EE310

Solved Problems on BJT

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By Turki Almadhi,

EE Dept., KSU,

Riyadh, Saudi Arabia

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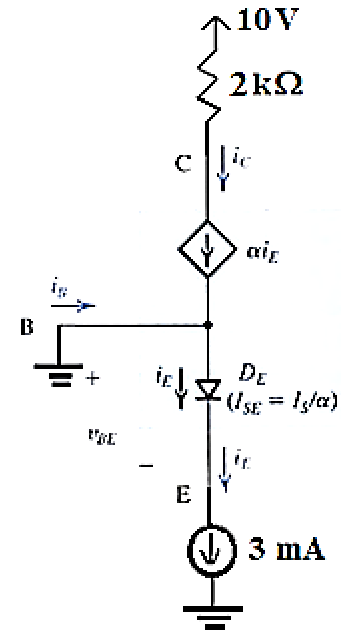
5.12 Using the *npn* transistor model of Fig. 5.5(b), consider the case of a transistor for which the base is connected to ground, the collector is connected to a 10-V dc source through a 2-kΩ resistor, and a 3-mA current source is connected to the emitter with the polarity so that current is drawn out of the emitter terminal. If $\beta = 100$ and $I_S = 10^{-15}$ A, find the voltages at the emitter and the collector and calculate the base current.



$$I_E = 3\text{ mA};\ I_{SE} = \frac{1}{\alpha} I_S = \frac{\beta+1}{\beta} I_S = 1.01 I_S$$

$$I_E = I_{SE} e^{\frac{V_{BE}}{V_T}} \rightarrow V_{BE} = V_T \times \ln(\frac{I_E}{I_{SE}}) = 0.747\text{ V}$$

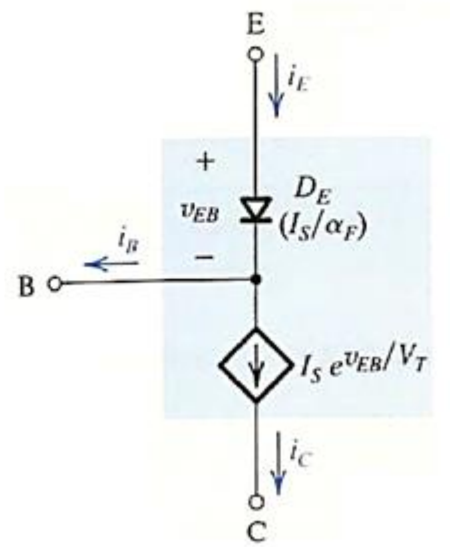
$$\because\ V_{BE} = V_B - V_E \ \rightarrow\ 0.747 = 0 - V_E \ \rightarrow\ V_E = -0.747\text{ V}$$

$$I_C = \alpha I_E = \frac{\beta}{\beta+1} I_E = 0.9901 \times 3 = 2.9703\text{ mA}$$

$V_C = 10 - 2.9703 \times 2 = 4.0594$ V (which verifies active mode)

$$I_B = I_E - I_C = 3 - 2.9703 = 29.7 \times 10^{-3}\text{ mA} = 29.7\ \mu\text{A}$$

5.19 A *pnp* power transistor operates with an emitter-to-collector voltage of 5 V, an emitter current of 10 A, and $V_{EB} = 0.85$ V. For $\beta = 15$, what base current is required? What is I_S for this transistor? Compare the emitter–base junction area of this transistor with that of a small-signal transistor that conducts $i_C = 1$ mA with $v_{EB} = 0.70$ V. How much larger is it?



$\because\ V_{EC} = 5,$ that means the pnp transistor is operating in the active mode.

Given that $I_{E1} = 10\text{ A} \ \rightarrow\ I_{B1} = \frac{10}{\beta+1} = \frac{10}{16} = 0.625\text{ A}$

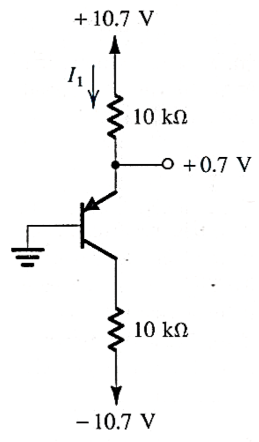
$$I_{C1} = \beta I_{B1} = 15 \times \frac{10}{16} = 9.375\text{ A};$$

$$I_{C1} = I_{S1}\, e^{\frac{V_{BE}}{V_T}} \ \rightarrow\ I_{S1} = I_{C1}\, e^{\frac{-V_{BE}}{V_T}} \ \rightarrow\ I_{S1} = 9.375 \times e^{\frac{-0.85}{26\times10^{-3}}} = 59.4 \times 10^{-15}\text{ A}$$

$$\frac{A_{EBJ1}}{A_{EBJ2}} = \frac{59.4 \times 10^{-15}\text{ A}}{I_{S2} = I_{C2}\, e^{\frac{-V_{BE}}{V_T}}} = \frac{59.4 \times 10^{-15}}{2.03 \times 10^{-15}} = 29.3$$

