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**Lecture 7**

**Bipolar junction transistor**

## 7.1 TRANSISTOR CONSTRUCTION

The transistor is a three-layer semiconductor device consisting of either two n- and one p-type layers of material (called npn transistor) or two p- and one n-type layers of material ( called pnp transistor). Both are shown in Figure 1 with the proper dc biasing,

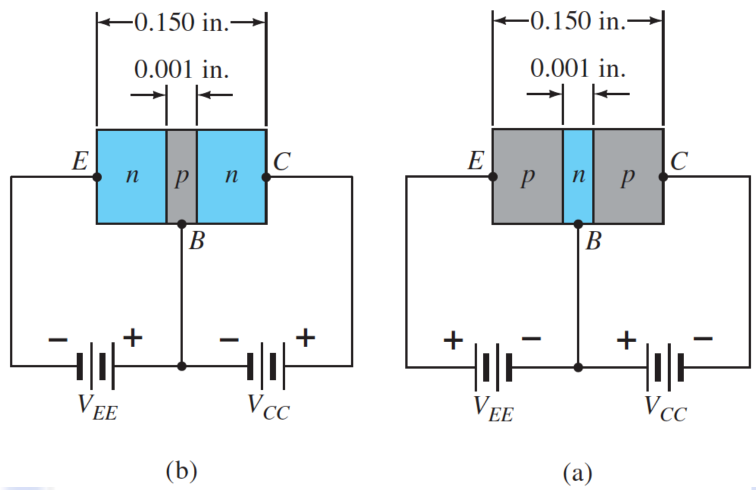


Figure 1: Types of transistors: (a) pnp; (b) npn.

Transistor composed from:

- The emitter layer is heavily doped.
- The base lightly doped.
- The collector only lightly doped.

For the biasing shown in Figure 1 the terminals have been indicated by the capital letters *E* for emitter , *C* for collector , and *B* for base. The outer layers have widths much greater than the sandwiched p - or n -type material.

## 7.2 TRANSISTOR OPERATION

The basic operation of the transistor will now be described using the pnp transistor of Figure 1a. In Figure 2a the pnp transistor has been redrawn without the base-to collector bias. Note the similarities between this situation and that of the forward-biased diode. The depletion region has been reduced in width due to the applied bias, resulting in a heavy flow of majority carriers from the p - to the n -type material.

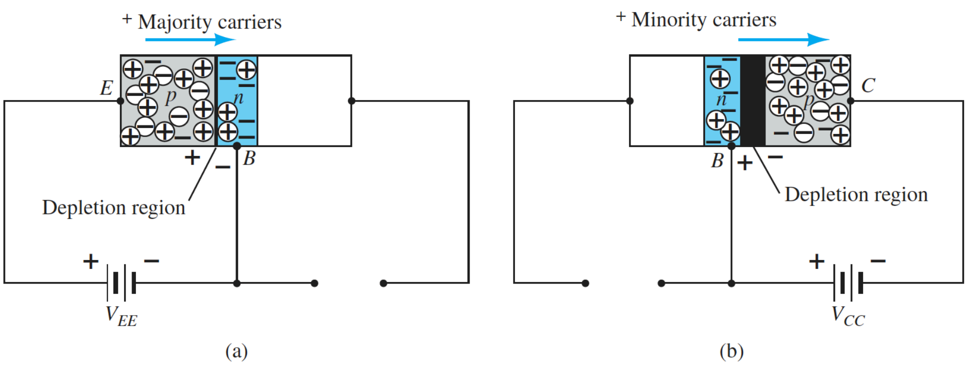


*Figure 2: Biasing a transistor: (a) forward-bias; (b) reverse-bias.*

Let us now remove the base-to-emitter bias of the pnp transistor of Figure 1a as shown in Figure 2b . Consider the similarities between this situation and that of the reverse-biased diode. Recall that the flow of majority carriers is zero, resulting in only a minority-carrier flow, as indicated in Figure 2b . In summary, therefore:

*One p–n junction of a transistor is reverse-biased, whereas the other is forward-biased.*

In Figure 3 both biasing potentials have been applied to a pnp transistor, with the resulting majority- and minority-carrier flows indicated. Note in Figure 3 the widths of the depletion regions, indicating clearly which junction is forward-biased and which is reverse-biased. As indicated in Figure 3 , a large number of majority carriers will diffuse across the forward biased p–n junction into the n -type material. The larger number of these majority carriers will diffuse across the reverse-biased junction into the p -type material connected to the collector terminal as indicated in Figure 3.

