Al-Mustaqbal University
College of Engineering and Technologies
Medical Instrumentation Technique Engineering Department
Class: 2nd
Subject: Electronic Circuits
Lecturer: Dr. Rami Qays Malik
Lecture: 7- Bipolar Junction Transistor Characteristics

Bipolar Junction Transistor Characteristics

INTRODUCTION

During the period 1904 to1947, the vacuum tube was the electronic device of interest and development. In 1904, the vacuum-tube diode was introduced by J. A. Fleming. Shortly thereafter, in 1906, Lee De Forest added a third element, called the control grid, to the vacuum diode, resulting in the first amplifier, the triode. In the following years, radio and television provided great stimulation to the tube industry. Production rose from about 1 million tubes in 1922 to about 100 million in 1937. In the early 1930s the four element tetrode and the five-element pentode gained prominence in the electron-tube industry. In the years to follow, the industry became one of primary importance, and rapid advances were made in design, manufacturing techniques, high-power and high-frequency applications, and miniaturization. On December 23, 1947, however, the electronics industry was to experience the advent of a completely new direction of interest and development. It was on the afternoon of this day that Dr. S. William Shockley, Walter H. Brattain, and John Bardeen demonstrated the amplifying action of the first transistor at the Bell Telephone Laboratories. The advantages of this three terminal solid-state device over the tube were immediately obvious: It was smaller and lightweight; it had no heater requirement or heater loss; it had a rugged construction; it was more efficient since less power was absorbed by the device itself; it was instantly available for use, requiring no warm-up period; and lower operating voltages were possible.

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Transistor construction

The transistor is a three-layer semiconductor device consisting of either two n-type and one p-type layers of material or two p- and one n-type layers of material. The former is called an NPN transistor, while the latter is called a PnP transistor.

Transistor composed from: (The emitter layer is heavily doped, with the base and collector only lightly doped)

The lower doping level decreases the conductivity (increases the resistance) of this material by limiting the number of carriers

The outer layers have widths much greater than the sandwiched p - or n - type material

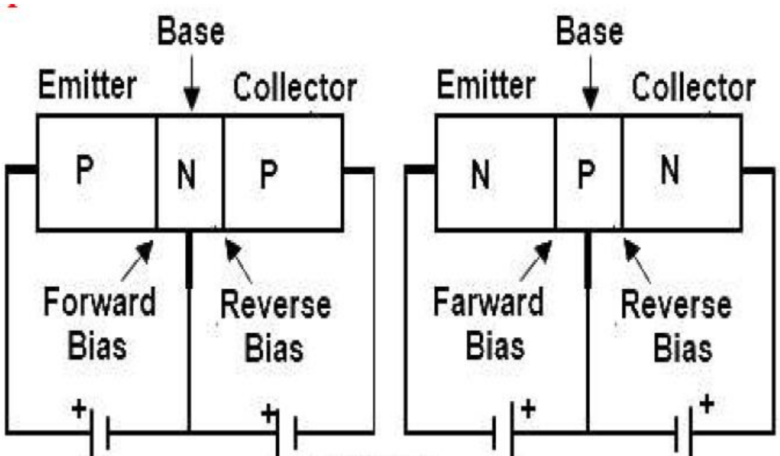

Figure (b)

The terminals have been indicated by the capital letters **E** for emitter, **C** for collector, and **B** for base, the term bipolar reflects the fact that holes and electrons participate in the injection process into the oppositely polarized material. If only one carrier is employed (electron or hole), it is considered a unipolar device.

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TRANSISTOR OPERATION

The basic operation of the transistor will now be described using the pnp transistor of Fig. 3.2a. The operation of the npn transistor is exactly the same if the roles played by the electron and hole are interchanged. In Fig. 3.3 the pnp transistor has been redrawn without the base-to-collector bias. 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.

Let us now remove the base-to-emitter bias of the pnp transistor of Fig. 3.4a as shown in Fig. 3.4.. Recall that the flow of majority carriers is zero, resulting in only a minority-carrier flow, as indicated in Fig. 3.4. In summary, therefore: One p-n junction of a transistor is reverse biased, while the other is forward biased.

