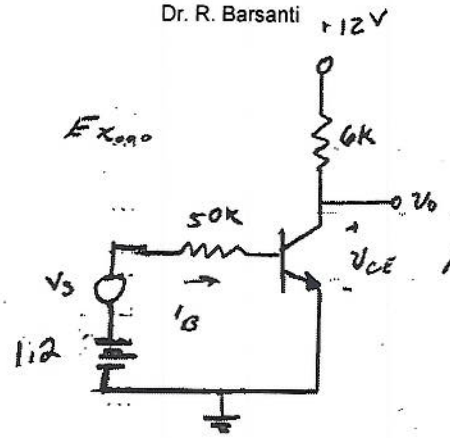


Exam



$V_{BE} = 0.7^V$ FIND: Small Signal Voltage Gain

1. <u>Find the Q pt.</u>

$$I_{BQ} = \frac{V_{BB} - V_{BE(on)}}{R_B} = \frac{1.2 - 0.7}{5K} = 10\mu A$$

$$I_{CQ} = \beta I_{BQ} = (100)(10\mu A) = 1^{mA}$$

$$V_{CEQ} = V_{CC} - I_{CQ} R_C = 12 - (1)(6) = 6^V$$

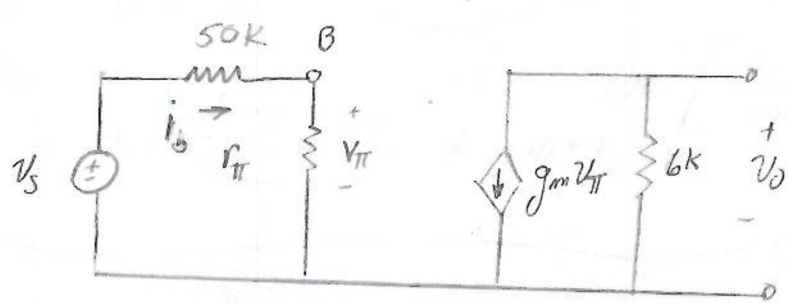
∴ 'Q' in <u>fwd active mode.</u>

2. <u>Small Signal Hybrid parameters</u>

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{1^{mA}} = 2.6K\Omega$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1^{mA}}{0.026} = 38.5\ ^{mA}/_{V}$$

$$A_v = \frac{V_o}{V_s} = -(g_m R_C)\left(\frac{r_\pi}{r_\pi + R_B}\right) = \underline{\underline{-11.4}}$$



$v_o = -g_m v_\pi R_C$

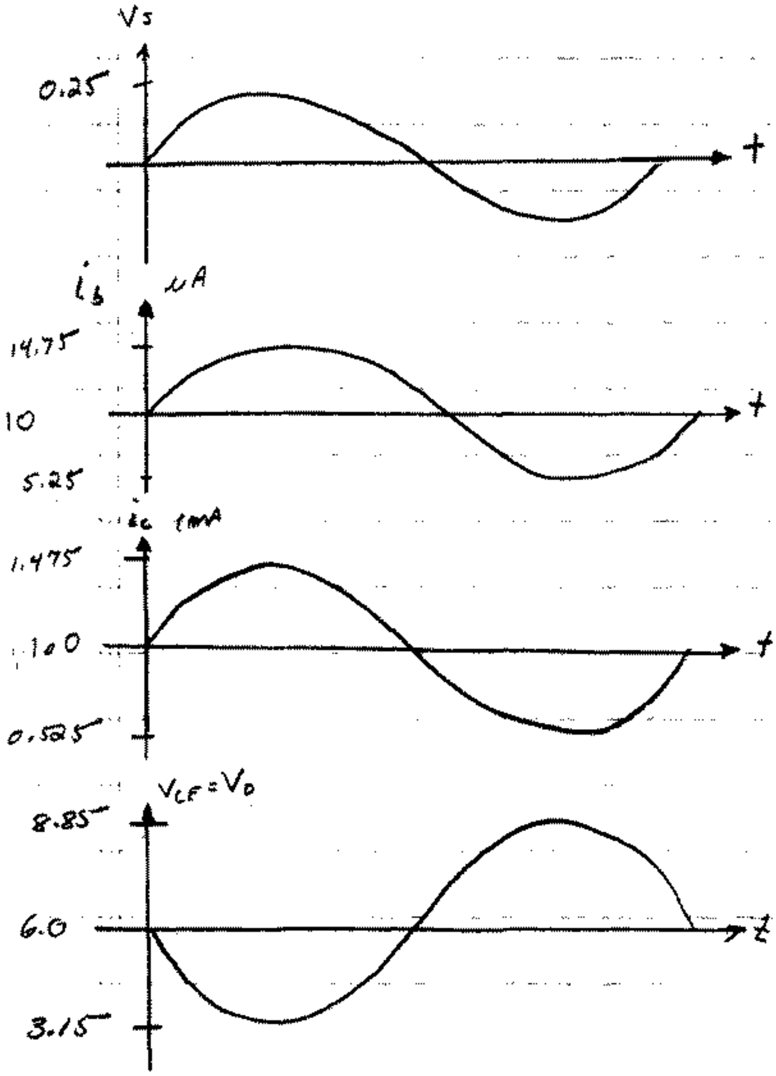
$v_\pi = \left(\frac{r_\pi}{r_\pi + R_B}\right) v_S$

