Lecture-7
Bipolar Junction Transistors (BJT)
Part-I Continued

1. **Common-Emitter (CE) Configuration:** Most BJT circuits employ the common-emitter configuration shown in Fig.1. This is due mainly to the fact that it is desirable to use the small base current as the control quantity rather than the emitter current. In the CE configuration, I_B, the input current, and V_{CE}, the output voltage, are the independent variables, whereas the input voltage V_{BE} and the output current I_C are the dependent variables. *npn* devices are most prevalent in both ICs and discrete component circuits which employ BJTs. Our discussion of the CE configuration concentrates on *npn* transistors. Most prevalent BJT which is a widely used industry is 2N2222A.

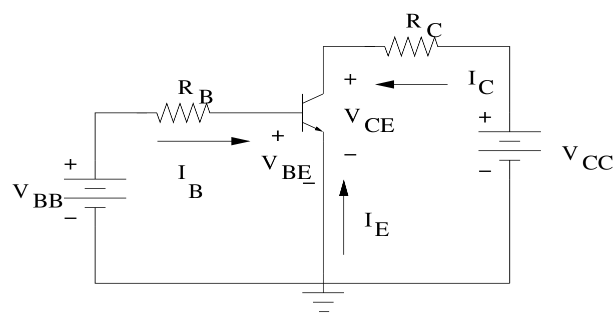

Figure 1: A Common Emitter circuit employing an *npn* transistor

(a) The Output Characteristics: The common-emitter output characteristics is the family of curves shown in Fig.2 in which I_C versus V_{CE} is plotted for various values of I_B. A load line corresponding to $R_C = 500\ \Omega$ and a supply voltage $V_{CC} = 10\ V$ has been superimposed on these characteristics. The output characteristics display three regions of operation, as did the common-base characteristics. The active region is discussed here; cut off and saturation are considered in the next section. In the active region, for an *npn* transistor, Eqn. (7) of LN-6 must be modified as

$$I_C = -\alpha_F I_E - I'_{C0}(e^{-V_{CB}/V_T} - 1) \tag{1}$$

For forward active region, ($V_{CB} > 0$, as collector base junction is reverse biased $\Rightarrow e^{-V_{CB}/V_T} \ll 1$). Hence we have

$$I_C = -\alpha_F I_E + I'_{C0} \tag{2}$$

Combination of this equation with Eqn. (10) of LN-5, yields, i.e, substituting $I_E = -(I_C + I_B)$ and re-arranging the terms we have,

$$I_C = \frac{\alpha_F I_B}{1-\alpha_F} + \frac{I'_{C0}}{1-\alpha_F} \qquad (3)$$

Indentifing $\beta_F = \alpha_F/(1-\alpha_F)$ we have the above equation written as

$$I_C = \beta_F I_B + (\beta_F + 1)I'_{C0} \qquad (4)$$

Typical of BJT operation in the active region is the fact that $I_B \gg I'_{C0}$. Thus we have

$$I_C = \beta_F I_B \qquad (5)$$

is an excellent approximation of the collector current and is used extensively. Eqn. (5) indicates controlled-source behavior in the active mode. By controlling the input current I_B, we can specify the output current I_C. The *dc forward current gain* h_{FE} is a quantity specified by device manufacturers and is defined as

$$h_{FE} = \frac{I_C}{I_B} \approx \beta_F \qquad (6)$$

The subscripts F and E denote "forward transfer" and common emitter,

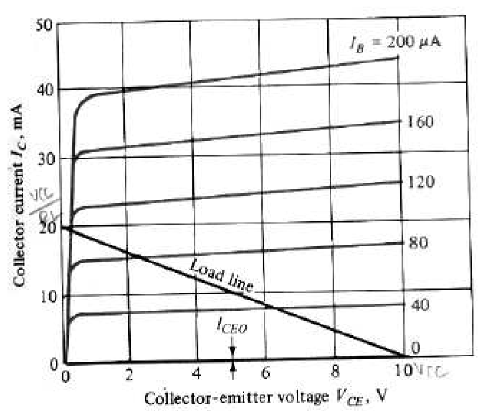

Figure 2: A Common Emitter output characteristics of *npn* transistor. A load line is superimposed

respectively. Because I'_{C0} is, in general, negligible compared with other currents in the active region, h_{FE} and β_F have essentially the same values.

