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Basic Concept of Switches

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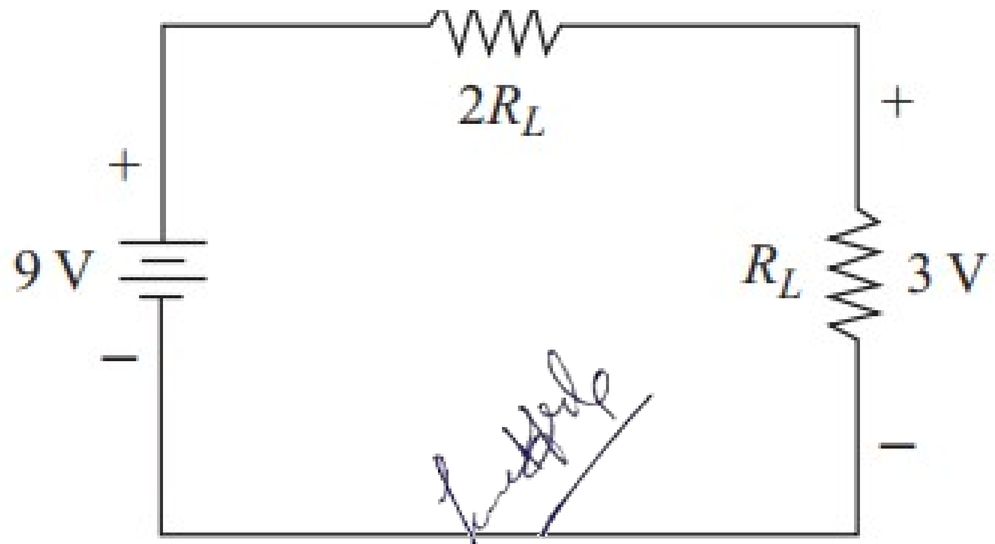
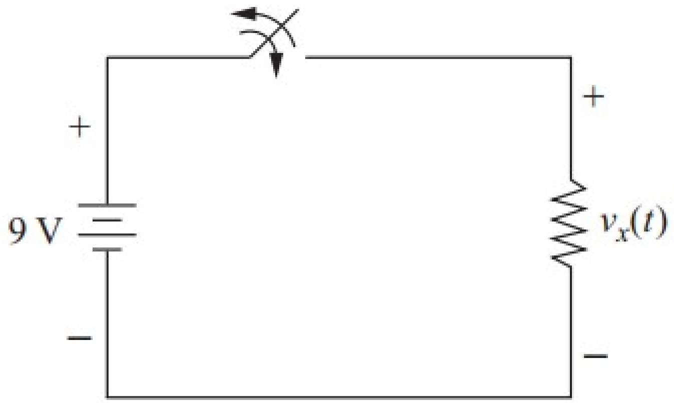
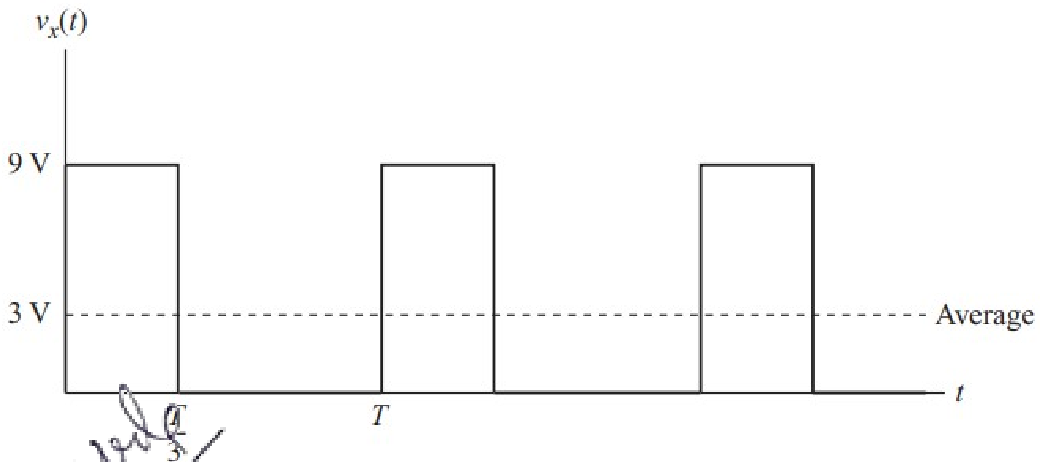
POWER ELECTRONICS CONCEPTS

- Consider the design problem of creating a 3-V dc voltage level from a 9-V battery.
- The purpose is to supply 3V to a load resistance. One simple solution is to use a voltage divider, as shown below



- To arrive at a more desirable design solution, consider the following circuit where a switch is opened and closed periodically.
- The output voltage is obviously not a constant dc voltage, but if the switch is closed for one-third of the period, the average value of Vx(denoted as Vx) is one-third of the source voltage.



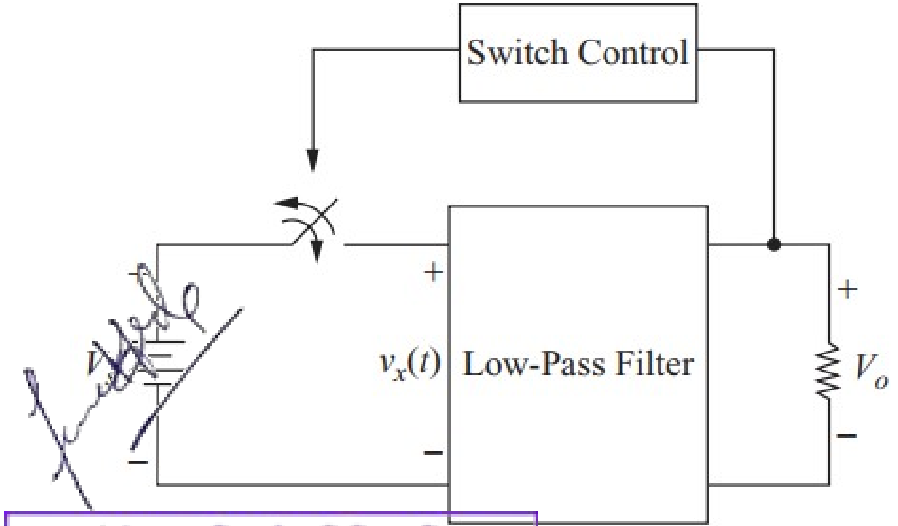


POWER ELECTRONICS CONCEPTS (CONT…)

- Average value is computed from the equation

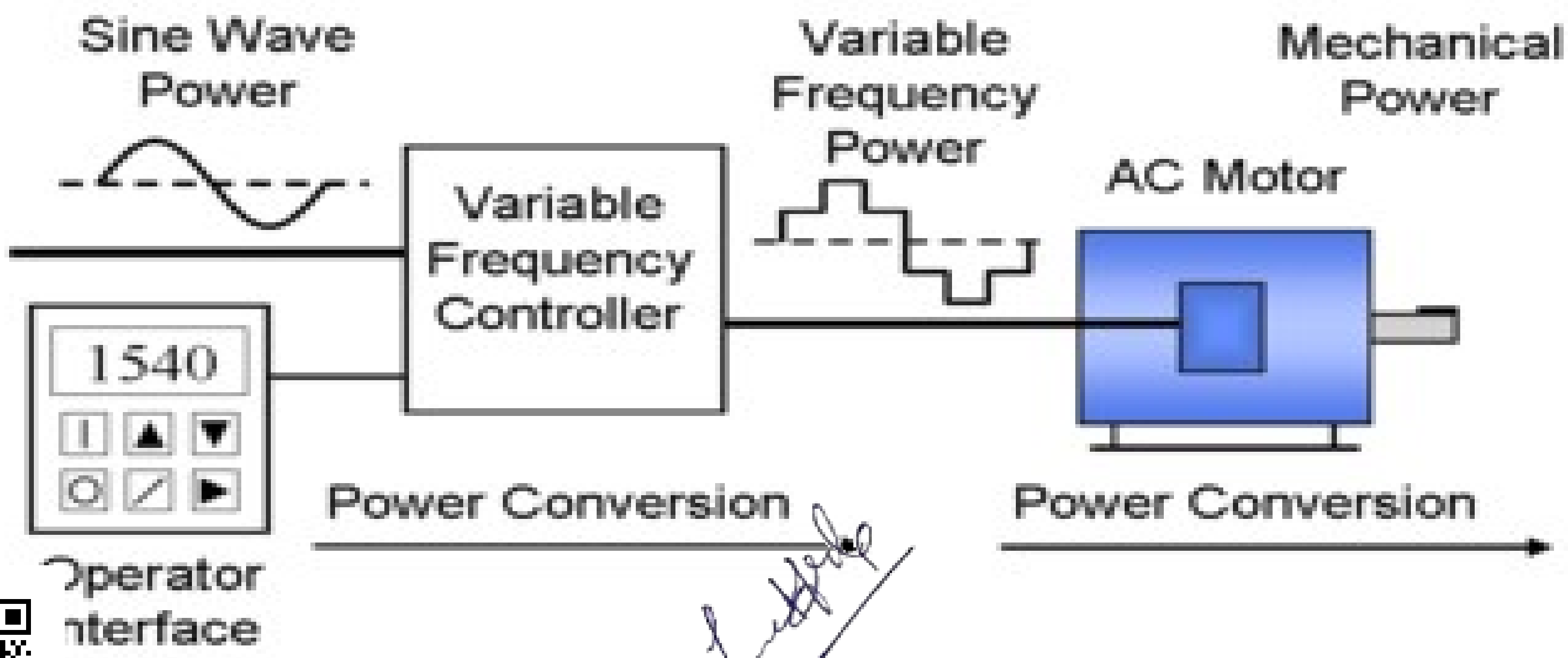
$$\text{avg}(v_x) = V_x = \frac{1}{T}\int_0^T v_x(t)\,dt = \frac{1}{T}\int_0^{T/3} 9\,dt + \frac{1}{T}\int_{T/3}^{T} 0\,dt = 3\text{ V}$$

- To create a 3-V dc voltage, vx is applied to a low-pass filter.
- Feedback is also used to control the switch and maintain the desired output voltage.

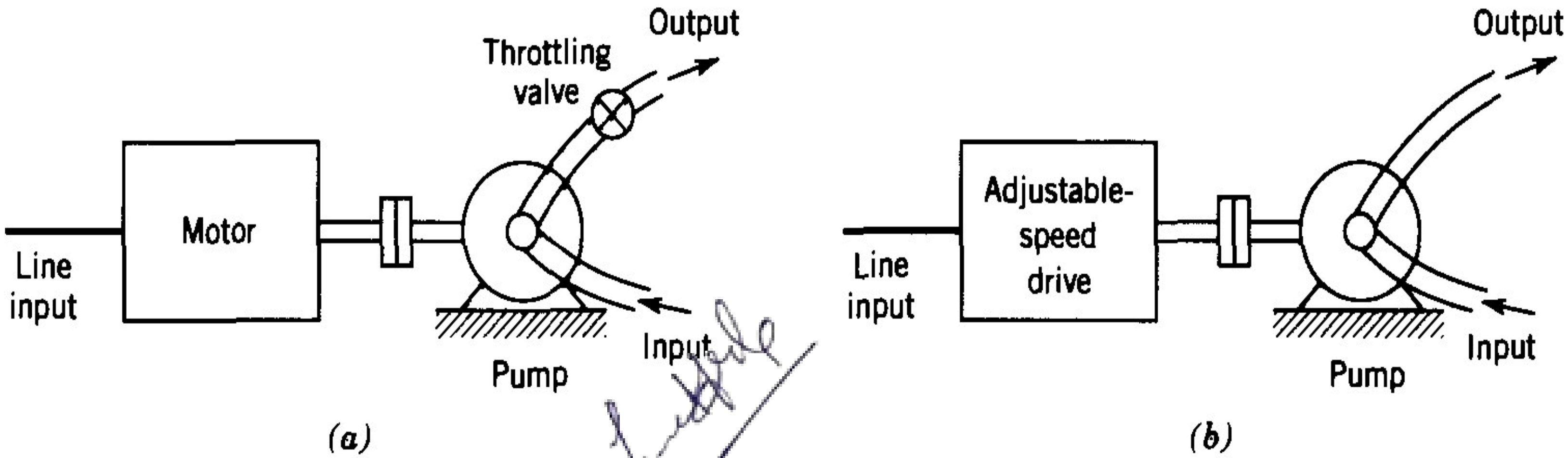


Power Electronics Concepts (Cont…)

- Variable-frequency drive(VFD) or adjustable-frequency drive used in electromechanical drive systems to control AC motor speed and torque by varying motor input frequency and voltage.



- Traditionally, motor-driven systems run at a nearly constant speed and their output, for example, flow rate in a pump, is controlled by wasting a portion of the input energy across a throttling valve. This waste is eliminated by an adjustable-speed electric drive, as shown below, by efficiently controlling the motor speed, hence the pump speed, by means of power electronics.



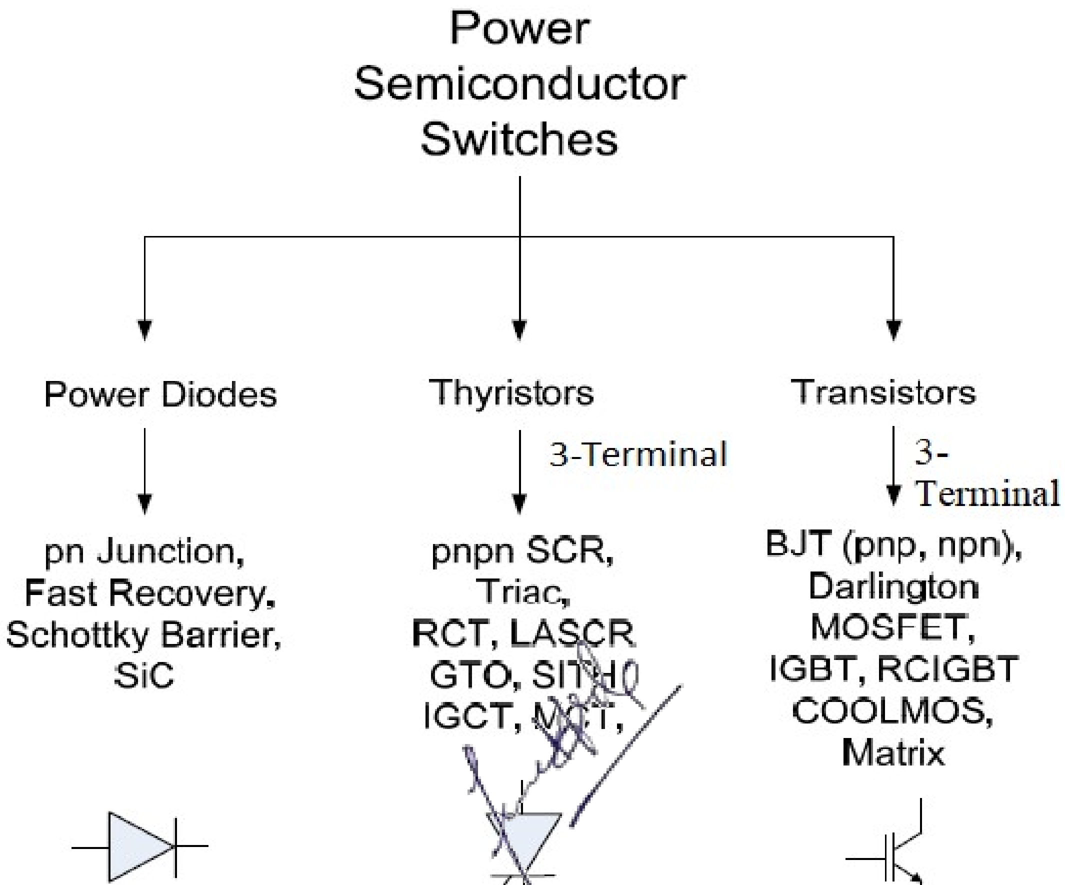
<u>ELECTRONIC SWITCHES</u>

- An electronic switch is characterized by having the two states *on and off, ideally being either a short circuit or an open circuit.*
- If the switch is ideal, either the switch voltage or the switch current is zero, making the power absorbed by it zero.
- The particular switching device used in a power electronics circuit depends on the existing state of device technology.
- Therefore, semiconductor devices are usually modeled as ideal switches so that circuit behavior can be emphasized.
- Switches are modeled as short circuits when on and open circuits when off.
- Transitions between states are usually assumed to be stantaneous, but the effects of non-ideal switching are scussed where appropriate.