3. Let $v_s = 0.25 \sin\omega t$ V

then: $i_b = \dfrac{v_s}{R_B + r_\pi} = 4.75 \sin\omega t \ \underline{\mu A}$

$i_c = \beta i_b = 0.475 \sin\omega t$ mA

$v_{ce} = -i_c R_C = -(0.475)6 \sin\omega t = \underline{\underline{-2.85 \sin\omega t}}$ V



Ex. Using last example: ; $V_A = 50^V$

FIND $\underline{r_o \; ; \; A_v}$

$$r_o = \frac{V_A}{I_{CQ}} = \frac{50}{1\,mA} = 50k\Omega$$

$$A_v = \frac{V_o}{V_s} = -g_m \overbrace{(R_C \| r_o)}^{6\|50 = 5.36} \left(\frac{r_\pi}{r_\pi + R_B}\right)$$

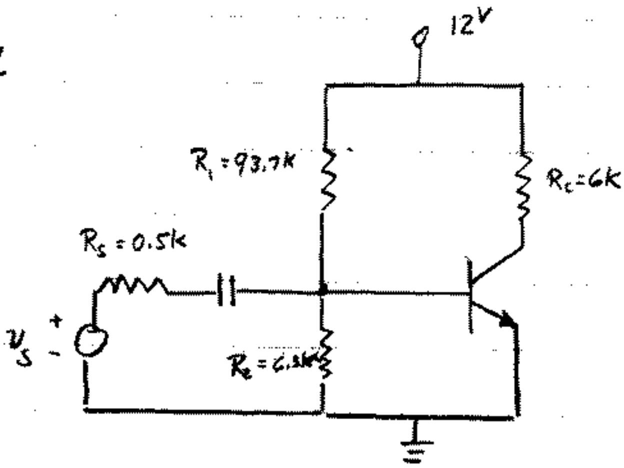
$$= -(38.5^{mA/V})(5.36k)\left(\frac{2.6}{2.6+50}\right) = \underline{\underline{-10.2}}$$

The output resistance r_o reduces the magnitude of A_v. Typically $r_o \gg R_C$, and in many cases can be neglected.

V. Common Emitter Amplifiers

A.

Exam 1



$V_{BE(ON)} = 0.7^V$

$V_A = 100^V$

$\beta = 100$

FIND: Small signal VOLTAGE gain.

