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Power Electronics

Power electronics is a subject that deals with the apparatus and equipment rated at power level (high voltage, high current and high power) rather than signal level and working on the principle of electronics.

Example: Thyristor, GTO, Power MOSFET, Power IGBT, TRIAC etc.

Power Device	Signal Device
1. Voltage and current rating is high	1. Voltage and current rating is low
2. Power handling capability is high	2. Power handling capability is low
3. Operate at power frequency	3. Operate at high frequency

Power Semiconductor Devices

Power semiconductor devices can be classified based on their

(i) Turn-on and turn-off characteristics.

(ii) Gate signal requirements.

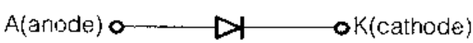
(a) **Diodes:** These are uncontrolled rectifying devices and their ON state and OFF state are controlled by nature of power supply.

(b) **Thyristors:** These devices have controlled turned-on by a gate signal. These devices are also called as semicontrolled devices.

(c) **Controllable switches:** Turn-on and turn-off of these devices can be done by application of control signals.

Power Diodes

Power diode is a 2 layer, 2 terminal p-n junction semiconductor device. It has one p-n junction formed by alloying, diffusion or epitaxial growth.

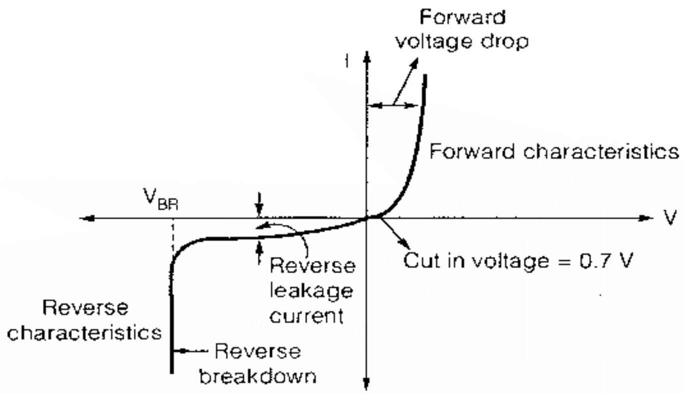


Remember:

- When voltage rating is less than 400 V epitaxial process is used for diode fabrication.
- When voltage rating is greater than 400 V diffusion process is used for diode fabrication.

Characteristics of Power Diodes

(a) Diode V-I Characteristics



Characteristics of Semiconductor Diode

Note:

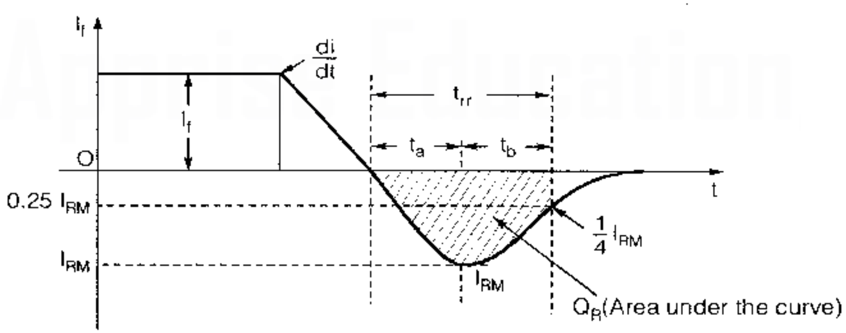
Peak inverse voltage (P.I.V.) specifies the maximum reverse voltage applied across diode by the source.

If (a) P.I.V. < V_{BR}, diode remain in blocking state.

(b) P.I.V. > V_{BR}, breakdown occurs and diode starts conducting in reverse direction.

(b) Reverse Recovery Characteristics

Due to the presence of excess stored charge carrier in the depletion region of diode, a reverse current immediately flow as soon as the forward diode current becomes zero.



