I-V Characteristics of BJT

Common-Emitter Output Characteristics
To illustrate the $I_C-V_{CE}$ characteristics, we use an enlarged $\beta_R$.

- **Reverse-Active Region**: $V_{CE} \leq V_{BE}$
  - $I_C = -(\beta_R + 1)I_B$

- **Saturation Region**: $V_{CE} \leq V_{BE} \leq 0$
  - $I_C = \beta_F I_B$

- **Forward Active Region**: $V_{CE} \geq V_{BE}$
  - $I_C = \beta_F I_B$

- **Cutoff Region**: $V_{CE} \leq V_{BE}$
  - $I_C = 0$

- **Collector Current (mA)**
  - $I_B = 100 \mu A$
  - $I_B = 80 \mu A$
  - $I_B = 60 \mu A$
  - $I_B = 40 \mu A$
  - $I_B = 20 \mu A$
  - $I_B = 0 \mu A$

**Parameter Values**
- $\beta_F = 25$
- $\beta_R = 5$
Common Base Output Characteristics

\[ i_E \quad B \quad C \quad i_C \quad v_{CB} \]

\[ i_E \quad B \quad C \quad i_C \quad v_{BC} \]
Forward-Active Region

- $\beta_F = 25; \beta_R = 5$
- $I_E = 0.6 \text{ mA}$
- $I_E = 0.4 \text{ mA}$
- $I_E = 0.2 \text{ mA}$
- $I_E = 0 \text{ mA}$
Common-Emitter Transfer Characteristic $i_C - v_{BE}$

$BE$ voltage changes as $-1.8 \text{ mV/} ^\circ \text{C}$ - this is its temperature coefficient (recall from diodes).
Common-Emitter Transfer Characteristic $i_C - v_{BE}$ (p. 180)

$$I_C = I_S \left\{ \exp \left( \frac{v_{BE}}{V_T} \right) - 1 \right\}$$

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Junction Breakdown - BJT has two diodes back-to-back. Each diode has a breakdown. The diode (BE) with higher doping concentrations has the lower breakdown voltage (5 to 10 V).

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Minority Carrier Transport in Base Region

\[ n(0) = n_{bo} \exp\left(\frac{V_{BE}}{V_T}\right) \]

\[ i_T = qAD \frac{dn}{dx} \]

Electron conc. in base (neglects recombination)

\[ (p_{no}, n_{po}) \]

\[ \text{Inj. Holes} \]

\[ \text{Inj. Elec.} \]

\[ \text{Coll. Elec.} \]

\[ \text{Emitter} \]

\[ \text{Base} \]

\[ \text{Collector} \]

\[ \text{Space Charge regions} \]
Transport current $i_T$ results from diffusion of minority carriers (holes in npn) across base region.

Base current $i_B$ is composed of holes injected back into E and C and $I_{REC}$ needed to replenish holes lost to recombination with electrons in B.

The minority carrier concentrations at two ends of base are

$$n_{bo} \quad \text{and} \quad n_{bo}$$

where $n_{bo}$ is the equilibrium electron density in the base region.

The junction voltages establish a minority carrier concentration gradient at ends of base region. For a narrow base, we get

$$W_B \quad \text{is the B width; } A \quad \text{is the cross-sectional area of B region.}$$

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$$n(0) = n_{bo} \exp \left( \frac{v_{BE}}{V_T} \right)$$

and

$$n(W_B) = n_{bo} \exp \left( \frac{v_{BC}}{V_T} \right)$$

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$$i_T = \left| qAD \frac{dn}{dx} \right| = -qAD \frac{n_{bo}}{W_B} \left\{ \exp\left(\frac{v_{BE}}{V_T}\right) - \exp\left(\frac{v_{BC}}{V_T}\right) \right\}.$$ 

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The saturation current is

$$I_S = qAD \frac{n_{bo}}{W_B} = qAD \frac{n_i^2}{N_{AB} W_B}.$$
**Base Transit Time**

Forward transit time is time associated with storing charge $Q$ in Base region and it is

$$\tau_F = \frac{Q}{i_T} \quad \text{with} \quad Q = qA[n(0) - n_{bo}]\frac{W_B}{2}.$$ 

Using

$$Q = qA n_{bo} \left\{ \exp \left( \frac{v_{BE}}{V_T} \right) - 1 \right\} \frac{W_B}{2}$$

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Q = q A n_{bo} \left\{ \exp \left( \frac{v_{BE}}{V_T} \right) - 1 \right\} \frac{W_B}{2}
\]
we get
\[
i_T = \frac{q A D_n}{W_B} n_{bo} \left\{ \exp \left( \frac{v_{BE}}{V_T} \right) - 1 \right\}
\]
and
\[
\tau_F = \frac{W_B^2}{2D_n} = \frac{W_B^2}{2V_T \mu_n}
\]
This defines an upper limit on frequency \( f \leq \frac{1}{2\pi \tau_F} \).

\[ \frac{f}{\tau_F} \leq \frac{1}{2\pi} \]

**Diagram:**
- \( n(x) \) axis with \( n(0) \) and \( n(W_B) = n_{bo} \) points.
- \( Q = \) excess minority charge in Base.
- \( n_{bo} \) and \( W_B \) labels.
- \( x \) axis.

\( Q \) represents the shaded area between the line and the axes.
PSPICE EXAMPLE

*Libraries:
* Local Libraries:
  .LIB ".\example10.lib"
* From [PSPICE NETLIST] section of C:\Program Files\OrcadLite\PSpice\PSpice.ini file:
  .lib "nom.lib"

*Analysis directives:
  .DC LIN V_V1 0 5 0.05
  + LIN I_I1 10u 100u 10u
  .PROBE V(*) I(*) W(*) D(*) NOISE(*)
  .INC ".\example10-SCHEMATIC1.net"
**** INCLUDING example10-SCHEMATIC1.net ****
* source EXAMPLE10
PSPICE EXAMPLE (Cont'd)

Q_Q1  N00060 N00159 0 Qbreakn
V_V1  N00060 0 0Vdc
I_I1  0 N00159 DC 0Adc

***** RESUMING example10-SCHEMATIC1-Example10Profile.sim.cir *****

.END

***** BJT MODEL PARAMETERS

Qbreakn
NPN
IS  1.000000E-15
BF  100
NF  1
VAF 80
BR  3
NR  1
VAR 30
CN  2.42
D   .87
JOB CONCLUDED
TOTAL JOB TIME .21
PSPICE EXAMPLE (Cont’d)