BJT – Part IV

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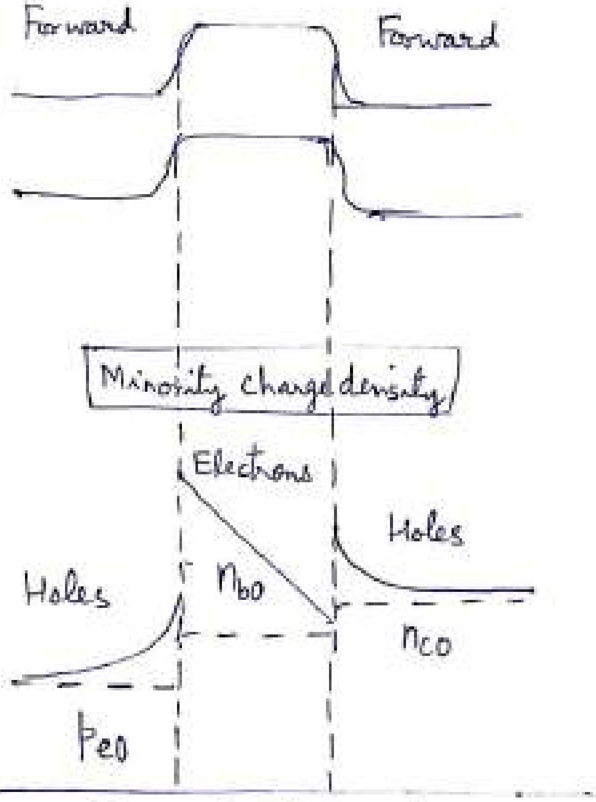
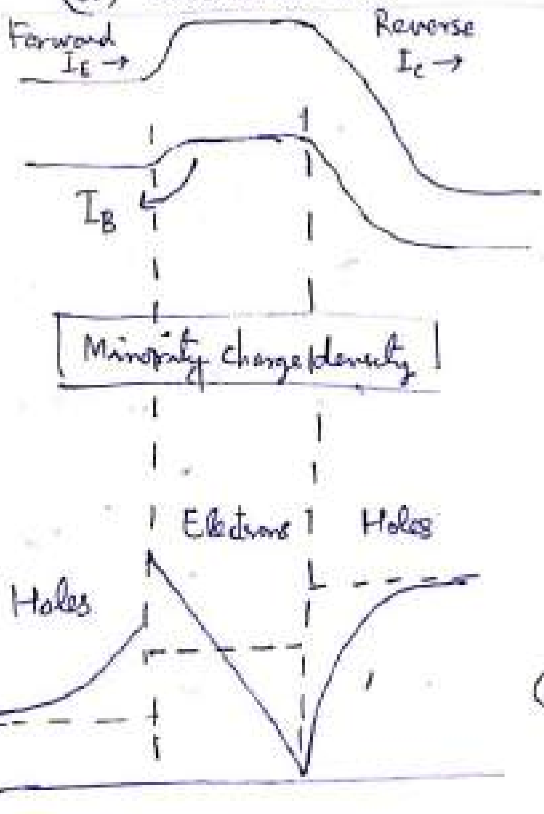
To understand the operation of a BJT as an amplifier or switching device it is useful to examine the device under conditions of saturation, forward active (or reverse active) and cut off. In Fig. 15, we show



(a) Saturation mode



(b) Forward active mode

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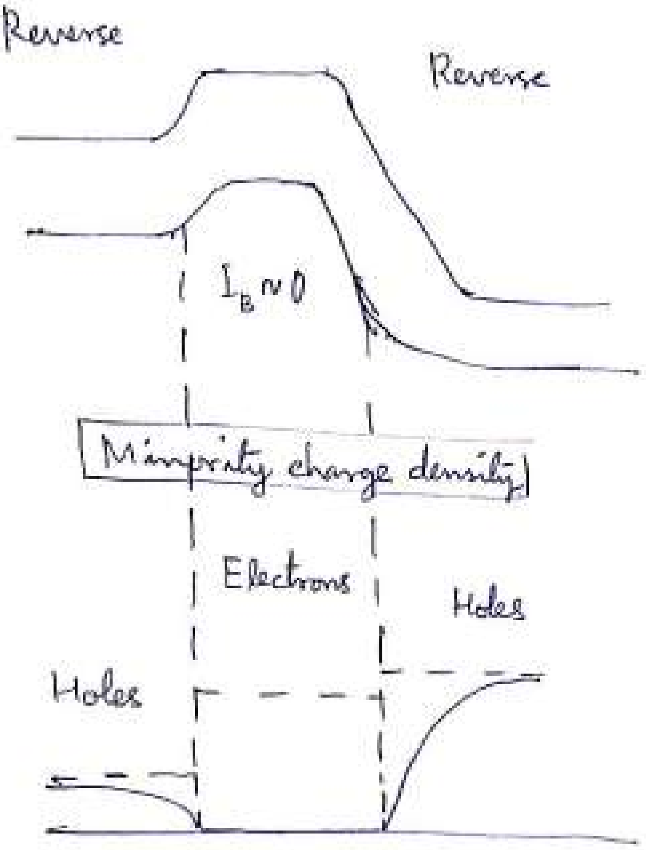