Power Electronics Switches

Classified with three major groups

1. Diodes:- On and off states controlled by the power circuit.
2. Thyristors:- Latched on by a control signal but must be turned off by the power circuit.
3. Controllable switches:- Turned on and off by control signals.



Switch Selection

The selection of a power device for a particular application depends on-

1. The required voltage and current levels
2. Switching characteristics
3. On-off control
4. Switching speeds
5. The associated power losses. When selecting a suitable switching device, the first consideration is the required operating point and turn-on and turn-off characteristics.

Classification of Switches

1. Uncontrolled turn on and off (e.g., diode)
2. Controlled turn on and uncontrolled turn off (e.g., SCR)
3. Controlled turn-on and –off characteristics (e.g., BJT, MOSFET, IGBT, GTO, MCT)
4. Continuous gate signal requirement (e.g., BJT, MOSFET, IGBT)
5. Pulse gate requirement (e.g., SCR, GTO, MCT)
6. Bipolar voltage withstand capability (SCR, GTO)
7. Unipolar voltage withstand capability (BJT, MOSFET, IGBT, GTO, MCT)
8. Bidirectional current capability (e.g., TRIAC)
9. Unidirectional current capability (e.g., SCR, GTO, BJT, MOSFET, IGBT, MCT, Diode)

CONT..

The power semiconductor devices have been grouped into following two categories:

(i)The old or conventional devices i.e.

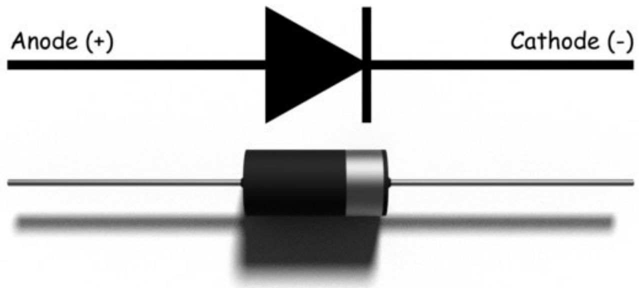
- Power diode
- Thyristor
- TRIAC
- GTO
- BJT and
- Power MOSFET

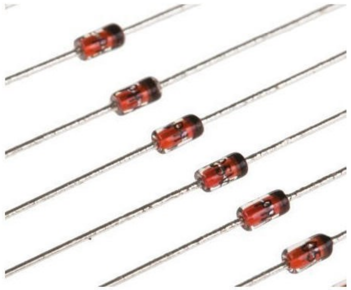
(ii)Modern power devices i.e. IGBT, SIT (static induction transistor), SITH(static induction thristor), MCT(MOS controlled Thyristor), IGCT (The integrated gate-commutated thyristor) and COOLMOS etc.

ELECTRONIC SWITCHES (CONT…)

The Diode

- A diode is the simplest electronic switch. It is uncontrollable in that the on and off conditions are determined by voltages and currents in the circuit





Diode Ideal Characteristics

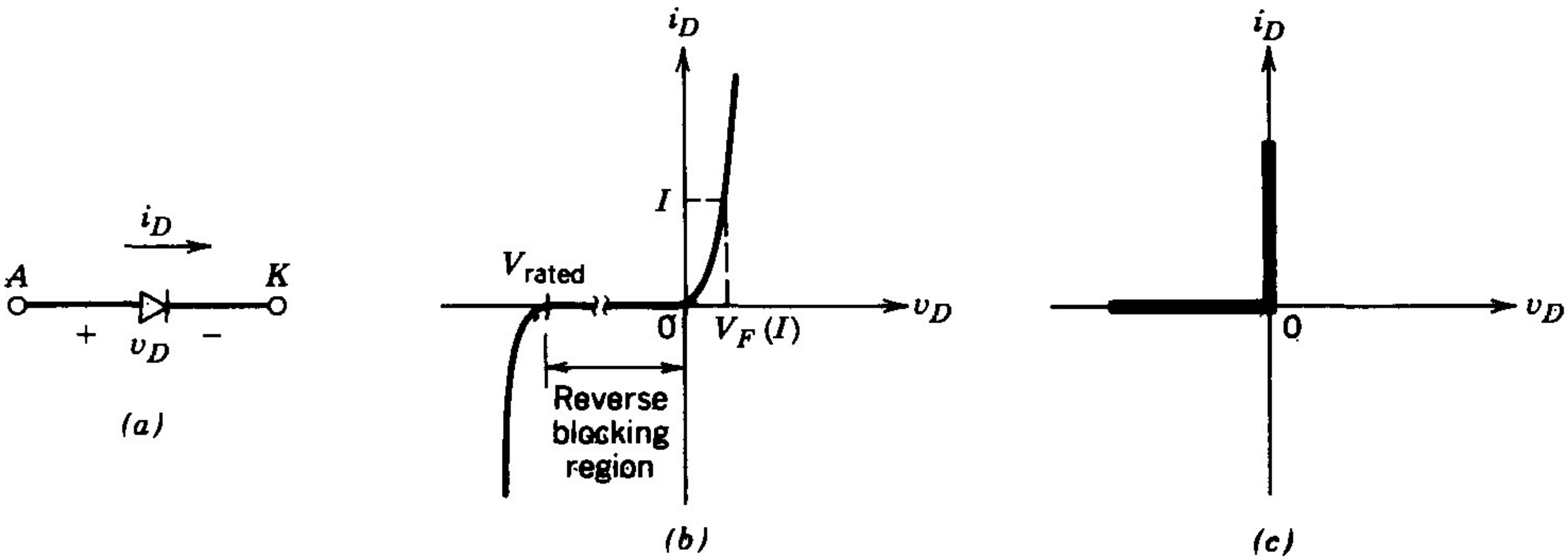
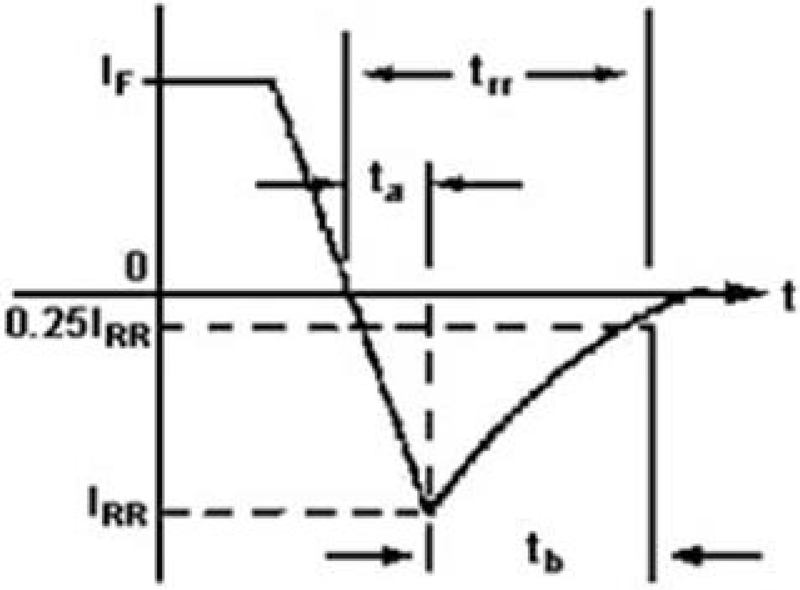
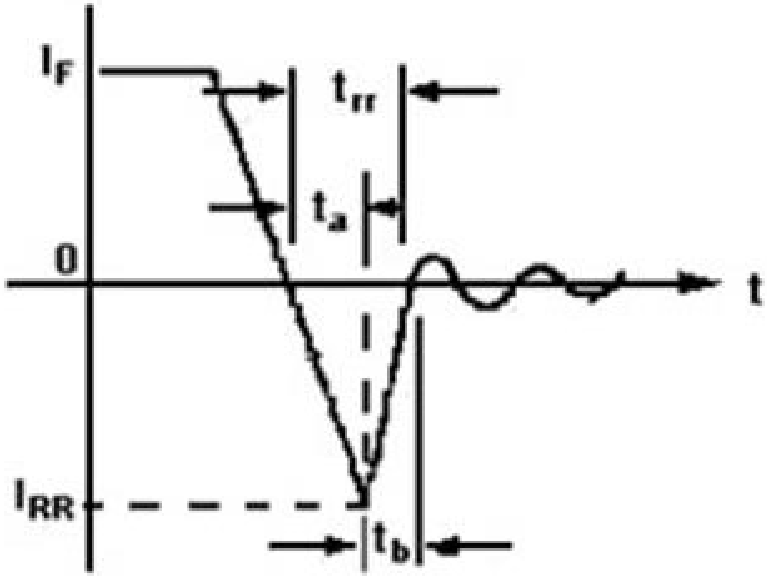


Figure Diode: (*a*) symbol, (*b*) *i–v* characteristics, (*c*) idealized characteristics.

TURN OFF CHARACTERISTICS



Soft recovery



Abrupt recovery

Turn off characteristics

- In diode turn on is instantaneous action but turn off is not instantaneous. "Softness factor" decided that how is the turn off chart.

$s_f = t_b / t_a$

- Where t_{rr}:- reverse recovery time
- I_{RM}:- Maximum reverse recovery current
- t_a:-time between zero crossing and the maximum reverse current and it is due to the charge stored in the depletion region of the junction
- t_b:-time between maximum reverse current I_{RR} and 25% of the of the maximum reverse current I_{RR} and is due to charge stored in the bulk semiconductor material .

Therefore $t_{rr} = t_a + t_b$

TYPES OF DIODES

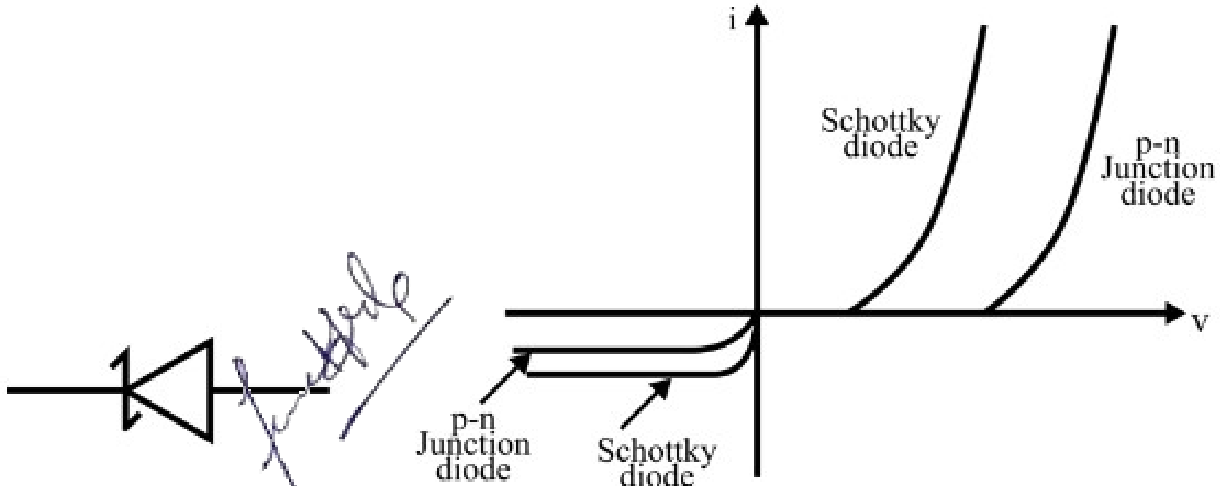
1. Schottky diodes:- These diodes are used where a low forward voltage drop (typically 0.3V) is needed in very low output voltage circuits. These diodes are limited in their blocking voltage capabilities to 50-100 V.

As compared to the p-n junction diode it has:

(a) Lower cut-in voltage

(b) Higher reverse leakage current

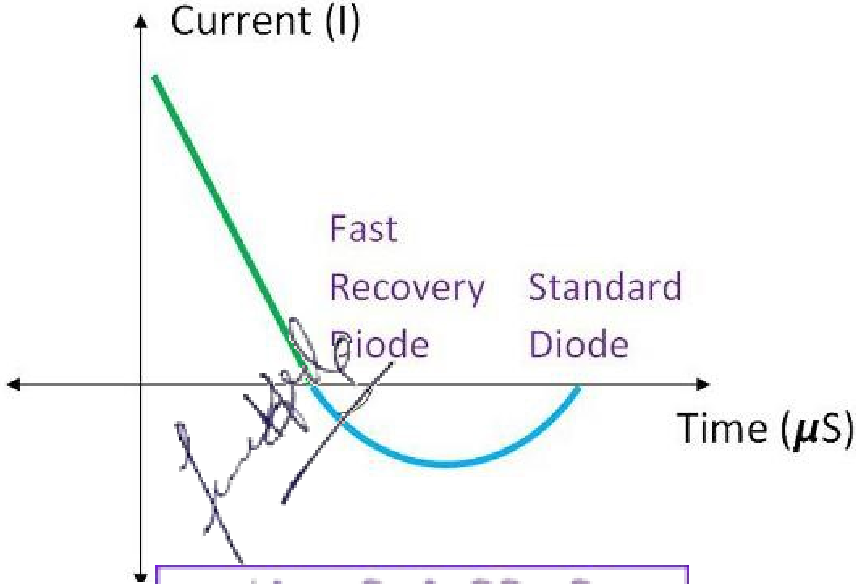
(c) Higher operating frequency



CONT…

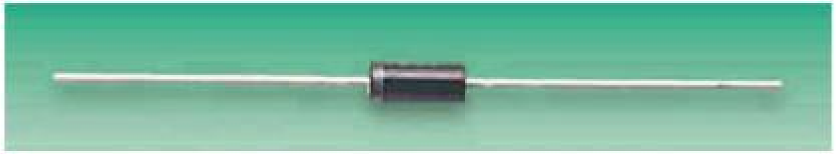
<u>2. Fast-recovery diodes:-</u> These are designed to be used in high frequency circuits in combination with controllable switches where a small reverse-recovery time is needed. At power levels of several hundred volts and several hundred amperes, such diodes have t_{rr} ratings of less than a few microseconds.

<u>3. Line frequency diodes:-</u> The on-state voltage of these diodes is designed to be as low as possible so larger t_{rr} . These diodes are available with blocking voltage ratings of several kilovolts and current ratings several kiloamperes.



Data sheet of power diode (1N5400-1N5408)

1A to 3A, Standard Axial Rectifiers



Trr = 1.5μ Sec (typical Value)

Features:

- 3.0 ampere operation at T_A = 75°C with no thermal runaway.
- High current capability.
- Low leakage.

Ampere General Purpose Rectifiers

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
I_O	Average Rectified Current 0.375" lead length at T_A = 75°C	3.0	A
$i_{f\ (surge)}$	Peak Forward Surge Current 8.3ms single half-sine-wave Superimposed on rated load (JEDEC method)	200	
P_D	Total Device Dissipation Derate above 25°C	6.25 50	W mW/°C
RθJA	Thermal Resistance, Junction to Ambient	20	°C/W
T_{stg}	Storage Temperature Range	-55 to +150	°C
T_J	Operating Junction Temperature		

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

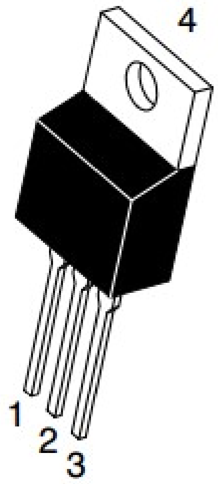
Data sheet of power diode (1N5400-1N5408

Electrical Characteristics T_A = 25°C unless otherwise noted

Parameter	Device							Units
	5400	5401	5402	5404	5406	5407	5408	
Peak Repetitive Reverse Voltage	50	100	200	400	600	800	1000	V
Maximum RMS Voltage	35	70	140	280	420	560	700	
DC Reverse Voltage (Rated V_R)	50	100	200	400	600	800	1000	
Maximum Reverse Current at rated V_R T_A = 25°C T_A = 100°C	5.0 500							µA
Maximum Forward Voltage at 3.0A	1.2							V
Maximum Full Load Reverse Current, Full Cycle T_A = 105°C	0.5							mA
Typical Junction Capacitance V_R = 4.0V, f = 1.0MHz	30							pF

DATA SHEET OF MUR 1610CT, 15CT, 20CT, 40CT, 60CT (FIRST RECOVERY DIODE)

Features



- Ultrafast 35 and 60 Nanosecond Recovery Times
- 175°C Operating Junction Temperature
- Popular TO-220 Package
- Epoxy Meets UL 94 V-0 @ 0.125 in
- High Temperature Glass Passivated Junction
- High Voltage Capability to 600 V
- Low Leakage Specified @ 150°C Case Temperature
- Current Derating @ Both Case and Ambient Temperatures
- Pb-Free Packages are Available

Mechanical Characteristics:

- Case: Epoxy, Molded
- Weight: 1.9 Grams (Approximately)
- Finish: All External Surfaces Corrosion Resistant and Terminal Leads are adily Solderable
- ead Temperature for Soldering Purposes:260°C Max. for 10 Seconds

DATA SHEET OF MUR 1610CT, 15CT, 20CT, 40CT, 60CT (FIRST RECOVERY DIODE)

MAXIMUM RATINGS

Rating	Symbol	MUR16					Unit
		10CT	15CT	20CT	40CT	60CT	
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	100	150	200	400	600	V
Average Rectified Forward Current — Per Leg Total Device, (Rated V_R), $T_C = 150°C$ — Total Device	$I_{F(AV)}$	8.0 16					A
Peak Rectified Forward Current — Per Diode Leg (Rated V_R, Square Wave, 20 kHz), $T_C = 150°C$	I_{FM}	16					A
Nonrepetitive Peak Surge Current (Surge applied at rated load conditions halfwave, single phase, 60 Hz)	I_{FSM}	100					A
Operating Junction Temperature and Storage Temperature	T_J, T_{stg}	−65 to +175					°C

exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the
nded Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect
iability.