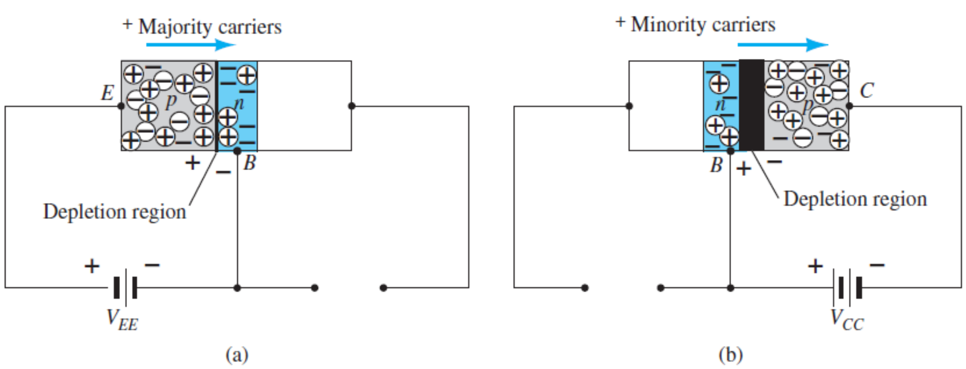

FIG. 3.4
Biasing a transistor: (a) forward-bias; (b) reverse-bias.

Applying Kirchhoff's current law to the transistor, we obtain

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$$I_E = I_C + I_B \tag{3.1}$$

The majority and minority carriers as indicated in Fig. 3.5. The minority-current component is called the leakage current and is given the symbol **ICO** (**IC** current with emitter terminal Open). The collector current, therefore, is determined in total by Eq. (3.2).

$$I_C = I_{C_{\text{majority}}} + I_{CO_{\text{minority}}} \tag{3.2}$$

For general-purpose transistors, IC is measured in milliamperes, while ICO is measured in microamperes or nanoamperes. ICO, like is for a reverse-biased diode, is temperature sensitive and must be examined carefully when applications of wide temperature ranges are considered. It can severely affect the stability of a system at high temperature if not considered properly. Improvements in construction techniques have resulted in significantly lower levels of ICO, to the point where its effect can often be ignored.

Common-base configuration

To fully describe the behavior of a three-terminal device such as the commonbase amplifiers requires two sets of characteristics one for the driving point or input parameters and the other for the output side.

Input parameters

- The input set for the common-base amplifier relates an input current (I E) to an input voltage (VBE) for various levels of output voltage (VCB).

- The emitter current is almost independent of collector-base voltage Vcb
- The emitter current IE increases rapidly with small increase in emitter base Voltage VBE it means that input resistance is very small.

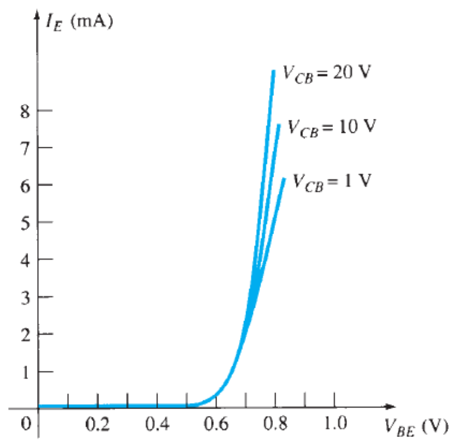


FIG. 3.7
Input or driving point characteristics for a common-base silicon transistor amplifier.

Output side

The output set relates an output current (I C) to an output voltage (V CB) for various levels of input current (I E) . The output or collector set of characteristics has three basic regions of interest the **(Active, cutoff, and saturation)**

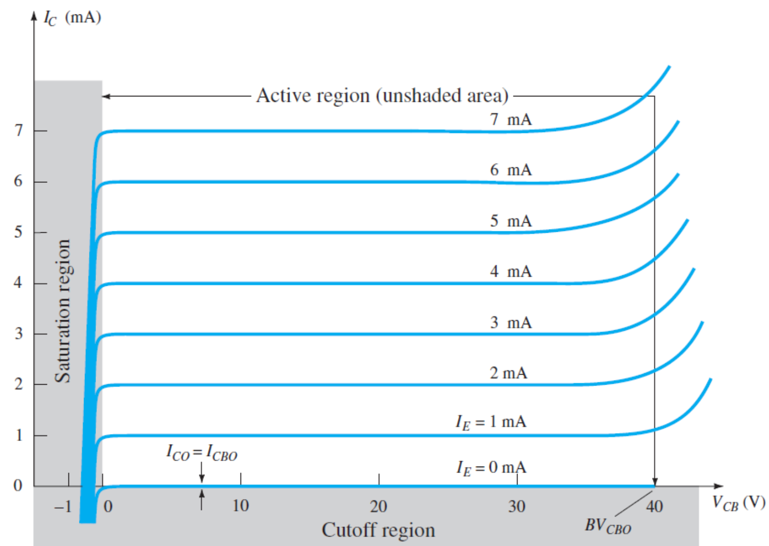
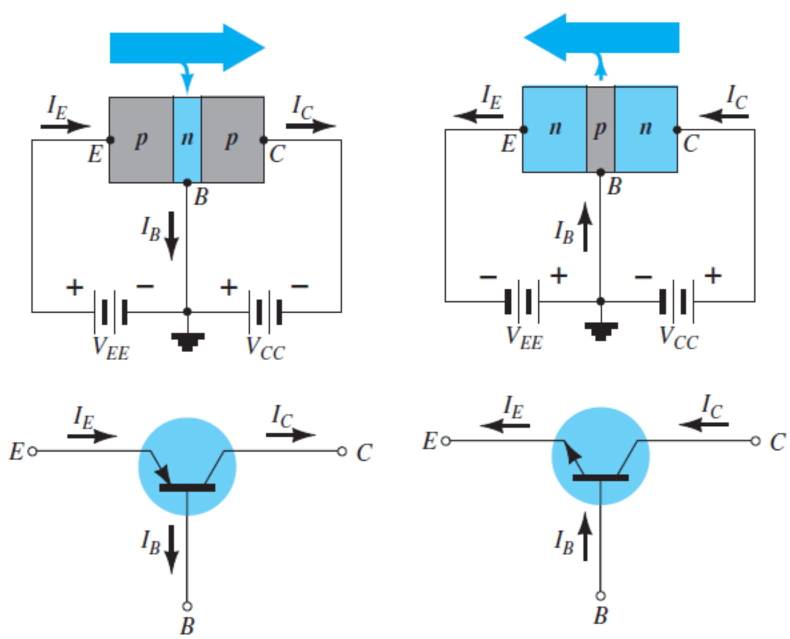


