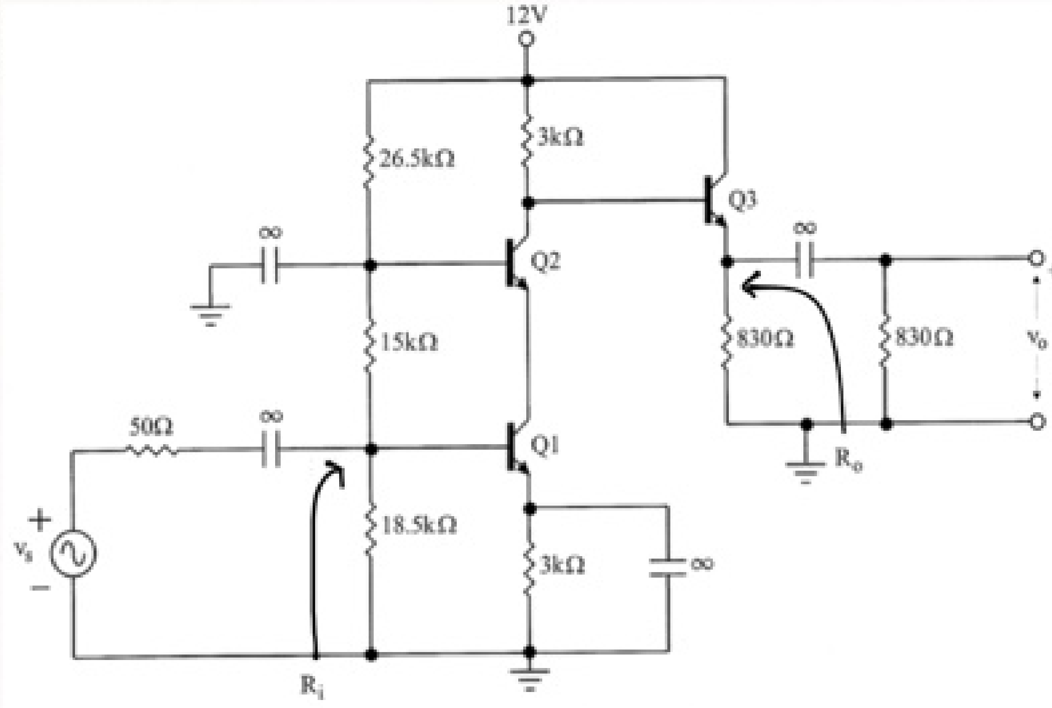
$$v_{B2} = v_{\pi_1}(-g_{m1})\left[R_C // (r_{\pi 2} + (\beta+1) R_{E2}//R_L)\right]$$

$$= v_{\pi_1} \frac{-200}{500}\left[2k // \left(500 + 201 \frac{730}{2}\right)\right]$$

$$= \underline{-156\, v_{\pi_1}}$$

$$A_M = 1(-156)(0.96) = \underline{-150}$$

Q8)

