K. ALAVI UTA

PROBLEM 4
BJT Biasing with Collector and Emitter Feedback

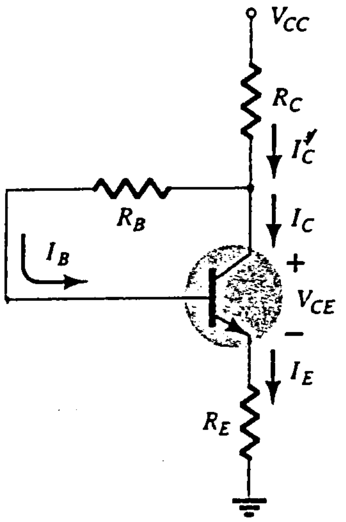
In class we analyzed the circuit given on the left by considering the redrawn circuit on the right.

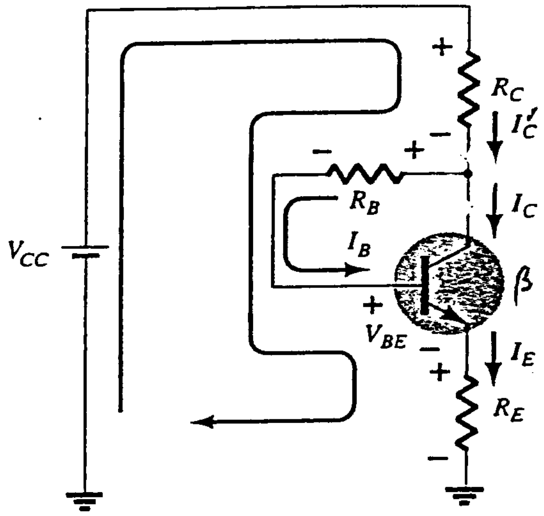
A. Express I'_C, and I_E in terms of I_B and I_C.

B. Write KVL on the loops shown,: do not make the assumption that $I_C = \beta I_B$.

C. NOW assume the transistor is operating in forward active region ($I_C = \beta I_B$). Obtain expressions for I_B, I_C, and V_{CE} in terms of R_B, R_C, R_E, V_{CC}, and β.

Work details of the solution on page 9. Give Final Answers here





FINAL ANSWERS

$I'_C = I_C + I_B$	$I_E = I_C + I_B$

KVL Big Loop: $V_{cc} = R_c I'_c + R_B I_B + V_{BE} + R_E I_E$

KVL Small Loop: $R_B I_B + V_{BC} = 0$

$I_B = \dfrac{V_{cc} - V_{BE}}{R_B + (\beta+1)(R_c + R_E)}$	$I_C = \dfrac{V_{cc} - V_{BE}}{\frac{1}{\beta} R_B + (\frac{\beta+1}{\beta})(R_c + R_E)}$

$V_{CE} = V_{cc} - (R_c + R_E)(\beta+1) I_B = V_{cc} - \dfrac{V_{cc} - V_{BE}}{1 + \dfrac{R_B}{(\beta+1)(R_c + R_E)}}$.

PROBLEM 4 continued

To FIND I_B: replace I_c' & I_E in the Big Loop KVL by

$I_c' = I_E = I_B + I_c = (\beta+1) I_B$

$\therefore \quad V_{cc} = R_c(\beta+1) I_B + R_B I_B + V_{BE} + R_E(\beta+1) I_B$

$$\therefore \quad \boxed{I_B = \frac{V_{cc} - V_{BE}}{R_B + (\beta+1)(R_c+R_E)}}$$

$$I_c = \beta I_B = \frac{\beta(V_{cc} - V_{BE})}{R_B + (\beta+1)(R_c+R_E)} = \frac{V_{cc} - V_{BE}}{\frac{1}{\beta}R_B + \left(\frac{\beta+1}{\beta}\right)(R_c+R_E)}$$

(The second form emphasizes that since β is large we can write $I_c \simeq \dfrac{V_{cc} - V_{BE}}{\frac{1}{\beta}R_B + (R_c+R_E)}$. Now if the resistances are chosen such that $\frac{1}{\beta}R_B \ll (R_c+R_E)$ Then $I_c \simeq$ independent of β $\Rightarrow$ Bias Stability)

