3. Power Transistors

Transistors which have high voltage and high current rating are called power transistors. Power transistors used as switching elements, are operated in saturation region resulting in a low - on state voltage drop. Switching speed of transistors is much higher than the thyristors. And they are extensively used in dc-dc and dc-ac converters with inverse parallel connected diodes to provide bi-directional current flow. However, voltage and current ratings of power transistor are much lower than the thyristors. Transistors are used in low to medium power applications. Transistors are current controlled device and to keep it in the conducting state, a continuous base current is required. Power transistors are classified as follows

- Bi-Polar Junction Transistors (BJTs)
- Metal-Oxide Semi-Conductor Field Effect Transistors (MOSFETs)
- Insulated Gate Bi-Polar Transistors (IGBTs)
- Static Induction Transistors (SITs)

3.1 BI-POLAR JUNCTION TRANSISTOR

The need for a large blocking voltage in the off state and a high current carrying capability in the on state means that a power BJT must have substantially different structure than its small signal equivalent. The modified structure leads to significant differences in the I-V characteristics and switching behavior between power transistors and its logic level counterpart.

3.2 POWER TRANSISTOR STRUCTURE

If we recall the structure of conventional transistor we see a thin p-layer is sandwiched between two n-layers or vice versa to form a three terminal device with the terminals named as Emitter, Base and Collector. The structure of a power transistor is as shown below. The difference in the two structures is obvious. A power transistor is a vertically oriented four layer structure of alternating p-type and n-type. The vertical structure is preferred because it maximizes the cross sectional area and through which the current in the device is flowing. This also minimizes on-state resistance and thus power dissipation in the transistor. The doping of emitter layer and collector layer is quite large typically 10^{19} cm^{-3}. A special layer called the collector drift region (n^-) has a light doping level of 10^{14}. The thickness of the drift region determines the breakdown voltage of the transistor.

The base thickness is made as small as possible in order to have good amplification capabilities, however if the base thickness is small the breakdown voltage capability of the transistor is compromised. Practical power transistors have their emitters and bases interleaved as narrow fingers as shown. The purpose of this arrangement is to reduce the effects of current crowding. This multiple emitter layout also reduces parasitic ohmic resistance in the base current path which reduces power dissipation in the transistor.

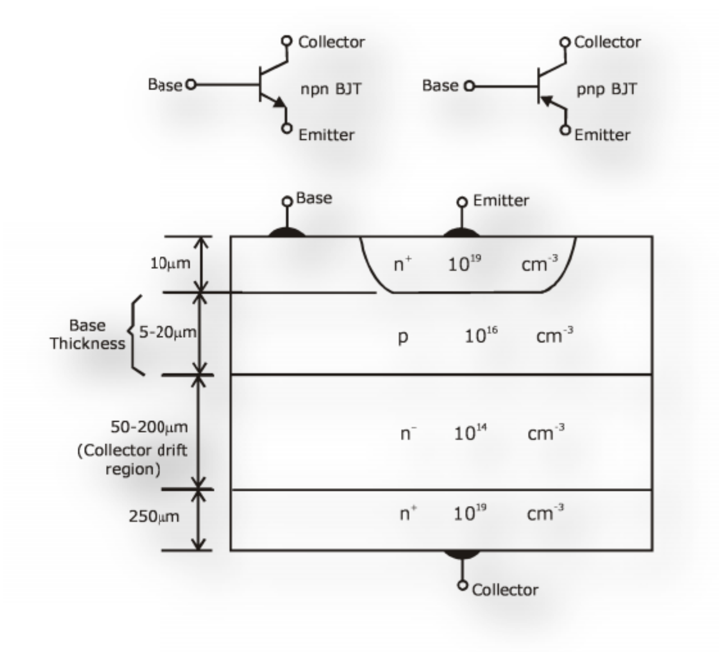

Fig. 1: Structure of Power Transistor

3.2 STEADY STATE CHARACTERISTICS

A Bi-Polar Junction Transistor is a 3 layer, 3 terminals device. The 3 terminals are base, emitter and collector. It has 2 junctions' collector-base junction (CB) and emitter-base junction (EB). Transistors are of 2 types, NPN and PNP transistors. The different configurations are common base, common collector and common emitter. Common emitter configuration is generally used in switching applications. The power transistor has steady state characteristics almost similar to signal level transistors except that the V-I characteristics has a region of quasi saturation as shown by figure 5.