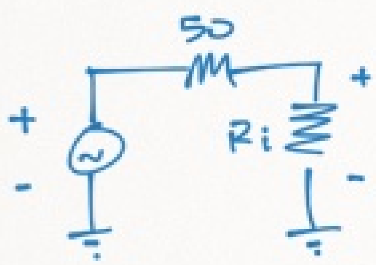


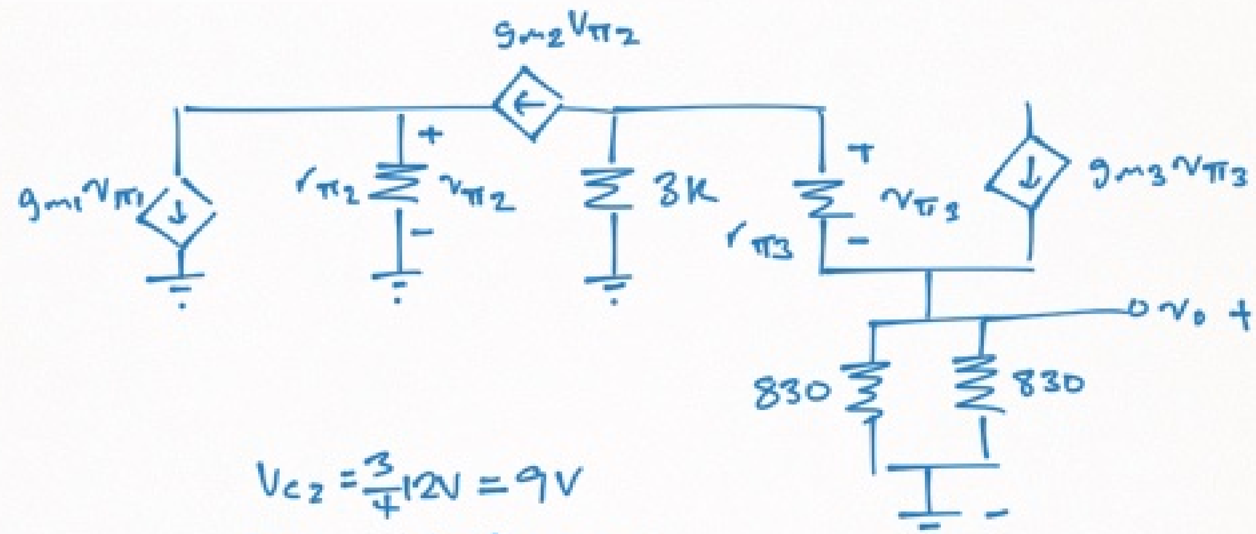
a) draw small signal model

b) show $\frac{v_{\pi 2}}{v_{\pi 1}}$ is exactly 1

c) calculate R_i, R_o, A_M

$\beta = 100$ $V_T = 25mV$





$R_i = 18.5K // 15K // r_{\pi 1}$

$I_{C2} = \frac{\beta}{\beta+1} I_{E2}$

$v_{\pi 2} \frac{I_{E2}}{V_T} = v_{\pi 1} \frac{I_{C1}}{V_T}$

$I_{C1} = I_{E2}$ $\therefore$ $v_{\pi 2} = v_{\pi 1}$

$V_{C2} = \frac{3}{4} 12V = 9V$

$I_{C2} = \frac{12-9}{3k} = 1mA$

$R_i = 18.5k // 15k // \frac{V_T}{I_{B2}} = 18.5k // 15k // \frac{25mV}{\frac{I_{C2}}{\beta}} = 1.9K\Omega$

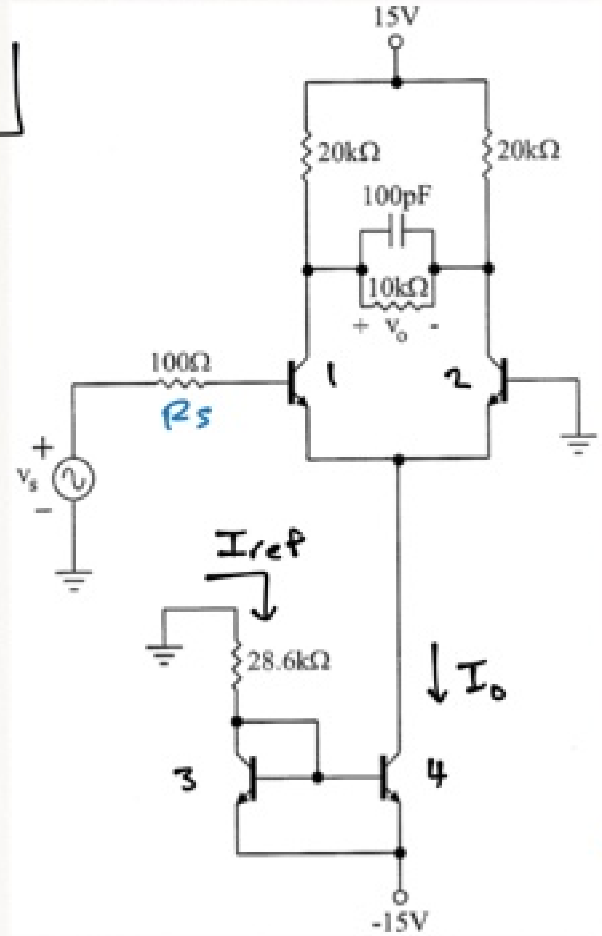
$R_o = 830 // \frac{r_{\pi 3} + 3K}{\beta + 1} = 830 // \frac{250 + 3k}{101} \simeq 31\Omega$

$r_{\pi 3} = \frac{V_T}{I_{B3}} = \frac{25mV}{\frac{I_{C2}}{\beta}} = \frac{25mV}{\frac{10mA}{\beta}} = 250\Omega$