DC Solution:

$$V_{TH} = \left(\frac{6.3k}{6.3k + 93.7k}\right) 12 = 0.756^V$$

$$R_{TH} = R_1 \| R_2 = 5.9K\,\Omega$$

$$I_{BQ} = \frac{0.756 - 0.7}{5.9K} = 9.5\,\mu A$$

$$I_{CQ} = \beta I_{BQ} = 0.95\ mA$$

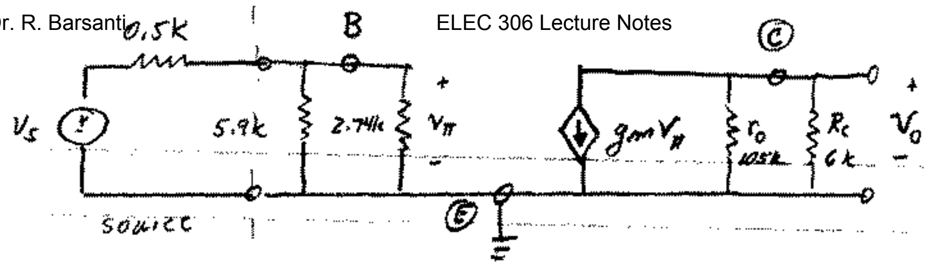
$$V_{CEQ} = 12 - (6)(0.95) = 6.31^V$$

FWD-ACTIVE ✓

AC Solution:

$$r_\pi = \frac{V_T}{I_{BQ}} = \frac{0.026}{9.5\mu A} = \underline{2.74K\Omega}\ , \quad g_m = \frac{I_{CQ}}{V_T} = \underline{36.5\ mA/V}$$

$$r_o = \frac{V_A}{I_{CQ}} = \frac{100}{0.95\ mA} = \underline{105K\Omega}$$



$$v_o = (-g_m V_\pi)(r_o \| R_c) = -(0.0365)(V_\pi)\, 5.68K = \underline{-207\, V_\pi}$$

$$v_\pi = v_s \left(\frac{R_{TH} / r_\pi}{R_{TH}/r_\pi + R_s} \right) = v_s \left(\frac{1.87}{2.37} \right) = 0.79\, v_s$$

$$v_o = (0.79)(-207)\, v_s = -163\, v_s \Rightarrow \boxed{A_v = \frac{v_o}{v_s} = -163}$$

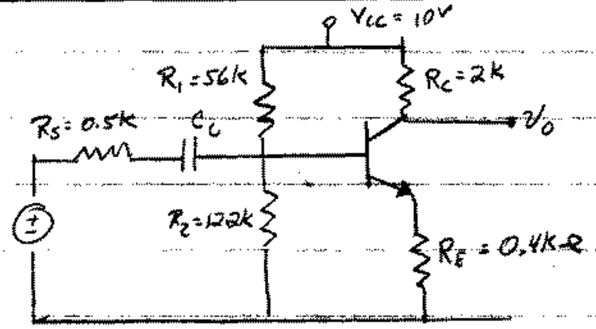
Notes: ① $R_i = R_1 \| R_2 \| r_\pi = 1.87 k\Omega$, this is relatively small compared to the source resist. $R_s = 0.5k$ and therefore put an appreciable load on the source.

e.g. $v_\pi \cong 80\%\ v_s$ (vice 99%)

② $R_o = r_o \| R_c = 5.68k$ which is relatively high for many loads.

B. Circuit w/ Emitter Resistor

Ex. 2



$\beta = 100$

$V_A = \infty$

$V_{BE(ON)} = 0.7^V$

<u>DC Solution:</u> $V_{TH} = 10\left(\frac{12.2}{12.2+56}\right) = 1.79^V$

$R_{TH} = 12.2 \| 56 = 10K$

KVL: BASE LOOP $\Rightarrow$ $-1.79 + I_B\,10k + 0.7 + (\beta+1) I_B\,(0.4K) = 0$

$$I_{BQ} = \frac{1.79 - 0.7}{10k + (101)0.4k} = 21.6\mu A$$

$\therefore I_{CQ} = \beta I_{BQ} = 2.16mA$;

KVL: OUTPUT LOOP : $-10 + I_{CQ}\,2k + V_{CE} + (\beta+1)(21.6\mu A)\,0.4K = 0$

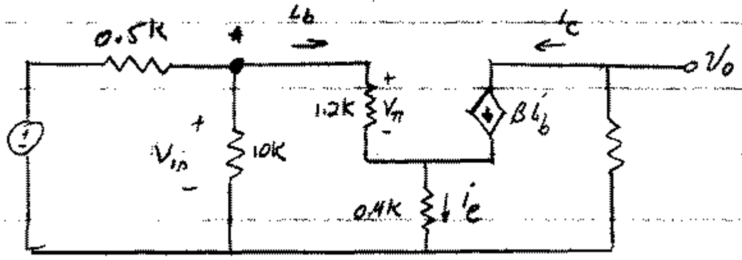
$V_{CE} = 10 - 4.32 - 0.87 = \underline{4.81^V}$

