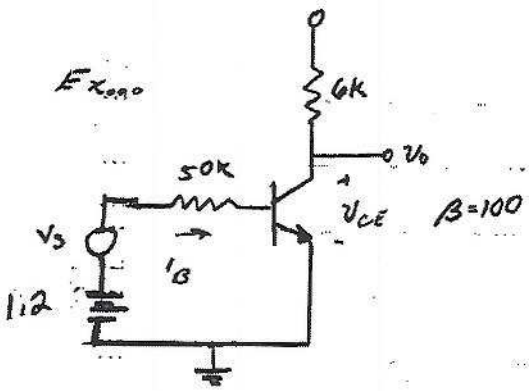




Example $V_{BE}=0.7V$ Find: Small Signal Voltage Gain

1. Find the Q pt.

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

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

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

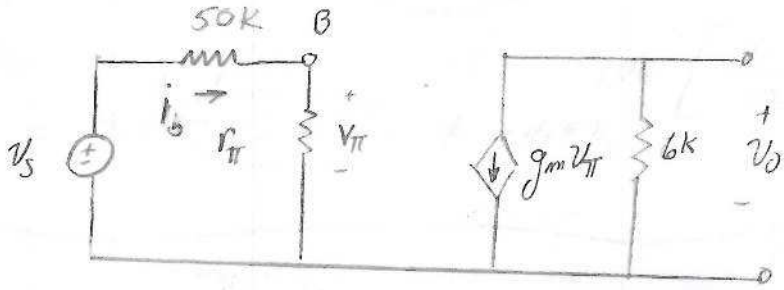
$\therefore$ 'Q' in fwd active mode.

2. Small Signal Hybrid parameters

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

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

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



$V_o = -g_m V_\pi R_C$

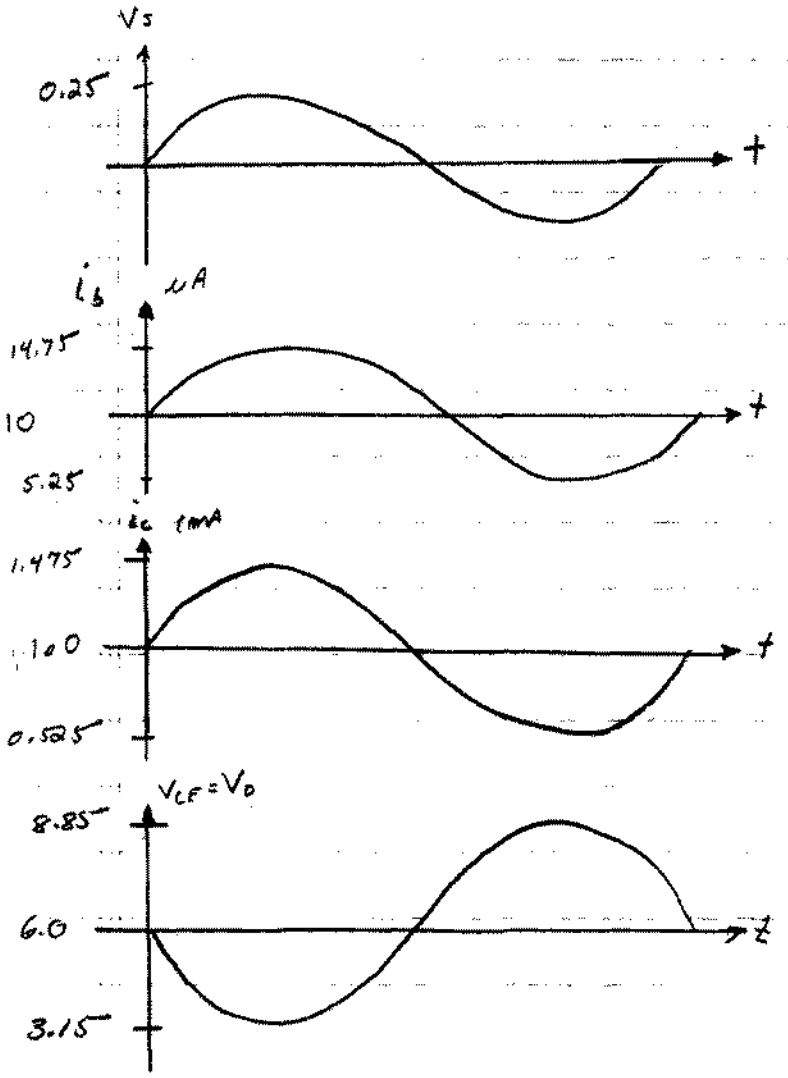
$V_\pi = \left(\frac{r_\pi}{r_\pi + R_B}\right) V_s$