Reverse Recovery Characteristics

$$t_{rr} = t_a + t_b = t_{off}$$

where, t_{rr} = Reverse recovery time

t_a = Time between $I_A = 0$ to $I_A = I_{RM}$

t_b = Time between I_{RM} to 25% of I_{RM}

I_{RM} = Reverse peak current.

$$t_{rr} = \left[\frac{2Q_R}{di/dt}\right]^{1/2} \quad \text{and} \quad I_{RM} = \left[2Q_R\left(\frac{di}{dt}\right)\right]^{1/2}$$

where, Q_R gives the amount of excess charge stored.

- **Softness factor (S)**

  It is measure of voltage transient appearing across the terminal of diode during recovery period.

$$S = \frac{t_b}{t_a}$$

when $S = 1$; $t_a = t_b$; Soft recovery

$S << 1$; Voltage spikes will be present and it indicates fast recovery.

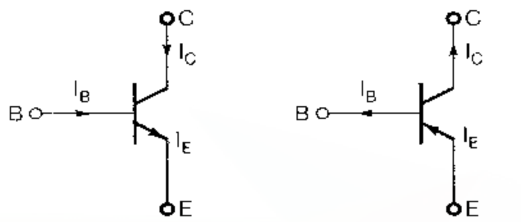
Types of Power Diode

Parameters	General Purpose Diode	Fast Recovery Diode	Schottky Diode
t_{rr}	25 µsec.	5 µsec or less	In nano second
Voltage rating	50 V to 5 kV	50 V to 3 kV	Reverse voltage blocking capability limited to 100 Volts.
Current rating	1 A to 1000 A	1 A to 1000 A	1 A to 300A
Application	(i) Battery charging (ii) Electric traction (iii) UPS (iv) Welding	(i) Choppers (ii) Commutation circuits (iii) SMPS (iv) Induction heating	(i) High frequency Instrumentation (ii) Switching power supplies

Power Transistor

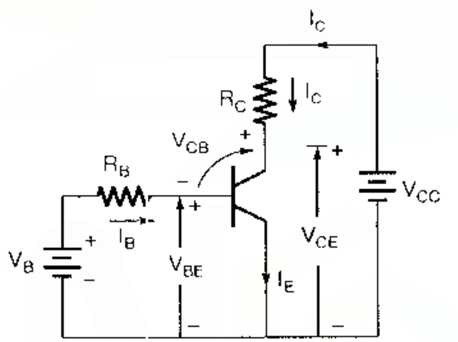
1. Power BJT (Bipolar Junction Transistor).
2. MOSFET (Metal-Oxide Semiconductor Field Effect Transistor)
3. Power IGBT (Insulated Gate Bipolar Transistor)

Power BJT

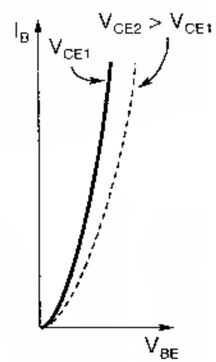


(n-p-n type) (p-n-p type)

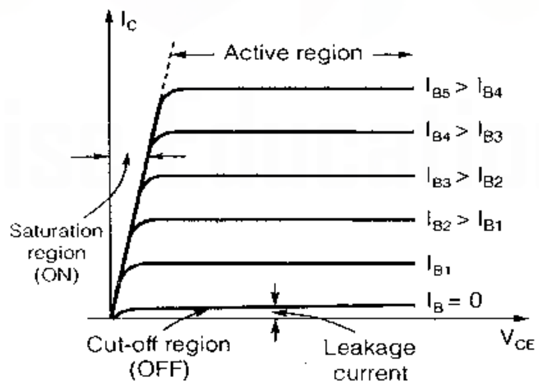
where, C, E = Main terminal
B = Control terminal