<u>Q is in FWD ACTIVE MODE!</u>

<u>Small Signal Solution</u>

$r_\pi = \frac{V_T}{I_{BQ}} = \frac{0.026}{21.6\mu A} = 1.20k\Omega$

$g_m = \frac{I_{CQ}}{V_T} = \frac{2.16}{26} = 83.1\ mA/V$, $r_o = \frac{V_A}{I_{CQ}} = \infty$



$v_o = -\beta i_b R_C$

Node A: $\frac{v_s - v_{in}}{0.5k} = \frac{v_{in}}{10k} + \frac{v_{in}}{1.2k + (\beta+1)0.4k}$

$\therefore v_{in}\left[\frac{1}{0.5} + \frac{1}{10} + \frac{1}{1.2 + 40.4}\right] = \frac{v_s}{0.5} \Rightarrow v_{in} = 0.94\,v_s$

$$i_b = \frac{v_{in}}{41.6k} = \frac{v_{in}}{2k + (\beta+1)R_E}$$

$$\therefore A_v = \frac{v_o}{v_s} = \frac{-\beta i_b R_c}{v_{in}/0.94} = \frac{-(100)\left(\frac{v_{in}}{41.6k}\right)(2k)}{v_{in}/0.94} = \underline{\underline{-4.52}}$$

Notes: ① $A_v \approx -R_C/R_E = -2/0.4 = -5$

② Can you show that for $A_v = \dfrac{-\beta i_b R_c}{v_{in} \dfrac{R_S}{R_S + r_\pi \| R_{TH} \| (\beta+1)R_E}}$

β	A_v
50	-4.41
100	-4.53
150	-4.57

? $\therefore$ A_v is nearly independent of β do to addition of R_E.

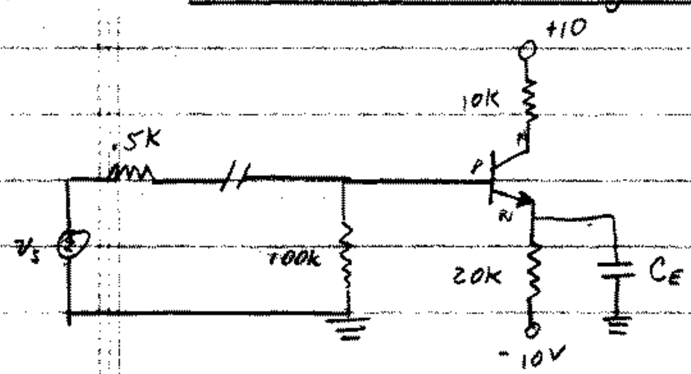
③ The input resistance of the amplifier is also increase so that $v_{in} \approx v_s$. The source is not heavily loaded.

C. Emitter bypass Capacitor

- There are times that the emitter resistor must be large for the purpose of dc design, but the large value degrades the small-signal voltage gain too severely.

- In such a case, an emitter bypass capacitor is used to short out all or part of R_E as seen by the ac signal.

Ex. Test Your Understanding 4.9



Given: $\beta = 100$

$V_{BE(ON)} = 0.7^V$

$V_A = 100^V$

a) A_V?   b) R_i seen by source?   c) R_o looking back into Amp.

a) DC Analysis

B-E Loop: $I_B(100k) + 0.7 + (\beta+1) I_B\, 20k - 10^V = 0$

$$I_B = \frac{9.3}{100k + 2020k} = \underline{4.4\mu A} \Rightarrow I_{CQ} = \underline{0.44^{mA}}$$