The power BJT has an emitter-base junction area 29.3 times larger than the small signal BJT.

6.28 For the circuits in Fig. P6.28, assume that the transistors have very large β. Some measurements have been made on these circuits, with the results indicated in the figure. Find the values of the other labeled voltages and currents.



(a)

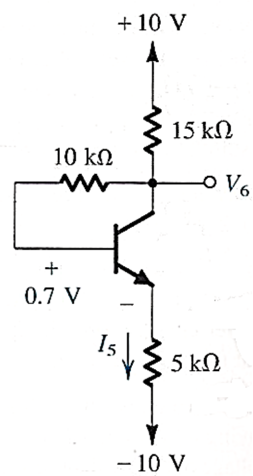
a)

$$I_1 = I_E = \frac{10.7-0.7}{10} = 1 \text{ mA}$$

$\because \beta$ is very large, we can assume I_B is 0 $\rightarrow$

$I_C = I_E = 1$ mA

$V_2 = 10 \times 1 + (-10.7) = -0.7$ V .



(d)

d)

Equating the collector and emitter currents:

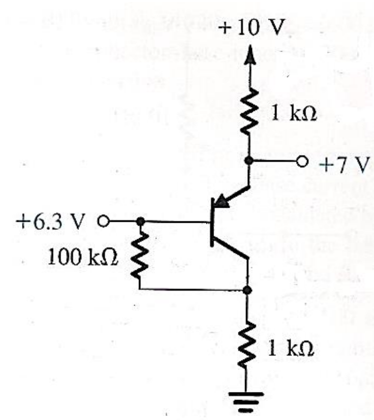
$I_C = I_E$

$$\frac{10-V_6}{15} = \frac{(V_6-0.7)-(-10)}{5} \rightarrow 10 - V_6 = 3V_6 + 27.9 \rightarrow$$

$4V_6 = -17.9 \rightarrow V_6 = -4.475$ V.

$$I_C = \frac{10-(-4.475)}{15} = 0.965 \text{ mA} = I_E = I_5$$

6.29 Measurements on the circuits of Fig. P6.29 produce labeled voltages as indicated. Find the value of β for each transistor.



(c)

To be able to find β, we must find two of the three currents: I_B, I_C, and I_E.

$$I_E = \frac{10-7}{1} = 3 \text{ mA}.$$

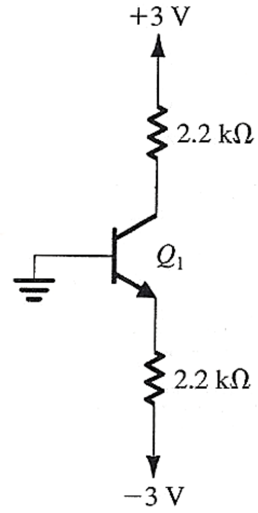
The current following into the lower 1-kΩ resistor is exactly equal to I_E; why?

$$V_C = 3 \times 1 = 3 \text{ V} \rightarrow I_B = \frac{6.3-3}{100} = 0.033 \text{ mA}$$

(I_B is flowing out of the base for a pnp transistor.)

$$I_E = (\beta+1)I_B \rightarrow \beta = \frac{I_E}{I_B} - 1 \approx 90.$$

6.35 For each of the circuits shown in Fig. P6.35, find the emitter, base, and collector voltages and currents. Use $\beta = 50$, but assume $|V_{BE}| = 0.8$ V independent of current level.