(a) npn transistor circuit characteristics



(b) Input characteristics

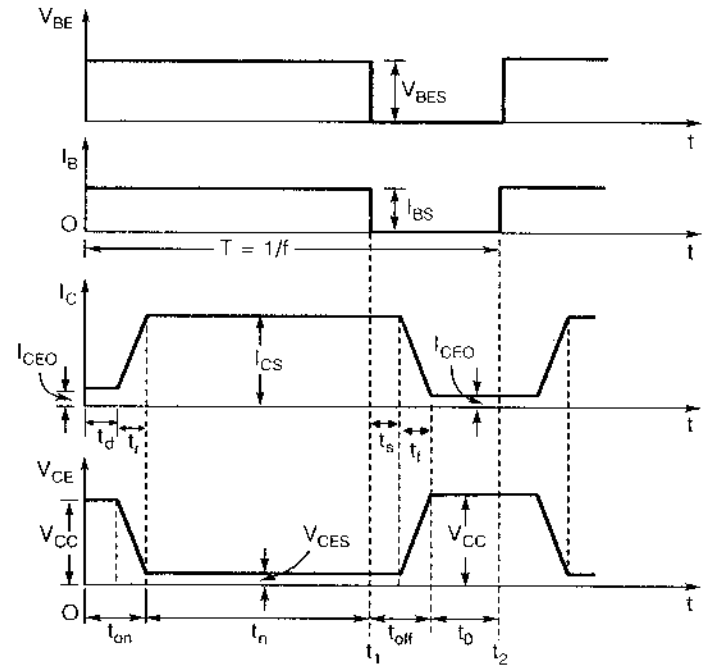


(c) Output characteristics

Remember:

- In switching operation : Cut-off region → OFF state
  Saturation region → ON state
- Active region is not used for switching application.
- Current flow in the device is due to the movement of both holes and electrons.

Switching Characteristics of n-p-n Transistor



where,
t_d = Delay time
t_r = Rise time
$t_{on} = t_d + t_r$
t_n = Conduction period
t_s = Storage time
t_f = Fall time
t_o = OFF period
$t_{off} = t_s + t_f$

V_{CES} = Small saturation voltage between collector and emitter

I_{CS} = Collector saturation current

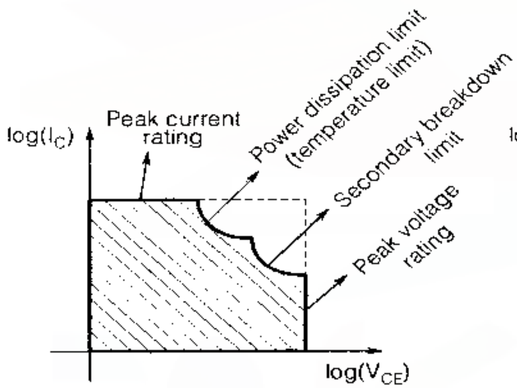
$$T = t_{on} + \text{Conduction period} + t_{off} + \text{OFF Period}$$

$$\text{frequency } (f) = 1/T$$

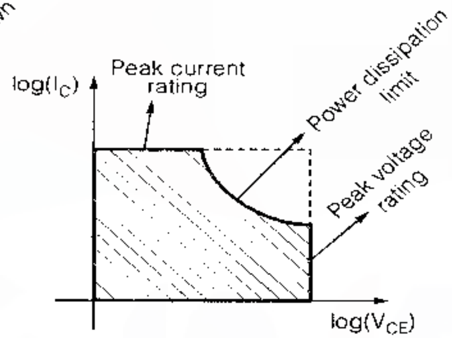
Remember:

t_{on} is in order of 30 to 300 ns.

Safe Operating Region for Power Transistor

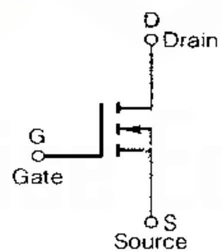


(Forward bias)



(Reverse bias)