FIG. 3.8
Output or collector characteristics for a common-base transistor amplifier.

1. Active region

The active region is defined by the biasing arrangements of Fig. 3.6.



At the lower end of the active region the emitter current (IE) is zero, and the collector current is simply that due to the reverse saturation current ICO , as indicated in Fig. 3.9 . The current ICO is so small (microamperes) in magnitude compared to the vertical scale of IC (milliamperes) that it appears on virtually the same horizontal line as IC = 0. The circuit conditions that exist when IE=0 for the common base- configuration

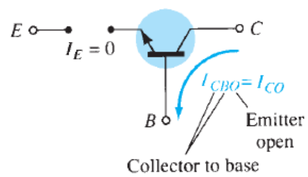


FIG. 3.9
Reverse saturation current.

- ICBO (the collector-to base current with the emitter leg open)
- Because of improved construction techniques, the level of ICBO for general purpose transistors in the low- and mid-power ranges is usually so low that its effect can be ignored.. In addition, keep in mind that ICBO , like I s , for the diode (both reverse leakage currents) is temperature sensitive. At higher temperatures the effect of ICBO may become an important factor since it increases so rapidly with temperature
- Note in Fig. 3.8 that as the emitter current increases above zero, the collector current increases to a magnitude essentially equal to that of the emitter current as determined by the basic transistor-current relations. Note also the almost negligible effect of VCB on the collector current for the active region. The curves clearly indicate that a first approximation to the relationship between IE and IC in the active region is given by

$$I_C \cong I_E$$

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2- Cutoff region

- As inferred by its name, the cutoff region is defined as that region where the collector current is 0 A, as revealed on Fig. 3.8 . In addition:
- In the cutoff region the base emitter and collector base junctions of a transistor are both reverse-biased

3. Saturation region

- The saturation region is defined as that region of the characteristics to the left of VCB = 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 VCB increases toward 0 V.
- In the saturation region the base emitter and collector base junctions are forward-biased.
- In fact, increasing levels of VCB have such a small effect on the characteristics that as a first approximation the change due to changes in VCB can be ignored and the characteristics drawn as shown in Fig. 3.10a.

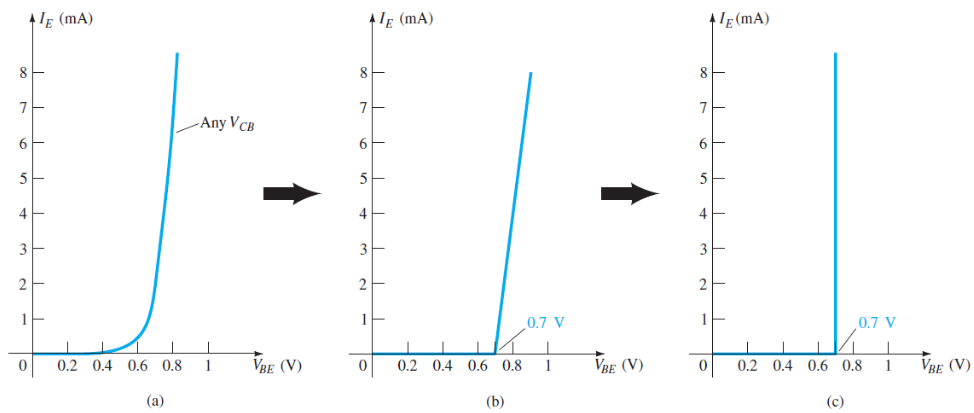

FIG. 3.10
Developing the equivalent model to be employed for the base-to-emitter region of an amplifier in the dc mode.