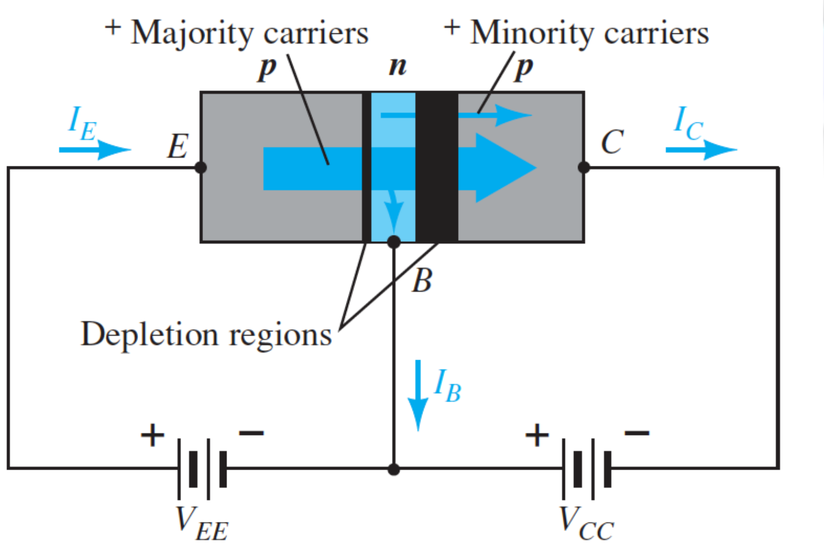


Figure 3: Majority and minority carrier flow of a pnp transistor.

Applying Kirchhoff's current law to the transistor of Figure 3 as if it were a single node, we obtain,

$$I_E = I_C + I_B \qquad (3.1)$$

**7.3 COMMON-BASE CONFIGURATION**

The common-base terminology is derived from the fact that the base is common to both the input and output sides of the configuration. In addition, the base is usually the terminal closest to, or at, ground potential. Throughout this text all current directions will refer to conventional (hole) flow rather than electron flow (Figure 4).

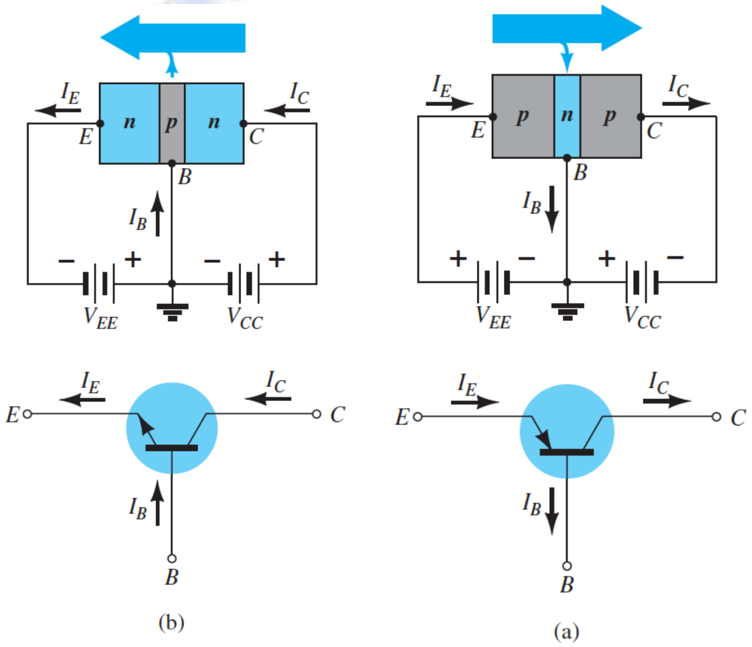


Figure 4: Notation and symbols used with the common-base configuration: (a) pnp transistor; (b) npn transistor.

All the current directions appearing in Figure 4 are the actual directions as defined by the choice of conventional flow. Note in each case that $I_E = I_C + I_B$.

To fully describe the behaviour of a three-terminal device such as the common-base amplifiers of Figure 4 requires two sets of characteristics—one for the **driving point** or **input parameters** and the other for the **output side**. The input set for the common-base amplifier as shown in Figure 5 relates an input current ($I_E$) to an input voltage ( $V_{BE}$ ) for various levels of output voltage ( $V_{CB}$ ).