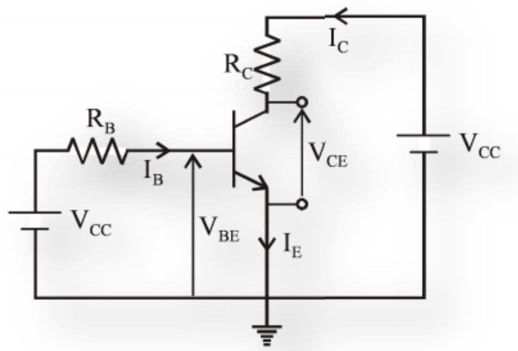

Fig 2 : NPN Transistor

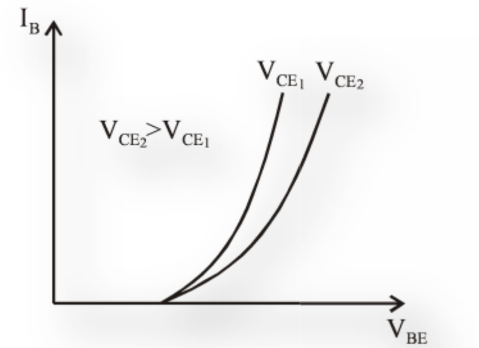

Fig 3: Input Characteristic

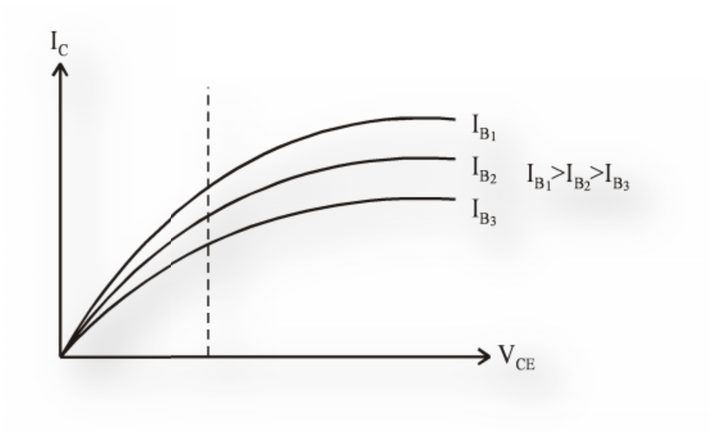

Fig 4: Output / Collector Characteristics

Transistors can be operated in 3 regions i.e., cut-off, active and saturation. In the cut-of region transistor is OFF, both junctions (EB and CB) are reverse biased. In the cut-off state the transistor acts as an open switch between the collector and emitter. In the active region, transistor acts as an amplifier (CB junction is reverse biased and EB junction is forward biased), In saturation region the transistor acts as a closed switch and both the junctions CB and EB are forward biased.

