VE320 Homework 6

Due Sep. 6, 11:40am

The following questions are about BJT, you can use the transistor geometry shown below. You may also find the last page useful.

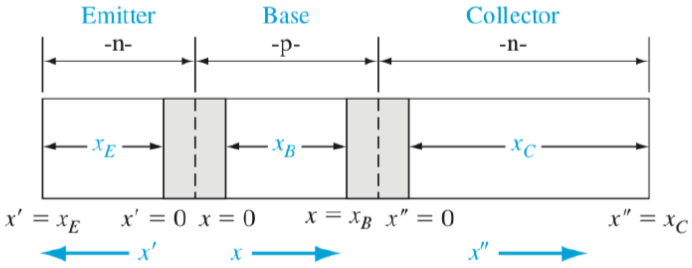


Figure 12.13 | Geometry of the npn bipolar transistor used to calculate the minority carrier distribution.

1.

For a uniformly doped $n^{++}p^{+}n$ bipolar transistor in the thermal equilibrium,

(a) Sketch the energy-band diagram.

(b) Sketch the electric field through the device.

(c) Repeat parts (a) and (b) for the transistor biased in the forward-active region.

2.

A uniformly doped silicon npn bipolar transistor at $T = 300K$ is biased in the forward-active mode. The doping concentrations are $N_E = 8 \times 10^{17} cm^{-3}$, $N_B = 10^{16} cm^{-3}$, and $N_C = 10^{15} cm^{-3}$.

(a) Find the thermal-equilibrium values p_{E0}, n_{B0}, and p_{C0}.

(b) Calculate the values of n_B at $x = 0$ and p_E at $x' = 0$ for $V_{BE} = 0.64V$.

(c) Sketch the minority carrier concentrations through the device and label each curve.

3.

(a) The following currents are measured in a uniformly doped npn bipolar transistor.

$I_{nE} = 0.50mA, I_{nC} = 0.495mA, I_{pE} = 3.5\mu A, I_R = 5\mu A, I_G = 0.5\mu A, I_{pc0} = 0.5\mu A$

Determine the following current gain parameters: $\gamma, \alpha_T, \delta, \alpha, \beta$ (see next page).

(b) If the required value of common-emitter current gain is $\beta = 120$, determine new values of I_{nC}, I_{pE} and I_R to meet this specification assuming $\gamma = \alpha_T = \delta$.

4.

The emitter in a BJT is often made very thin to achieve high operating speed. In this problem, we investigate the effect of emitter width on current gain. Consider the emitter injection efficiency given by

$$\gamma = \frac{1}{1 + \frac{p_{E0} D_E L_B}{n_{B0} D_B L_E} \cdot \frac{\tanh(x_B/L_B)}{\tanh(x_E/L_E)}}$$

Assume that $N_E = 100 N_B, D_E = D_B, L_E = L_B$. Also let $x_B = 0.1 L_B$.

Plot the emitter injection efficiency for $0.01 L_E \le x_E \le 10 L_E$.

From these results, discuss the effect of emitter width on the current gain.

5.

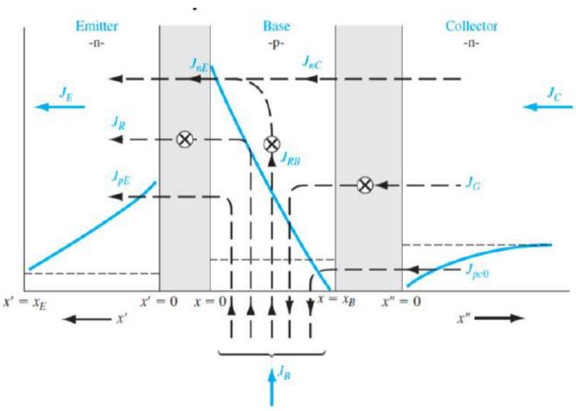
An npn bipolar transistor is biased in the forward-active mode. (*a*) The collector current is $I_C = 1.2$ mA when biased at $V_{CE} = 2$ V. The Early voltage is $V_A = 120$ V. Determine (*i*) the output resistance r_o, (*ii*) the output conductance g_o, and (*iii*) the collector current when biased at $V_{CE} = 4$ V. (*b*) Repeat part (*a*) if the collector current is $I_C = 0.25$ mA when biased at $V_{CE} = 2$ V and the Early voltage is $V_A = 160$ V.

6.

A uniformly doped silicon npn bipolar transistor at $T = 300$ K has parameters $N_E = 2 \times 10^{18}\ \text{cm}^{-3}$, $N_B = 2 \times 10^{16}\ \text{cm}^{-3}$, $N_C = 2 \times 10^{15}\ \text{cm}^{-3}$, $x_{BO} = 0.85\ \mu\text{m}$, and $D_B = 25\ \text{cm}^2/\text{s}$. Assume $x_{BO} \ll L_B$ and let $V_{BE} = 0.650$ V. (*a*) Determine the electron diffusion current density in the base for (*i*) $V_{CB} = 4$ V, (*ii*) $V_{CB} = 8$ V, and (*iii*) $V_{CB} = 12$ V. (*b*) Estimate the Early voltage.

7.

