Experiment No 2: BJT Characteristics

Theory

The transistor is a two junction, three terminal semiconductor device which has three regions namely the emitter region, the base region, and the collector region. There are two types of transistors. An *npn* transistor has an *n* type emitter, a *p* type base and an *n* type collector while a *pnp* transistor has a *p* type emitter, an *n* type base and *a p* type collector. The emitter is heavily doped, base region is thin and lightly doped and collector is moderately doped and is the largest. The current conduction in transistors takes place due to both charge carriers- that is electrons and holes and hence they are named Bipolar Junction Transistors (BJT).

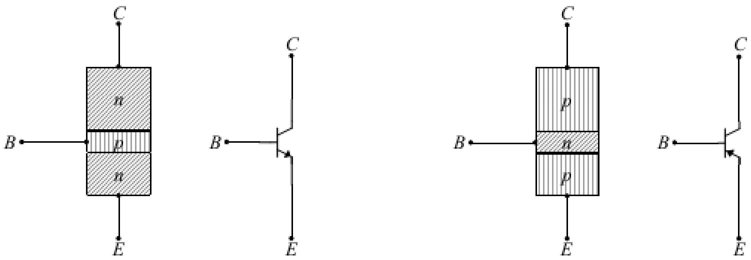

Figure 1 npn and pnp transistor regions and symbol

Depending upon the biasing of the two junctions, emitter-base (EB) junction and collector-base(CB) the transistor is said to be in one of the four modes of operation.

E B Juncion	CB Junction	Mode
Reverse biased	Reverse biased	Cut-off
Forward biased	Reverse biased	Active
Forward biased	Forward biased	Saturation
Reverse biased	Forward biased	Reverse Active

Figure 2 Transistor modes of operation

The transistor is used as a switch in Cut-off (OFF) and Saturation (ON) regions and as an amplifier in Active region. Reverse Active mode is rarely used (it is used as input stage in TTL gates in digital circuits).
The transistor can be considered as a two port network. Three configurations are possible depending upon which terminal acts as input port, output port, and the common terminal. They are common base, common emitter, and common collector configuration. In this experiment we will consider common emitter configuration in which the input is applied between base and emitter, and the output taken at collector with respect to emitter. This is the most popular configuration used in both switches and amplifiers.

Operation of transistor in active mode:

We consider here the active mode of operation, by forward biasing the base-emitter junction and reverse biasing the base-collector junction as shown in Fig 3. Electrons diffuse from the emitter into the base and holes diffuse from the base into the emitter. The electrons diffused into based region become minority carriers in base. Since the base region is lightly doped and thin, very few electrons will recombine with the holes in the base region and contribute to base current and majority of the electrons arrive at the base-collector depletion region and are swept through the depletion layer due to the electric field. These electrons contribute to the collector current. The direction of motion of electrons is shown by the arrows in red colour in Fig 3.

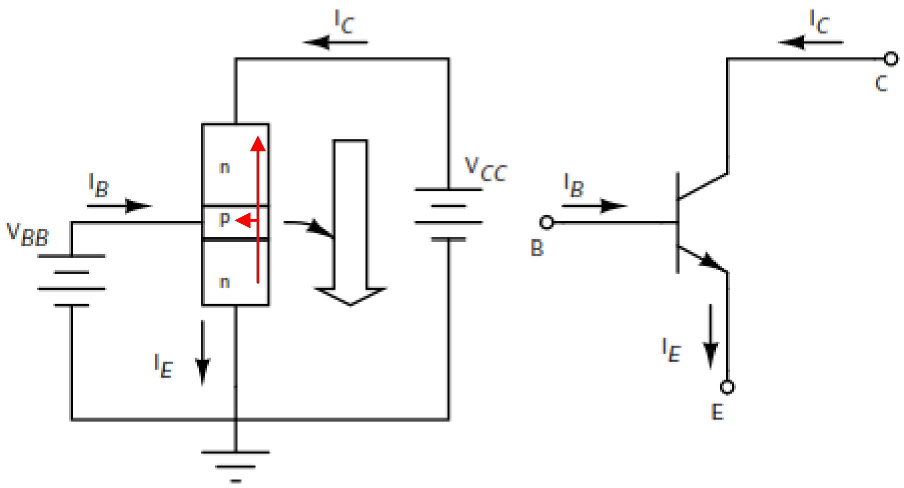

Figure 3 Operation of a transistor

CE input characteristics:

The input characteristics are obtained as family of I_B -V_{BE} curves at constant V_{CE}. Since the base emitter junction is forward biased, the I_B -V_{BE} (Fig.4) characteristics resemble that of a forward biased junction diode. The increase in V_{CE} causes increase in reverse bias to C-B junction. This causes the depletion region to widen and penetrate into the base region more reducing effective base width. This results in less base current to flow and hence increase in V_{CE} causes the characteristics to shift to the right as shown in Fig. 5.

