Lecture 11: PNP Bipolar Junction Transistor
Physical Operation. BJT Examples.

The second type of BJT is formed from \textit{pnp} doped regions as

\textbf{(Fig. 6.10)}

Differences between \textit{pnp} and \textit{npn} BJTs are:

- Biasing voltages are \textbf{applied oppositely} to the \textit{npn}, though still forward biasing EBJ and reverse biasing the CBJ for active mode operation, for example.
- Current is primarily composed of holes (in the \textit{p} type regions) rather than electrons as in the \textit{npn} BJT.
- The current direction conventions are \(i_E\) \textbf{into} the emitter while \(i_C\) and \(i_B\) are \textbf{out} from the device.

The circuit symbol for the \textit{pnp} BJT is

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Once again, the filled arrow is always located on the emitter and helps us to remember the direction of the emitter current. Notice that the currents are pointed in opposite directions compared to the \textit{nnp} BJT.

For biasing in the active mode, a possible circuit is

\[
\begin{align*}
V_{EB} & \quad I_E \\
V_{BC} & \quad I_C
\end{align*}
\]

(Fig. 6.13b)

As with the \textit{nnp}, for the \textit{pnp} BJT in the active mode and with the current convention shown above

\begin{align*}
  i_C &= \alpha i_E \\
  i_B &= (1 - \alpha) i_E \\
  i_C &= \beta i_B \\
  \beta &= \frac{\alpha}{1 - \alpha} \\
  \alpha &= \frac{\beta}{\beta + 1}
\end{align*}

Consequently, we need to only memorize this one set of equations for use with both \textit{nnp} and \textit{pnp} BJTs, plus the current conventions for these two BJTs.
Examples

We’ll now consider a few examples of the DC analysis of \( npn \) and \( pnp \) BJT circuits.

Example N11.1 (text Example 6.2). Design the following circuit so that \( I_C = 2 \) mA and \( V_C = 5 \) V. For this particular transistor, \( \beta = 100 \) and \( V_{BE} = 0.7 \) V at \( I_C = 1 \) mA.

The “design” of this circuit is to determine the \( R_C \) and \( R_E \) that provide the specified \( I_C \) and \( V_C \).

For \( I_C = 2 \) mA, then

\[
\frac{15 - V_C}{R_C} = 2 \text{ mA} \quad \text{or} \quad R_C = \frac{15 - 5}{2 \times 10^{-3}} = 5 \text{ k}\Omega.
\]
We’re assuming that the transistor is in the active mode with the EBJ forward biased and the CBJ reversed biased.

For the forward biased EBJ junction,

\[ i_C = I_S e^{\frac{v_{BE}}{V_T}} \]  \hspace{1cm} (6.1),(6)

It’s given that at \( I_C = 1 \text{ mA}, V_{BE} = 0.7 \text{ V}. \) What is \( V_{BE} \) when \( I_C = 2 \text{ mA} \)? Using (6) for two different \( i_C \) and \( v_{BE} \) we find that

\[ \frac{i_{C1}}{i_{C2}} = e^{\frac{v_{BE1}-v_{BE2}}{V_T}} \quad \text{or} \quad \frac{v_{BE1}-v_{BE2}}{V_T} = \ln \left( \frac{i_{C1}}{i_{C2}} \right) \]

Therefore,

\[ v_{BE2} = v_{BE1} + V_T \ln \left( \frac{i_{C2}}{i_{C1}} \right) \]  \hspace{1cm} (7)

For this particular case,

\[ V_{BE2} = 0.7 + 25 \times 10^{-3} \ln \left( \frac{2}{1} \right) = 0.717 \text{ V} \]

This is not much of an increase from 0.7 V, which is what we typically observe when the BJT is in the active mode. (So, it’s quite common to assume \( V_{BE} = 0.7 \text{ V} \) for all \( i_C \) when a BJT operates in the active mode.)