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

then: $i_b = \frac{v_s}{R_B + r_\pi} = 4.75 \sin \omega t$ μA

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

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



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

Find r_o & A_v

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

$6 \| 150 = 5.36$

$$A_V = \frac{V_o}{V_s} = -g_m (R_c \| r_o)\left(\frac{r_\pi}{r_\pi + R_B}\right)$$

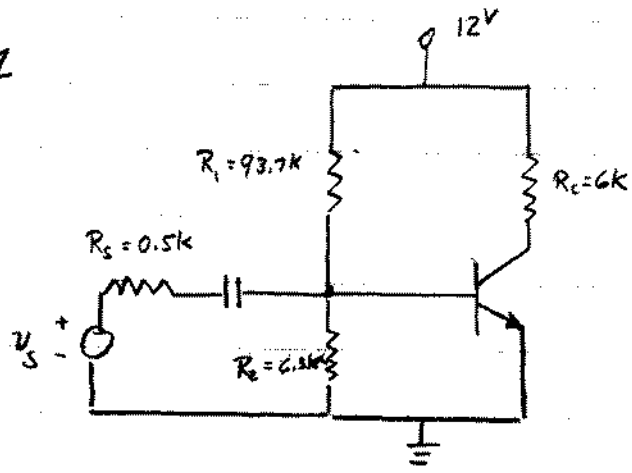
$$= -(38.5^{mA/V})(5.36k)\left(\frac{2.6}{2.6+50}\right) = \underline{-10.2}$$

The output resistance r_o reduces the magnitude of A_V. Typically $r_o >> R_c$, and in many cases can be neglected.

V. Common Emitter Amplifiers

A.

Example 1



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

$V_A = 100V$

$\beta = 100$

Find: Small signal voltage gain.

DC Solution:

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

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

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

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

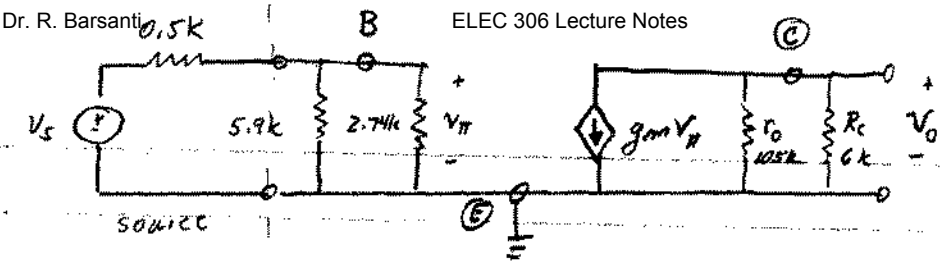
$$V_{CEQ} = 12 - (6)(0.95) = 6.31V$$

} FWD-ACTIVE ✓

AC Solution:

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

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



$$v_o = (-g_m v_\pi)(r_o \| R_c) = -(0.0365)(v_\pi)\,5.68k = -.207\, v_\pi$$

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

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

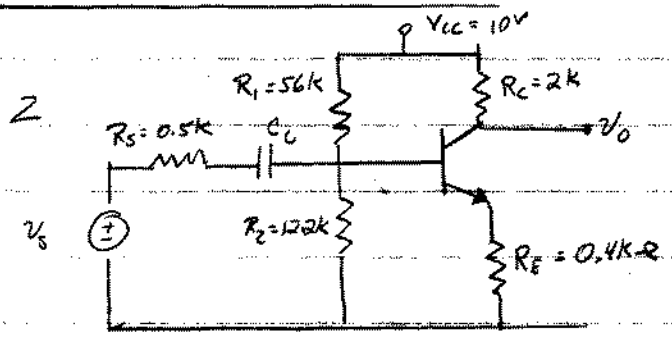
Notes: ① $R_i = R_1 \| R_2 \| r_\pi = 1.87k\Omega$, this is relatively small compared to the source resist. $R_s = 0.5k\Omega$ and therefore put an appreciable load on the source.