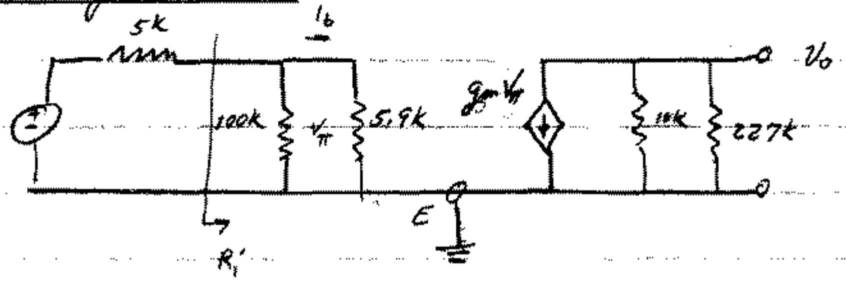
C-E Loop: $-20 + I_{CQ}10K + V_{CEQ} + 20K\, I_{EQ} = 0$

$$V_{CEQ} = 20 - 4.4 - 8.8 = \underline{6.8^V} \checkmark \Rightarrow \underline{\text{Fwd Active}}$$

AC Parameters: $r_\pi = \frac{V_T}{I_{BQ}} = 5.9k$, $g_m = \frac{I_{CQ}}{V_T} = 16.9\ {}^{mA}/_{V}$

$$r_o = \frac{V_A}{I_{CQ}} = \underline{227K\Omega}$$

Small Signal Model



$$V_o = -g_m V_\pi \left(10k \| 227k\right) = (0.0169)(0.918)V_s\,(9.58k) = \underline{-148 V_s}$$

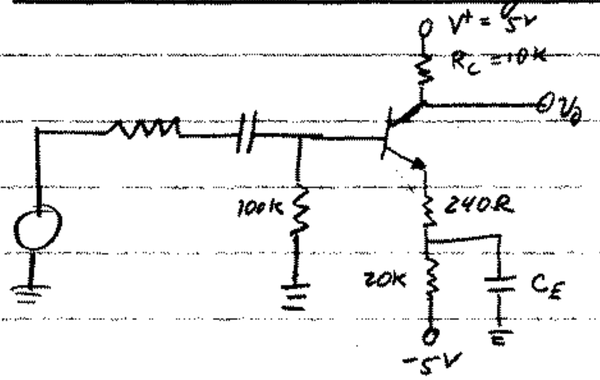
$$V_\pi = V_s\left(\frac{100k \| 5.9k}{100k \| 5.9k + 0.5k}\right) = 0.918\ V_s$$