V_{CE}: going around external loop we get

$$V_{cc} = R_c I_c' + V_{CE} + R_E I_E$$

or $\boxed{V_{CE} = V_{cc} - (R_c+R_E)(\beta+1) I_B}$

$$\text{or} \quad V_{CE} = V_{cc} - \frac{(R_c+R_E)(\beta+1)(V_{cc}-V_{CE})}{R_B + (\beta+1)(R_c+R_E)}$$

$$V_{CE} = V_{cc} - \frac{V_{cc} - V_{BE}}{1 + \dfrac{R_B}{(\beta+1)(R_c+R_E)}}$$

Now if $R_B \ll (\beta+1)(R_c+R_E)$ then $V_{CE} \simeq V_{cc} - (V_{cc} - V_{BE})$

& $V_{CE} \simeq V_{BE}$ again $\Rightarrow$ Bias stability (V_{CE} also independent of β)

PROBLEM 1 GRAPHICAL METHOD

$I_C - V_{CE}$

GIVEN: A BJT has the characteristics given in the graphs (I_B-V_{BE} and ~~I_B-V_{BE}~~) on PAGE 3. The BJT is connected in the following circuit.

REQUIRED:

A. Obtain the equations for the load lines corresponding to the input and output sides, in terms of R_C, R_B, V_{CC} and V_{in}.

Load Line for input side:	$R_B i_B + v_{BE} - v_{in} = 0$ OR $i_B = -\frac{1}{R_B} v_{BE} + \frac{1}{R_B} v_{in}$
Load Line for output side:	$R_C i_C + v_{CE} - V_{CC} = 0$ OR $i_C = -\frac{1}{R_C} v_{CE} + \frac{1}{R_C} V_{CC}$

B. The load lines drawn correspond to $R_C = 220\ \Omega$, $R_B = 3.3\ k\Omega$. What is the value for V_{CC} and for $I_{Cshort\text{-}circuit}$? Note we must refer to 2nd graph on page 3

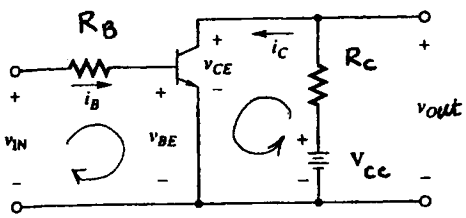
V_{CC} = 1.0 V,	$I_{Cshort\text{-}circuit}$ = 4.55 mA,

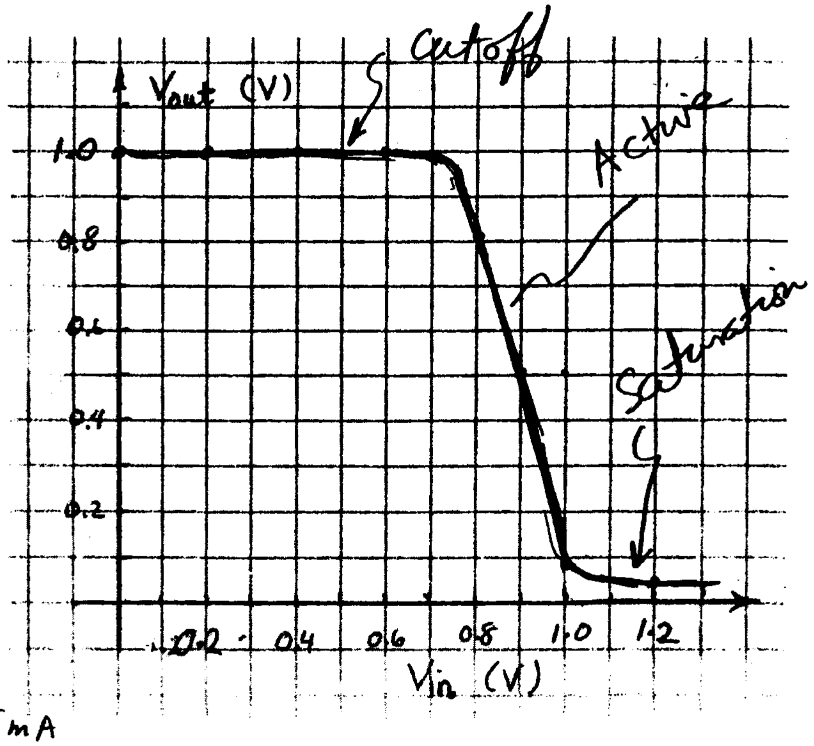
C. What values of V_{in} correspond to the 7 load lines drawn on the I_B-V_{BE} graph? Find values for V_{out} correspond to the 7 values for V_{in} **and plot the Transfer Characteristic** (V_{out} vs. V_{in}). Also obtain values for I_C/I_B . Look at graph on top horizontal intersection ⇒ V_{in}