If α_F were truly constant, then, according to Eqn. (3), I_C would be independent of V_{CE} and the curves of Fig. 2 would be horizontal. Assume that, because of the Early effect, α_F increases by only 0.1 percent, from 0.995 to 0.996, as $|V_{CE}|$ increases from a few volts to 10 V. Then the value of β_F increases From $0.995/(1-0.995) = 200$ to $0.996/(1-0.996) = 250$, or about 25 percent. This numerical example illustrates that a very small change (0.1 percent) in α_F is reflected in a very large change (25 percent) in the value of F and hence on the common-emitter curves. Therefore, the common-emitter characteristics are normally subject to a wide variation even among transitions of a given type. This variation in β_F is an important consideration in circuit design. The influence of the Early effect on the CE output curves is demonstrated graphically in Fig. 3. In Fig. 3 we plot curves of I_C versus V_{CE} for various values of V_{BE} for a "typical" *npn* transistor. If we extend the linear portion of these curves back to the V_{CE} axis, as is indicated by the dashed lines, they would all meet at the common point $-V_A$. The voltage V_A is called the *Early voltage* for which typical values lie between 50 and 100 V. The Early voltage determines the slope of the I_C versus V_{CE} characteristic (in Fig.3) for a given operating value of V_{BE}. The reciprocal of this slope has the dimensions of ohms, and, in succeeding section dealing with BJT models, this effect will manifest itself as a resistance associated with the controlled source.

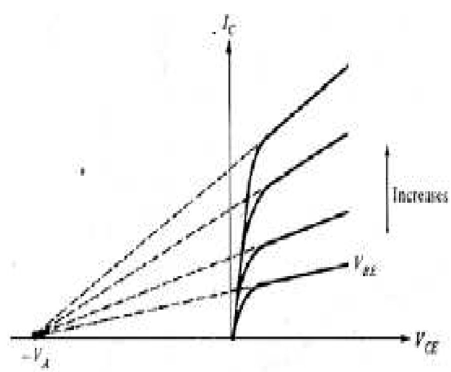

Figure 3: Common-emitter output characteristics for an npn transistor with V_{BE} as a parameter. The curves are extended back (dashed lines) to the negative V_{CE} axis and intersect as the Early voltage

(b) The Input Characteristics: The input characteristics (shown in Fig. 4) are curves which display the relationship between I_B and V_{BE} for different values of V_{CE}. We observe that, with the collector shorted to the emitter and the emitter forward- Biased, the input characteristic is essentially that of a forward-biased diode. If V_{BE} becomes zero, then I_B will be zero, since under these conditions both emitter and collector junctions will be short-circuited. In general, increase in $|V_{CE}|$ with constant V_{BE} causes a decrease in base width W due to the Early effect and results in a decreasing recombination base current. These considerations account for the shape of input characteristics shown in Fig.4.

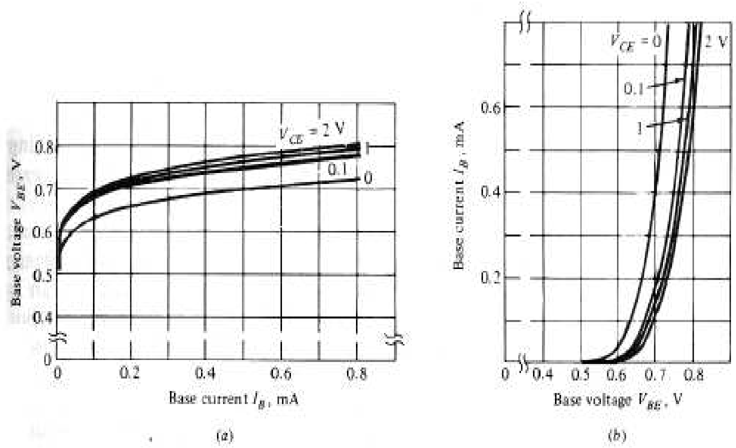

Figure 4: (a) Common-emitter input characteristics (V_{BE} versus I_B) for the 2N2222A transistor; (b) the curves in part a plotted as I_B versus V_{BE}. Note the similarity with the diode characteristic.

(c) Reverse-Active Mode: The Reverse-Active Mode the input and output characteristics of the inverted transistor have the same general shape as in Figs.2 and 4. The reverse-active input characteristics display the behavior of the forward-biased collector-base junction. Recall that in the reverse-active mode, α_R and β_R have lower values than α_F and β_F, respectively. Consequently, for a given value of I_B, lower values of I_E exist in the reverse-active mode than in the forward-active region.

2. **Summary of Voltages:** Typical values of the transistor operating voltages are listed in the Table-1. It is reasonable to expect that the temperature variation of voltage across a forward-biased junction is the same as that for diode, namely, $-2.2\ mV/^oC$. In saturation the transistor consists of two forward biased diodes back to back in series opposing. Hence it is to be anticipated

that the temperature-induced voltage change in one junction will be canceled by the change in the other junction.

Quantity	V_{CE} at edge of saturation	V_{CE}(sat)	V_{BE} Cut-in	V_{BE} Active	V_{BE} Saturation	V_{BE} Cutoff
Value (in V)	0.3	0.2	0.7	0.7	0.8	0

Table 1: Typical Junction Voltages at 25^oC

3. **DC Models:** We can construct a dc model for each operating region of the BJT from the pervious discussions of Ebers-Moll Equations. The model for the forward active region is displayed in the Fig.5(a) and is based on the Eqn.(19) of LN-5. Because reverse saturation currents are generally negligibly small, their effect is usually omitted. The battery in the base-emitter circuit is V_{BE} and from the table-1, is usually 0.7 V. The controlled source relates I_C and I_B in the active region.
   In saturation region, the equilavent circuit is shown in the Fig.5(b) is useful for determinig the currents and voltages in the circuit. The two batteries represent the values of the terminal voltages $V_{BE(\text{sat})}$ and $V_{CE(\text{sat})}$.