THE POWER DIODE (CONT…)

THERMAL CHARACTERISTICS (Per Diode Leg)

Parameter	Symbol	Value		Unit
Maximum Thermal Resistance, Junction–to–Case	$R_{\theta JC}$	3.0	2.0	°C/W

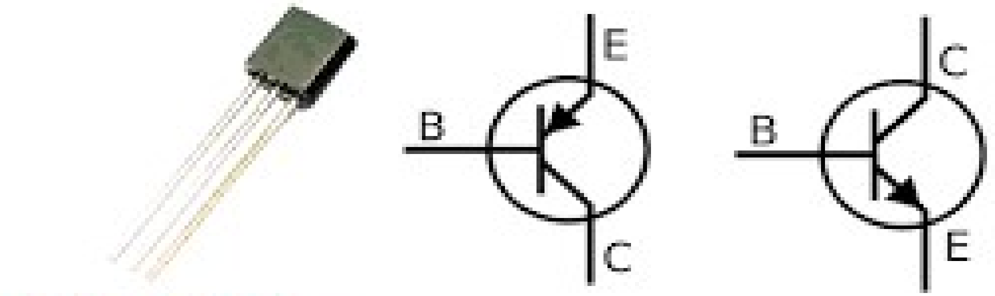
ELECTRICAL CHARACTERISTICS (Per Diode Leg)

Characteristic	Symbol	1620	1640	1660	Unit
Maximum Instantaneous Forward Voltage (Note 1) (i_F = 8.0 A, T_C = 150°C) (i_F = 8.0 A, T_C = 25°C)	v_F	 0.895 0.975	 1.00 1.30	 1.20 1.50	V
Maximum Instantaneous Reverse Current (Note 1) (Rated DC Voltage, T_C = 150°C) (Rated DC Voltage, T_C = 25°C)	i_R	 250 5.0	 500 10		μA
Maximum Reverse Recovery Time .0 A, di/dt = 50 A/μs)).5 A, I_R = 1.0 A, I_{REC} = 0.25 A)	t_{rr}	 35 25	 60 50		ns

'est: Pulse Width = 300 μs, Duty Cycle ≤ 2.0%

TRANSISTORS

- Bipolar Junction Transistor (**BJT**) is a Semiconductor device constructed with three doped Semiconductor Regions (Base, Collector and Emitter) separated by two p-n Junctions, Figure 1. The p-n Junction between the Base and the Emitter has a Barrier Voltage (V_0) of about 0.6 V, which is an important parameter of a **BJT**.



Typical Bipolar Junction Transistor   PNP BJT   NPN BJT

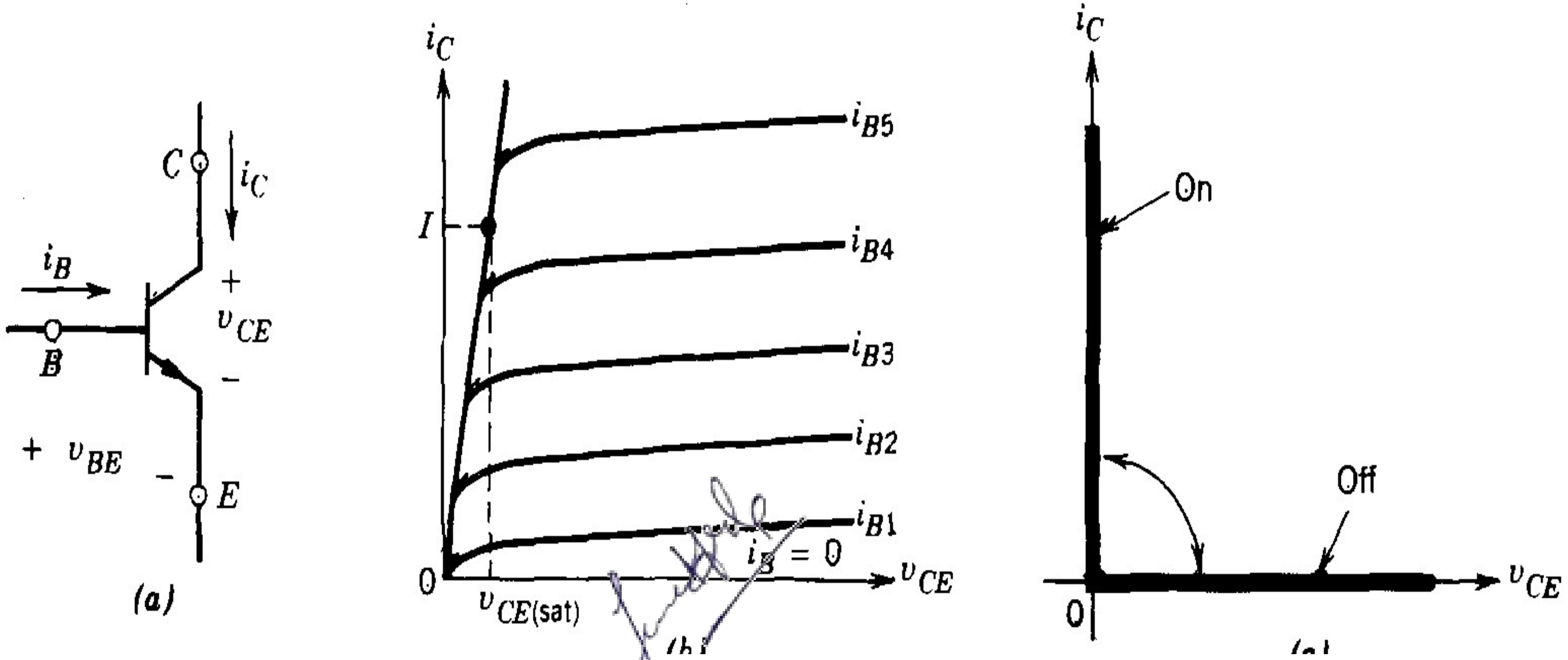
Transistor is not used in power electronics applications mainly because of

- Lower switching frequency
- …reased power losses of higher frequency
- …gher requirement of switching power

CHARACTERISTICS OF TRANSISTOR

$$I_B > \frac{I_C}{h_{FE}}$$

where h_{FE} is the dc current gain of the device.



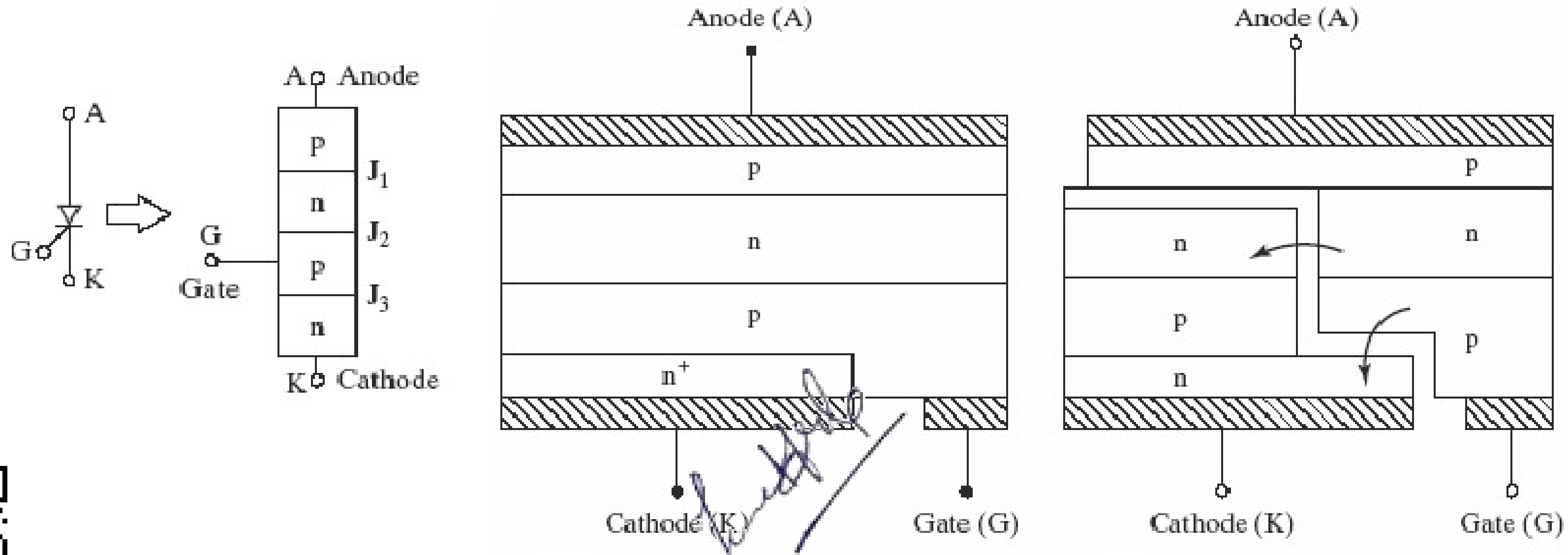
Γ: (a) symbol, (b) i–v characteristics, (c) idealized characteristics.

THYRISTORS

- Thyristors are electronic switches used in some power electronic circuits where control of switch turn-on is required.
- Types-SCR (Silicon Controlled Rectifier)
- GTO (Gate Turnoff Thyristor)
- MCT (MOS Controlled Thyristor)

THYRISTORS

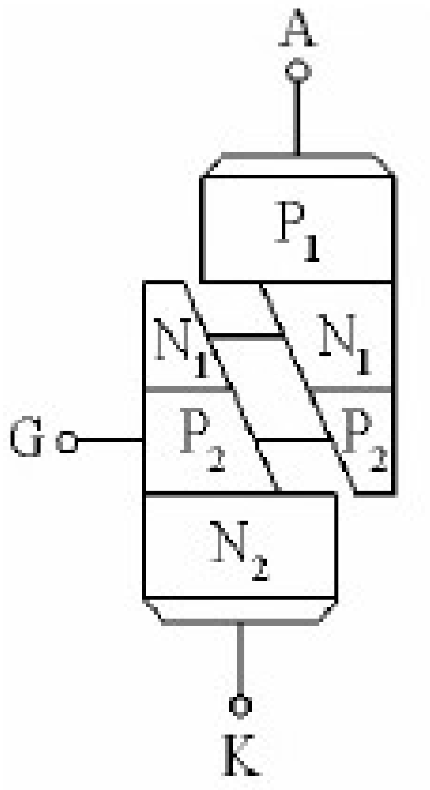
- The thyristor is a four layer, three terminal semiconducting device, with each layer consisting of alternately N-type or P-type material, for example P-N-P-N. The main terminals, labeled anode and cathode, area cross the full four layers, and the control terminal, called the gate, is attached top-type material near to the cathode.



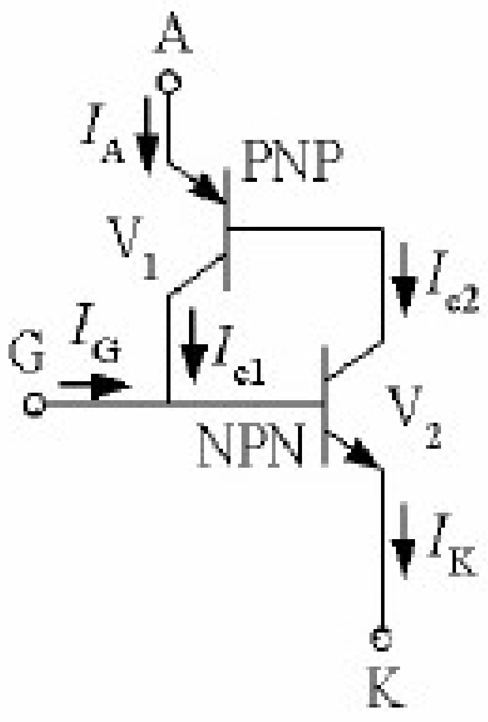
Cross section of *pnpn* structure

Split sections of *npn* and *pnp*

Structure and equivalent circuit of Thyristor



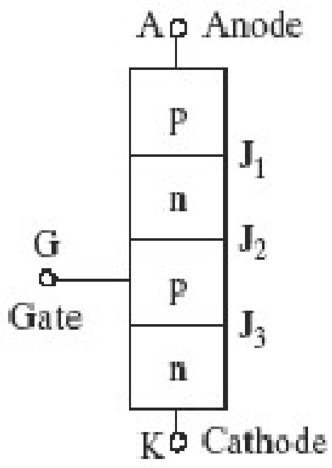
a)



b)

Operation

- When the anode is at a positive potential V_{AK} with respect to the cathode with no voltage applied at the gate, junctions J1 and J3 are forward biased, while junction J2 is reverse biased. As J2 is reverse biased, no conduction takes place.
- Now if *V_{AK} is increased beyond the breakdown voltage V_{BO} of the thyristor, avalanche breakdown of J2 takes place and the thyristor starts conducting.*
- If a positive potential *VG is applied at the gate terminal with respect to the cathode, the breakdown of the junction J2 occurs at alower value of V_{AK}. By selecting an appropriate value of V_G, the thyristor can be switched in to the on state suddenly.*



THE THYRISTOR (CONT…)

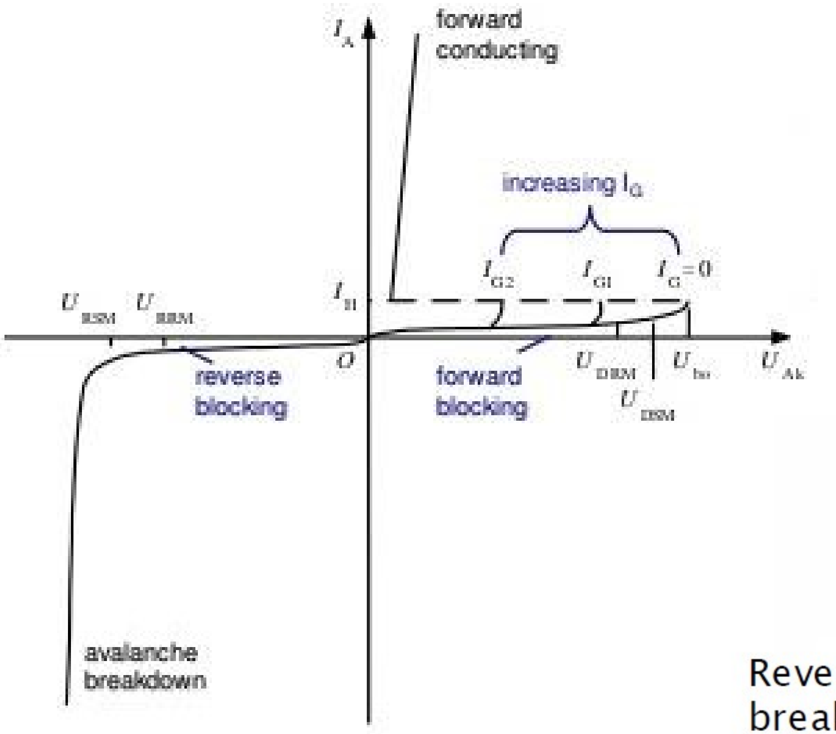
Methods to trigger Thyristor

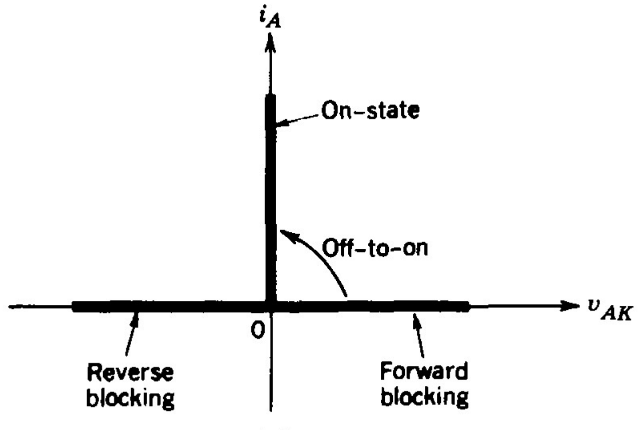
- Avalanche breakdown: High voltage across anode and cathode.
- High dv/dt
- Light activation
- High Junction voltage
- **Gate triggering**