(a)

Assuming the transistor is in active mode:

$$V_E = -0.8 \;\rightarrow\; I_E = \frac{-0.8-(-3)}{2.2} = \frac{2.2}{2.2} = 1 \text{ mA}$$

$$I_B = \frac{I_E}{\beta+1} = \frac{1}{51} = 19.61\times10^{-3} \text{ mA}$$

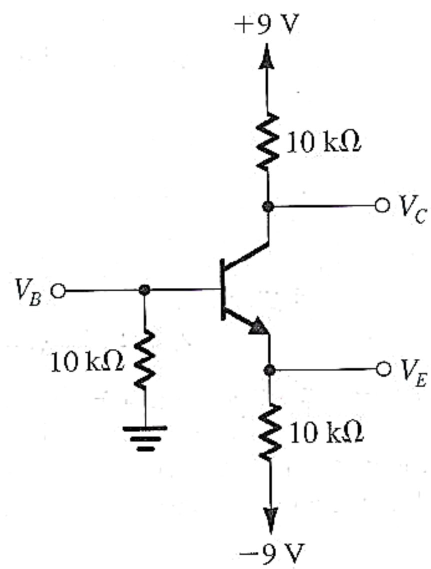
$$I_C = \beta I_B = 50\times33.78\times10^{-3} = 0.980 \text{ mA}$$

$$V_B = 0$$

$$V_C = 3 - 2.2\times0.980 = 0.844 \text{ V.}$$

$V_{BC} = 0-(0.844) = -0.844 \;\leq\; 0.4 \;\rightarrow\;$ the CBJ is *reverse*-biased $\rightarrow$ the transistor is in active mode as assumed!

5.26 For the circuit shown in Fig. P5.26, measurement indicates that $V_B = -1.5$ V. Assuming $V_{BE} = 0.7$ V, calculate V_E, α, β, and V_C. If a transistor with $\beta = \infty$ is used, what values of V_B, V_E, and V_C result?



(i) Note: the negative value of V_B indicates that the base current is going (into) the base which is the right direction for an npn BJT.

$$I_B = \frac{0-(-1.5)}{10} = 0.15 \text{ mA}$$

(current is in mA because the resistance is in kΩ.)

$$V_E = V_B - 0.7 = -1.5 - 0.7 = -2.2 \text{ V}$$

$$I_E = \frac{V_E-(-9)}{10} = \frac{-2.2+9}{10} = \frac{6.8}{10} = 0.68 \text{ mA}$$

$$I_C = I_E - I_B = 0.68 - 0.15 = 0.53 \text{ mA}$$

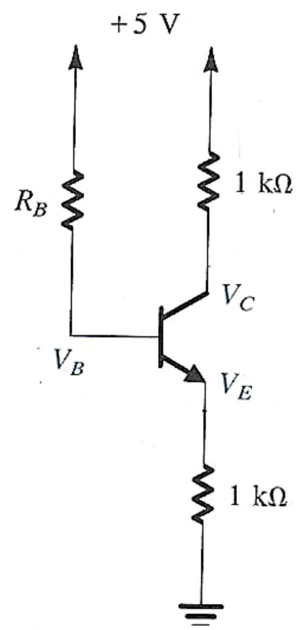
$V_C = 9 - 0.53\times10 = 3.7 \text{ V} \;\rightarrow\; V_{BC} = -1.5 - 3.7 = -5.2 \text{ V} \leq 0.4 \text{ V},$

which means the transistor is operating in the active mode.

$$\beta = \frac{I_C}{I_B} = \frac{0.53}{0.15} = 3.5333 \;\rightarrow\; \alpha = \frac{\beta}{\beta+1} = \frac{3.5333}{4.5333} = 0.7794 = \frac{I_C}{I_E}$$

(ii) $I_B = 0 \;\rightarrow\; V_B = 0 \;\rightarrow\; V_E = -0.7 \text{ V} \;\rightarrow\; V_C = 0.7 \text{ V}$

5.78 For the circuit in Fig. P5.78, find V_B, V_E, and V_C for $R_B = 100$ kΩ, 10 kΩ, and 1 kΩ. Let $\beta = 100$.



(i) $R_B = 100$ kΩ

Assuming the transistor is in active mode:

$(\beta+1)I_B = I_E$

$101 \times \frac{5-(0.7+V_E)}{100} = \frac{V_E}{1} \ \rightarrow \ 4.3 - V_E = \frac{100}{101}V_E$

$\rightarrow V_E = 2.16 \text{ V} \ \rightarrow \ I_E = \frac{2.16}{1} = 2.16 \text{ mA}$

$V_B = V_E + 0.7 = 2.16 + 0.7 = 2.86 \text{ V}$

$V_C = 5 - 1 \times I_C = 5 - (\frac{100}{101}) \times I_E = 2.86 \text{ V}$

$V_{BC} = V_B - V_C = 0 \ \leq \ 0.4 \text{ V} \ \rightarrow$ the BJT is in active mode as assumed.