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



$\beta = 100$

$V_A = \infty$

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

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

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

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

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

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

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

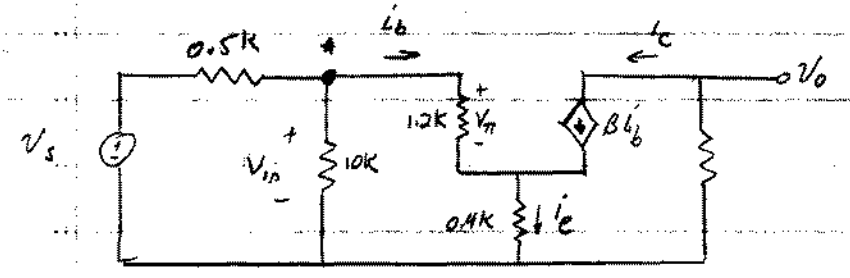
$V_{CE} = 10 - 4.32 - 0.87 = \underline{4.81^V}$

Q IS IN FWD ACTIVE MODE!

Small Signal Solution

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

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



$V_o = -\beta i_b R_C$

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

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

$$i_b = \frac{v_{in}}{41.6k} = \frac{v_{in}}{1.2k + (\beta+1)R_E}$$

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

Notes: ① $A_v \approx -\frac{R_c}{R_E} = -\frac{2}{0.4} = -5$

② Can you show that for $A_v = \frac{-\beta i_b R_c}{v_{in}} = \frac{\frac{R_3}{R_3 + R_{TH} \| R_{TH} \| (\beta+1)R_E}}{}$

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.

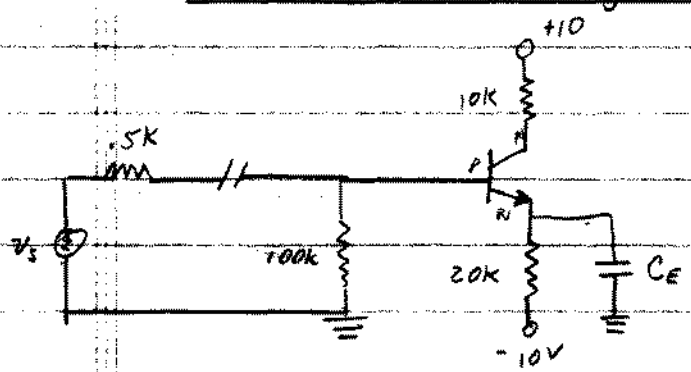
③ The input resistance of the amplifier is also increase so that $v_{in} \approx v_s$. The source is not heavily loaded.

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: $\beta = 100$

$V_{BE(on)} = 0.7V$

$V_A = 100V$

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

a) DC Analysis

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

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

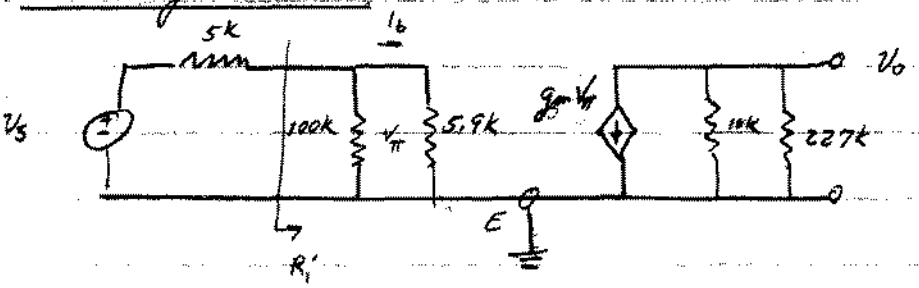
C-E Loop: $-20 + I_{CQ}10K + V_{CEQ} + 20K\, I_{EQ} = 0$

$V_{CEQ} = 20 - 4.4 - 8.8 = \underline{6.8^V}$ ✓ $\Rightarrow$ 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