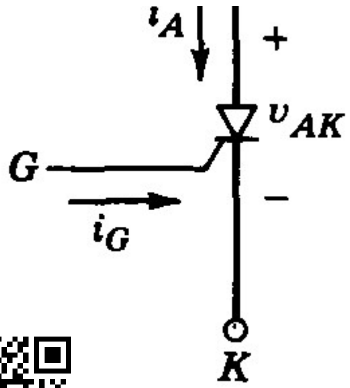
Static Characteristics of Thyristor

- Blocking occurs when reverse biased current is applied.(does not depend on gate current)
- When forward biased and gate current applied: Conduction occurs.
- Once turned ON goes on conducting even if in the absence of gate current.
- Gets turned OFF when decreasing current goes to zero by using external power circuit

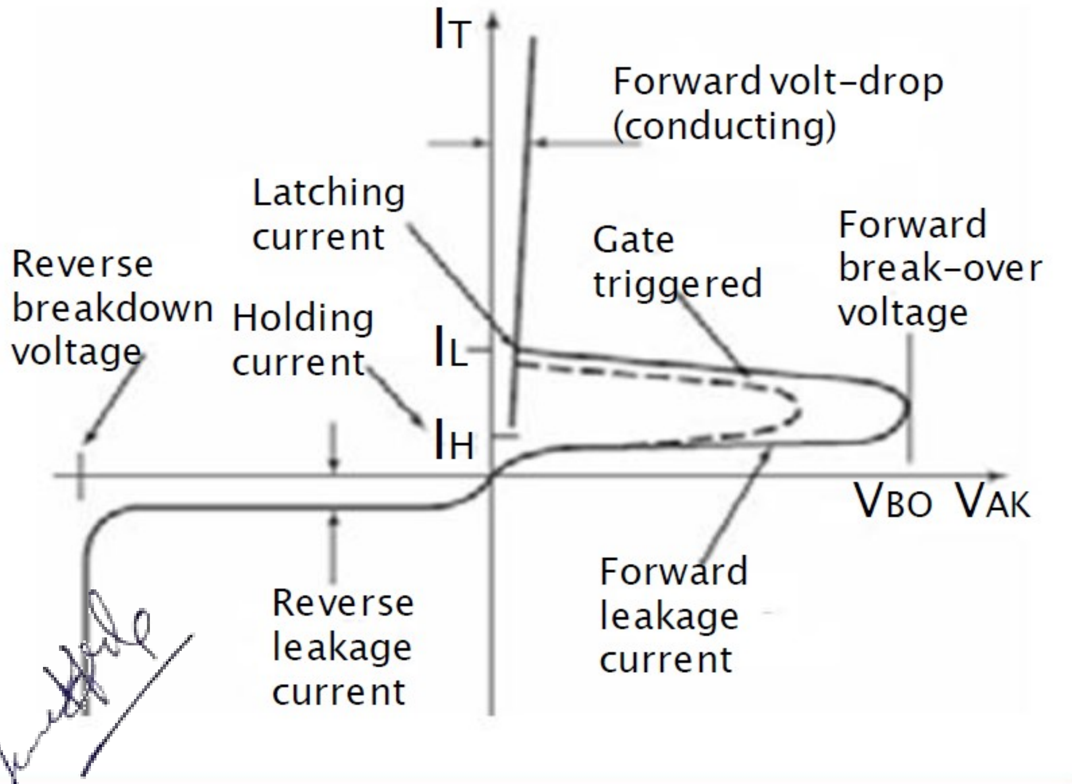
Characteristics of SCR







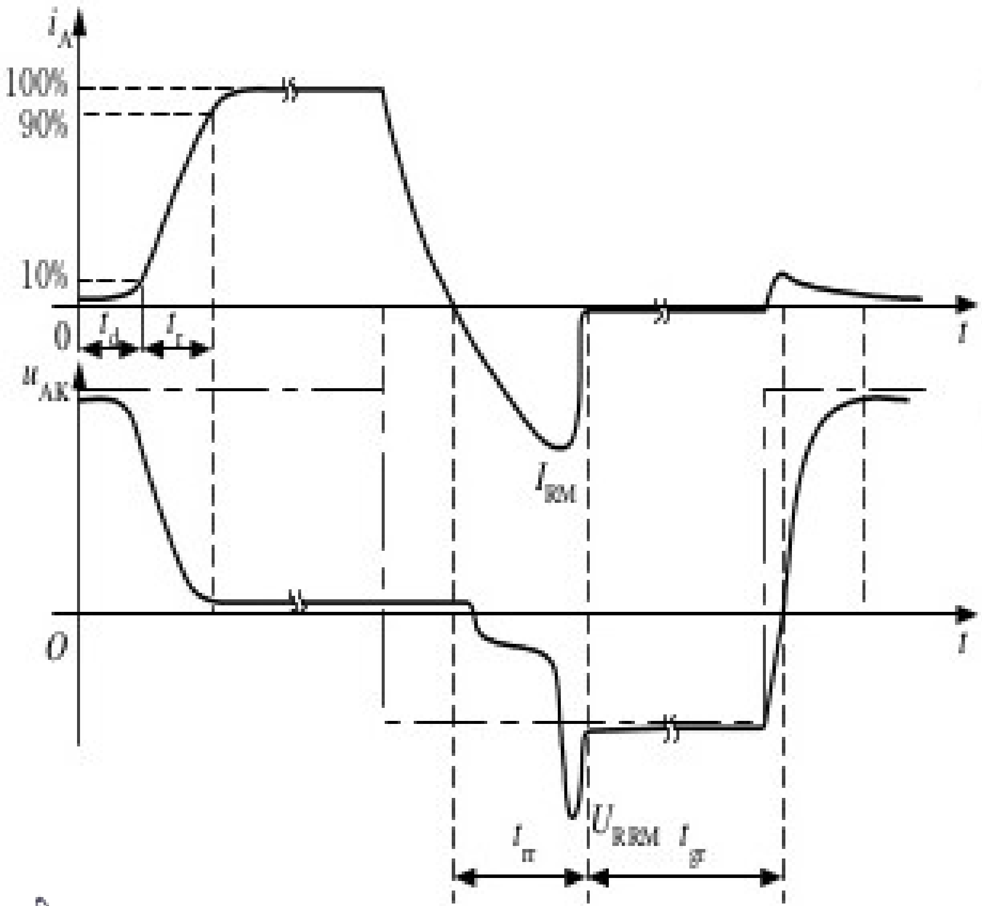
(a)



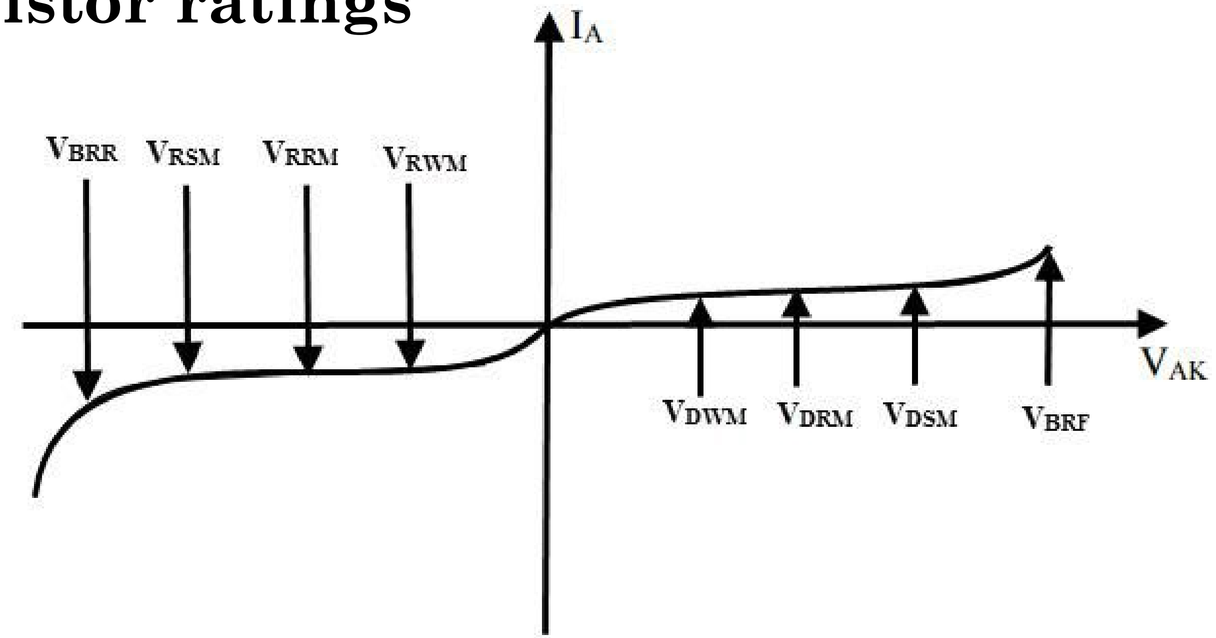
istor: (*a*) symbol, (*b*) *i*–*v* characteristics, (*c*) idealized characteristics.

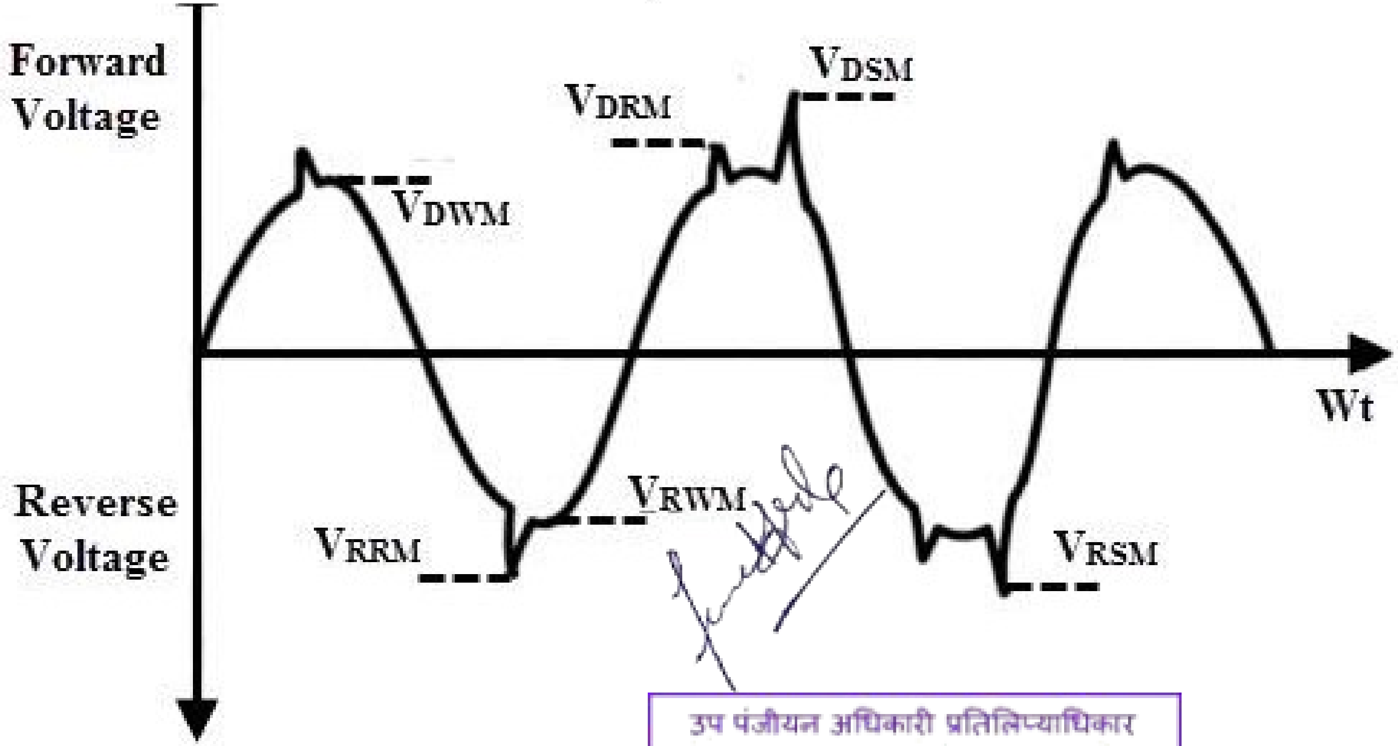
Switching Characteristics of Thyristor

- **During turn ON**
  - *td: Delay time*
  - *tr: Rise time*
  - *tgt: Gate turn ON time*
- **During turn OFF**
  - *trr: Reverse recovery time*
  - *tgr: Forward recovery time*
  - *tq: Turn OFF time*



Thyristor ratings





Thyristor ratings

Anode voltage rating

- Peak Working Forward Blocking or Forward OFF State Voltage (VDWM)
- Peak Repetitive Forward Blocking Voltage (VDRM)
- Peak Non-Repetitive or Surge Forward Blocking Voltage (VDSM)
- Peak Working Reverse Voltage (VRWM)
- Peak Repetitive Reverse Voltage (VRRM)
- Peak Non Repetitive Reverse Voltage (VRSM)
- Forward dv/dt Rating
- Voltage Safety Factor of SCR (VSF)

$$V_{SF} = \frac{Peak\ Repetitive\ Reverse\ Voltage\ (V_{RRM})}{2 \times RMS\ Value\ of\ Input Voltage}$$

- Finger Voltage of SCR (VFV)

THYRISTOR RATINGS

Current ratings

- Maximum RMS Current Rating (IRMS)
- Maximum Average Current Rating (IAV)
- Maximum Surge Current (ISM)
- I^2R Rating of SCR
- di/dt Rating of SCR

Gate Specification of SCR

- Gate Current to Trigger (IGT)
- Gate Triggering Voltage (VGT)
- Non Triggering Gate Voltage (VNG)
- Peak Reverse Gate Voltage (VGRM)
- Average Gate Power Dissipation (PGAR)
- Peak Forwarded Gate Current (IGRM)

DATA SHEET OF BTW69-1200N (50 A –1200 V NON INSULATED SCR THYRISTOR)

Features
On-state rms current: 50 A Blocking voltage: 1200 V
Gate current: 50 mA

Table 1. Device summary

Symbol	Value
$I_{T(RMS)}$	50 A
V_{DRM}/V_{RRM}	1200 V
I_{GT}	50 mA

Table 2. Absolute maximum ratings (limiting values)

Symbol	Parameter			Value	Unit
$I_{T(RMS)}$	On-state current rms (180° conduction angle)		T_c = 102 °C	50	A
$IT_{(AV)}$	Average on-state current (180° conduction angle)		T_c = 102 °C	31	A
I_{TSM}	Non repetitive surge peak on-state current	t_p = 8.3 ms	T_j = 25 °C	763	A
		t_p = 10 ms		700	
I^2t	I^2t Value	t_p = 10 ms	T_j = 25 °C	2450	A^2s
dI/dt	Critical rate of rise of on-state current Gate supply: I_G = 100 mA, dI_G/dt = 1 A/µs			100	A/µs
I_{GM}	Peak gate current	t_p = 20 µs	T_j = 125 °C	8	A
$P_{G(AV)}$	Average gate power dissipation		T_j = 125 °C	1	W
T_{stg} T_j	Storage junction temperature range Operating junction temperature range			- 40 to + 150 - 40 to + 125	°C
V_{GM}	Maximum peak reverse gate voltage			5	V

