Bipolar Junction Transistors (BJT)

Signal amplification is important in many applications, such as telecommunications. Before the advent of transistors, signal amplification was accomplished using vacuum tubes. Transistors are much smaller and do not need a long warm-up time needed with vacuum tubes. The invention of the bipolar junction transistor started a revolution which placed electronics on a path of miniaturization; a fact that would have been impossible with vacuum tubes. In summary, the transistor and subsequently the integrated circuit must certainly qualify as two of the greatest inventions of the twentieth century.
BJT Structure

By placing two PN junctions together we can create a bipolar transistor. A BJT transistor has three terminals. The base (B), the collector (C), and the emitter (E).

- Transistors are three-terminal devices. The terminals are labelled the base, the emitter and the collector. Each BJTs consist of two pn junctions (where a ‘p type’ material joins to a ‘n type material’). Therefore, a transistor may be made up from a piece of p type material sandwiched between two n type regions (npn), or it may be made up from a piece of ‘n type’ material sandwiched between two ‘p type' regions (pnp)
3 Currents and 3 Voltages in the BJT

\textit{npn} Transistor

\[ \begin{align*}
C & \quad I_C \\
B & \quad I_B \\
E & \quad I_E
\end{align*} \]

\[ \begin{align*}
V_{BE} & \\
V_{CB} & \\
V_{CE} &
\]
Equivalent circuit of the transistors in the active mode

NPN

\[ i_C = \beta i_B \]

Equivalent Circuit of the NPN BJT in the ACTIVE mode

PNP

Equivalent Circuit of the PNP BJT in the ACTIVE mode
Large-Signal Equivalent-Circuit Models of the *nnp* BJT operating in the active mode

\[ i_E = \left( I_S / \alpha \right) e^{v_{BE} / V_T} \]

Voltage - controlled Current Source

(b) Current - controlled Current Source
\[ i_C = I_s e^{v_{BE}/V_T} \]
\[ i_B = \frac{i_C}{\beta} = \left( \frac{I_S}{\beta} \right) e^{v_{BE}/V_T} \]
\[ i_E = \frac{i_C}{\alpha} = \left( \frac{I_S}{\alpha} \right) e^{v_{BE}/V_T} \]

\[ i_C = \alpha i_E; i_B = (1-\alpha) i_E = \frac{i_E}{\beta + 1} \]

\[ i_C = \beta i_B; i_E = (\beta + 1) i_B \]
\[ \beta = \frac{\alpha}{1-\alpha} \]

- The basic principle involves the use of the voltage between two terminals to control the current flowing in the third terminal.
- Current is conducted by both electrons and holes, therefore the name bipolar.
- \( \alpha \) is called the common-base current gain.
- \( \beta \) is called the common-emitter current gain.
The $i_C$-$v_{CB}$ Characteristics of an $nnpn$ Transistor

\[ i_C = I_s e^{v_{BE}} / V_T \]
Measuring the $i_C$-$v_{CE}$ Characteristics of the BJT

$$i_C = I_s e^{v_{BE}} / V_T \left(1 + \frac{v_{CE}}{V_A}\right)$$

(a)

(b)

Early Voltage (50 - 100 V)
Amplification in BJT:

1. We first derive the Input/Output transfer characteristics of a “skeleton” BJT circuit.
2. Then we see, on a qualitative basis, how those characteristics can be used in the amplification.
3. After that we “calculate” the actual voltage amplification factor.
4. Finally, we develop a systematic approach that will be used to analyze/design more complicated and general amplifier circuits.
1. Deriving the Input/Output transfer characteristics of a “skeleton” BJT circuit.

This characteristics have been explained in class.
2. Then we see, on a qualitative basis, how those characteristics can be used in the amplification.

Now assume that

\[ V \dot{I} \]

\[ V \dot{i} \quad + \quad V_{BE} \]

*Small pure sinusoidal*

*Large pure Constant (dc)*

Symbolized by
The circuit now looks like this

We want now to see how the output will change in response to the changes in the input.
AC Small-Signal Analysis

**First Separate**

Each *current* and *voltage*

into

**Constant Component**
Which we denote by

**Time-varying component**
Which we denote by

The total we denote by
DC
Large-signal
AC Small Signal

The diagram shows a transistor circuit with the following labels:
- $v_i$: Input voltage
- $v_{be}$: Base-emitter voltage
- $v_{ce}$: Collector-emitter voltage
- $i_b$: Base current
- $i_c$: Collector current
- $i_e$: Emitter current
- $R_C$: Collector resistor
- $v_o$: Output voltage