Consequently,

\[ V_E = -0.717 \text{ V} \]

Next,

\[ i_C = \alpha i_E \quad \Rightarrow \quad i_E = \frac{i_C}{\alpha} = \frac{\beta + 1}{\beta} i_C \]
then \[ I_E = \frac{100 + 1}{100} \cdot 2 \text{ mA} \quad \text{or} \quad I_E = 2.02 \text{ mA} \]

We can use this emitter current to select the proper resistor \( R_E \):

\[ I_E = \frac{V_E - (-15 \text{ V})}{R_E} \]

or

\[ R_E = \frac{-0.717 + 15}{2.02 \times 10^{-3}} = 7.07 \text{ k\( \Omega \)} \]

That completes the design.

One last thing, though. Notice how small the base current \( I_B \) is relative to \( I_C \) and \( I_E \):

\[ I_B = I_C - I_E = 20 \mu \text{A} \]

This is typical of BJTs operating in the active mode.

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**Example N11.2** (text Exercise 6.13). Determine \( I_E, I_B, I_C, \) and \( V_C \) in the circuit below if \( \beta = 50 \) and \( V_E = -0.7 \text{ V} \).
Because $V_B = 0$, then the given $V_E$ means the BJT may be operating in the **active mode** since $V_{BE} = 0.7$ V. (It could also be operating in the saturation mode.) We’ll assume active mode operation for now, and confirm this assumption when we’re finished.

(i) Compute $I_E$.

$$I_E = \frac{-0.7 - (-10)}{10,000} = 0.93 \text{ mA}$$

(ii) Compute $I_C$.

$$I_C = \alpha I_E = \frac{\beta}{\beta + 1} I_E = \frac{50}{51} \cdot 0.93 \text{ mA} = 0.91 \text{ mA}$$

(iii) Compute $I_B$.

$$I_C = \beta I_B \quad \Rightarrow \quad I_B = \frac{I_C}{\beta} = \frac{0.91 \text{ mA}}{50} = 18.2 \text{ \mu A}$$

(iv) Compute $V_C$.

$$V_C = 10 - 5,000 \cdot I_C = 5.45 \text{ V}$$
Note that since $V_{CB} = V_C - V_B = 5.45 - 0 = 5.45$ V is greater than zero (thus reverse biasing the CBJ) and the EBJ is forward biased, the $n$-$p$-$n$ BJT is indeed operating in the active mode, as assumed.

**Example N11.3** (text Exercise 6.14). Given that $V_B = 1.0$ V and $V_E = 1.7$ V, determine $\alpha$ (and $\beta$) for the transistor in the circuit below. Also calculate $V_C$.

![Circuit diagram](Fig. E6.14)

Because $V_{EB} = V_E - V_B = 0.7$ V, the $p$-$n$-$p$ transistor may be operating in the active mode, which is what we will assume.

(i) Determine $\alpha$ and $\beta$. We’ll use the relationships $i_C = \alpha i_E$ and $i_C = \beta i_B$ to determine $\alpha$ and $\beta$.

From the circuit, $I_B = \frac{V_B}{100 \times 10^3} = \frac{1.0}{100 \times 10^3} = 10 \mu$A
and 

\[ I_E = \frac{10 - 1.7}{5,000} = 1.66 \text{ mA} \]

Using KCL:

\[ I_C = I_E - I_B = 1.66 \times 10^{-3} - 10 \times 10^{-6} = 1.65 \text{ mA}. \]

Therefore,

\[ \beta = \frac{I_C}{I_B} = \frac{1.65 \times 10^{-3}}{10 \times 10^{-6}} = 165 \]

and \( \alpha = \frac{I_C}{I_E} = \frac{1.65 \times 10^{-3}}{1.66 \times 10^{-3}} = 0.994 \)

Alternatively, \( \alpha = \frac{\beta}{\beta + 1} = 0.994 \)

(ii) Compute \( V_C \).

\[ V_C = -10 \text{ V} + 5,000 \cdot I_C = -10 \text{ V} + 5,000 \cdot 1.65 \times 10^{-3} \]

or \( V_C = -1.75 \text{ V.} \)

Note that this \( V_C \) means that the CBJ is reversed biased by the voltage \( 1.0 - (-1.75) = 2.75 \text{ V.} \) Hence, the active mode operation for the \( pnp \) BJT is the proper assumption since we’ve already determined that the EBJ is forward biased.