Module-2
Power Transistors

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Module-2

Power Transistors: Introduction, Bipolar Junction Transistors – Steady State Characteristics, Switching Characteristics, Switching Limits, Power MOSFETs – Steady State Characteristics, Switching Characteristics, IGBTs; BJT Base Drive, MOSFET Gate Drive, Isolation of Gate and Base Drives, Pulse transformers and Optocouplers.

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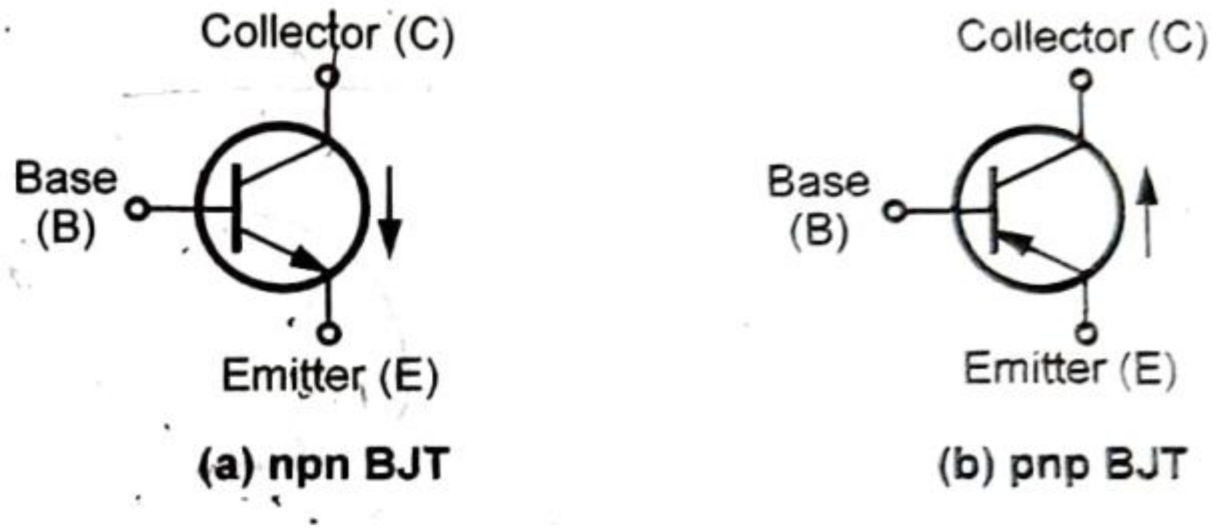
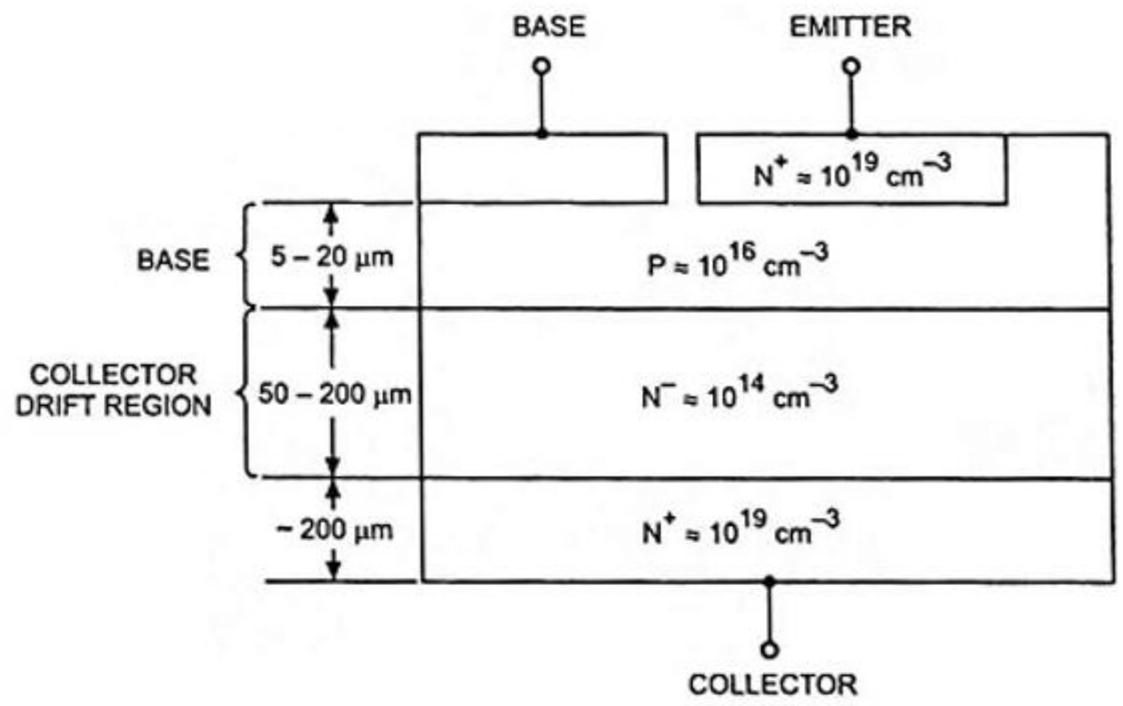
Introduction: Power transistors are devices that have controlled turn-on and turn-off characteristics. These devices are used a switching devices and are operated in the saturation region resulting in low on-state voltage drop. They are turned on when a current signal is given to base or control terminal. The transistor remains on so long as the control signal is present. Power transistors are classified as follows.

- Bipolar Junction Transistor(BJT)
- Metal-oxide semiconductor filed-effect transistors(MOSFETs)
- Static Induction transistors(SITs)
- Insulated-gate bipolar transistors(IGBTs)

Power Bipolar Junction Transistors (BJT):

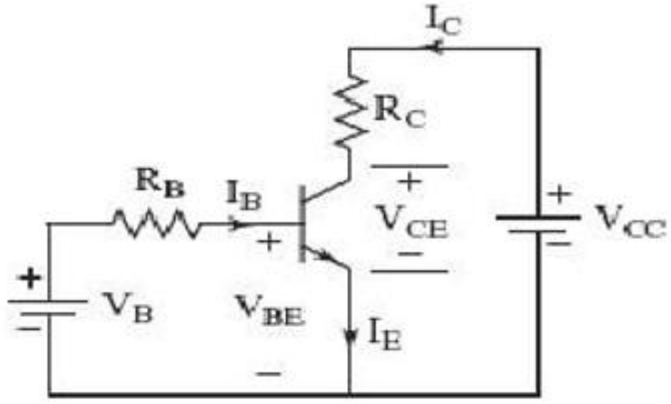


Structure of BJT:

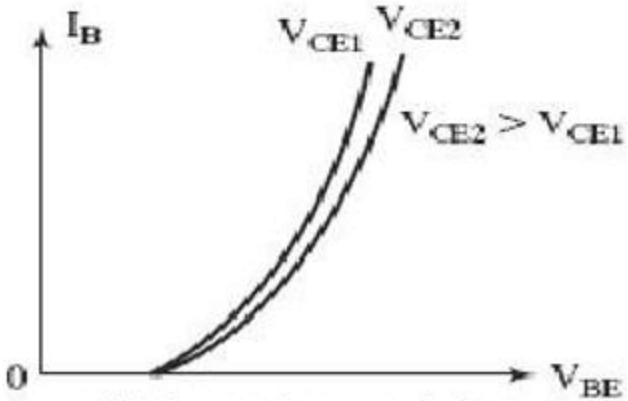


Cross Section of Typical Vertical NPN Power BJT

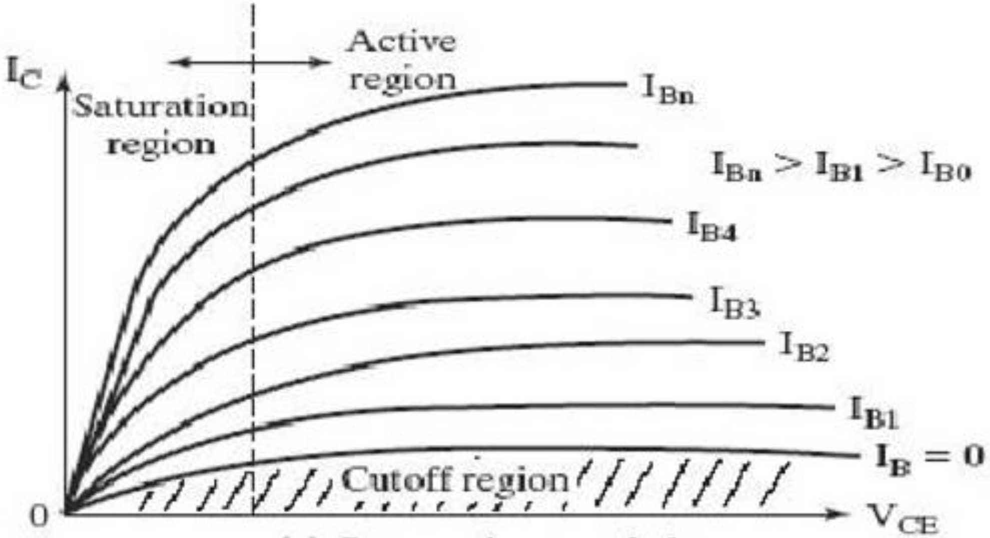
Steady State Characteristics of BJT:



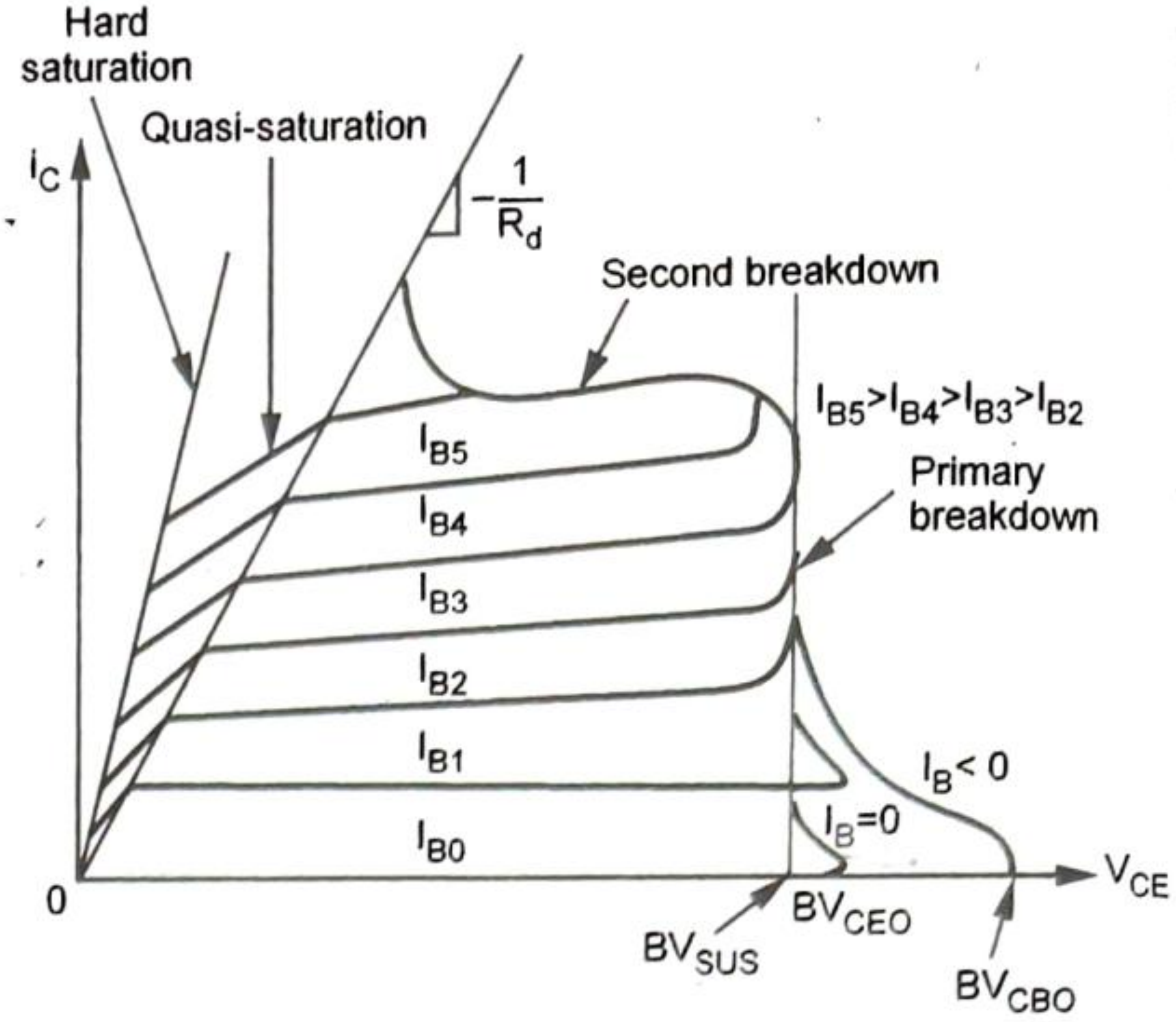
(a) Circuit diagram



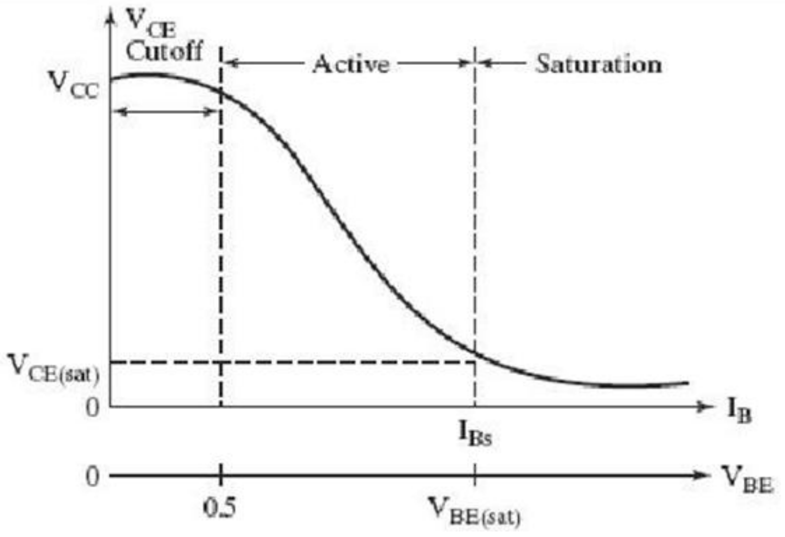
(b) Input characteristics



(c) Output characteristics

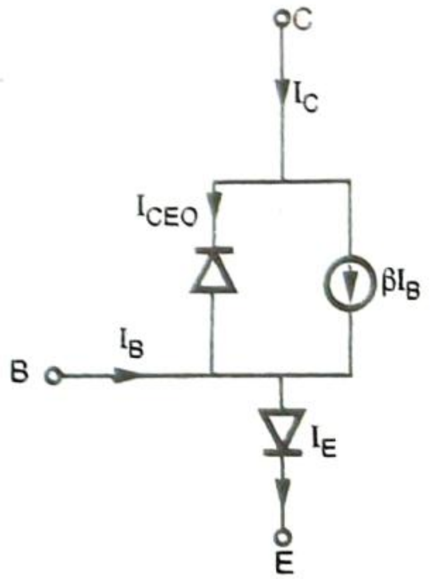


Transfer Characteristics



1) Cut off Region: BE and CB →RB
2) Active Region: BE →FB , CB →RB
3) Quasi Saturation: BE and CB →FB
4) Hard Saturation: BE and CB →FB