Note $V_{out} = V_{CE}$

V_{in} (V)	0.4	0.6	0.7	0.8	0.9	1.0	1.2
V_{out} (V)	1.0	1.0	1.0	0.82	0.50	0.~~0~~1	0.0~~8~~4
I_C/I_B	0/0	0/0	0/0	100	100	$\frac{4.1\,mA}{66\,\mu A} = 70$	$\frac{4.4\,mA}{125\,\mu A} \cong 35$

$\frac{4.1}{66} =$





$$\text{(1)}\begin{cases} R_B i_B + v_{BE} - v_{in} = 0 \Rightarrow \\ i_B = -\frac{1}{R_B} v_{BE} + \frac{1}{R_B} v_{in} \end{cases}$$

$$\text{(2)}\begin{cases} v_{CE} - V_{cc} + R_c i_c = 0 \Rightarrow \\ i_c = -\frac{1}{R_c} v_{CE} + \frac{1}{R_c} V_{cc} \end{cases}$$

$$I_{csc} = \frac{V_{cc}}{R_c} = \frac{1.0\ V}{2.2\ k\Omega} = 4.55\ mA$$

PROBLEM 1 continued

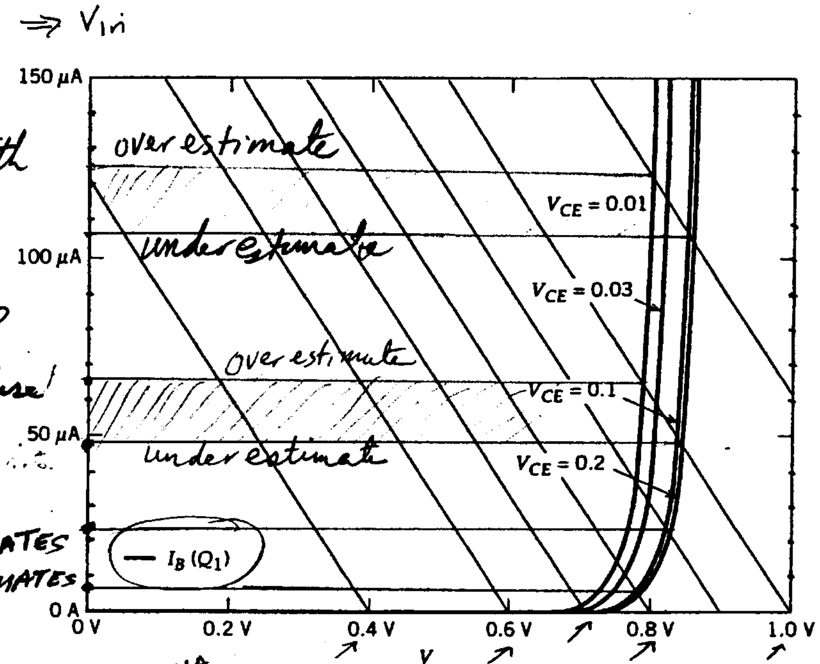
Horizontal Intersects ⇒ V_{in}

Now we use load line intersections with the diode iv to find i_B.