A uniformly doped pnp silicon bipolar transistor has a base doping of $N_B = 10^{16}\ \text{cm}^{-3}$, a collector doping of $N_C = 10^{15}\ \text{cm}^{-3}$, a metallurgical base width of $x_{B0} = 0.70\ \mu\text{m}$, a base minority carrier diffusion coefficient of $D_B = 10\ \text{cm}^2/\text{s}$, and a B–E cross-sectional area of $A_{BE} = 10^{-4}\ \text{cm}^2$. The transistor is biased in the forward-active mode with $V_{EB} = 0.625$ V. Neglecting the B–E space charge width and assuming $x_B \ll L_B$, (*a*) determine the change in neutral base width as V_{BC} changes from 1 to 5 V, (*b*) find the corresponding change in collector current, (*c*) estimate the Early voltage, and (*d*) find the output resistance.



J_{nE}: Due to the diffusion of minority carrier electrons in the base at $x = 0$.

J_{nC}: Due to the diffusion of minority carrier electrons in the base at $x = x_B$.

J_{RB}: The difference between J_{nE} and J_{nC}, which is due to the recombination of excess minority carrier electrons with majority carrier holes in the base. The J_{RB} current is the flow of holes into the base to replace the holes lost by recombination.

J_{pE}: Due to the diffusion of minority carrier holes in the emitter at $x' = 0$.

J_R: Due to the recombination of carriers in the forward-biased B–E junction.

J_{pc0}: Due to the diffusion of minority carrier holes in the collector at $x'' = 0$.

J_G: Due to the generation of carriers in the reverse-biased B–C junction.

Diffusion of electrons into the base from emitter

$$J_{nE} = \frac{eD_B n_{B0}}{L_B}\left\{\frac{1}{\sinh(x_B/L_B)} + \frac{[\exp(eV_{BE}/kT) - 1]}{\tanh(x_B/L_B)}\right\}$$

Diffusion of electrons leaving the base

$$J_{nC} = \frac{eD_B n_{B0}}{L_B}\left\{\frac{[\exp(eV_{BE}/kT) - 1]}{\sinh(x_B/L_B)} + \frac{1}{\tanh(x_B/L_B)}\right\}$$

Diffusion of holes into the emitter from base

$$J_{pE} = \frac{eD_E p_{E0}}{L_E}\left[\exp\left(\frac{eV_{BE}}{kT}\right) - 1\right] \cdot \frac{1}{\tanh(x_E/L_E)}$$

$$J_R = \frac{e x_{BE} n_i}{2\tau_0}\exp\left(\frac{eV_{BE}}{2kT}\right) = J_{r0}\exp\left(\frac{eV_{BE}}{2kT}\right)$$

$$p_{E0} = \frac{n_i^2}{N_E} \quad \text{and} \quad n_{B0} = \frac{n_i^2}{N_B}$$

$$J_{s0} = \frac{eD_B n_{B0}}{L_B \tanh(x_B/L_B)}$$

Emitter injection efficiency

$$\gamma \approx \frac{1}{1 + \frac{N_B}{N_E} \cdot \frac{D_E}{D_B} \cdot \frac{x_B}{x_E}} \qquad (x_B \ll L_B), (x_E \ll L_E)$$

Base transport factor

$$\alpha_T \approx \frac{1}{1 + \frac{1}{2}\left(\frac{x_B}{L_B}\right)^2} \qquad (x_B \ll L_B)$$

Recombination factor

$$\delta = \frac{1}{1 + \frac{J_{r0}}{J_{s0}} \exp\left(\frac{-eV_{BE}}{2kT}\right)}$$

Common-base current gain

$$\alpha = \gamma\alpha_T\delta \approx \frac{1}{1 + \frac{N_B}{N_E} \cdot \frac{D_E}{D_B} \cdot \frac{x_B}{x_E} + \frac{1}{2}\left(\frac{x_B}{L_B}\right)^2 + \frac{J_{r0}}{J_{s0}} \exp\left(\frac{-eV_{BE}}{2kT}\right)}$$

Common-emitter current gain

$$\beta = \frac{\alpha}{1-\alpha} \approx \frac{1}{\frac{N_B}{N_E} \cdot \frac{D_E}{D_B} \cdot \frac{x_B}{x_E} + \frac{1}{2}\left(\frac{x_B}{L_B}\right)^2 + \frac{J_{r0}}{J_{s0}} \exp\left(\frac{-eV_{BE}}{2kT}\right)}$$

$$\gamma = \left(\frac{J_{nE}}{J_{nE} + J_{pE}}\right) = \frac{1}{\left(1 + \frac{J_{pE}}{J_{nE}}\right)} = \frac{1}{1 + \frac{p_{E0} D_E L_B}{n_{B0} D_B L_E} \cdot \frac{\tanh(x_B/L_B)}{\tanh(x_E/L_E)}}$$

$$\alpha_T = \frac{J_{nC}}{J_{nE}} \approx \frac{\exp(eV_{BE}/kT) + \cosh(x_B/L_B)}{1 + \exp(eV_{BE}/kT)\cosh(x_B/L_B)}$$

$$\approx \frac{1}{\cosh(x_B/L_B)} \approx \frac{1}{1 + \frac{1}{2}(x_B/L_B)^2} \approx 1 - \frac{1}{2}(x_B/L_B)^2$$

$$\delta = \frac{J_{nE} + J_{pE}}{J_{nE} + J_R + J_{pE}}$$

$$\alpha = \left(\frac{J_{nE}}{J_{nE} + J_{pE}}\right)\left(\frac{J_{nC}}{J_{nE}}\right)\left(\frac{J_{nE} + J_{pE}}{J_{nE} + J_R + J_{pE}}\right)$$