Mathematical Analysis:



The current gain (β) of the transistor is,

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

The collector, emitter and base currents are related as,

$$I_E = I_C + I_B$$

$$I_E = \beta I_B + I_B = (\beta + 1) I_B$$

$I_B = \frac{I_C}{\beta}$, hence above equation will be,

$$I_E = \frac{\beta + 1}{\beta} I_C$$

$$I_C = \alpha I_E$$

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

Transistors as a switch:

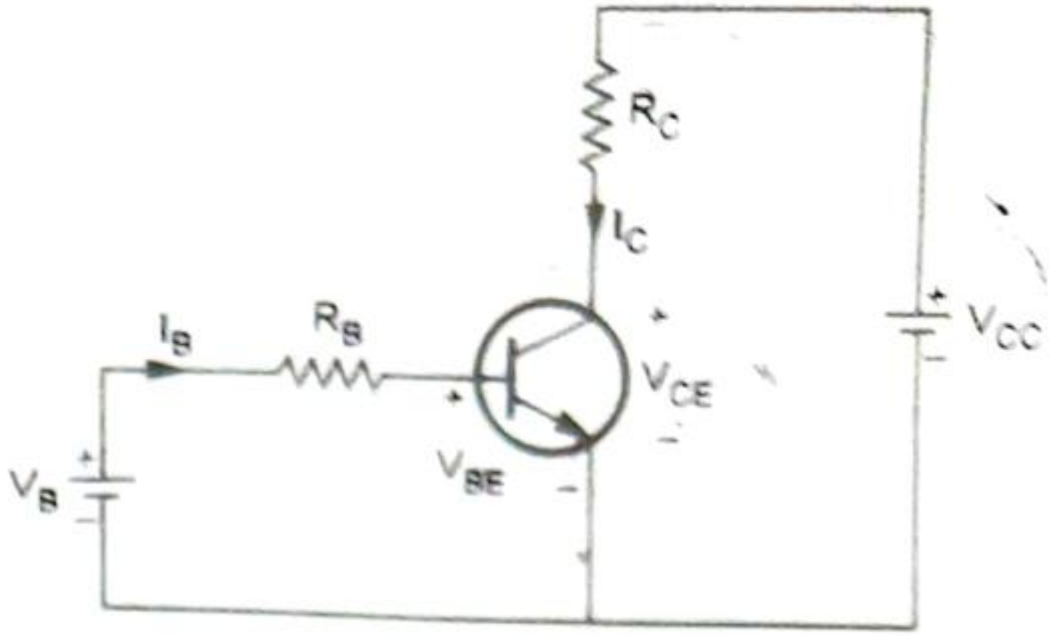
$$I_B = \frac{V_B - V_{BE}}{R_B}$$

$$V_C = V_{CE} = V_{CC} - I_C R_C$$

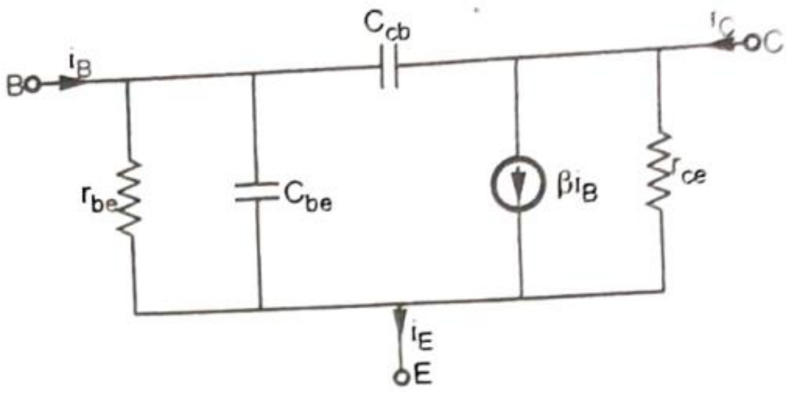
$$V_C = V_{CC} - \beta \frac{R_C \ \ V_B - V_{BE}}{R_B}$$

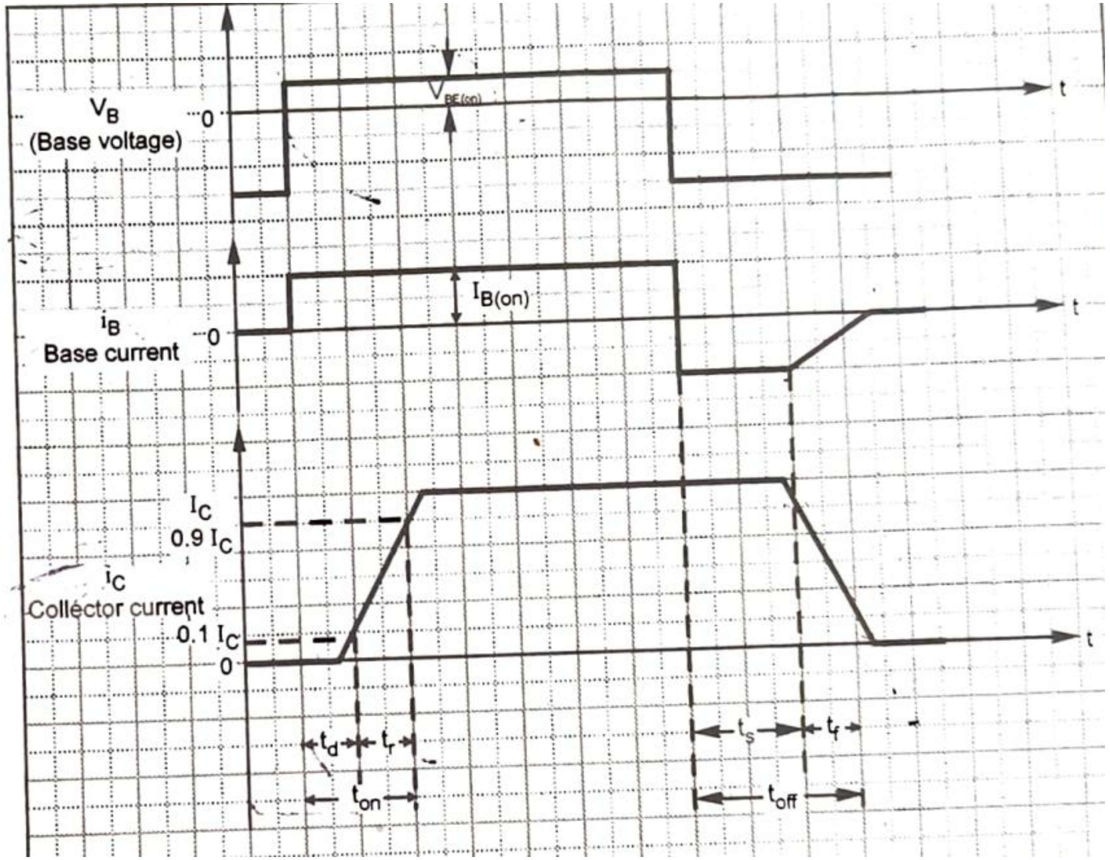
$$V_{CE} = V_{CB} + V_{BE}$$

$$V_{CB} = V_{CE} - V_{BE} \qquad \text{.... (1)}$$



Switching characteristics of BJT:

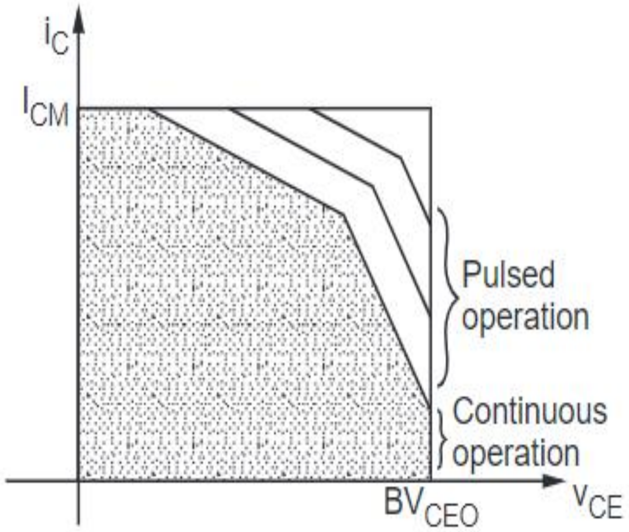




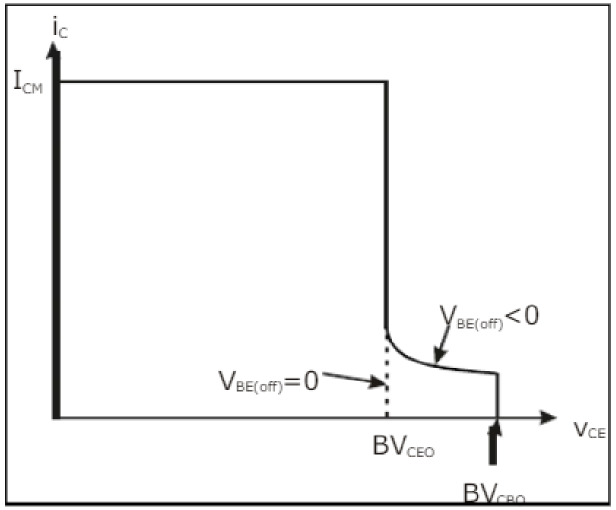
Switching Limits:

1. **Second Breakdown:** It is a destructive phenomenon that results from the current flow to a small portion of the base, producing localized hot spots. If the energy in these hot spots is sufficient the excessive localized heating may damage the transistor.

2. Forward Biased Safe Operating Area FBSOA: During turn-on and on-state conditions, the average junction temperature and second breakdown limit the power handling capability of a transistor. The manufacturer usually provides the FBSOA curves under specified test conditions. FBSOA indicates the Ic – Vce limits of the transistor and for reliable operation the transistor must not be subjected to greater power dissipation than that shown the FBSOA curve.



Reverse Biased Safe Operating Area RBSOA: During turn-off, a high current and high voltage must be sustained by the transistor, in most cases with the base-emitter junction reverse-biased. The collector-emitter voltage must be held to a safe level at or below a specified value of collector current. The manufacturer provides Ic -Vce during reverse-biased turn off as reverse-biased safe area (RBSOA)



Breakdown Voltages:

BV_{SUS}: The maximum voltage between the collector and emitter that can be sustained across the transistor when it is carrying substantial collector current

BV_{CEO}: The maximum voltage between the collector and emitter terminal with a base open circuited.

BV_{CBO}: This is the collector to base break down voltage when the emitter is open-circuited.

Base Drive Control: This is required to optimize the base drive of the transistor sufficient base current is required to drive BJT is saturation. Storage time determines turn-on and turn-off times of BJT.
Some common types of optimizing base drives of transistors are

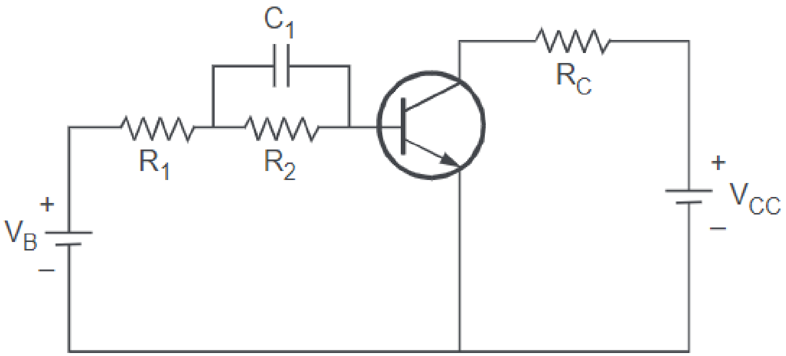
1. Turn on Control

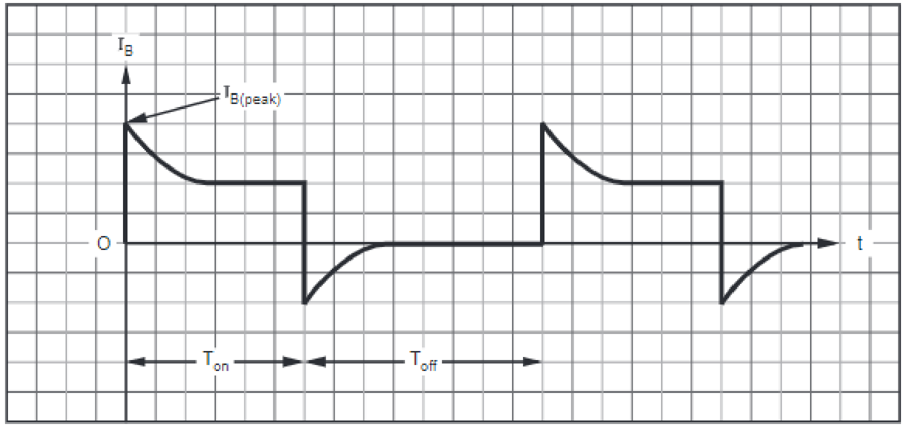
2. Turn off Control

3. Proportional Base Control

4. Anti-Saturation Control

Turn on Control:



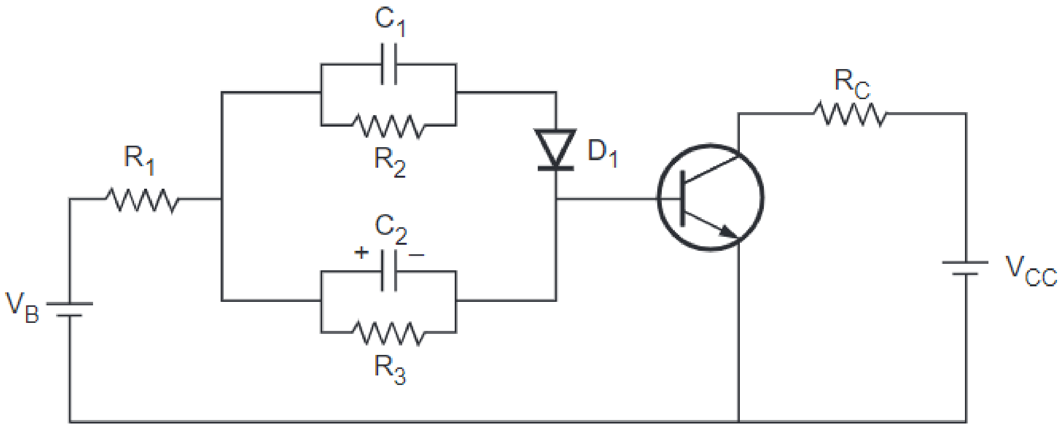


$$I_{B(peak)} = \frac{V_B - V_{BE}}{R_1}$$

$$\tau_2 = R_2 C_1$$

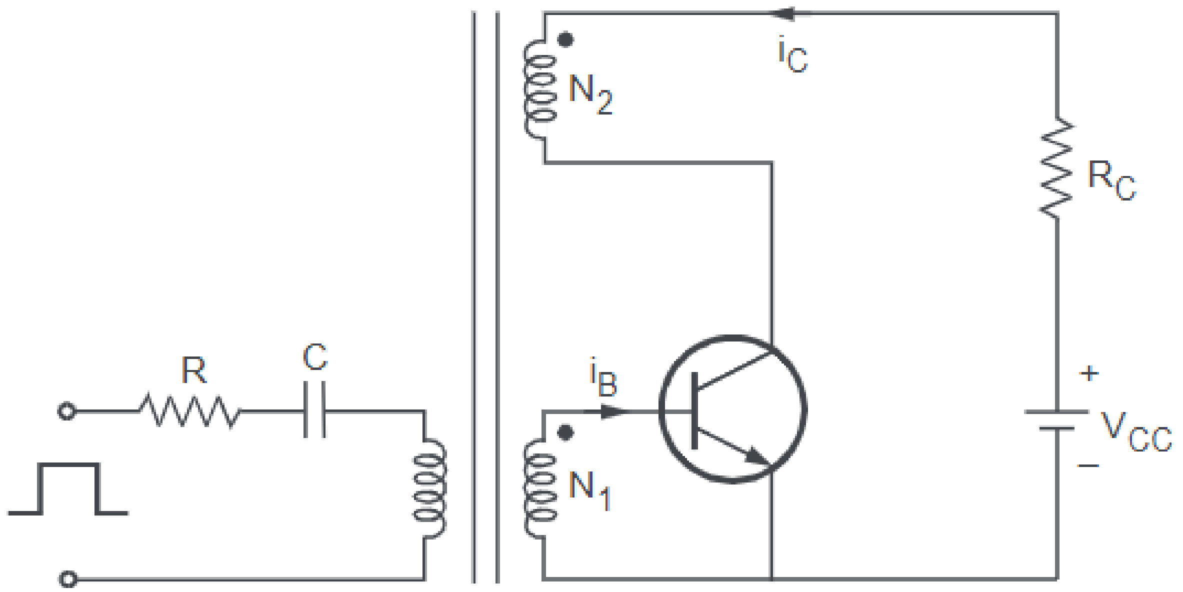
$$\tau_1 = \frac{R_1 R_2 C_1}{R_1 + R_2}$$

Turn-off Control:



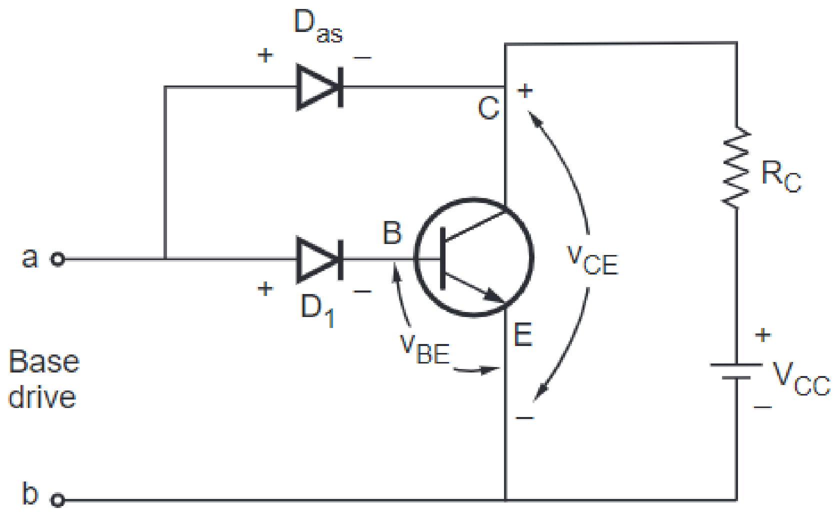
If the input voltage is changed to during turn-off, the capacitor voltage V_C is added to as reverse voltage across the transistor. There will be base current peaking during turn-off. As the capacitor C_1 discharges, the reverse voltage will be reduced to a steady state value, if different turn-on, turn-off characteristics are required a turn-off circuit using R_3 and R_4 may be added. The diode D_1 isolates the forward base drive circuit from the reverse base drive circuit during turn-off.

Proportional Base Control:



$$\frac{N_2}{N_1} = \frac{I_C}{I_B} = \frac{\beta I_B}{I_B} = \beta$$

Anti saturation Control:



$$v_{a\text{-}b} = v_{D1} + v_{BE}$$

Similarly for loop a - D_{as} - C - E we can write,

$$v_{a\text{-}b} = v_{Das} + v_{CE}$$

Hence equating the two equations,

$$v_{D1} + v_{BE} = v_{Das} + v_{CE}$$

Normally $v_{Das} = v_{D1}$. Hence above equation becomes,

$$v_{CE} = v_{BE}$$

Merits of BJT:

1. BJTs have small turn-on and turn-off times, hence their switching frequencies are higher.
2. BJTs have small turn-on losses.
3. The base drive has full control over the operation of BJT.
4. BJ Ts do not require commutation circuits.
5. BJT is a bipolar device.
6. BJTs are available easily with much-reduced costs.

Demerits of BJT:

1. Drive circuit of BJ T is complex.
2. Storage charge in base reduces switching frequencies.
3. Negative temperature coefficient creates problems in the paralleling of BJTs.

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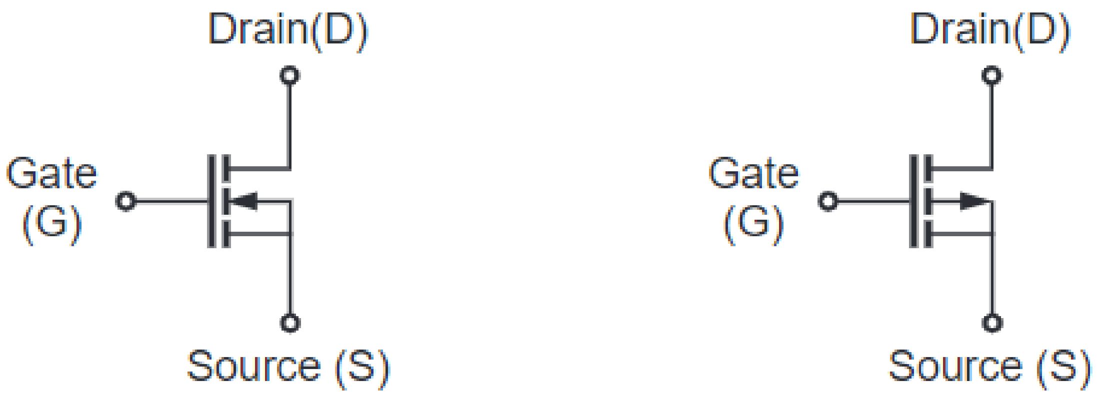
Applications of BJT:

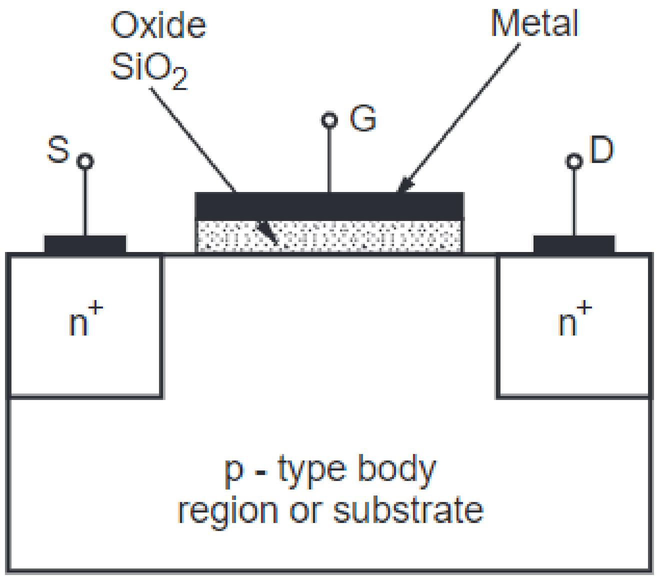
1. Switched Mode Power Supplies
2. Bridge inverters
3. DC to DC converter (choppers)
4. Power factor correction techniques

Power MOSFET:

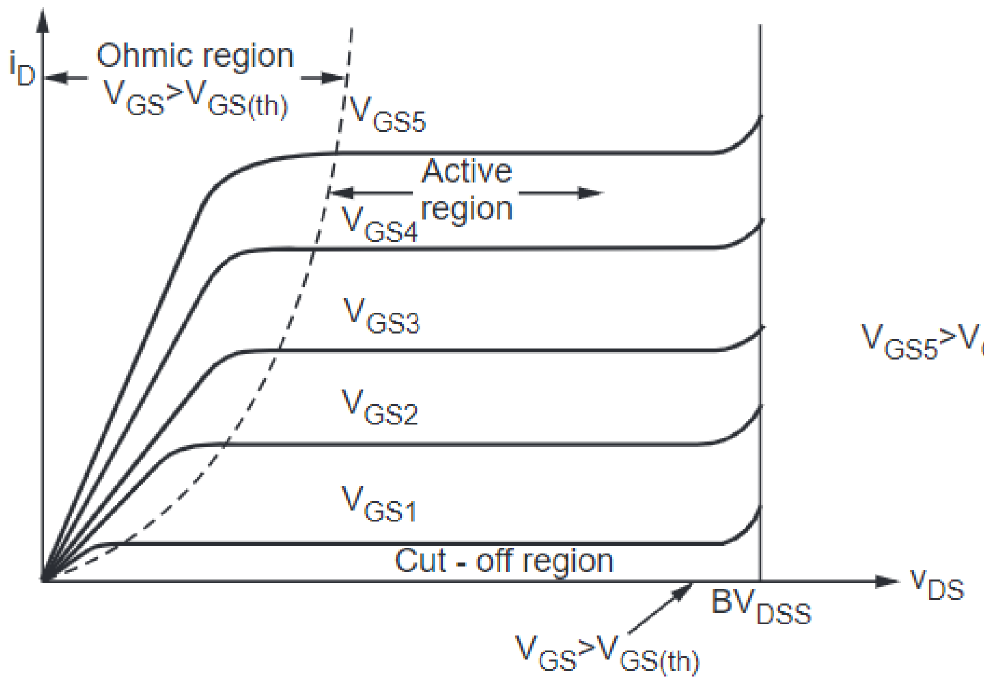


(a) n-channel (b) p-channel

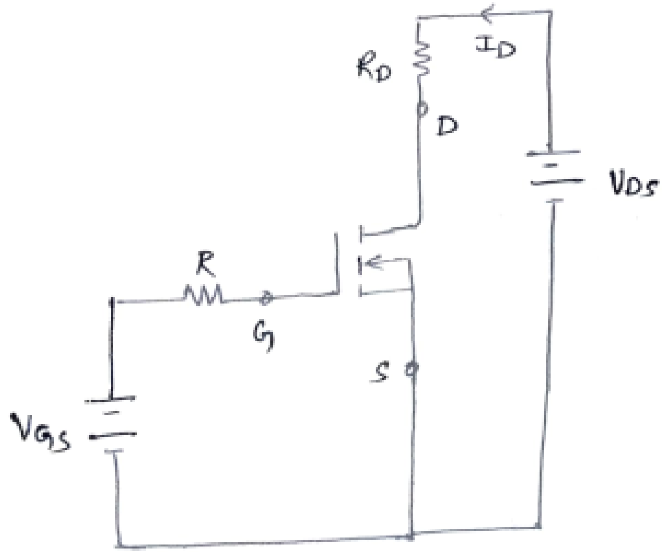
Structure of MOSFET:



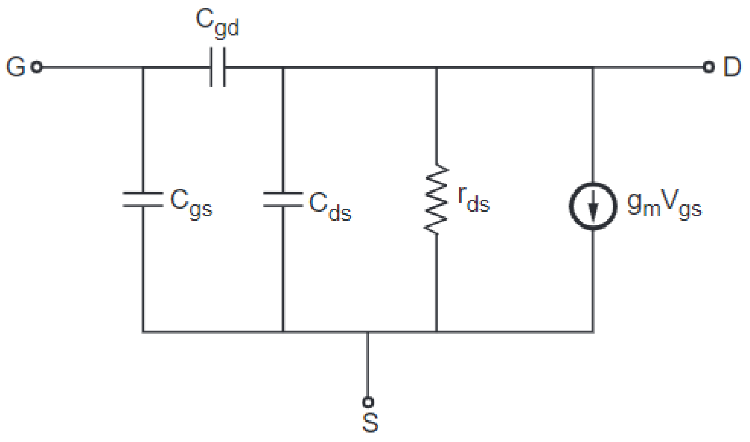
Static Characteristics of MOSFET:

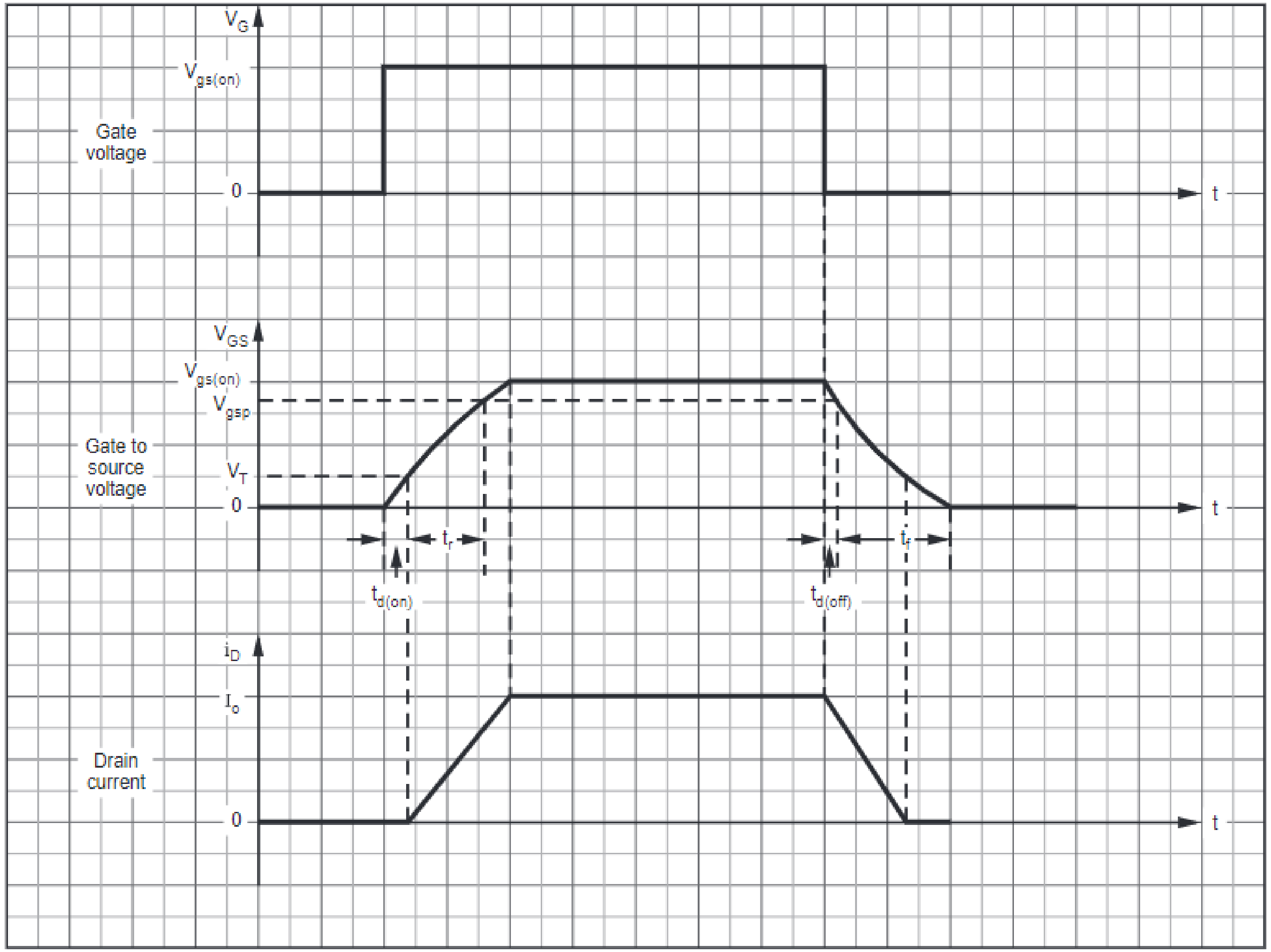


$V_{GS5} > V_{GS4} > V_{GS3} > V_{GS2} \cdots\cdots$

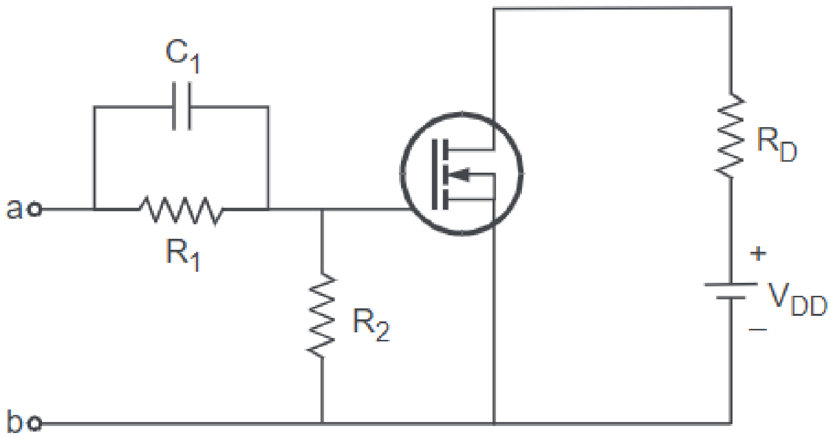


Switching Characteristics of MOSFET:





Gate Drive:



Merits of MOSFETs:

1. MOSFETs are majority carrier devices.
2. MOSFETs have positive temperature coefficient, hence their paralleling is easy.
3. MOSFETs have very simple drive circuits.
4. MOSFETs have short turn on and turn off times, hence they operate at high frequencies.
5. MOSFETs do not require commutation circuits.
6. Gate has full control over the operation of MOSFET.

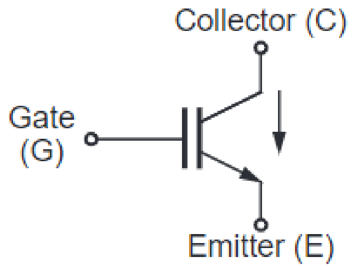
Demerits of MOSFET:

1. On-state losses in MOSFETs are high.
2. MOSFETs are used only for low power applications.
3. MOSFETs suffer from static charge.

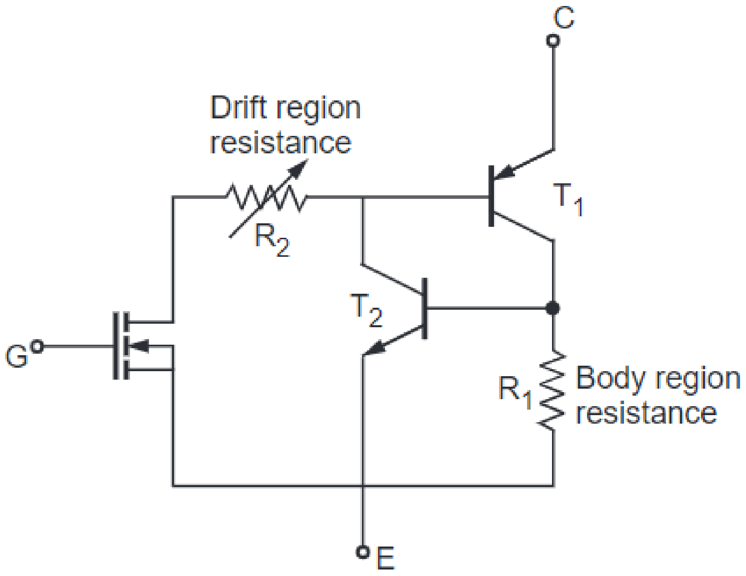
Applications of MOSFETs:

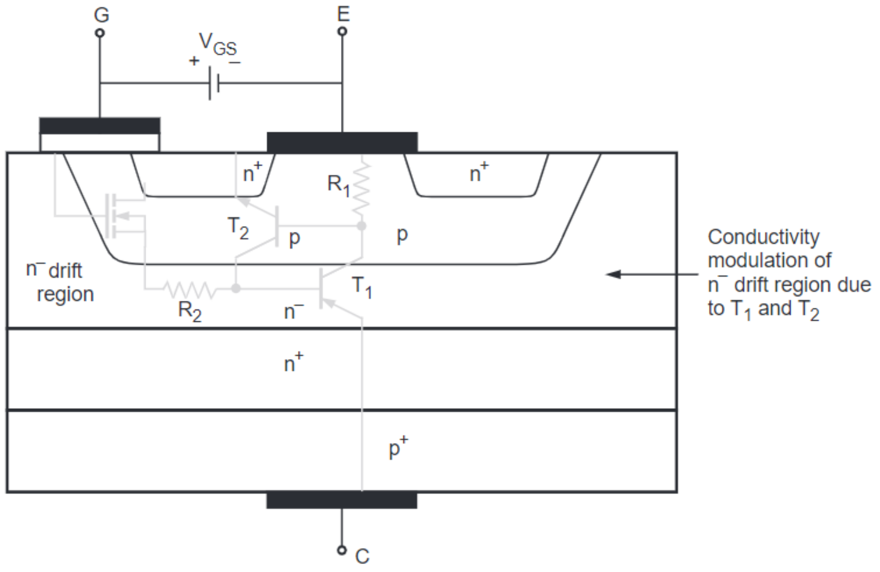
1. High frequency and low power inverters.
2. High frequency SMPS.
3. High frequency inverters and choppers.
4. Low power AC and DC drives.