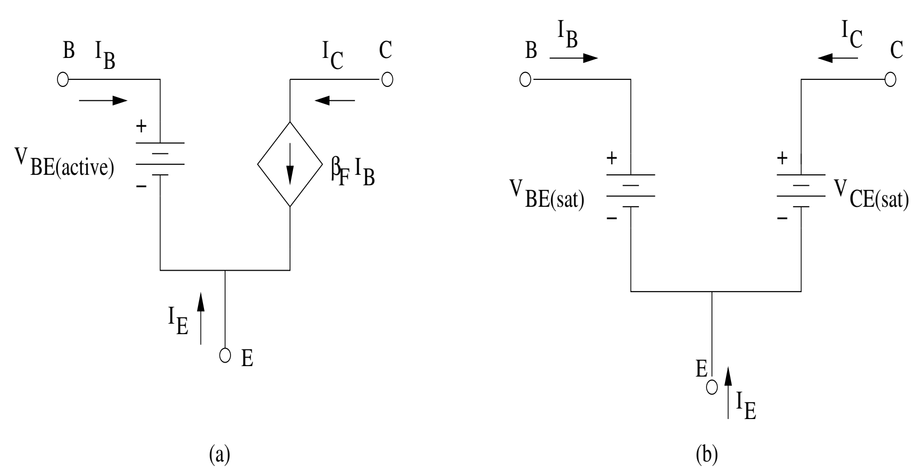

Figure 5: Large-signal (dc) equivalent circuits for an *npn* transistor for (a) forward-active and (b) saturation-region operation

4. **Examples:**

   (a) Example-1: Determine the region of operation and the values of I_B, I_C, and V_{CE} for the circuit shown in the Fig.6(a) for R_B equal to (i) 300 $k\Omega$ and (b) 150 $k\Omega$. The transistor used has $\beta_F = 100$. Neglect the reverse saturation currents.
   Solution: Assume that the transistor is in the forward-active region. Now use the equivalent DC-model shown in the Fig.5(a). Calculate the V_{CE} if $V_{CE} > 0$ then the assumption that the BJT is operating the forward active region is correct otherwise it may be in any of the other modes. Hence we have the circuit shown in the Fig.6(b).
   (i) Writing KVL for the emitter-base loop is

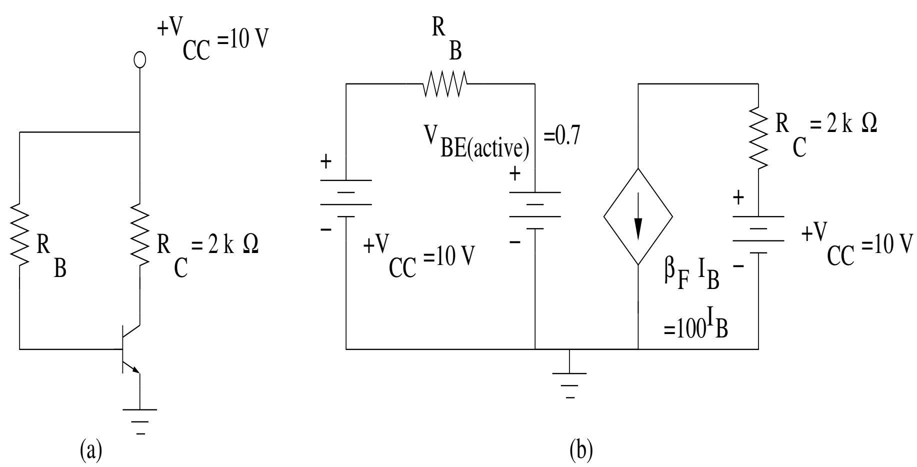

Figure 6: (a) Schematic diagram of the CE configuration; (b) equivalent circuit of the part (a)

$$-V_{CC} + I_B R_B + V_{BE} = 0$$

solving for I_B and subsituting values gives

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = 31.0\mu\ A$$

The collector loop relations are

$$I_C = \beta_F I_B = 3.1\ mA$$

$$-V_{CC} + I_C R_C + V_{CE} = 0 \Rightarrow V_{CE} = 3.80\ V$$

Hence the intial assumption that BJT is operating in the forward-active region is correct.
(ii) Similarly for $R_B = 150\ k\Omega$ we get $I_B = 62.0\ \mu A$, $I_C = 6.20\ mA$ and $V_{CE} = -2.40\ V$ ($V_{CE} < 0.3\ V$). This shows that the assumption that BJT in forward-active region is wrong. Let BJT be in the saturation region. The we have $V_{BE(\text{sat})} = 0.8\ V$ and $V_{CE(\text{sat})} = 0.2\ V$. Using these values we have $I_B = 0.0613\ mA$, $I_C = 4.90\ mA$