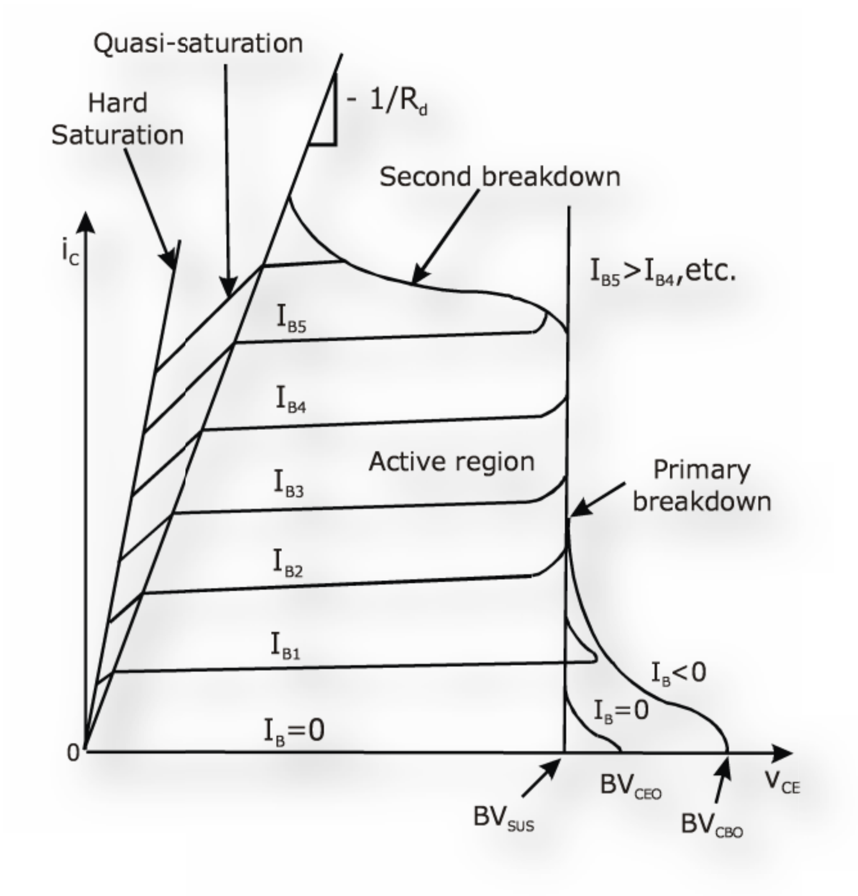

Fig. 5: Characteristics of NPN Power Transistors

There are four regions clearly shown: Cutoff region, Active region, quasi saturation and hard saturation. The cutoff region is the area where base current is almost zero. Hence no collector current flows and transistor is off. In the quasi saturation and hard saturation, the base drive is applied and transistor is said to be on. Hence collector current flows depending upon the load. The power BJT is never operated in the active region (i.e. as an amplifier) it is always operated between cutoff and saturation. The BV_{SUS} is the maximum collector to emitter voltage that can be sustained when BJT is carrying substantial collector current. The BV_{CEO} is the maximum collector to emitter breakdown voltage that can be sustained when base current is zero and BV_{CBO} is the collector base breakdown voltage when the emitter is open circuited. The primary breakdown shown takes place because of avalanche breakdown of collector base junction. Large power dissipation normally leads to primary breakdown. The second breakdown shown is due to localized thermal runaway.

3.3 TRANSFER CHARACTERISTICS

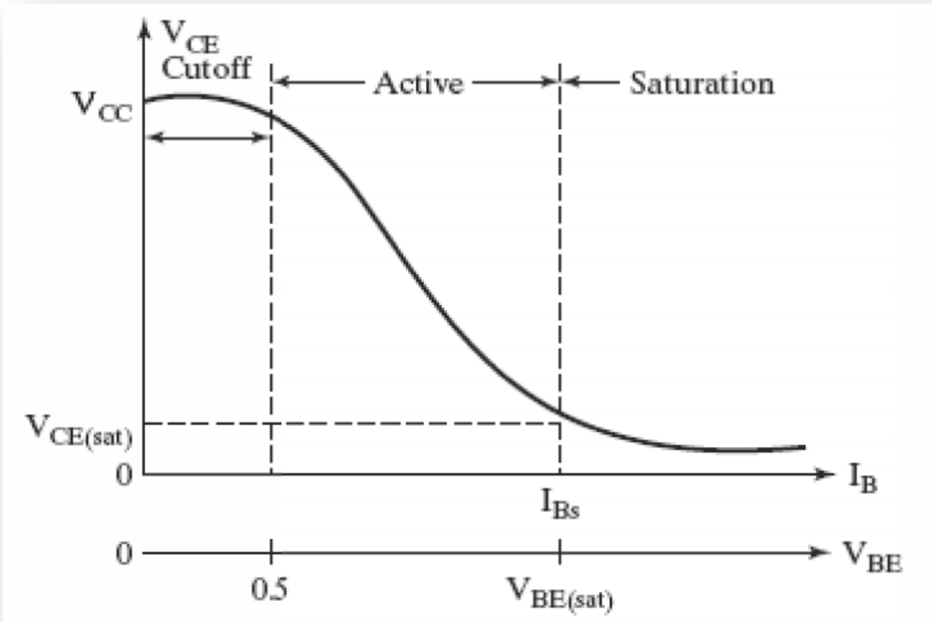

Fig. 6: Transfer Characteristics

$$I_E = I_C + I_B$$

$$\beta = h_{fE} = \frac{I_C}{I_B}$$

$$I_C = \beta I_B + I_{CEO}$$

$$\alpha = \frac{\beta}{\beta + 1}$$

$$\beta = \frac{\alpha}{1 - \alpha}$$

3.4 SWITCHING CHARACTERISTICS

An important application of transistor is in switching circuits. When transistor is used as a switch it is operated either in cut-off state or in saturation state. When the transistor is driven into the cut-off state it operates in the non-conducting state. When the transistor is operated in saturation state it is in the conduction state. Thus the non-conduction state is operation in the cut-off region while the conducting state is operation in the saturation region.

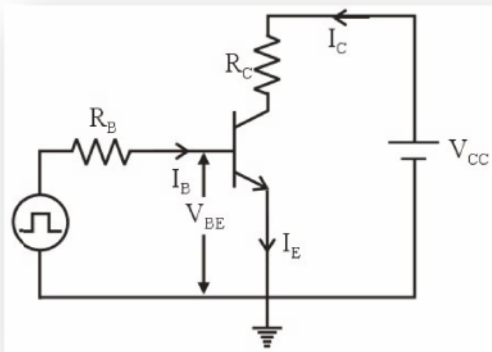

Fig 7: Switching Transistor in CE Configuration

As the base voltage V_B rises from 0 to V_B, the base current rises to I_B, but the collector current does not rise immediately. Collector current will begin to increase only when the base emitter junction is forward biased and V_{BE} > 0.6V. The collector current I_C will gradually increase towards saturation level $I_{C(sat)}$. The time required for the collector current to rise to 10% of its final value is called delay time t_d. The time taken by the collector current to rise from 10% to 90% of its final value is called rise time t_r. Turn on times is sum of t_d and t_r.

$$t_{on} = t_d + t_r$$

The turn-on time depends on

- Transistor junction capacitances which prevent the transistors voltages from changing instantaneously.
- Time required for emitter current to diffuse across the base region into the collector region once the base emitter junction is forward biased. The turn on time t_{on} ranges from 10 to 300 ns. Base current is normally more than the minimum required to saturate the transistor. As a result excess minority carrier charge is stored in the base region.