Table 3. Electrical characteristics (T_j = 25 °C, unless otherwise specified)

Symbol	Test conditions			Value	Unit
I_{GT}	V_D = 12 V, R_L = 33 Ω		MIN.	8	mA
			MAX.	50	
V_{GT}			MAX.	1.3	V
V_{GD}	$V_D = V_{DRM}$, R_L = 3.3 kΩ	T_j = 125 °C	MIN.	0.2	V
I_H	I_T = 500 mA, gate open		MAX.	100	mA
I_L	I_G = 1.2 x I_{GT}		TYP.	125	mA
t_{gt}	I_T = 50 A, $V_D = V_{DRM}$, I_G = 200 mA, dI_G/dt = 0.2 A/µs		TYP.	2	µs
dV/dt	V_D = 67% V_{DRM}, gate open	T_j = 125 °C	MIN.	1000	V/µs
t_q	V_D = 800 V, I_{TM} = 50 A, V_R = 75 V, t_p = 100 µs, dI_{TM}/dt = 30 A/µs, dV_D/dt = 20 V/µs	T_j = 125 °C	TYP.	100	µs
V_{TM}	I_{TM} = 100 A, t_p = 380 µs	T_j = 25 °C	MAX.	1.6	V
V_{t0}	Threshold voltage	T_j = 125 °C	MAX.	0.9	V
R_D	Dynamic resistance	T_j = 125 °C	MAX.	8.5	mΩ
I_{DRM} I_{RRM}	$V_D = V_{DRM}$ $V_R = V_{RRM}$	T_j = 25 °C	MAX.	10	µA
		T_j = 125 °C		5	mA

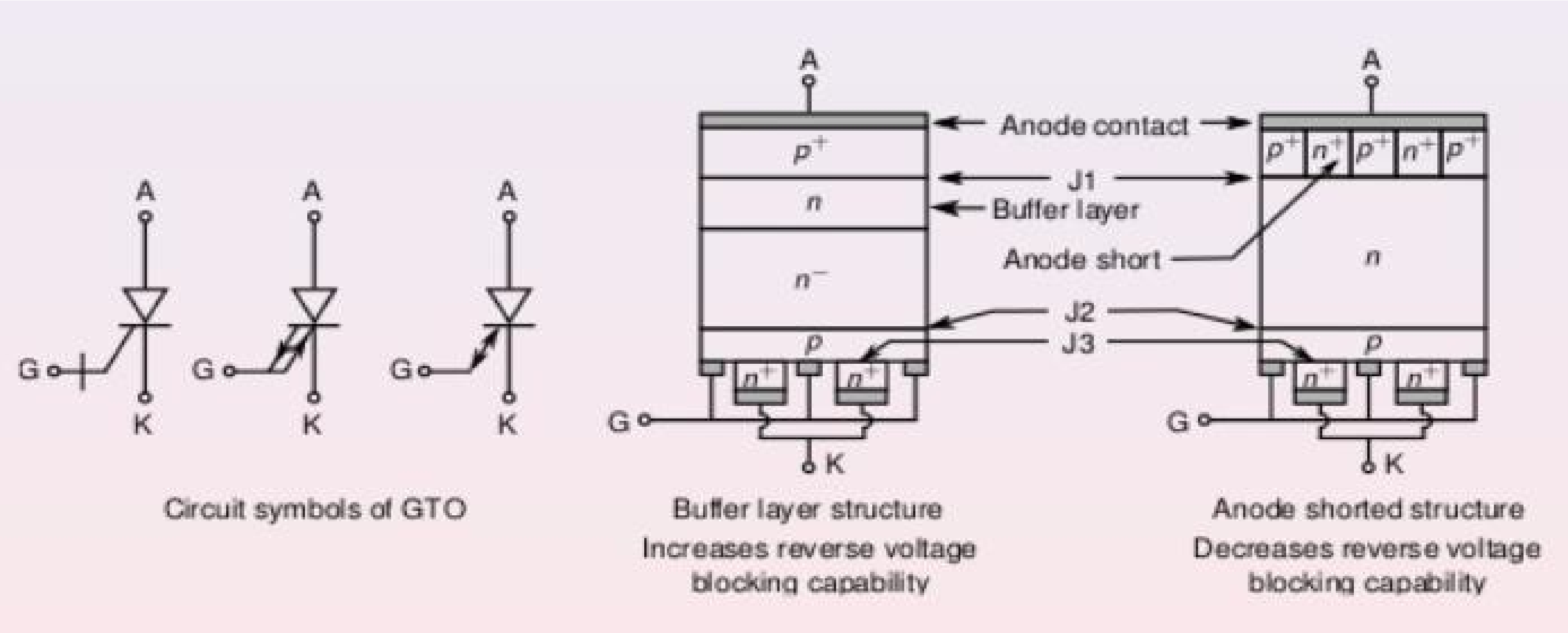
TYPES OF THYRISTOR

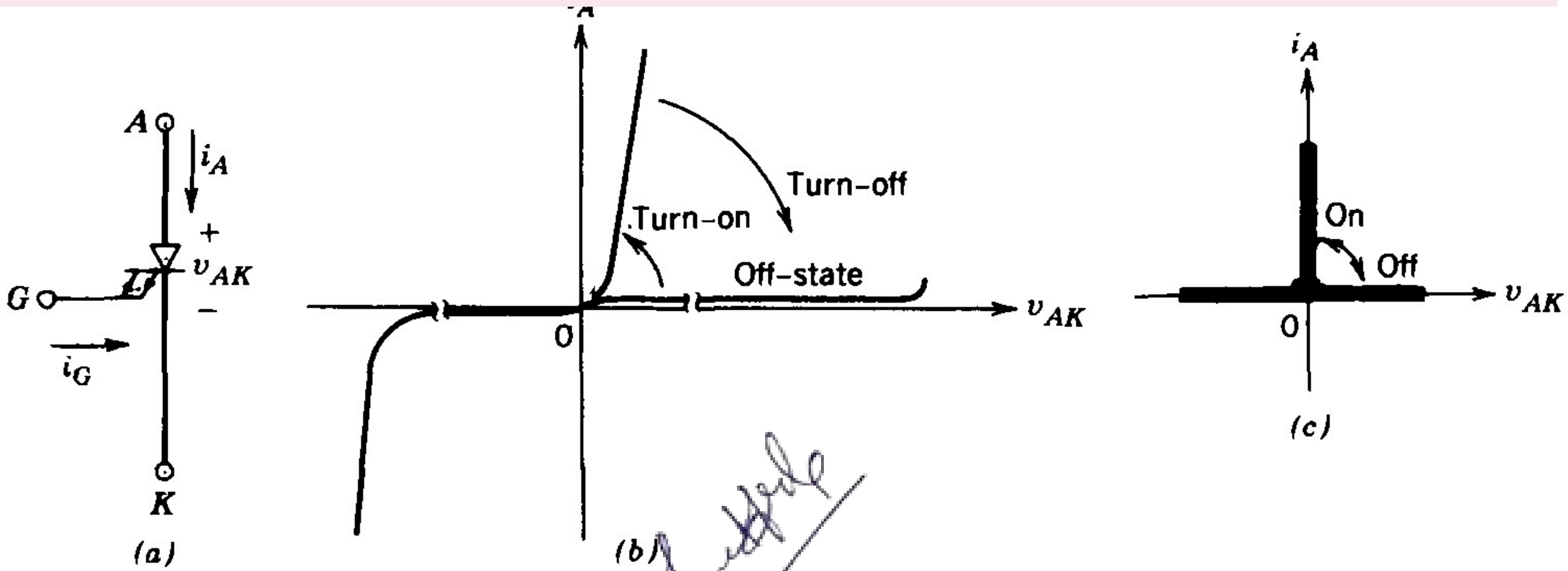
- SCR
- GTO
- IGCT
- MCT
- Static Induction Thyristors (SITh)
- Optically Triggered Thyristors (LTTs)
- Bi-directional Thyristors (BCT)

GATE TURN OFF THYRISTOR (GTO)

Like thyristor, the GTO is a current controlled minority carrier (i.e. bipolar) device.

- GTOs differ from conventional thyristor in that, they are designed to turn off when a negative current is sent through the gate, there by causing a reversal of the gate current.
- A relatively high gate current is needed to turn off the device with typical turn off gains in the range of 4-5.
- During conduction, on the other hand, the device behaves just like a thyristor with very low ON state voltage drop



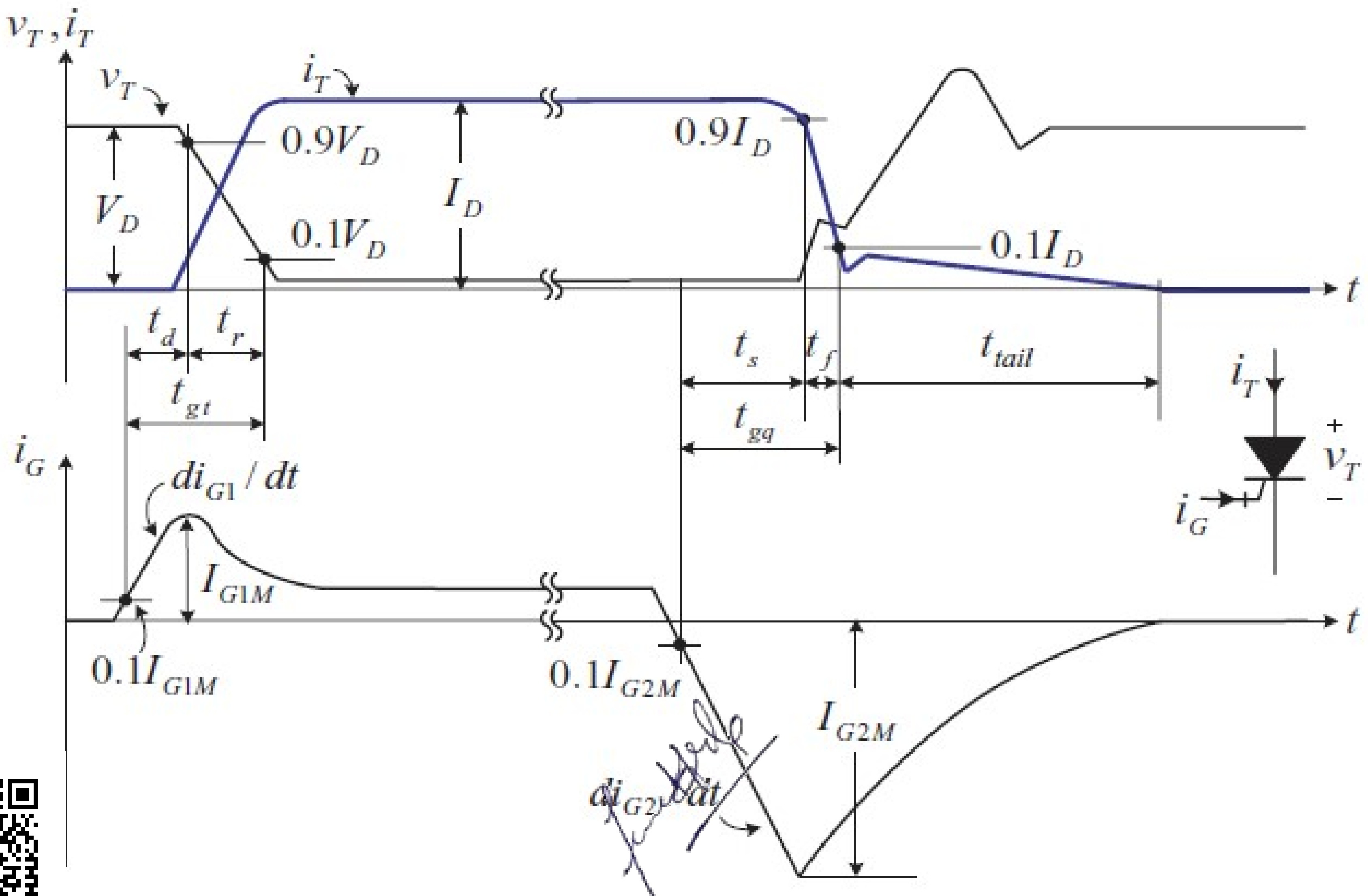


TO: (*a*) symbol, (*b*) *i–v* characteristics, (*c*) idealized characteristics.

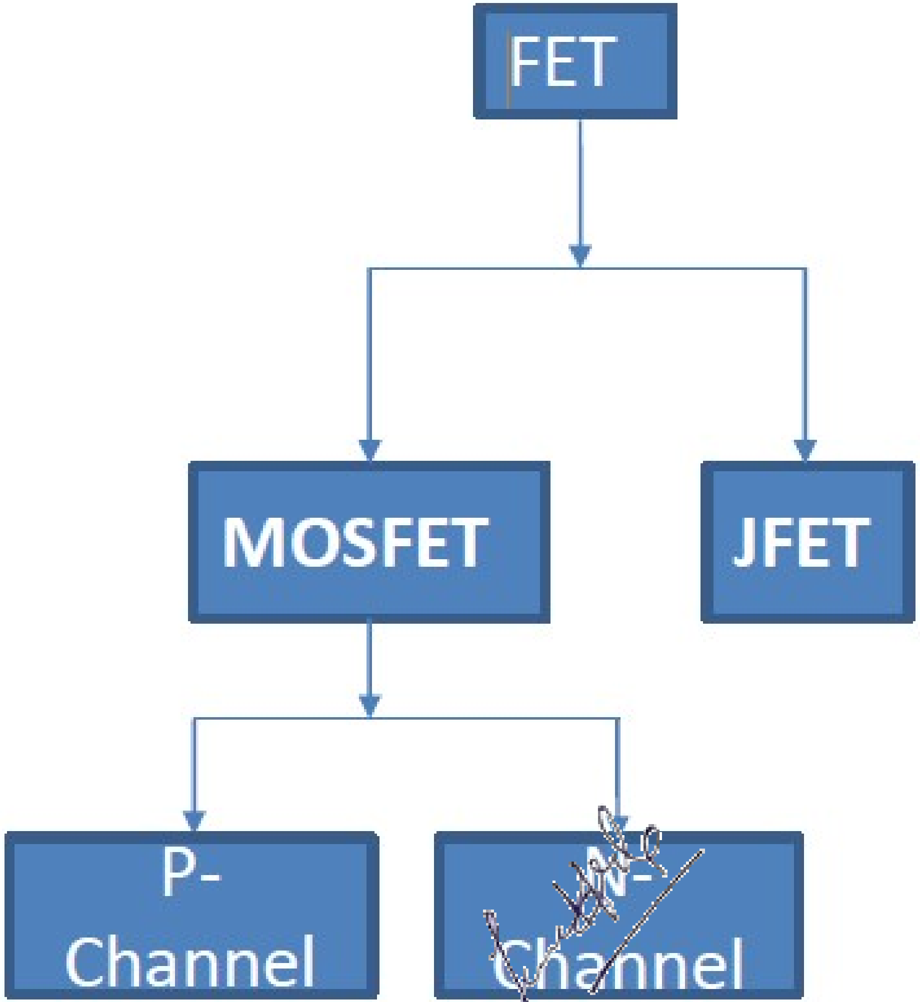
STEADY STATE CHARACTERISTICS OF GTO

- The latching current of a GTO is considerably higher than a thyristor of similar rating.
- The forward leakage current is also considerably higher.
- Infact, if the gate current is not sufficient to turn on a GTO it operates as a high voltage low gain transistor with considerable anode current.
- It should be noted that a GTO can block rated forward voltage only when the gate is negatively biased with respect to the cathode during forward blocking state. Atleast, a low value resistance must be connected across the gate cathode terminal. Increasing the value of this resistance reduces the forward blocking voltage of the TO