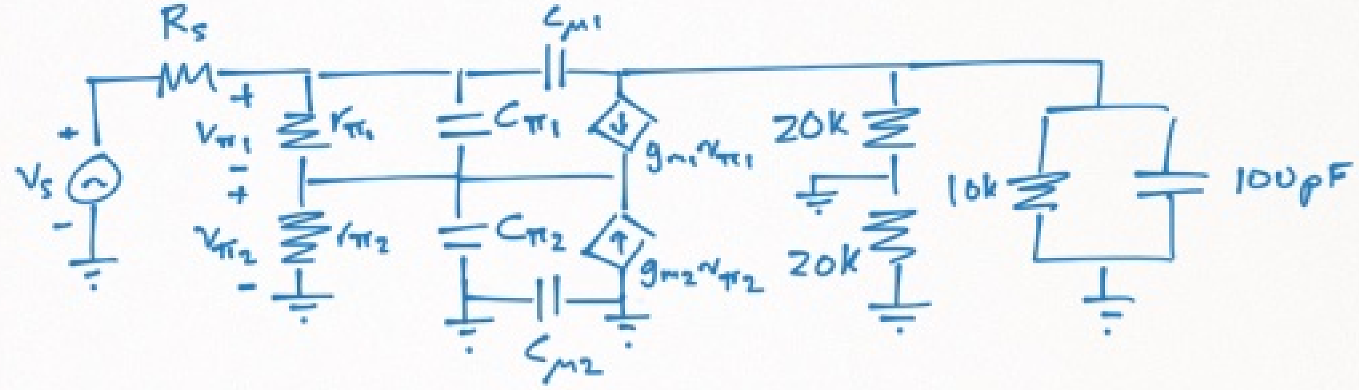
$I_{C2} \simeq I_{E3} = \frac{V_{E3}}{R_{E3}} = \frac{V_{C2} - 0.7}{830} = 10mA$