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$$\alpha_{dc} = \frac{I_C}{I_E}$$

$$I_C = \alpha I_E + I_{CBO}$$

$$\alpha_{ac} = \left.\frac{\Delta I_C}{\Delta I_E}\right|_{V_{CB}=\text{constant}}$$

EXAMPLE 3.1

a. Using the characteristics of Fig. 3.8, determine the resulting collector current if $I_E = 3$ mA and $V_{CB} = 10$ V.
b. Using the characteristics of Fig. 3.8, 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 Figs. 3.7 and 3.8, determine V_{BE} if $I_C = 4$ mA and $V_{CB} = 20$ V.
d. Repeat part (c) using the characteristics of Figs. 3.8 and 3.10c.

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 Fig. 3.8, $I_E \cong I_C = 4$ mA. On Fig. 3.7 the resulting level of V_{BE} is about **0.74 V**.
d. Again from Fig. 3.8, $I_E \cong I_C = 4$ mA. However, on Fig. 3.10c, V_{BE} is **0.7 V** for any level of emitter current.

Biasing

The proper biasing of the common-base configuration in the active region can be determined quickly using the approximation and assuming for the moment that IB = 0 mA. The result is the configuration of Fig. 3.11 for the pnp transistor. The arrow of the symbol defines the direction of conventional flow for IE = IC. The dc supplies are then inserted with a polarity that will support the resulting current direction. For the NPN transistor the polarities will be reversed.

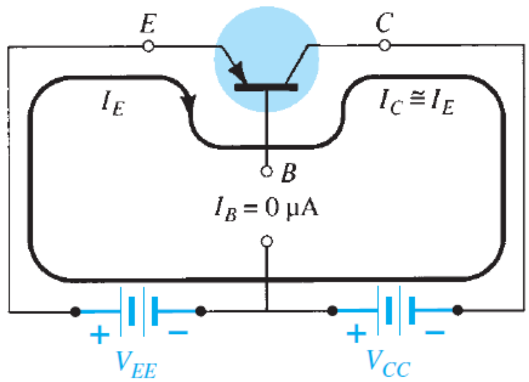
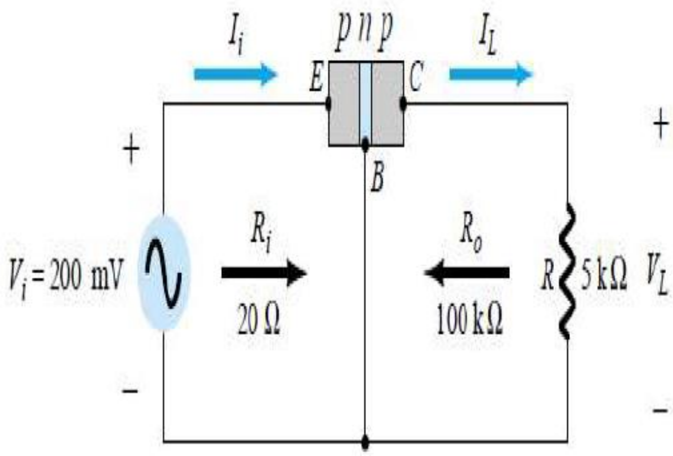


FIG. 3.11

Establishing the proper biasing management for a common-base pnp transistor in the active region.

TRANSISTOR AMPLIFYING ACTION

For the common-base configuration the ac input resistance determined by the characteristics of Fig. 3.7 is quite small and typically varies from 10 to 100 _. The output resistance as determined by the curves of Fig. 3.8 is quite high (the more horizontal the curves the higher the resistance) and typically varies from 50 k_ to 1 M_ (100 k_ for the transistor of Fig. 3.12). The difference in resistance is due to the forward-biased junction at the input (base to emitter) and the reverse-biased junction at the output (base to collector). Using a common value of 20 _ for the input resistance, we find that



$$I_i = \frac{V_i}{R_i} = \frac{200\ \text{mV}}{20\ \Omega} = \mathbf{10\ mA}$$

If we assume for the moment that $\alpha_{ac} = 1$ $(I_c = I_e)$,

$$I_L = I_i = 10\ \text{mA}$$

and

$$V_L = I_L R$$
$$= (10\ \text{mA})(5\ \text{k}\Omega)$$
$$= \mathbf{50\ V}$$

I_i p n p I_L

The voltage amplification is

$$A_v = \frac{V_L}{V_i} = \frac{50\ \text{V}}{200\ \text{mV}} = \mathbf{250}$$

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