When the input voltage is reversed from V_{B1} to $-V_{B2}$ the base current also abruptly changes but the collector current remains constant for a short time interval t_S called the storage time. The reverse base current helps to discharge the minority charge carries in the base region and to remove the excess stored charge form the base region. Once the excess stored charge is removed the baser region the base current begins to fall towards zero. The fall-time t_f is the time taken for the collector current to fall from 90% to 10% of $I_{C(sat)}$. The turn off time t_{off} is the sum of storage time and the fall time. $t_{off} = t_s + t_f$

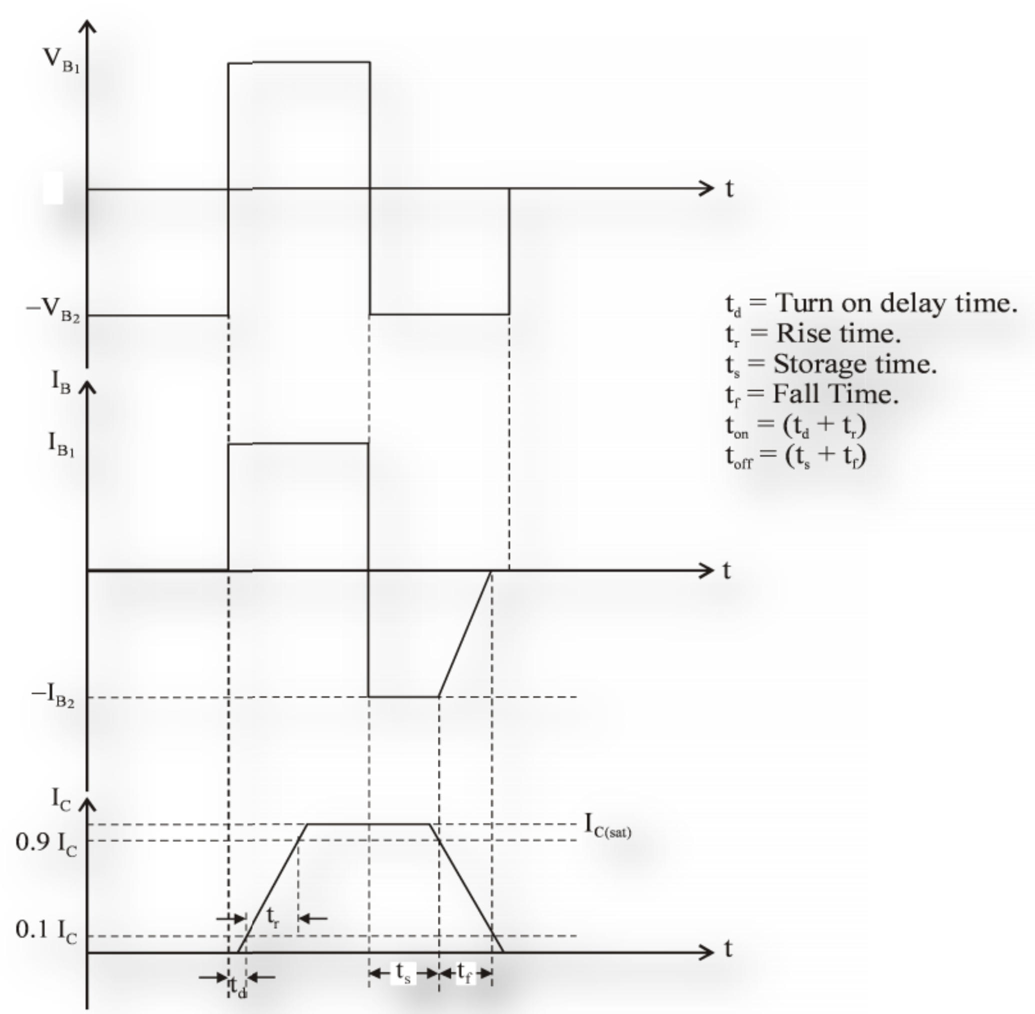

Fig 8: Switching Times of Bipolar Junction Transistor