Q9

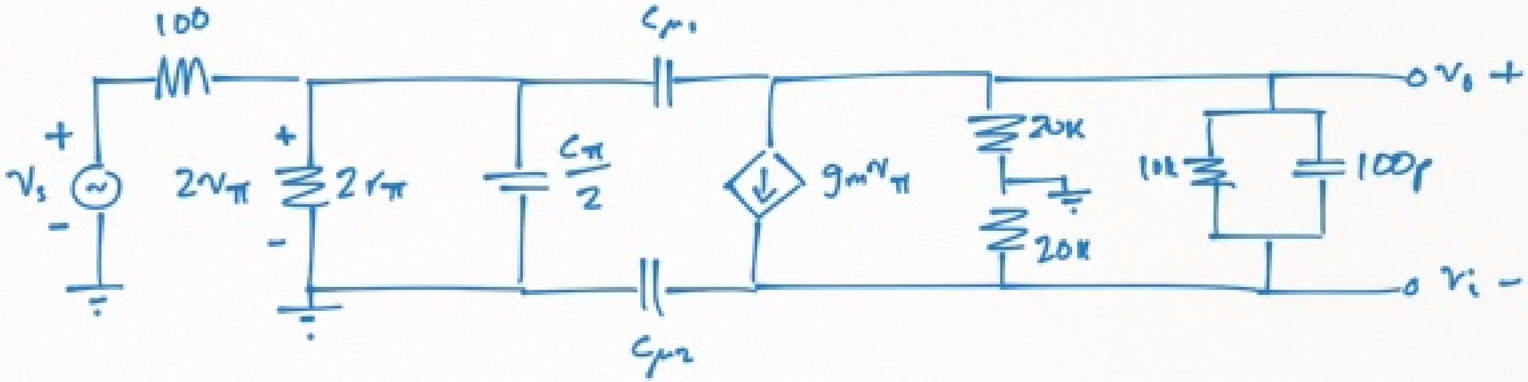
FIND A_d & ω_{H3dB}



SMALL SIGNAL MODEL



$-v_{\pi 1} = v_{\pi 2}$



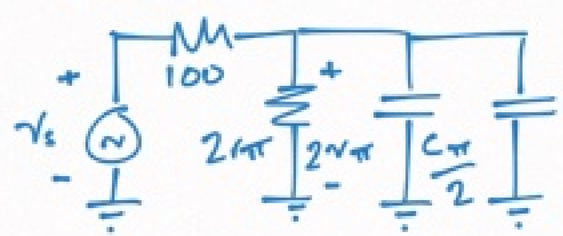
$V_{B4} = -15 + 0.7 = -14.3V$

$$I_{REF} = \frac{0 - -14.3V}{28.6k} = 0.5mA$$

$I_o \simeq I_{REF} = 0.5mA$

$I_{C1} = I_{C2} \simeq \frac{1}{2} I_o = 0.25mA$

MILLERS

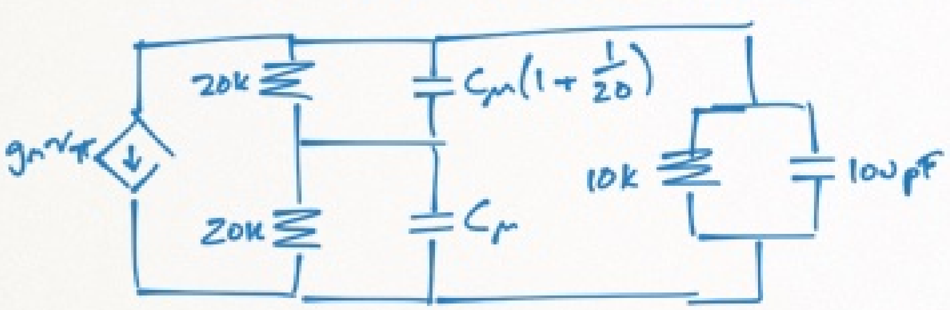


$$C_\mu\left(1 - \frac{v_1}{2v_\pi}\right) = C_\mu\left(1 - \frac{I_1 20k}{2\frac{25m}{I_c}}\right)$$

$$I_1 = -g_m v_\pi \frac{10k}{20k + 10k + 20k}$$

CBJ (collector-base junction)

$V_{C1} = V_{C2} = 15 - (0.25mA)20k = 10V$



$$A_d = \frac{v_o}{v_s} = \frac{v_o}{v_\pi} \cdot \frac{v_\pi}{v_s} = -g_m\, 40k \| 10k \cdot \frac{1}{2}\frac{2r_\pi}{2r_\pi + 100} = -40$$

$$\omega_{PH1}^{oc} = \frac{1}{100 \| 2r_\pi (2p + 84p)} = 113(10^6)\frac{rad}{s}$$

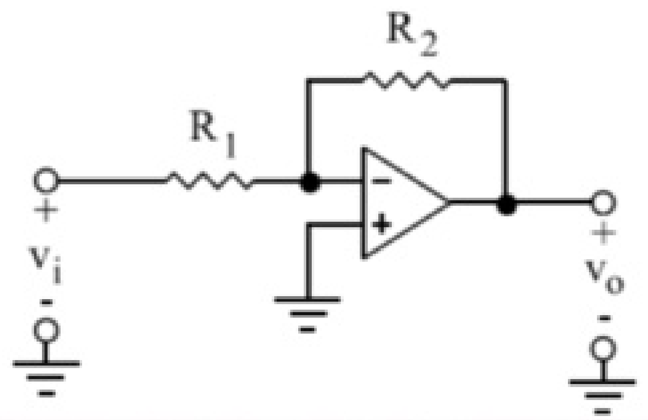
$$\omega_{PH2}^{oc} = \frac{1}{10k \| 40k\ (100p)} = 1.25(10^6)\frac{rad}{s}$$