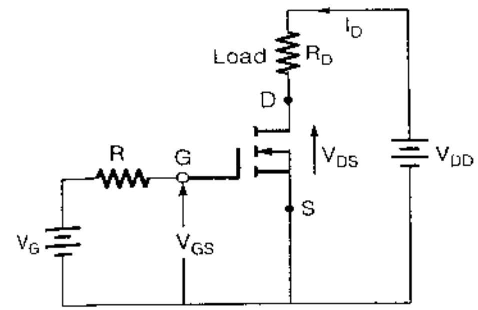
Power MOSFET



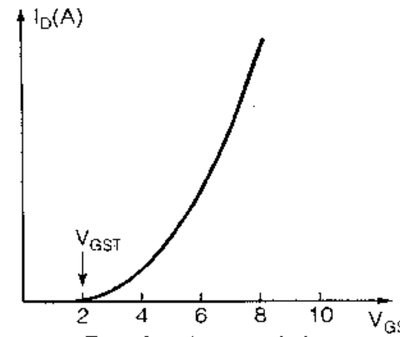
N-channel enhancement power MOSFET

where, D, S = Main terminal

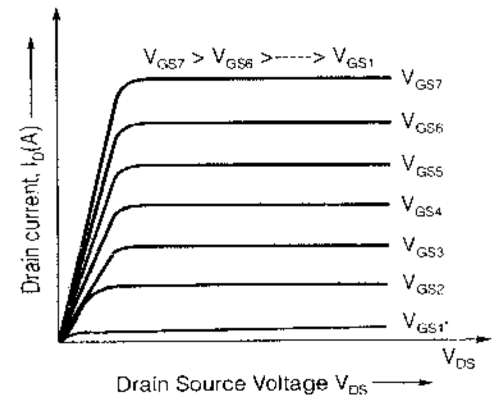
G = Control terminal



n-channel power MOSFET circuit diagram



Transfer characteristic



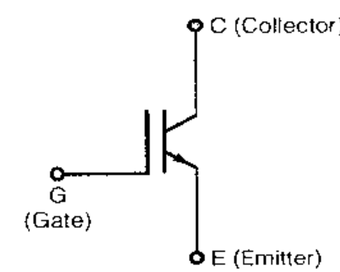
Output characteristics of a power MOSFET

Remember:

- n-channel enhancement MOSFET is more common because of higher mobility of electrons.
- The control signal (IB) in BJT is much larger than the control signal (Gate current) required in a MOSFET.

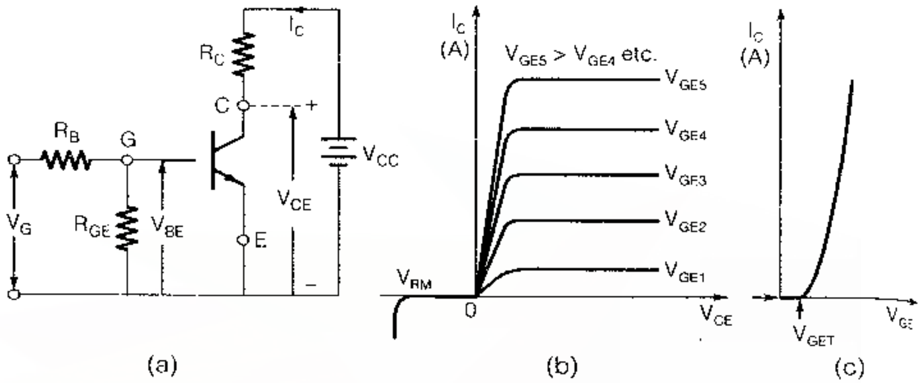
Power IGBT

This device combines into it the advantages of both MOSFET and BJT.



Circuit Symbol

IGBT Characteristics



IGBT (a) Circuit diagram (b) Static V-I characteristics and (c) Transfer characteristics

Comparison

BJT	MOSFET	IGBT
1. Bipolar device	1. Unipolar device	1. Bipolar device
2. Low ON-state voltage drop	2. High ON-state voltage drop .	2. Low ON-state voltage drop
3. Low ON state conduction power loss	3. High ON state conduction power loss	3. Low ON state conduction power loss
4. High switching power loss	4. Low switching power loss	4. Low switching power loss
5. Low input impedance	5. High input impedance	5. High input impedance
6. Current controlled device	6. Voltage controlled device	6. Voltage controlled device
7. Negative temperature coefficient for resistance	7. Positive temperature coefficient for resistance	7. Positive temperature coefficient for resistance
8. Secondary break down occur	8. Secondary break down will not occur	8. Secondary break down will not occur
9. Parallel operation is not advisable	9. Parallel operation is possible	9. Parallel operation is possible
10. 1200 V, 800 A, (10-20) kHz	10. 500 V, 140 A, 1 MHz	10. 1200 V, 500 A, 50 kHz
11. Application: UPS, charging batteries	11. SMPS	11. Inverters, choppers