Power IGBT:

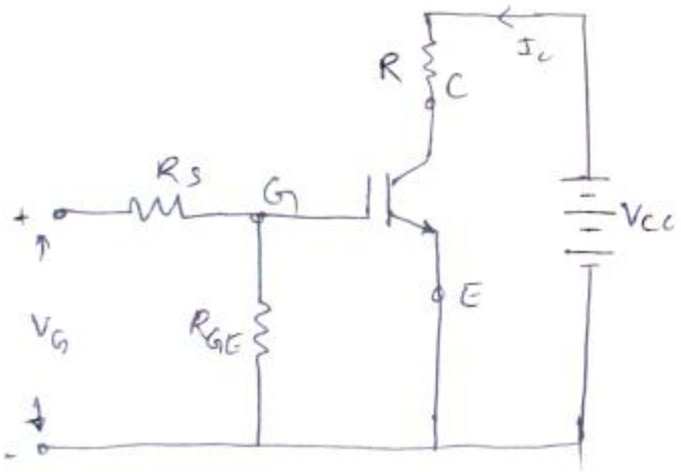


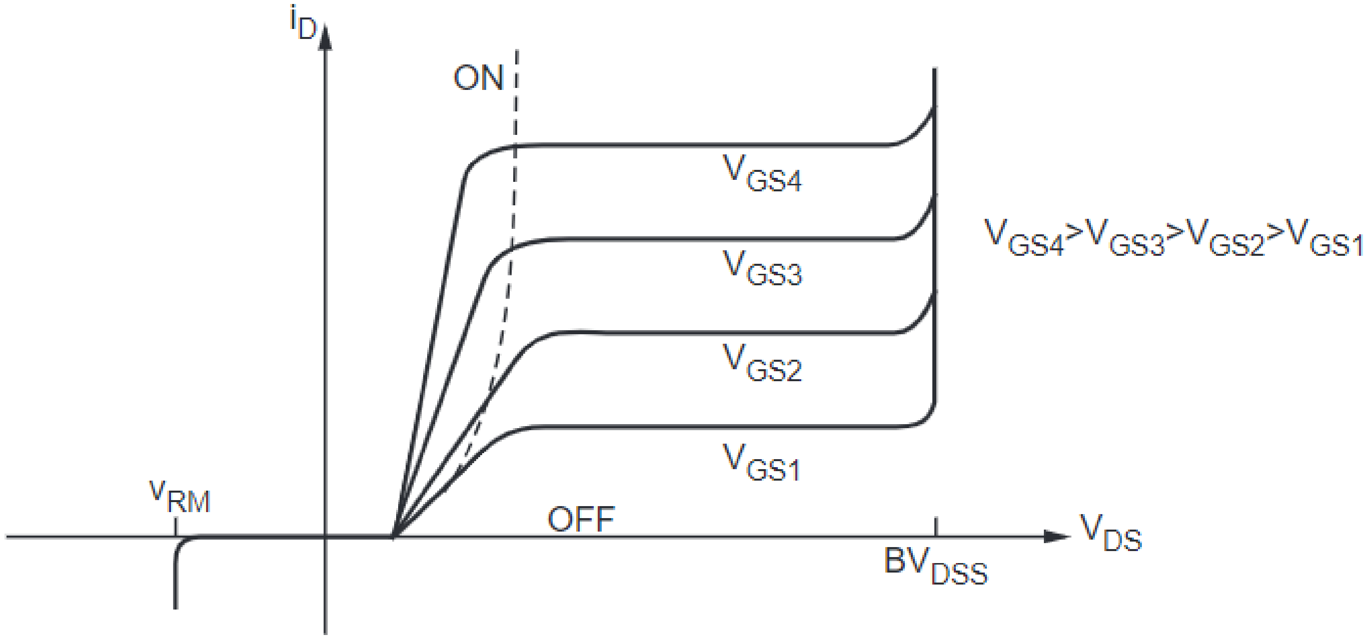
Structure of IGBT



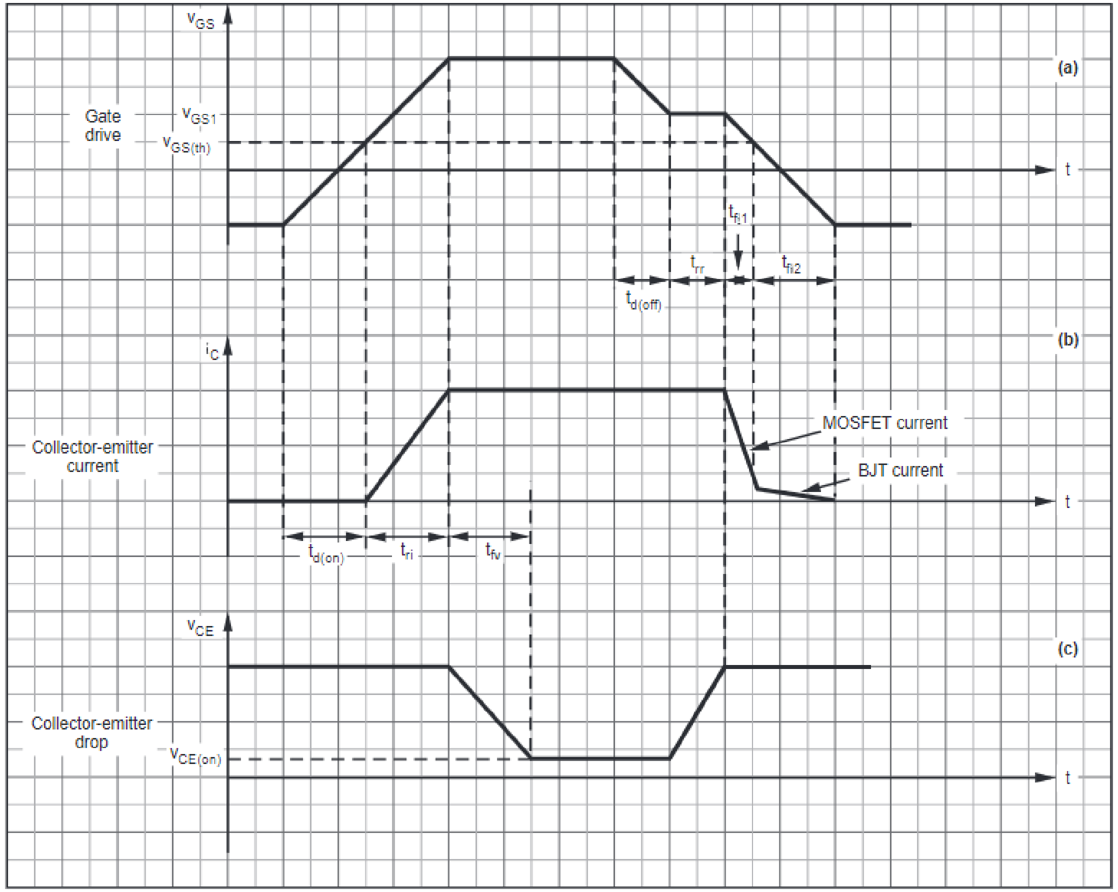


Steady State (V-I) characteristics of IGBT:





Switching Characteristics of IGBT:



Merits of IGBT

1. Voltage controlled device. Hence drive circuit is very simple.
2. On-state losses are reduced.
3. Switching frequencies are higher than thyristors.
4. No commutation circuits are required.
5. Gate have full control over the operation of IGBT.
6. IGBTs have approximately flat temperature coefficient.

Demerits of IGBT

1. IGBTs have static charge problems.
2. IGBTs are costlier than BJTs and MOSFETs.

Applications of IGBTs

1. AC motor drives, i.e. inverters.
2. DC to DC power supplies, i.e choppers.
3. UPS systems.
4. Harmonic compensators.


thank you