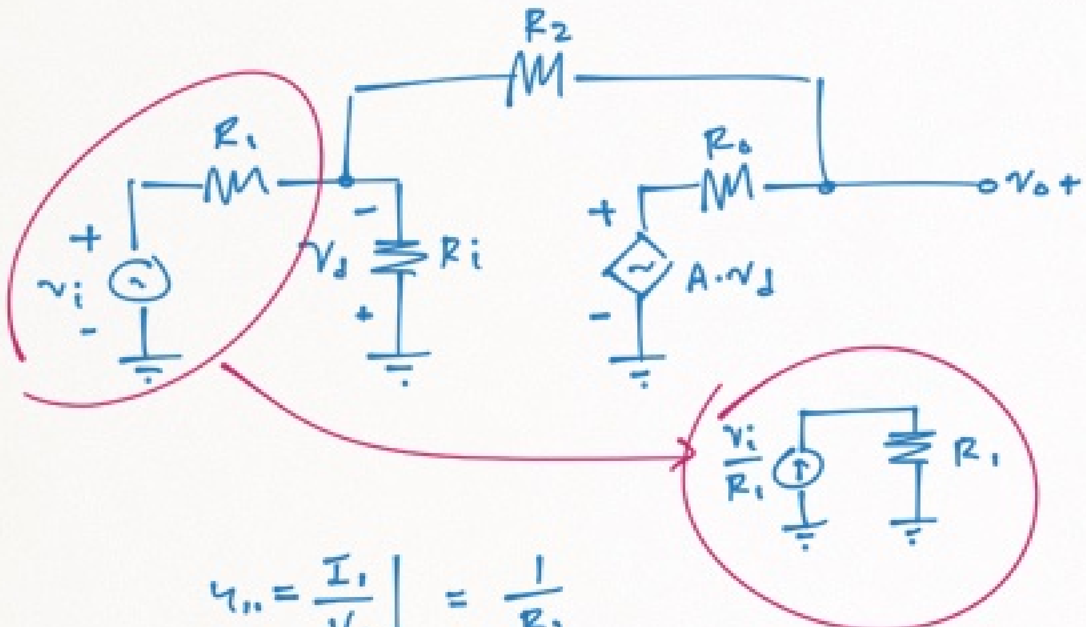
$$\omega_{PH3}^{oc} = \frac{1}{20k \| 30k\ \frac{C_\mu}{2}(1 + \frac{1}{20})} = 41.7(10^6)\frac{rad}{s}$$

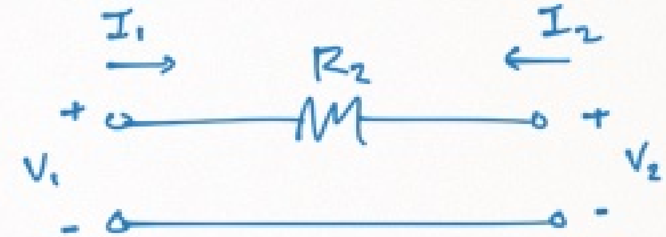
P7Q2

Use feedback techniques to show that the circuit shown in figure1 has a gain of $-R_2/R_1$.