$V_o = -g_m V_\pi (10k \,//\, 227k) = (0.0169)(0.918) V_s (9.58k) = -148 V_s$

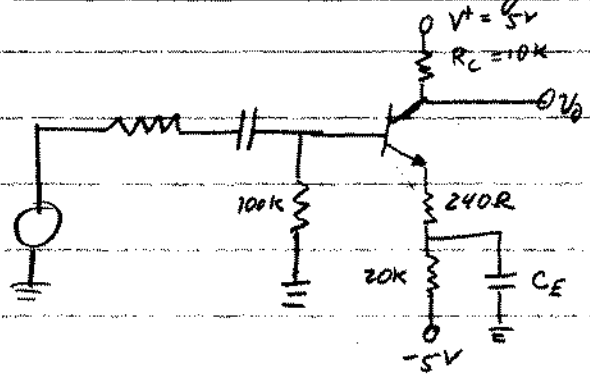
$V_\pi = V_s \left(\frac{100k \,//\, 5.9k}{100k \,//\, 5.9k + 0.5k} \right) = 0.918\, V_s$

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

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

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

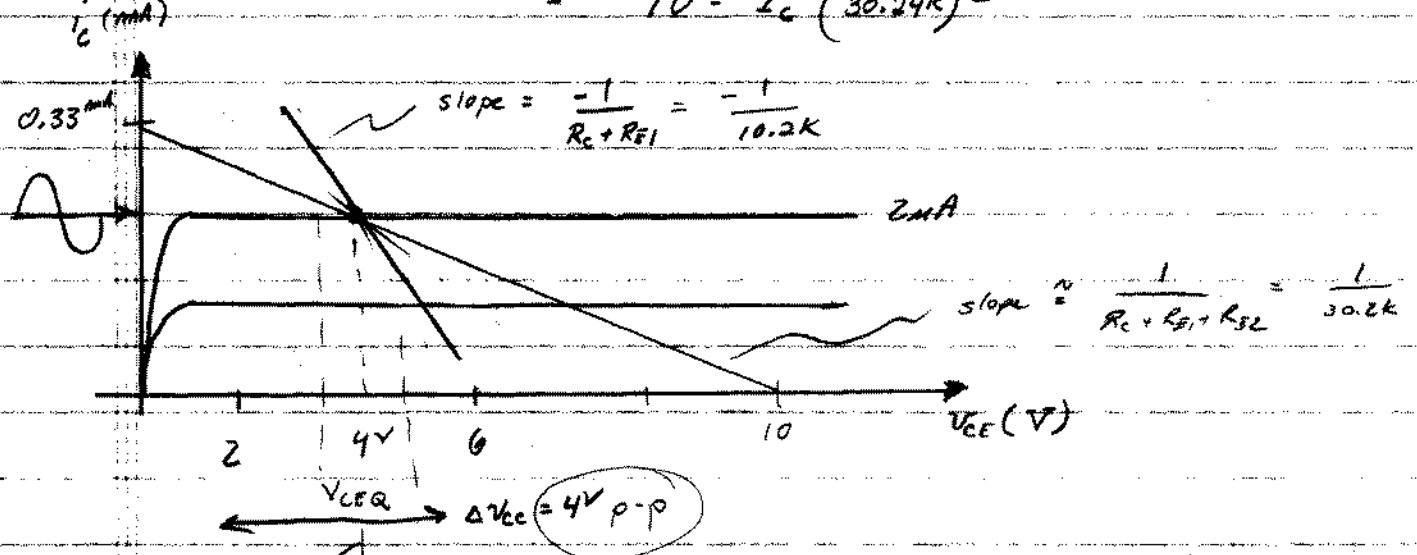
V AC LOAD LINE ; MAX. Symmetrical Swing



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

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

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

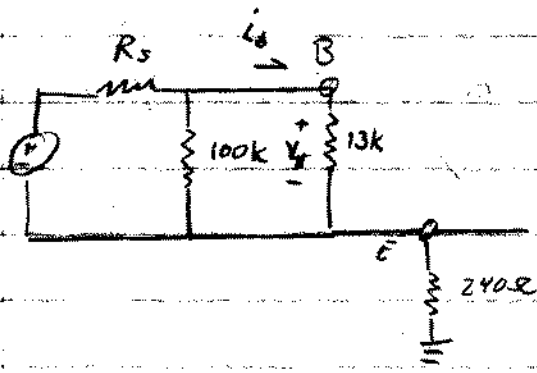
MAX Symmetrical Swing $I_{CQ} = \frac{10 - V_{CEQ}}{30.24} \approx \frac{4}{30.24} = \underline{0.2\ mA}$