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(c) Cut off mode

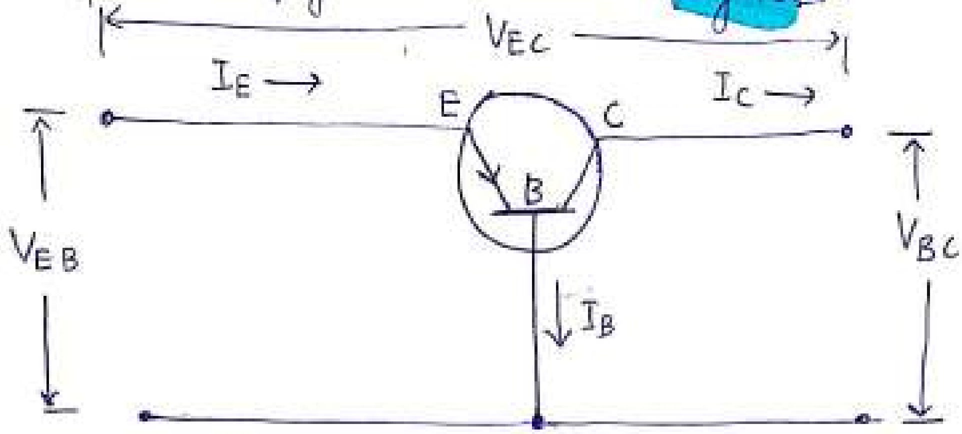
Fig. 15. The band profile and minority charge distribution in a BJT under (a) saturation, (b) forward active and (c) cut off modes

The band profile and the minority carrier distribution for each of these modes. Note that in saturation where both EBJ and BCJ are forward biased, a large minority carrier density (electrons for the NPN device) is injected into the base region. This plays an important role in device switching, as will be discussed later. In cutoff mode there is essentially no minority charge in the base, since the EBJ and BCJ are both reverse biased. In forward ~~bias~~ active mode, the mode used for amplifiers, the EBJ is forward biased while the BCJ is reverse biased. Under this mode $I_C >> I_B$, providing current gain.

(P.T.O.)

BJT-BIASING IN CIRCUITS

The three terminal bipolar transistor can be biased in one of three different configurations shown in Fig. 16(a).



(a) Common base

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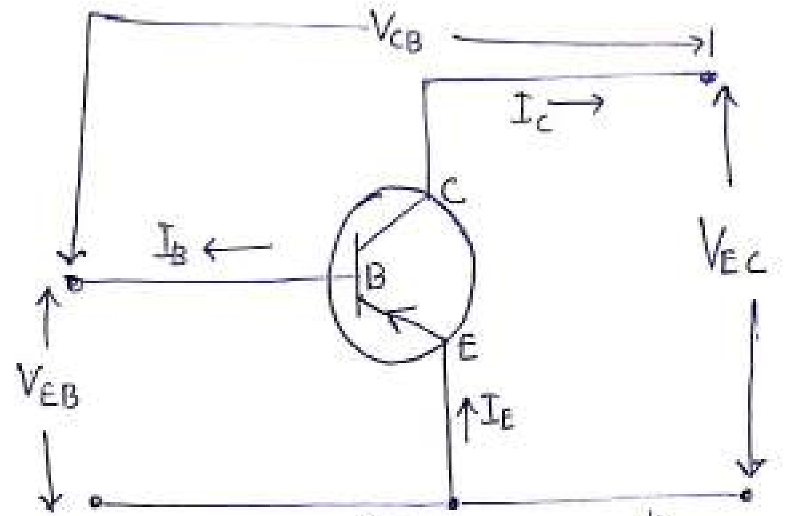
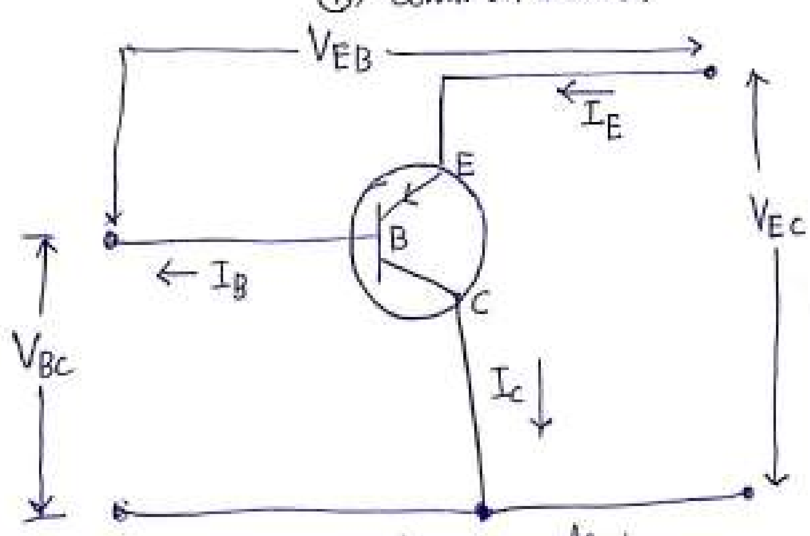