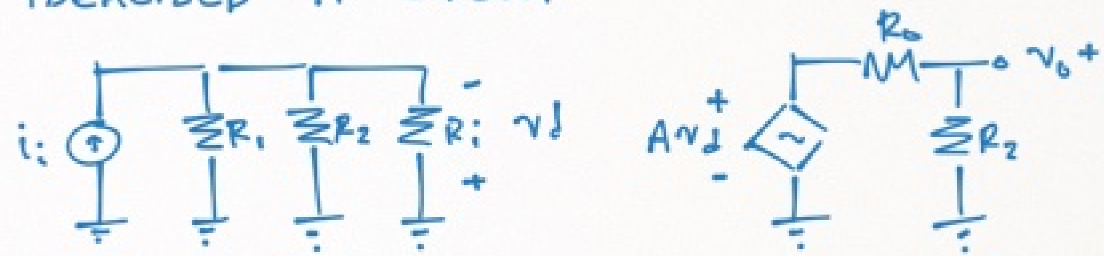
USE SHUNT-SHUNT

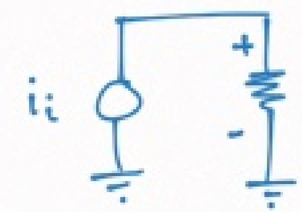






IDEALIZED A CIRCUIT





$$y_{11} = \frac{I_1}{V_1}\bigg|_{V_2=0} = \frac{1}{R_2}$$

$$y_{12} = \frac{I_1}{V_2}\bigg|_{V_1=0} = -\frac{1}{R_2}$$

$$y_{21} = \frac{I_2}{V_1}\bigg|_{V_2=0} = y_{12} = -\frac{1}{R_2}$$

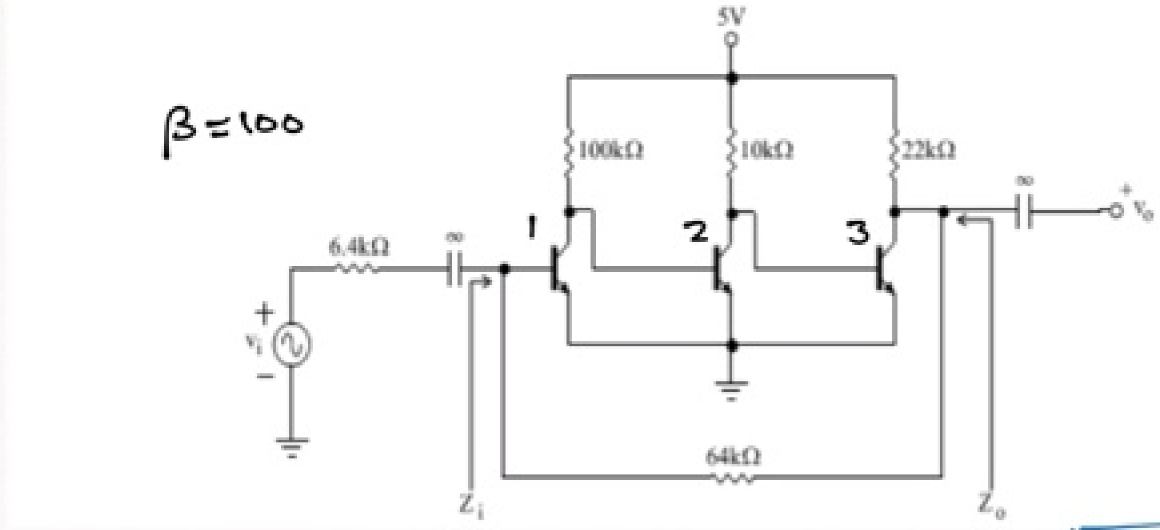
$$y_{22} = \frac{I_2}{V_2}\bigg|_{V_1=0} = \frac{1}{R_2}$$

$$A_F = \frac{v_o}{i_i} \simeq \frac{1}{\beta} = -R_2$$

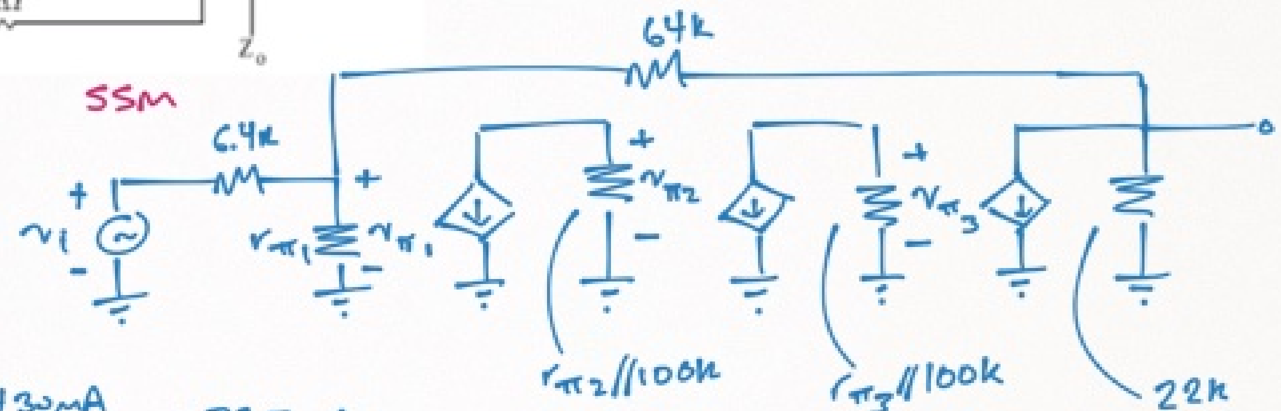
$$A_{Fv} = \frac{v_o}{v_i} = \frac{v_o}{i_i R_1} = \frac{-R_2}{R_1}$$

P7Q4 | For the circuit shown in figure 3 calculate A_M, Z_i, and Z_o, all at mid band.

$\beta = 100$



SSM



get currents

$$I_{c2} = \frac{5-0.7}{10k} = 430\mu A$$

$$I_{c1} = \frac{5-0.7}{100k} - I_{B2} = \frac{5-0.7}{100k} - \frac{430\mu A}{100} = 38.7\mu A$$

$$I_{c3} = \frac{5 - 0.7 - I_{B1}(64K)}{22K} - \overset{\frac{38.7\mu}{100}}{I_{B1}} = 194 mA$$

r_π / g_m

$$r_{\pi 1} = \beta \frac{V_T}{I_{c1}} = 100 \frac{25mV}{38.7\mu A} = 64.6K$$

$$r_{\pi 2} = 100 \frac{25mV}{430\mu A} = 5.18K$$

$$r_{\pi 3} = 100 \frac{25mV}{194mA} = 12.9K$$

$$v_{\pi 2} = -5.5k\, g_{m1} v_{\pi 1} = -5.5k$$