(ii) $R_B = 10$ kΩ

Assuming the transistor is in active mode:

$(\beta+1)I_B = I_E$

$101 \times \frac{5-(0.7+V_E)}{10} = \frac{V_E}{1} \ \rightarrow \ 4.3 - V_E = \frac{10}{101}V_E$

$\rightarrow V_E = 3.91 \text{ V} \ \rightarrow \ I_E = \frac{3.91}{1} = 3.91 \text{ mA}$

$V_B = V_E + 0.7 = 3.91 + 0.7 = 4.61 \text{ V}$

$V_C = 5 - 1 \times I_C = 5 - (\frac{100}{101}) \times I_E = 1.13 \text{ V}$

$V_{BC} = V_B - V_C = 3.48 \text{ V} > 0.4 \text{ V} \ ! \rightarrow$ the BJT is saturated.

Restarting, and considering $V_{CE(sat)} = 0.2$ V :

$I_E = I_C + I_B$

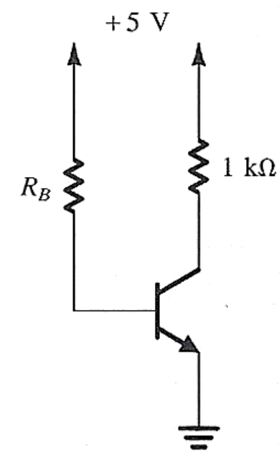
$\frac{V_E}{1} = \frac{5-V_C}{1} + \frac{5-V_B}{10}$

$\frac{V_E}{1} = \frac{5-(0.2+V_E)}{1} + \frac{5-(0.7+V_E)}{10}$

$V_E = 4.8 - V_E + 0.43 - 0.1V_E \ \rightarrow 2.1V_E = 5.23 \ \rightarrow V_E = 2.49 \text{ V}.$

$V_C = 0.2 + V_E = 2.69 \text{ V}; \quad V_B = 0.7 + V_E = 3.19 \text{ V}.$

D5.65 For the circuit in Fig. P5.65 select a value for R_B so that the transistor saturates with an overdrive factor of 10. The BJT is specified to have a minimum β of 20 and $V_{CEsat} = 0.2$ V. What is the value of forced β achieved?



Useful relationships:

$$I_{B(EdgeOfSaturation)} = I_{B(EOS)} = \frac{I_{C(sat)}}{\beta_{\min}};\ \beta_{forced} = \frac{I_{C(sat)}}{I_B};$$

$$\text{Over Drive Factor (ODF)} \triangleq \frac{I_B}{I_{B(EOS)}}$$

$$I_{C(sat)} = \frac{5-0.2}{1} = 4.8\text{ mA}$$

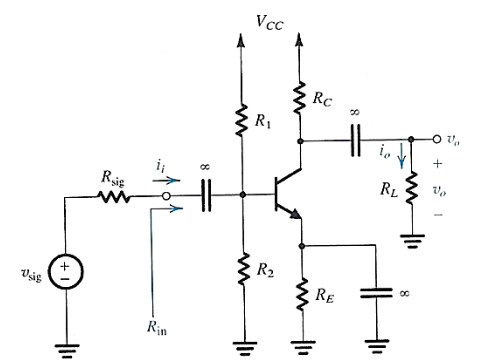
$$I_{B(EOS)} = \frac{I_{C(sat)}}{\beta_{\min}} = \frac{4.8}{20} = 0.24\text{ mA} \rightarrow I_B = I_{B(EOS)} \times ODF = 2.4\text{ mA}$$

$$I_B = \frac{5-0.7}{R_B} \rightarrow R_B = \frac{4.3}{2.4} = 1.792\text{ k}\Omega$$

$$\beta_{forced} = \frac{I_{C(sat)}}{I_B} = \frac{4.8\text{ mA}}{2.4\text{ mA}} = 2;$$

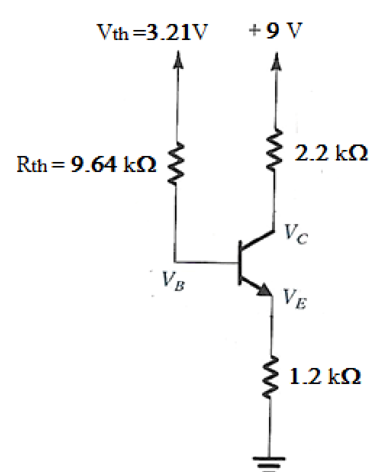
Note that β_{forced} is only defined in saturation and it changes with I_B and always is less than $\beta_{\min}$.