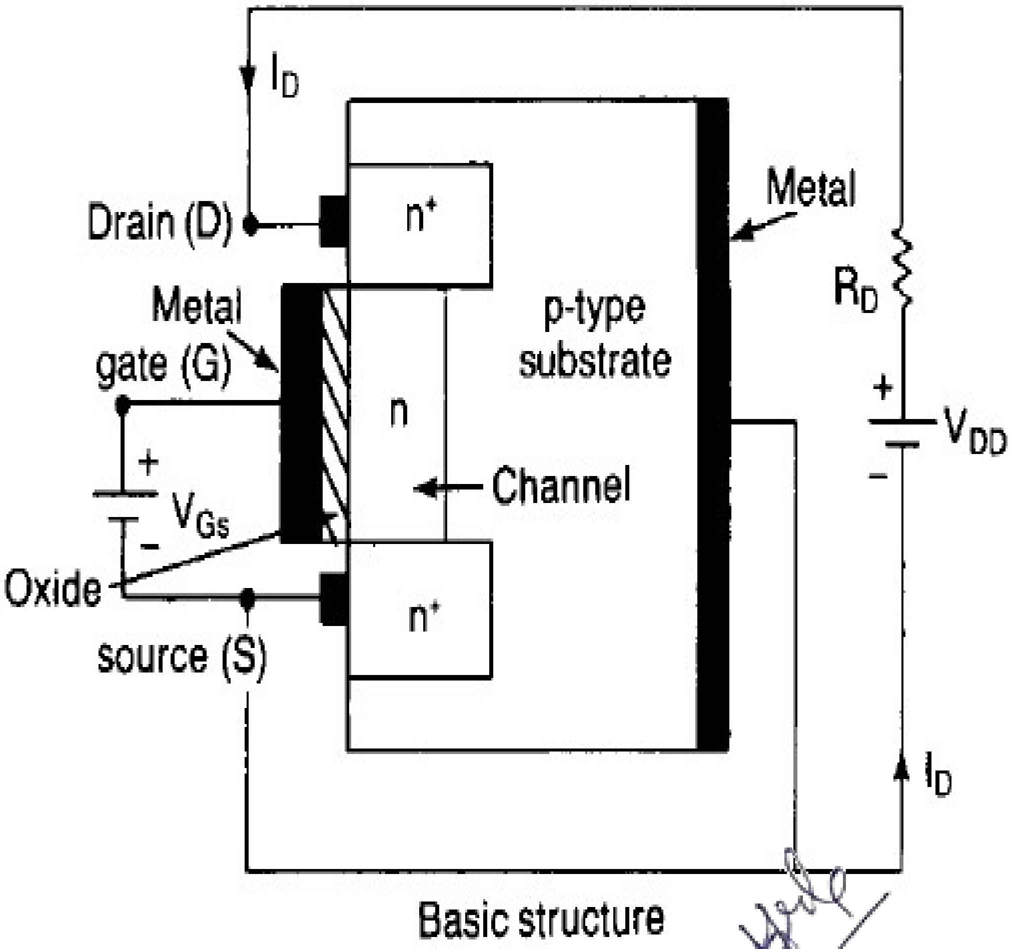
Dynamic characteristics of GTO

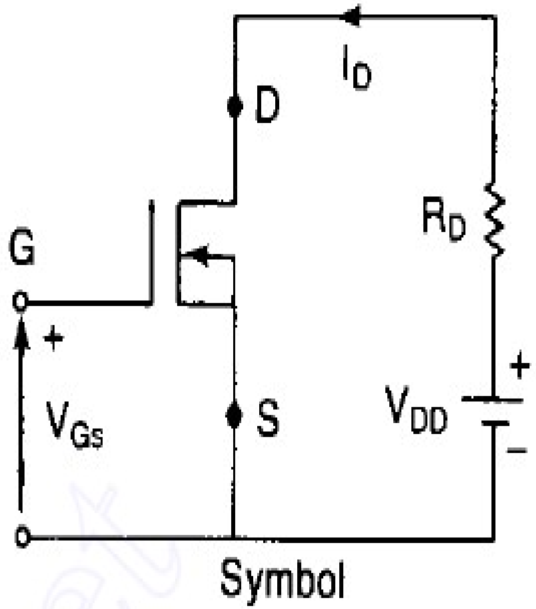


Power MOSFET :-Power-Metal Oxide Semiconductor Field Effect Transistor



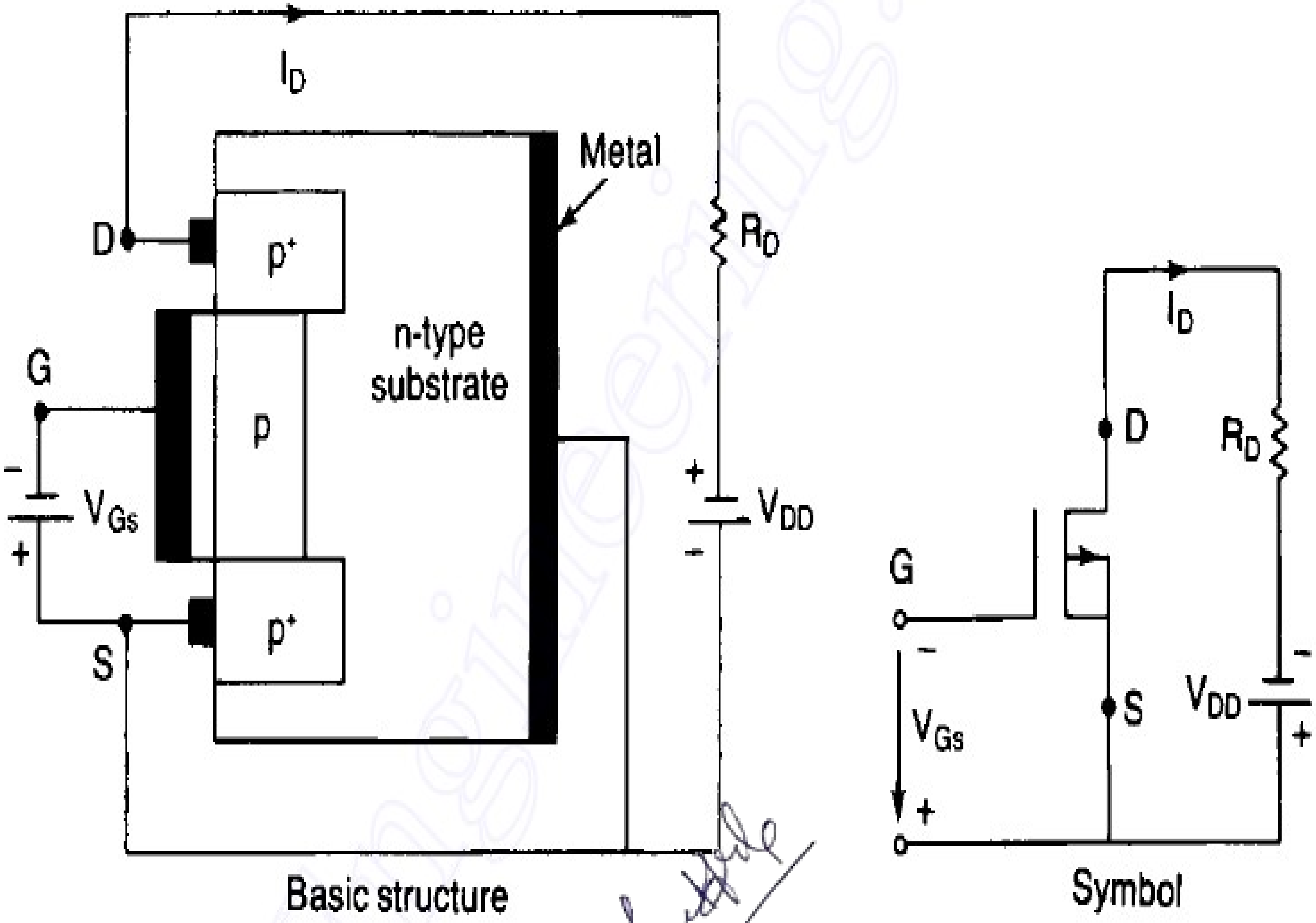
N-CHANNEL DEPLETION TYPE MOSFET





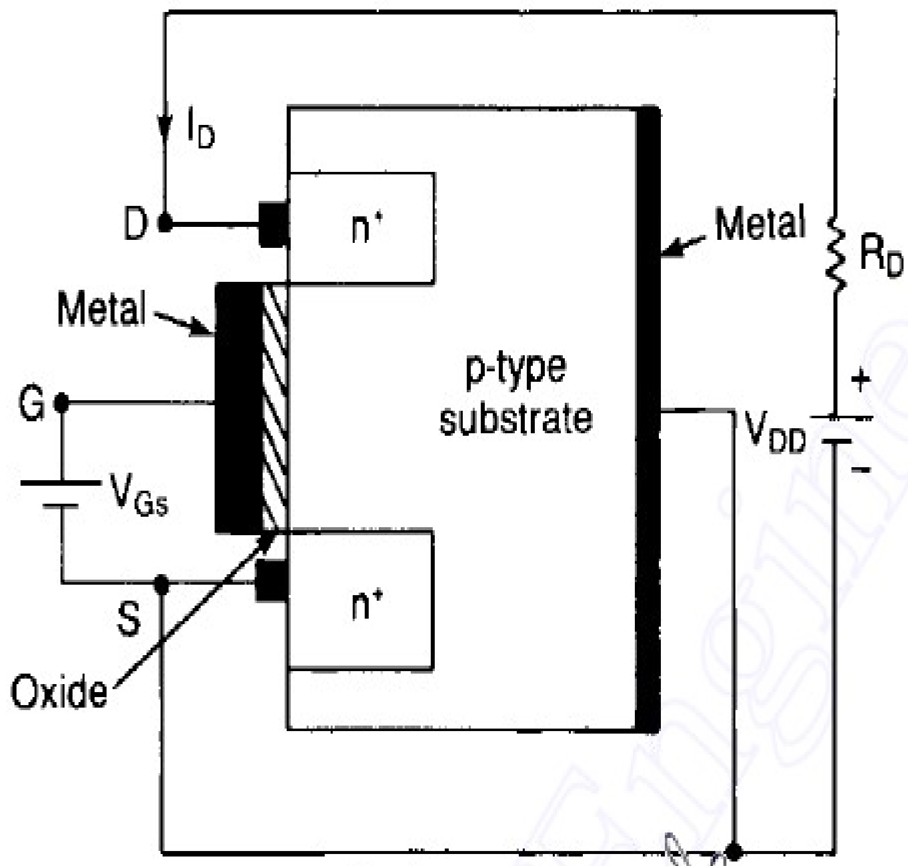
(a) n-channel depletion-type MOSFET

P-CHANNEL DEPLETION TYPE MOSFET

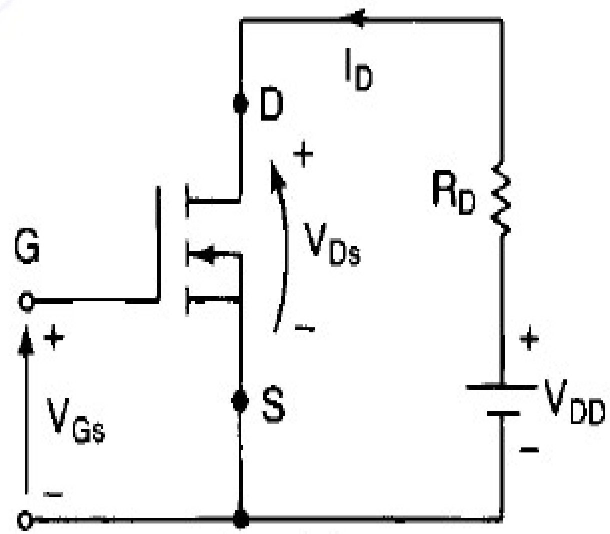


(b) p-channel depletion-type MOSFET

N-CHANNEL ENHANCEMENT TYPE MOSFET



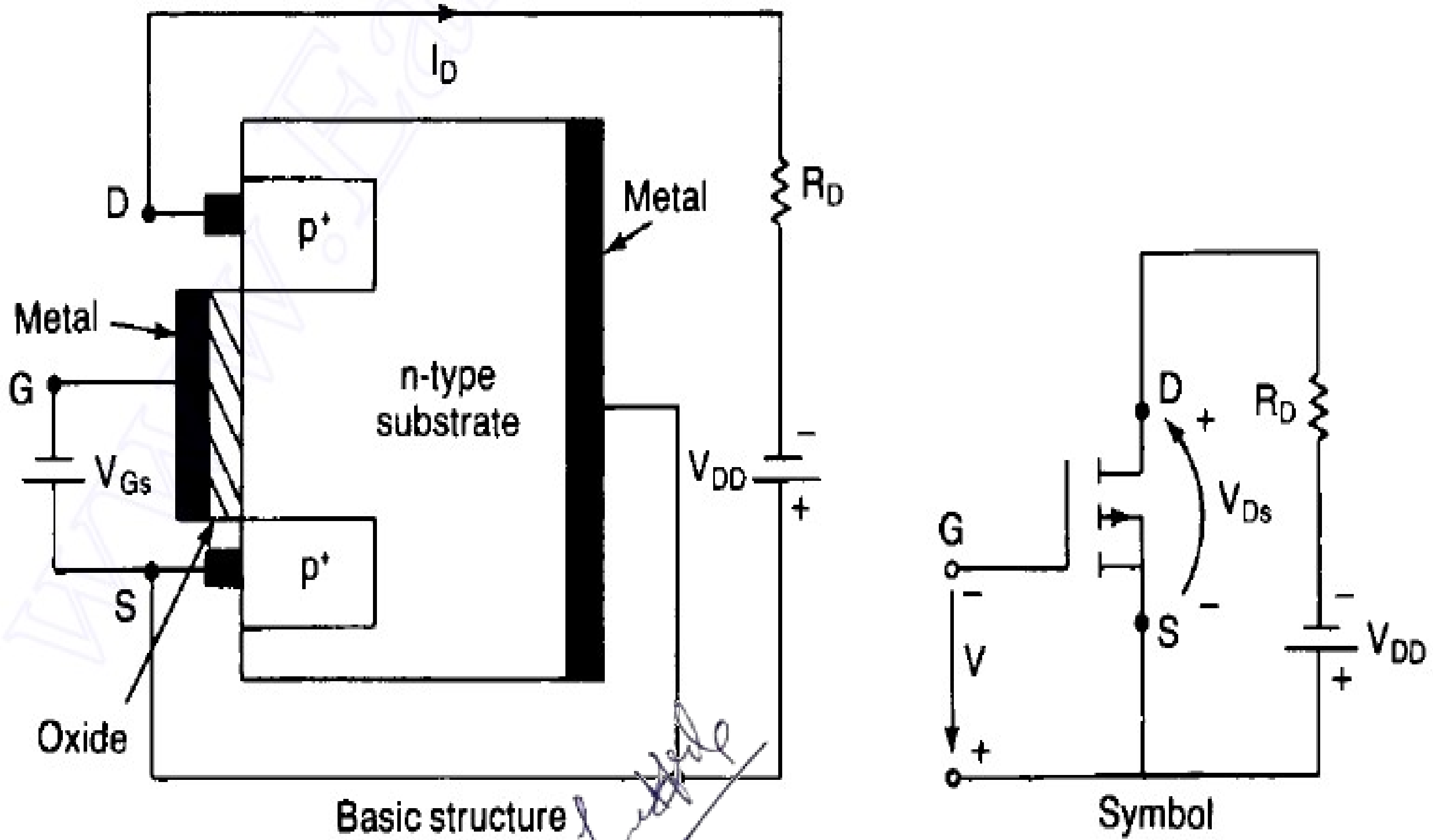
Basic structure



Symbol

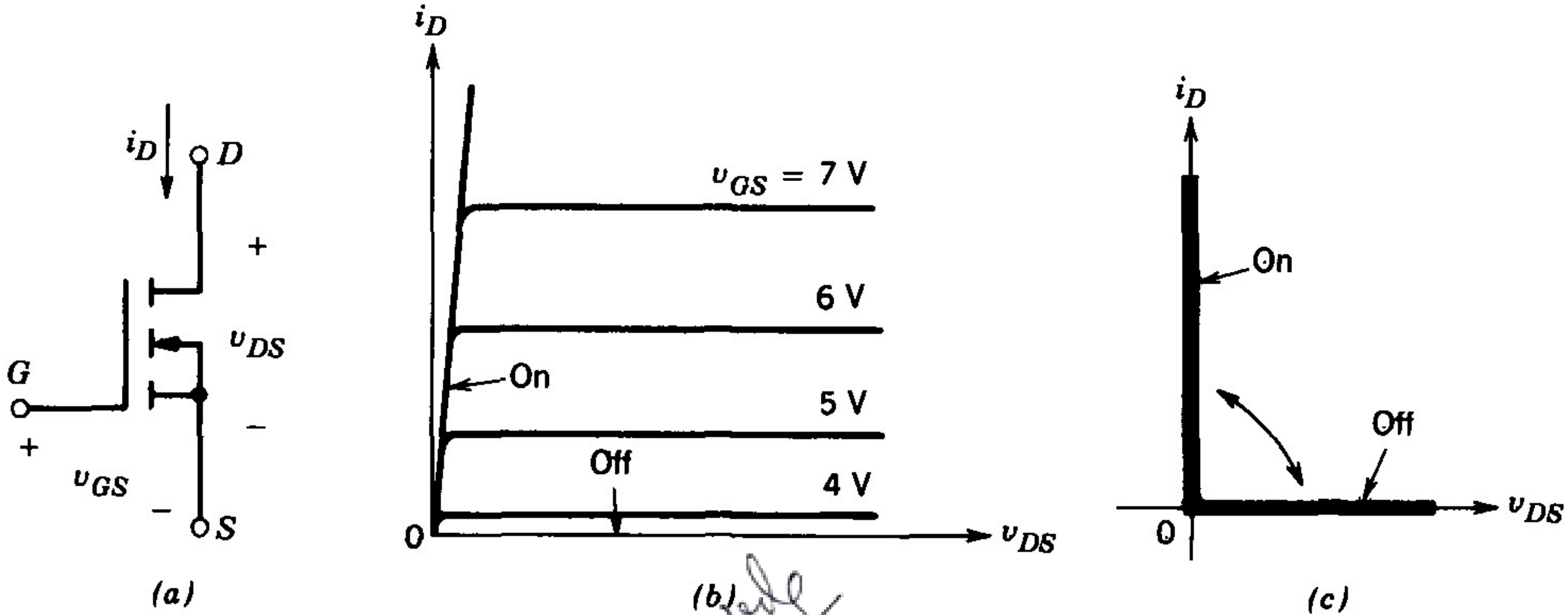
(a) n-channel enhancement-type MOSFET

P-CHANNEL ENHANCEMENT TYPE MOSFET



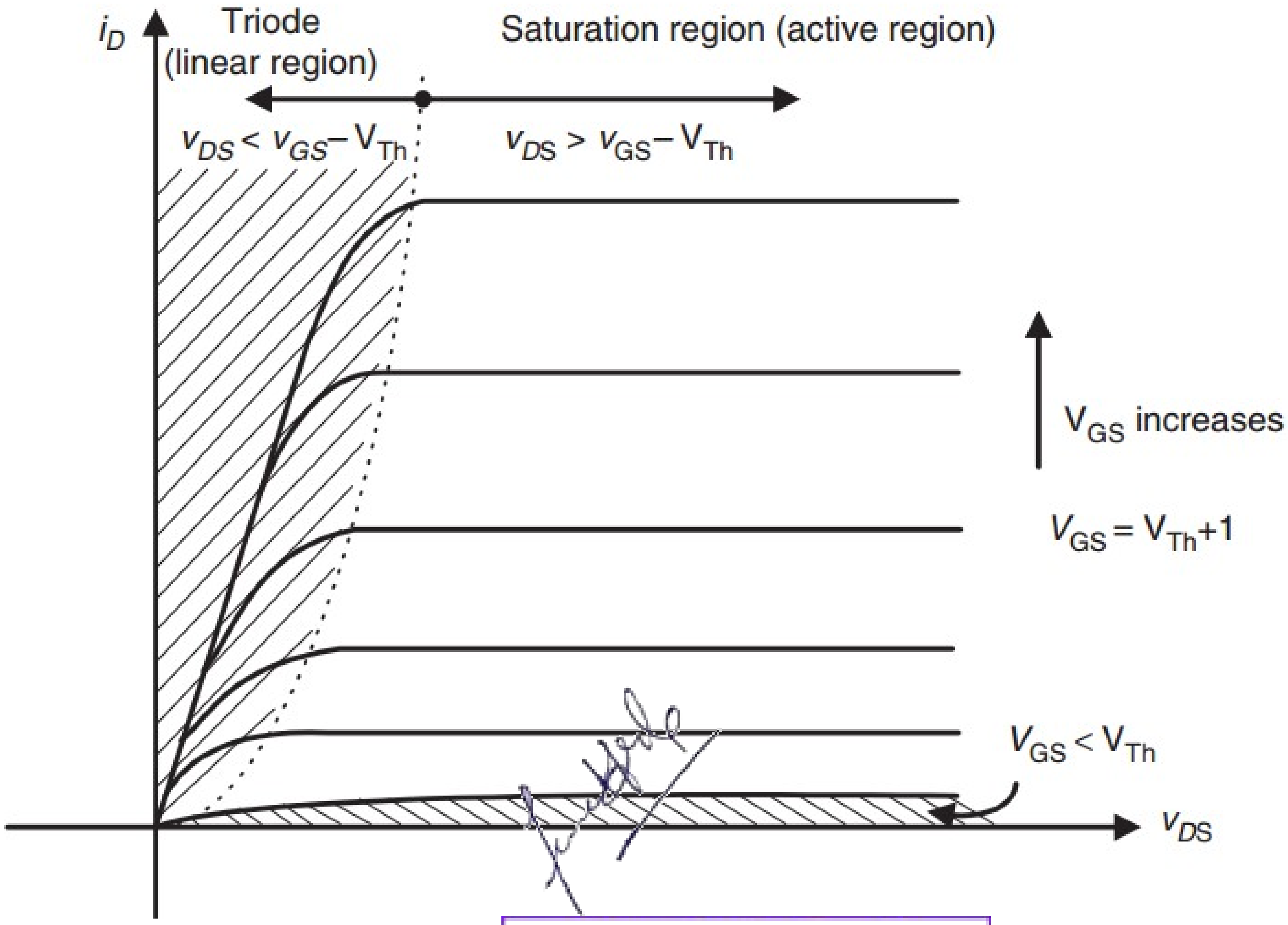
(b) p-channel enhancement-type MOSFET

N-CHANNEL ENHANCEMENT TYPE MOSFET CHARACTERISTICS

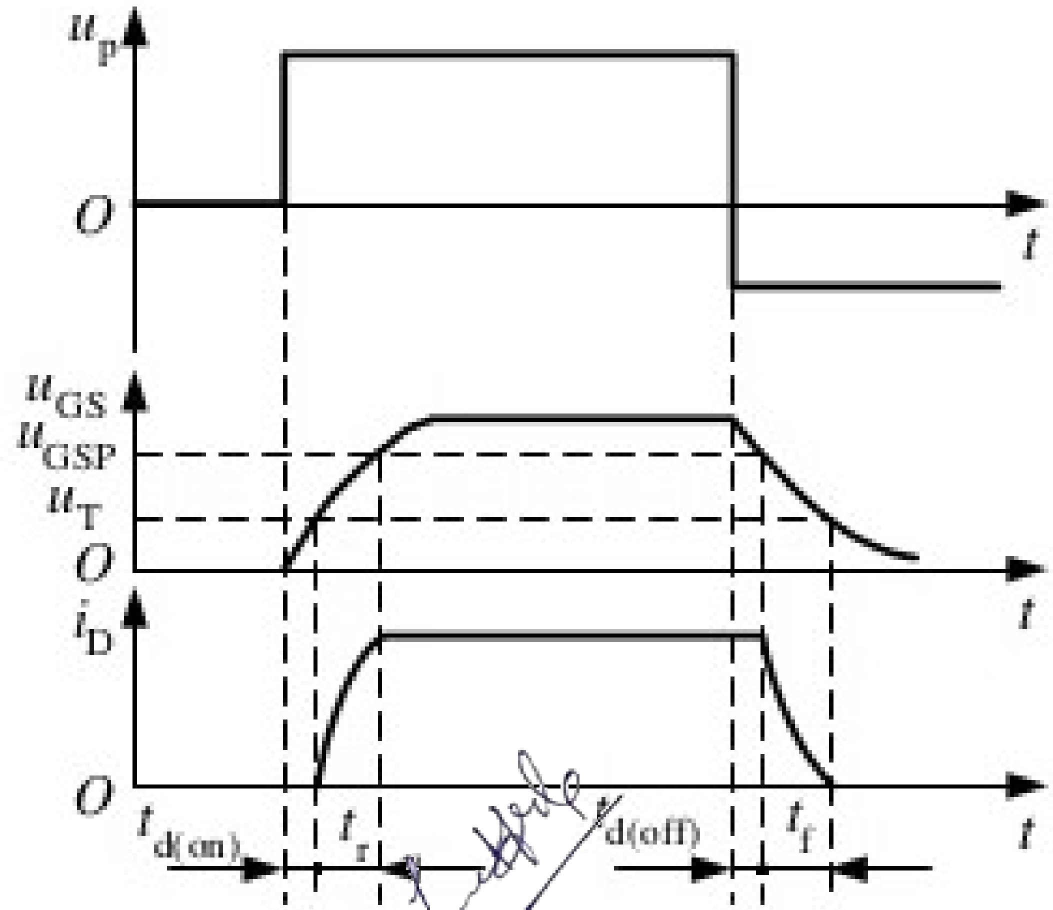


channel MOSFET: (*a*) symbol, (*b*) *i*–*v* characteristics, (*c*) idealized

MOSFET Static Characteristics



MOSFET Switching Characteristics