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

$\Delta V_{ce(max)} = \underbrace{\Delta i_{c(max)} [R_C + R_{E1}]}_{\text{see load line}} = 4V$ peak-peak

eg $\boxed{2 \to 6V}$

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



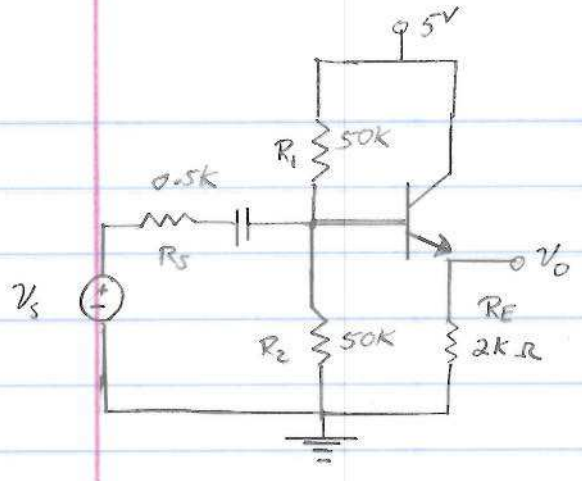
$V_{bc} = 13K\, I_b$

$\Delta V_{bc}(max) = 13k\left(\frac{.4mA}{100}\right)$

$= 52\,mV$

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

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

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

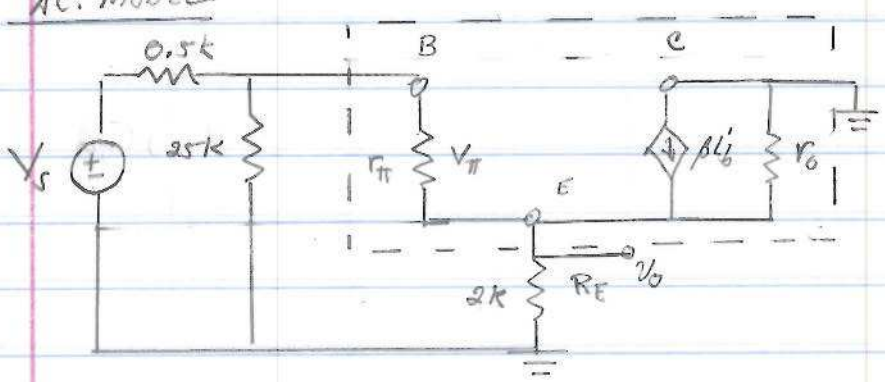
$I_{CQ} = 100\, I_B = \boxed{0.793\,mA}$, $V_{CEQ} = 5 - 7.93^{mA}(101)2k = \boxed{3.4^V}$

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

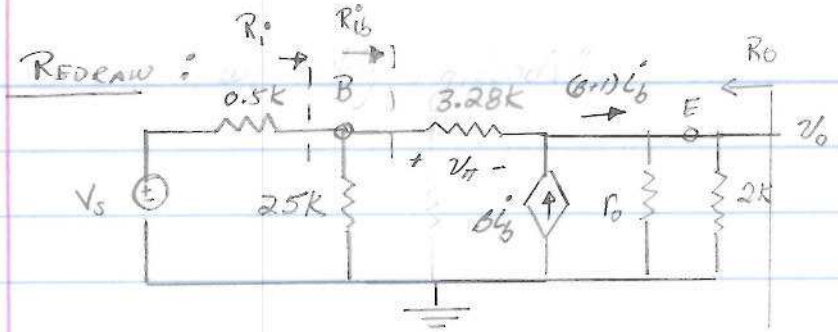
$g_m = \frac{I_{CQ}}{V_T} = \frac{0.793^{mA}}{0.026} = \underline{30.5\ ^{mA}/_V}$

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

AC. MODEL



REDRAW:



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

$$R_i' = 25K \| R_{ib} = 25K \,//\, 201K = \underline{22.2K\Omega}$$

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

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

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

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

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