a) $A_v = V_o/V_s = \boxed{-148}$

b) $R_{in} = 100k \| 5.9k = \boxed{5.58k}$

c) $R_o = 10k \| 227k = \boxed{9.58k}$

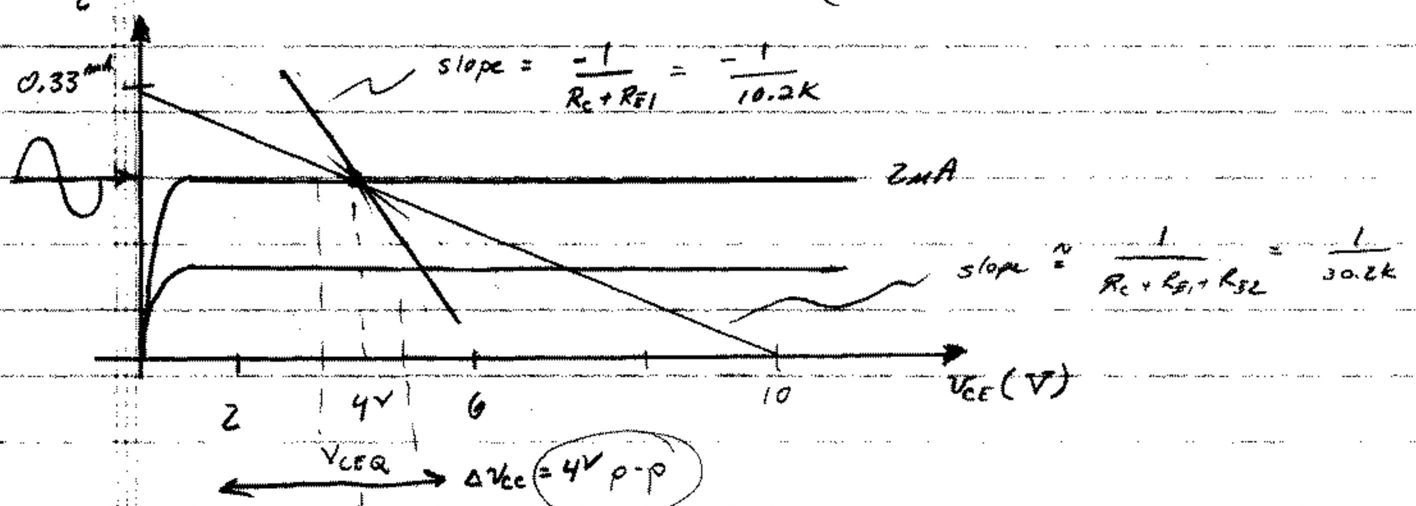
V AC LOAD LINE ; MAX. Symmetrical Swing



DC LOAD LINE : $-V^+ + I_C R_C + V_{CE} + I_E(R_{E1} + R_{E2}) - V^- = 0$

$$V_{CE} = (V^+ + V^-) - I_C\left[R_C + \left(\frac{1+\beta}{\beta}\right)(R_{E1} + R_{E2})\right]$$

$$= 10 - I_C(30.24k)$$



AC LOAD LINE $i_c R_C + v_{ce} + i_e R_{E1} = 0$

$$i_c = \frac{-v_{ce}}{R_C + R_{E1}} \qquad \text{assuming } i_c = i_e$$

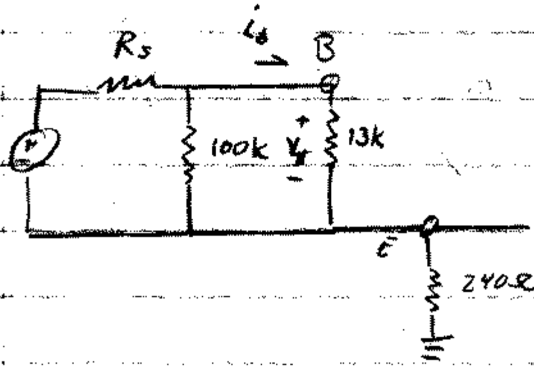
note : when $v_{ce} = i_c = 0$ we are at the 'Q' pt.

MAX Symmetrical Swing $\quad I_{CQ} = \frac{10 - \overset{\approx 4}{V_{CEQ}}}{30.24} = \underline{0.2^{mA}}$

$$\therefore \Delta i_{c(max)} = 2(0.2^{mA}) = 0.4^{mA} \text{ peak - peak}$$

$$\Delta v_{ce(max)} = \underbrace{\Delta i_{c(max)}[R_C + R_{E1}]}_{\text{see load line}} = 4^V \text{ peak - peak} \quad \text{eg } \boxed{2 \to 6^V}$$

Note: $r_\pi = \frac{V_T}{I_{BQ}} = \frac{26\,mV}{2\mu A} = 13K\Omega$

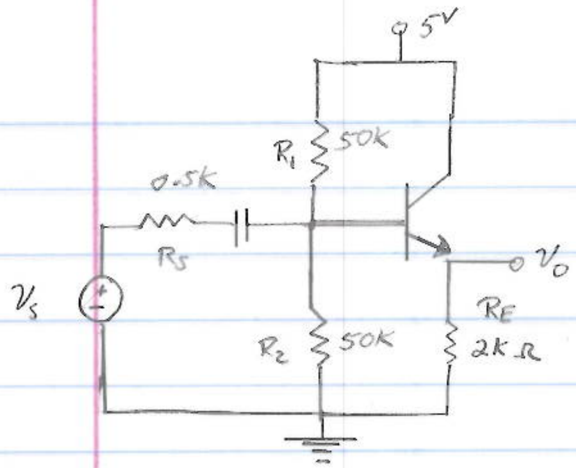


$v_{be} = 13K\,i_b$

$\Delta v_{be}(max) = 13K\left(\frac{.4mA}{100}\right)$
$= 52\,mV$

This exceeds the small signal model assumption of $\pm 10mV$ or 20mV p-p!