5.130 For the common-emitter amplifier shown in Fig. P5.130, let $V_{CC} = 9$ V, $R_1 = 27$ kΩ, $R_2 = 15$ kΩ, $R_E = 1.2$ kΩ, and $R_C = 2.2$ kΩ. The transistor has $\beta = 100$ and $V_A = 100$ V.



Calculate the dc bias current I_E. If the amplifier operates between a source for which $R_{sig} = 10$ kΩ and a load of 2 kΩ, replace the transistor with its hybrid-π model, and find the values of R_{in}, the voltage gain v_o/v_{sig}, and the current gain i_o/i_i.

We first draw the DC equivalent circuit (all caps are open-circuited), then we find Thevenin's equivalent looking out of the base.



DC equivalent circuit

$$R_{th} = R_1 \,||\, R_2 = 27\text{ k}\Omega \,||\, 15\text{ k}\Omega = \frac{27\times 15}{27+15} = 9.64\text{ k}\Omega$$

$$V_{th} = \frac{R_2}{R_1+R_2}\times V_{CC} = \frac{15}{27+15}\times 9 = 3.21\text{ V}$$

Assuming the transistor is in active mode:

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

$$101\times\frac{3.21-(0.7+V_E)}{9.64} = \frac{V_E}{1.2} \rightarrow 2.51 - V_E = 0.0796 V_E$$

$$\rightarrow V_E = 2.325 \text{ V} \rightarrow I_E = \frac{2.325}{1.2} = 1.9375 \text{ mA};$$

$$I_C = (\frac{100}{101}) \times I_E = 1.918 \text{ mA}$$

$$V_B = V_E + 0.7 = 2.325 + 0.7 = 3.025 \text{ V}$$

$$V_C = 9 - 2.2 \times I_C; = 9 - 2.2 \times 1.918 = 4.78 \text{ V}$$

$$V_{BC} = V_B - V_C = 3.025 - 4.78 = \text{ -1.755 V} \leq \text{ 0.4 V}$$

$\rightarrow$ the BJT is in active mode as assumed.

$$g_m = \frac{I_C}{V_T} = \frac{1.918}{26} = 73.8 \text{ mS};$$

$$r_\pi = \frac{V_T}{I_B} = \beta \frac{V_T}{I_C} = \frac{\beta}{g_m} = \frac{100}{73.8} \times 10^3 = 1.355 \text{ k}\Omega$$

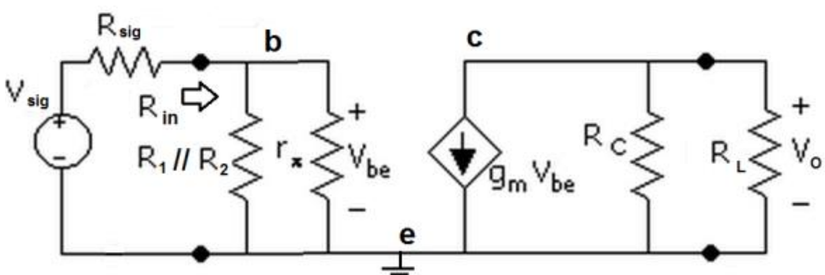
$$R_{in} = R_1 \,||\, R_2 \,||\, r_\pi = R_{th} \,||\, r_\pi = 9.64 \,||\, 1.355 = 1.18 \text{ k}\Omega$$

$$\frac{v_{be}}{v_{sig}} = \frac{R_{in}}{R_{in} + R_{sig}} = \frac{1.19}{1.19 + 10} = 0.106$$

$$v_o = -g_m v_{be} \times (R_C \,||\, R_L) = -77.3 v_{be} \rightarrow \frac{v_o}{v_{be}} = -77.3$$

$$A_V = \frac{v_o}{v_{sig}} = \frac{v_o}{v_{be}} \times \frac{v_{be}}{v_{sig}} = 0.106 \times (-77.3) = -8.2 \text{ V/V}$$

$$\frac{v_o}{v_{be}} = \frac{i_o \times R_L}{i_i \times R_{in}} = -77.3 \rightarrow \frac{i_o}{i_i} = \frac{R_{in}}{R_L} \times \frac{v_o}{v_{be}} = -45.6 \text{ A/A}$$



Small signal equivalent circuit