(b) Common emitter



(c) Common collector

Fig. 16 Three possible configurations under which a BJT can be used in circuits.

The configuration chosen depends upon the applications. As shown, one of the terminals can be chosen as a common terminal between the input and output terminals. The full I-V characteristics of a BJT in the common-base and common-emitter configuration are shown in Fig. 17.

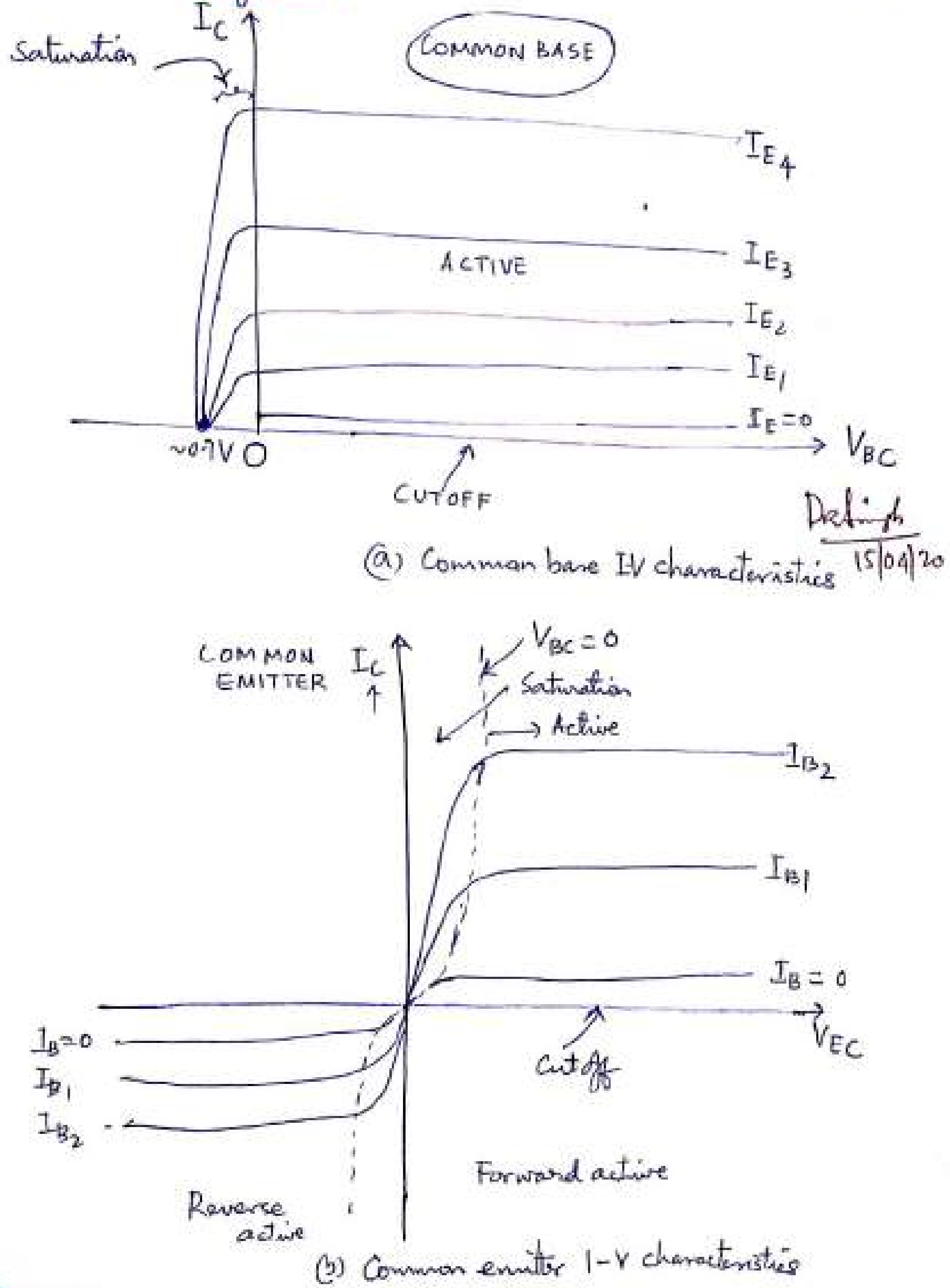


Fig. 17 A schematic of the current-voltage characteristics of a BJT in the (a) common base (b) common emitter configurations.

In the common-base configuration the cut off mode occurs when the emitter current is zero. Note that the emitter current is finite, the collector current does not go to zero at $V_{CB} = 0$. The BCJ has to be forward biased at the turn on voltage ($\sim 0.7V$ for Si devices) to balance the injected emitter current.

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In common-emitter mode, the cutoff mode occurs when the base current is zero and indicates the region where the EBJ is no longer forward biased. The saturation region is represented by the region where $V_{CE} = V_{BE}$ and both EBJ and BCJ are forward biased.

CURRENT-VOLTAGE: THE EBERS-MOLL MODEL

It is useful in circuit applications to represent the I-V characteristics derived by us in terms of a simple physical model. Several models have been developed to do so. Here we will discuss the Ebers-Moll model. We can write the current given in Eqs. (21) and (28) as

$$I_E = -I_{ES}\left[\exp\left(\frac{eV_{BE}}{k_BT}\right) - 1\right] + \alpha_R I_{CS}\left[\exp\left(-\frac{eV_{CB}}{k_BT}\right) - 1\right] \rightarrow (32)$$

$$I_C = \alpha_F I_{ES}\left[\exp\left(\frac{eV_{BE}}{k_BT}\right) - 1\right] - I_{CS}\left[\exp\left(-\frac{eV_{CB}}{k_BT}\right) - 1\right] \rightarrow (33)$$