The reciprocal of the slope of the linear part of the characteristic gives the dynamic input resistance of the transistor.

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B}$$

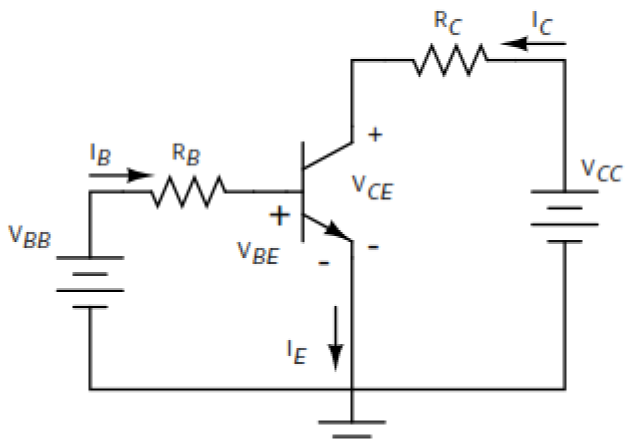

Figure 4 CE characteristics

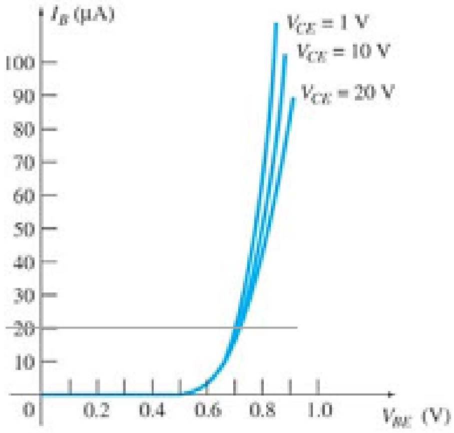

Figure 5 Family of input characteristics

Output Characteristics

These characteristics are obtained as family of I_C-V_{CE} at different values of I_B. At small values of V_{CE}, the collector voltage is less than that of base causing CB junction to get forward biased. This causes the transistor to enter saturation region where both the junctions are forward biased. For a given base bias, increase in VCE reduces the forward bias and eventually reverse bias the CB junction. This now results in narrowing the base width and thereby reducing base current. This makes the collector current to slightly increase at higher values of VCE causing the characteristics to exhibit some slope. This is Early effect. The collector current is given by

$$I_C = I_S e^{\frac{V_{BE}}{V_T}} \left(1 + \frac{V_{CE}}{V_A}\right)$$

where, V_A is Early voltage.

One can estimate Early voltage by extending the linear portion of Ic curves in the second quadrant. All these curves are found to meet at V_A. See Fig. 6.

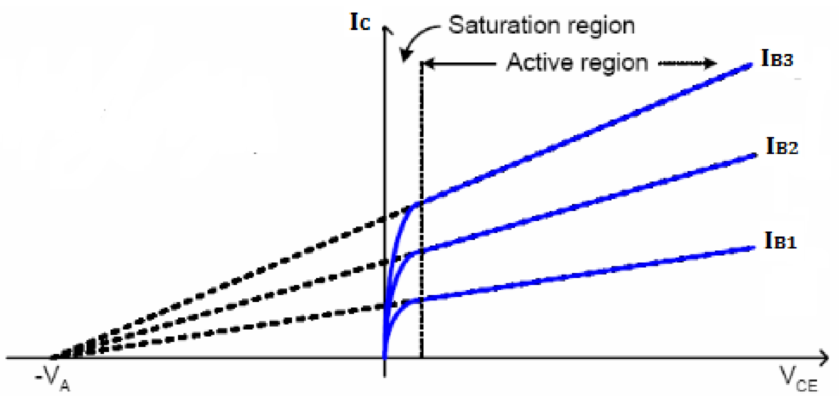

Figure 6 Output characteristics

One can find output conductance from the slope of the linear portion of the characteristic curves and also find $\beta = \frac{\Delta I_C}{\Delta I_B}$ to be defined at a given value of V_{CE}.