MOSFET SWITCHING CHARACTERISTICS

1) Turn On delay time td:- Time that is required to charge the input capacitance to threshold voltage level.

2)Rise time (tr):-tr is the gate charging time from the threshold level to full gate voltage V_{GSp} which is required to drive MOSFET to full linear region.

3) Turn off delay time(td off):- Time required for the input capacitance to discharge from the overdrive gate voltage V1 to the pinch off region.

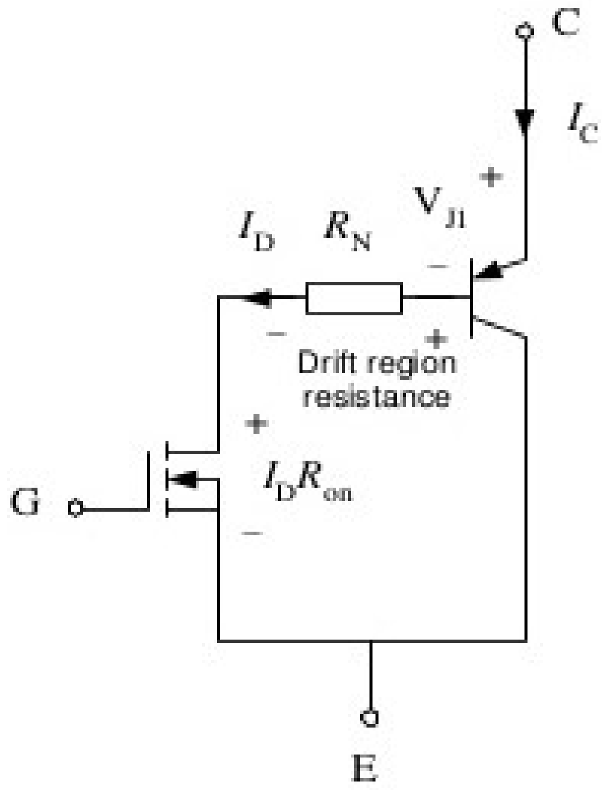
4) Fall time(tf):- Is the time required for i/p capacitance to discharge from the pinch off region to threshold voltage. If $V_{GS} <= V_T$ the MOSFET is off.

IGBT (INSULATED GATE BIPOLAR TRANSISTOR)

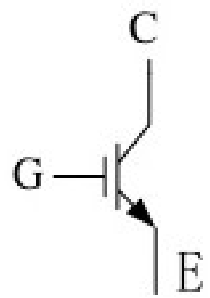
IGBT is preferred over MOSFET as it's ON-state loss is less as compared to Power MOSFET with easy driving process.

Applications:

- ➢It is used for high power applications (Kw to Mw)
- ➢Generally used for 500-1700V converter applications.