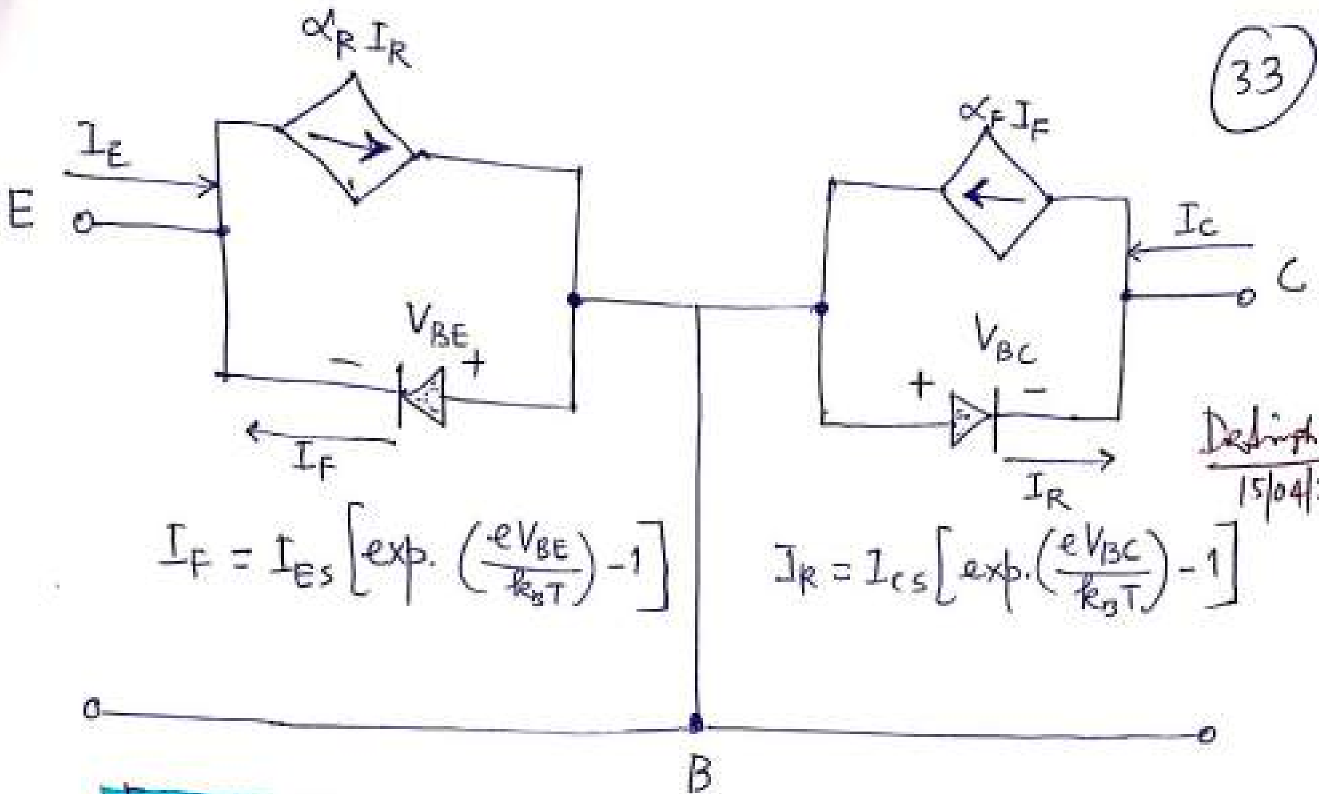
Where

$$I_{ES} = \frac{eAD_b n_{bo}}{L_b} \coth\left(\frac{W_{bn}}{L_b}\right) + \frac{eAD_e p_{eo}}{L_e} \rightarrow (34)$$

$$I_{CS} = \frac{eAD_c p_{co}}{L_c} + \frac{eAD_b n_{bo}}{L_b} \coth\left(\frac{W_{bn}}{L_b}\right) \rightarrow (35)$$

$$\alpha_F I_{ES} = \alpha_R I_{CS} = \frac{eAD_b n_{bo}}{L_b \sinh\left(\frac{W_{bn}}{L_b}\right)} \rightarrow (36)$$

Notice the symmetry underlying these equations. This symmetry allows us to develop a simple model described in Fig. 18.



$$I_F = I_{ES}\left[\exp.\left(\frac{eV_{BE}}{k_BT}\right) - 1\right] \qquad I_R = I_{CS}\left[\exp.\left(\frac{eV_{BC}}{k_BT}\right) - 1\right]$$

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Fig. 18. The Ebers-Moll equivalent circuit of a bipolar transistor [looks at the device as made up of two coupled diodes]

The parameter α_F represents the common-base current gain in the forward active mode, I_{CS} gives the reverse bias BCJ current, α_R is the common-base current gain for the inverse active mode (i.e., EBJ is reverse biased and CBJ is forward biased) and I_{ES} gives the reverse-bias EBJ current. These equations represent two diodes that rely are coupled to each other. The Ebers-Moll model is primarily useful to develop a physical description of the bipolar device.