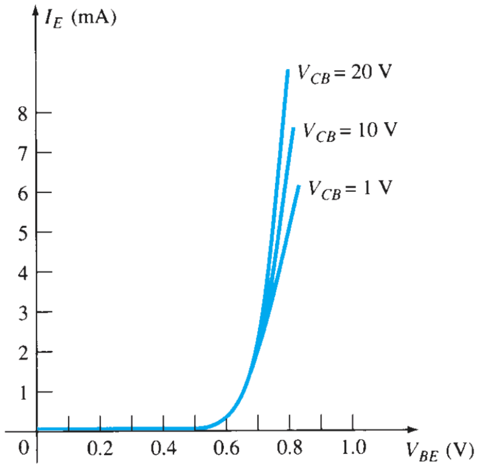


Figure 5: Input or driving point characteristics for a common-base silicon transistor amplifier.

The output set relates an output current ( $I_C$ ) to an output voltage ( $V_{CB}$ ) for various levels of input current ( $I_E$ ) as shown in Figure 6. The output or collector set of characteristics has three basic regions of interest, as indicated in Figure 6: the **active**, **cutoff** , and **saturation** regions. The active region is the region normally employed for linear (undistorted) amplifiers. In particular:

*In the* ***active region*** *the base–emitter junction is forward-biased, whereas the collector– base junction is reverse biased.*

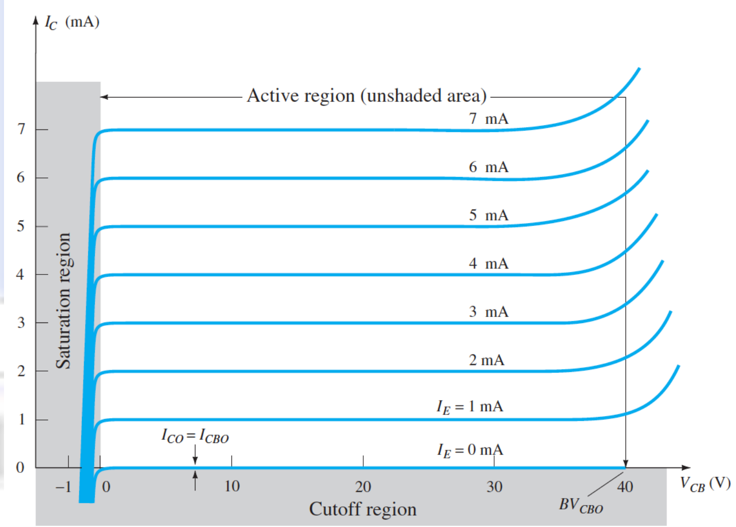


*Figure 6:Output or collector characteristics for a common-base transistor amplifier.*

The curves clearly indicate that a first approximation to the relationship between $I_E$ and $I_C$ in the active region is given by

$$I_C \cong I_E \qquad (3.3)$$

As inferred by its name, the cutoff region is defined as that region where the collector current is 0 A, as revealed on Figure 6. In addition:

*In the **cutoff region** the base–emitter and collector–base junctions of a transistor are both reverse-biased.*

The saturation region is defined as that region of the characteristics to the left of $V_{CB}=0\ V$. The horizontal scale in this region was expanded to clearly show the dramatic change in characteristics in this region. Note the exponential increase in collector current as the voltage $V_{CB}$ increases toward 0 V.

*In the **saturation region** the base–emitter and collector–base junctions are forward-biased.*

That is, once a transistor is in the "on" state, the base-to-emitter voltage will be assumed to be the following:

$$V_{BE} \cong 0.7\ V \qquad (3.4)$$

Example 1:

a. Using the characteristics of Figure 6 , determine the resulting collector current if $I_E$=3 mA and $V_{CB}$ =10 V.
b. Using the characteristics of Figure 6 , determine the resulting collector current if $I_E$ remains at 3 mA but $V_{CB}$ is reduced to 2 V.
c. Using the characteristics of Figures 5 and 6 , determine $V_{BE}$ if $I_C$ = 4 mA and $V_{CB}$ =20 V.

Solution:

a. The characteristics clearly indicate that $I_C \cong I_E$ = 3 mA.

b. The effect of changing $V_{CB}$ is negligible and I C continues to be 3 mA.

c. From Figure 6 , $I_E \cong I_C$ = 4 mA. On Figure 5 the resulting level of V BE is about 0.74 V.