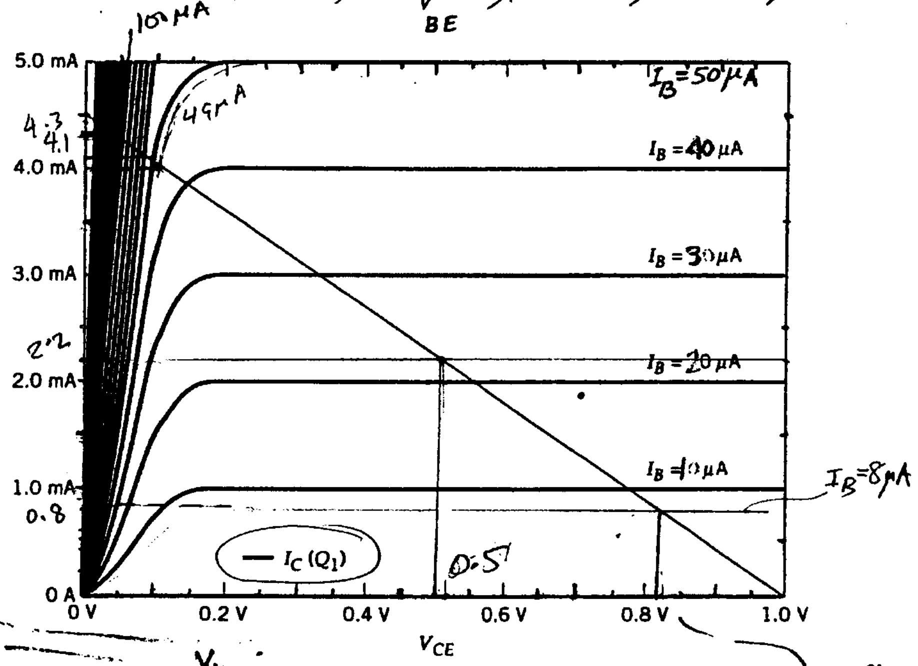
Q: WHICH IV CURVE SHOULD WE USE

A: for $V_{CE} > 0.1$, we must use the rightmost

for small values of V_{CE} this iv curve will UNDERESTIMATES I_B. & leftmost, OVERESTIMATES



From I_C-V_{CE} Graph it is obvious that small I_B ⇒ large V_{CE} & large I_B → small V_{CE} (See load line cross section with constant I_B curves)



ACCURATE

cutoff
$$\begin{cases} V_{in} = 0.4V, I_B = 0 \Rightarrow I_C = 0 \\ V_{in} = 0.6V \to I_B = 0 \Rightarrow I_C \approx 0 \\ V_{in} = 0.7V \Rightarrow I_B \simeq 0 \quad I_C \simeq 0 \end{cases}$$

$$\begin{cases} V_{in} = 0.8V \to I_B = 8\mu A \\ V_{in} = 0.9V \to I_B = 22\mu A \end{cases}$$

$$\begin{cases} V_{in} = 1.0V \to 49\mu A < I_B < 66\mu A \\ V_{in} = 1.2V \to 107\mu A < I_B < 125\mu A \end{cases}$$

Now we use the bottom graph (I_C vs. V_{CE})

V_{in}

0.8V $I_B = 8\mu A \to I_C = 0.8\,mA$ & $V_{CE} = 0.82V$

0.9V $I_B = 22\mu A \to I_C = 2.2\,mA$ $V_{CE} = 0.50V$

1.0V $\begin{cases} I_B = 49\mu A \quad I_C \simeq 4.0\,mA \times \; V_{CE} = 0.09V \\ \underline{I_B = 66\mu A} \to \underline{I_C \simeq 4.1\,mA} \checkmark \underline{V_{CE} \simeq 0.08V} \end{cases}$

1.2V $\begin{cases} I_B = 108\mu A \to I_C \simeq 4.3\,mA \times \; V_{CE} \simeq 0.05V \\ \underline{I_B = 125\mu A} \to I_C \simeq 4.4\,mA \checkmark \underline{V_{CE} \simeq .04V} \end{cases}$