An important application of the Ebers-Moll model is to find ~~out~~ the conditions for the saturation mode. In the common-emitter mode, the saturation condition is given by

$$V_{CE}(sat) = V_{BE} + V_{CB} = V_{BE} - V_{BC} \longrightarrow (37)$$

NOTE: Both V_{BE} and V_{BC} ($= -V_{CB}$) are positive.

We also have the current conservation expression

$$I_E + I_B + I_C = 0 \longrightarrow (38)$$

Using this equation to eliminate I_E from Eq. (32), we can obtain the values of V_{BE} and V_{BC} in terms of I_C, I_B and the parameters I_{ES}, I_{CS}, α_R and α_F. This gives for $V_{CE(sat)}$

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$$V_{CE(sat)} = V_{BE} - V_{BC}.$$

$$= \frac{k_B T}{e} \log_e \left[\frac{I_C(1-\alpha_R) + I_B}{\alpha_F I_B - (1-\alpha_F) I_C} \cdot \frac{I_{CS}}{I_{ES}} \right] \longrightarrow (39)$$

Substituting for I_{CS}/I_{ES} from Eq. (36), we get

$$V_{CE(sat)} = \frac{k_B T}{e} \log_e \left[\frac{I_C(1-\alpha_R) + I_B}{\alpha_F I_B - (1-\alpha_F) I_C} \cdot \frac{\alpha_F}{\alpha_R} \right] \longrightarrow (40)$$

NOTE:

Typical values of $V_{CE(sat)}$ are 0.1 V and 0.2 V.