Emitter Follower



$\beta = 100$

$V_{BE,ON} = 0.7^V$

$V_A = 80^V$

DC ANALYSIS : $V_{TH} = 5\left(\frac{50}{50+50}\right) = \underline{2.5^V}$

$R_{TH} = 50K // 50K = \underline{25K\Omega}$

$$I_B = \frac{2.5 - 0.7}{25k + (101)2k} = 7.93\,\mu A$$

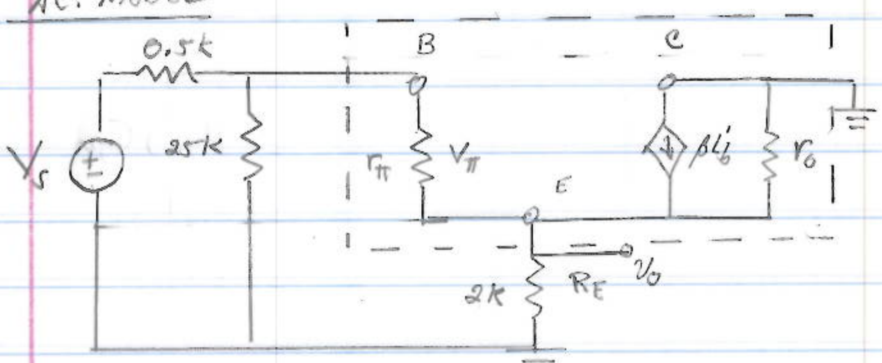
$I_{CQ} = 100\ I_B = \boxed{0.793\ mA}$, $V_{CEQ} = 5 - 7.93^{\mu A}(101)2k = \boxed{3.4^V}$

AC Parameters : $r_\pi = \frac{V_T \beta}{I_{CQ}} = \frac{(0.026)(100)}{0.793^{mA}} = \underline{3.28K\Omega}$

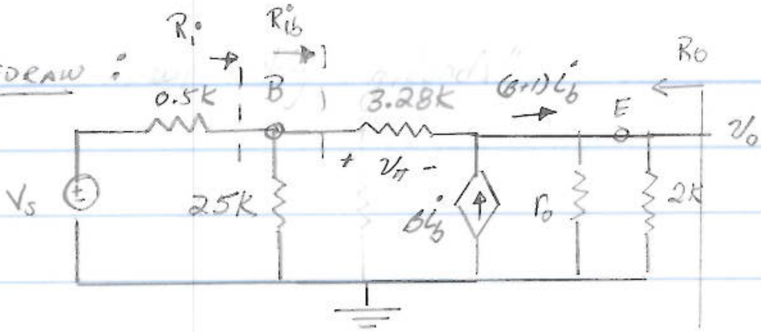
$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.793^{mA}}{0.026} = \underline{30.5\ ^{mA}/_{V}}$$

$$r_o = \frac{V_A}{I_{CQ}} = \frac{80}{0.793^{mA}} \cong \underline{100K\Omega}$$

AC. MODEL



REDRAW :



$$R_{ib} = 3.28k + (101)(100k \| 2k) = \underline{201K\Omega}$$

$$R_i = 25K \| R_{ib} = 25k \| 201k = \underline{22.2K\Omega}$$

$$R_o = \left(\frac{r_\pi}{\beta+1}\right) \| r_o \| R_E = \frac{3.28k}{101} \| 100k \| 2k = \underline{32\Omega}$$

$$A_v = \frac{v_o}{v_i} = \frac{(1+\beta)(r_o \| R_E)}{r_\pi + (1+\beta)(r_o \| R_E)} \cdot \left(\frac{R_i}{R_i + R_S}\right)$$

$$= \frac{(101)\ (100/2)k}{3.28k + (101)(100/2k)} \left(\frac{22.2}{22.2+0.5}\right) = \boxed{0.962}$$

$$A_i = (1+\beta)\left(\frac{R_1 \| R_2}{R_1 \| R_2 + R_{ib}}\right)\left(\frac{r_o}{r_o + R_E}\right)$$

$$= (101)\left(\frac{25k}{25k + 201k}\right)\left(\frac{100k}{100k + 2k}\right) = \boxed{10.9}$$