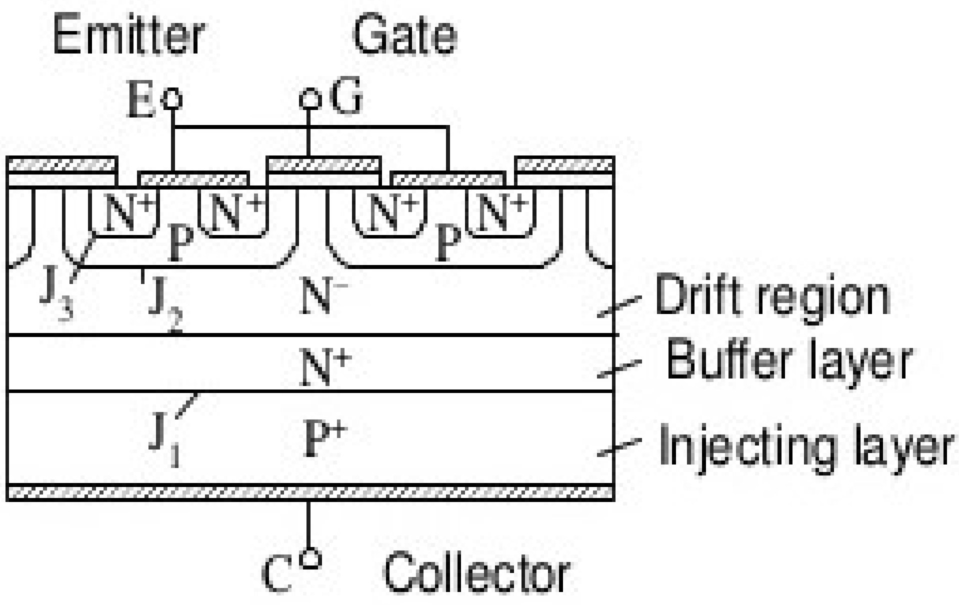
Equivalent Circuit

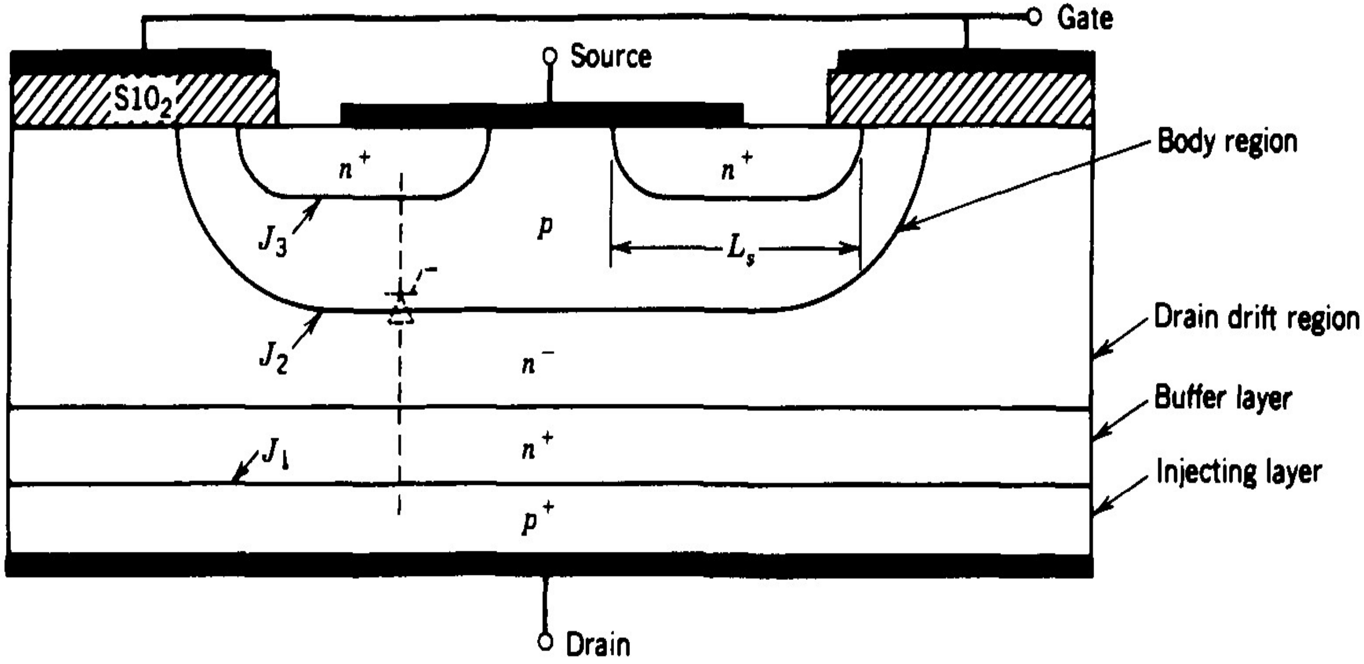


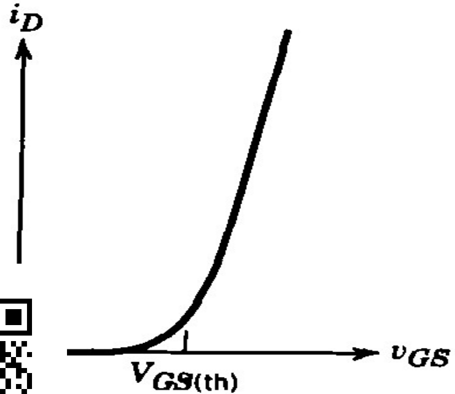
Symbol

IGBT PHYSICS OF DEVICE OPERATION

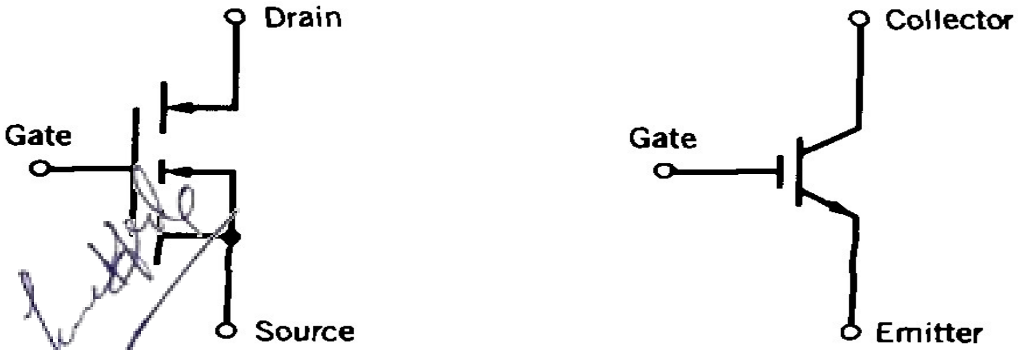
- It is multiple cell structure.
- It's basic structure is same as power MOSFET, only one extra region is there.
- During ON-state, minority carriers are injected into drift region which leads to conductivity modulation.
- It has slower switching time, less ON state resistance compared to power MOSFET. So it can used for high voltage applications. 1700V)





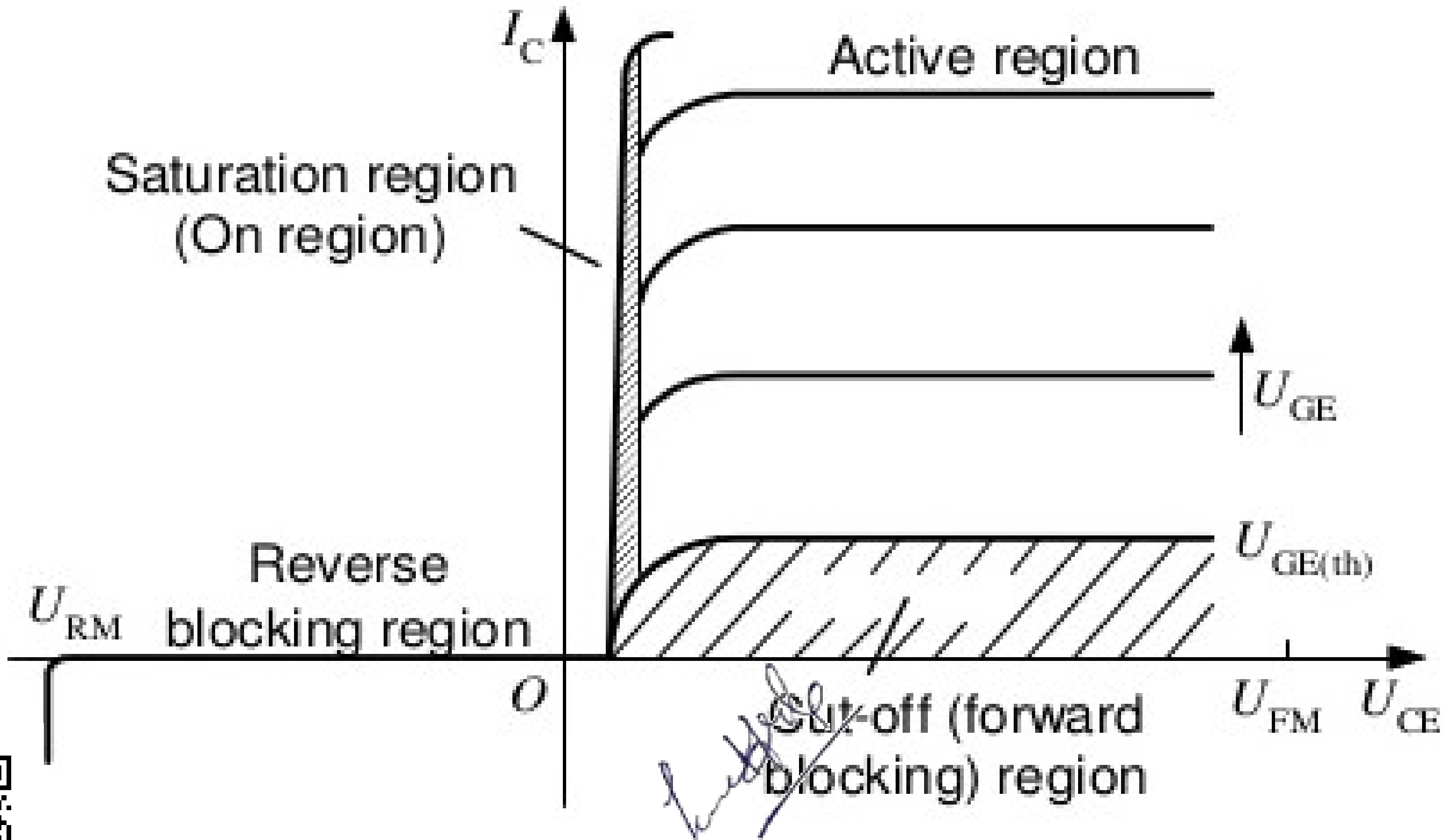


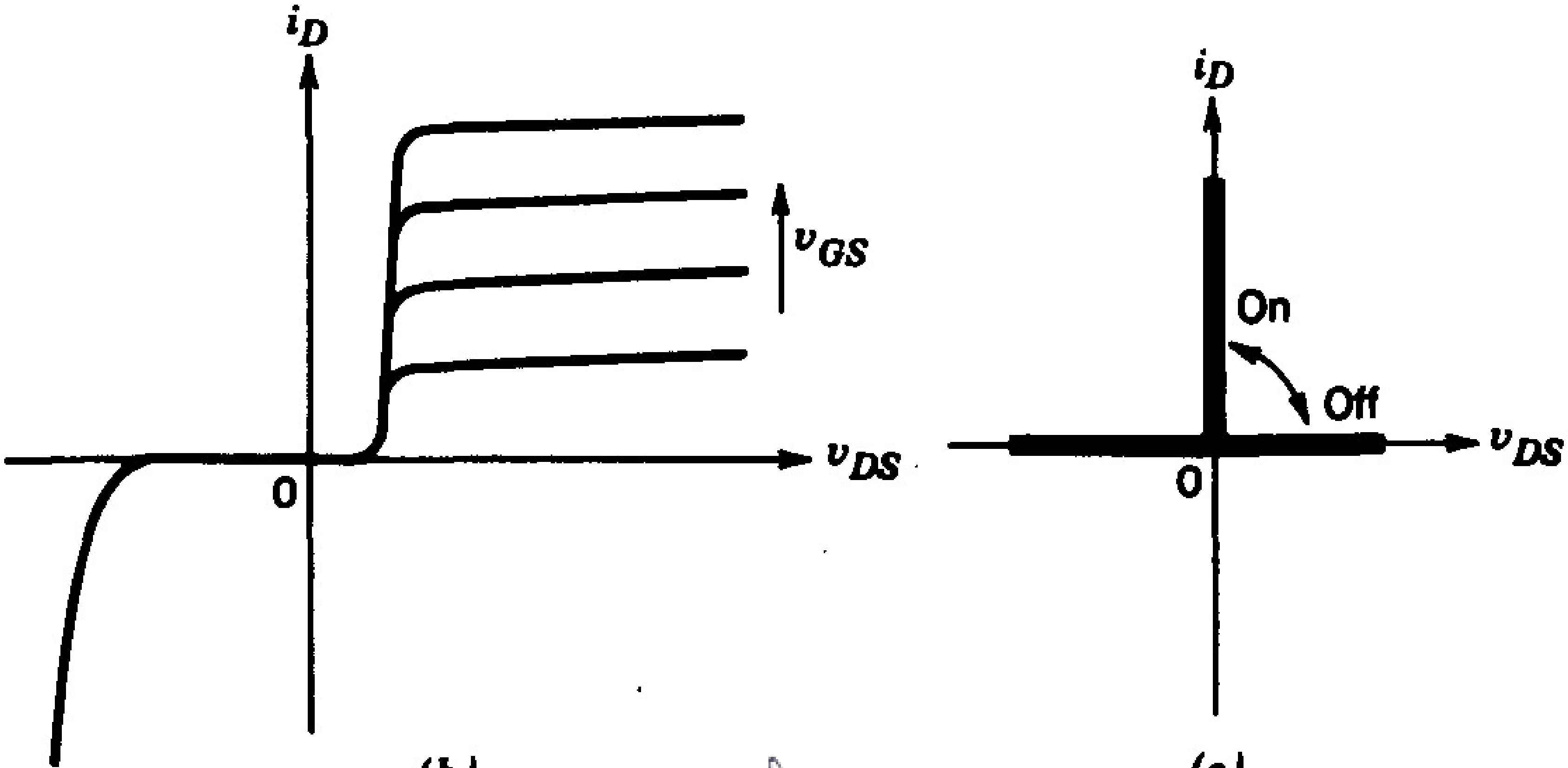
sfer characteristics;



n-channel IGBT circuit symbols

IGBT Static Characteristics



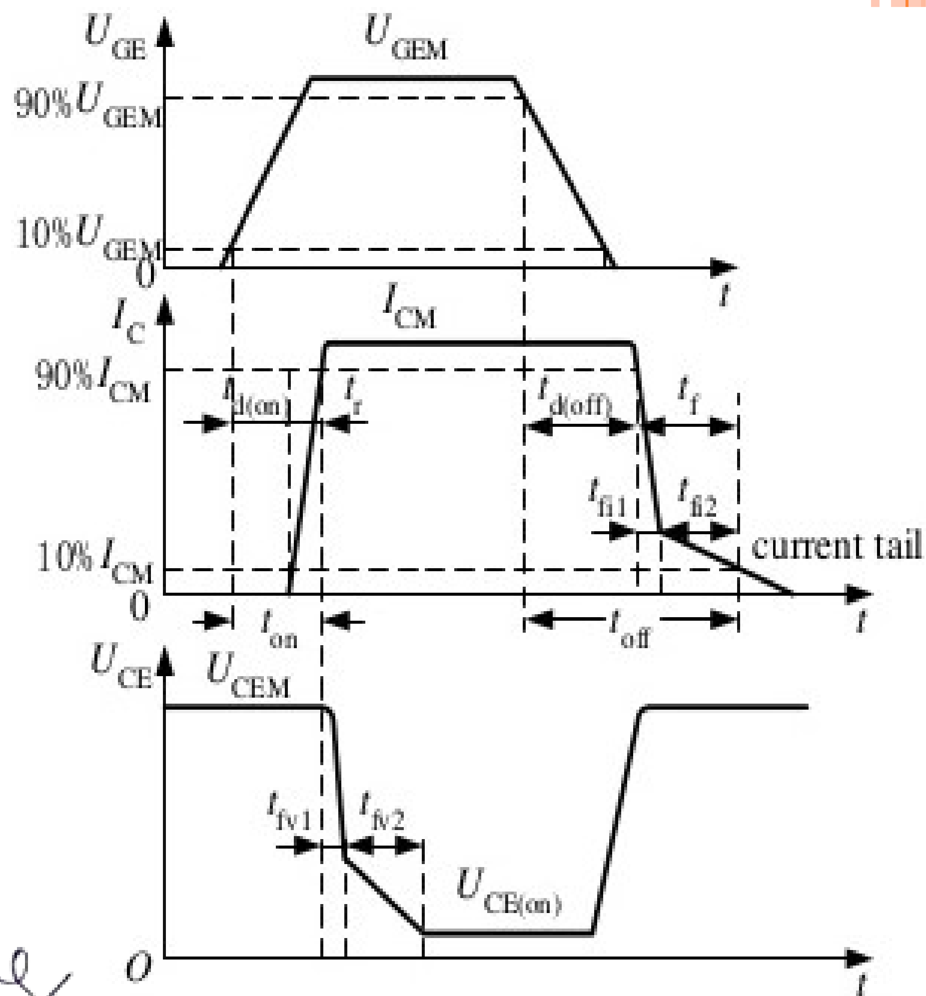


(b) (c)

i–v characteristics idealized characteristics.

IGBT Switching Characteristics

- The turn-ON process of both IGBT and power MOSFET are same.
- But there is difference in turn-OFF process of both the devices.
- In case of IGBT turn-OFF occurs due to stored in drift region.



MOSFET DATA SHEET (N-CHANNEL)

ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_{DS}	Drain-source Voltage (V_{GS} = 0)	500	V
V_{DGR}	Drain- gate Voltage (R_{GS} = 20 kΩ)	500	V
V_{GS}	Gate-source Voltage	± 30	V
I_D	Drain Current (continuous) at T_c = 25 °C	10.6	A
I_D	Drain Current (continuous) at T_c = 100 °C	6.4	A
I_{DM}(•)	Drain Current (pulsed)	42.4	A
P_{tot}	Total Dissipation at T_c = 25 °C	135	W
	Derating Factor	1.08	W/°C
dv/dt(1)	Peak Diode Recovery voltage slope	4.5	V/ns
T_{stg}	Storage Temperature	-65 to 150	°C
T_j	Max. Operating Junction Temperature	150	°C

DYNAMIC

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
g_{fs} (*)	Forward Transconductance	V_{DS} > $I_{D(on)}$ x $R_{DS(on)max}$ I_D =5.3 A	5	8		S
C_{iss} C_{oss} C_{rss}	Input Capacitance Output Capacitance Reverse Transfer Capacitance	V_{DS} = 25 V f = 1 MHz V_{GS} = 0		1480 210 25		pF pF pF

CONT.....

SWITCHING ON

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
$t_{d(on)}$ t_r	Turn-on Time Rise Time	V_{DD} = 250 V I_D = 5.3 A R_G = 4.7 Ω V_{GS} = 10 V (see test circuit, figure 3)		25 13		ns ns
Q_g Q_{gs} Q_{gd}	Total Gate Charge Gate-Source Charge Gate-Drain Charge	V_{DD} = 160 V I_D = 10 A V_{GS} = 10 V		38 10 17	49	nC nC nC

SWITCHING OFF

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
$t_{r(Voff)}$ t_f t_c	Off-voltage Rise Time Fall Time Cross-over Time	V_{DD} = 160 V I_D = 10 A R_G = 4.7 Ω V_{GS} = 10 V (see test circuit, figure 5)		13 15 25		ns ns ns

IGBT Data Sheet

(Tc = 25°C)

Item		Symbol	Ratings	Unit
Collector to emitter voltage		V_{CES}	600	V
Gate to emitter voltage		V_{GES}	±30	V
Collector current	Tc = 25°C	I_C	90	A
	Tc = 100°C	I_C	50	A
Collector peak current		ic(peak) Note1	180	A
Collector to emitter diode forward peak current		i_{DF}(peak) Note2	100	A
Collector dissipation		P_C	328.9	W
Junction to case thermal impedance (IGBT)		θj-c	0.38	°C/W
Junction to case thermal impedance (Diode)		θj-cd	2.0	°C/W
Junction temperature		Tj	150	°C
Storage temperature		Tstg	–55 to +150	°C

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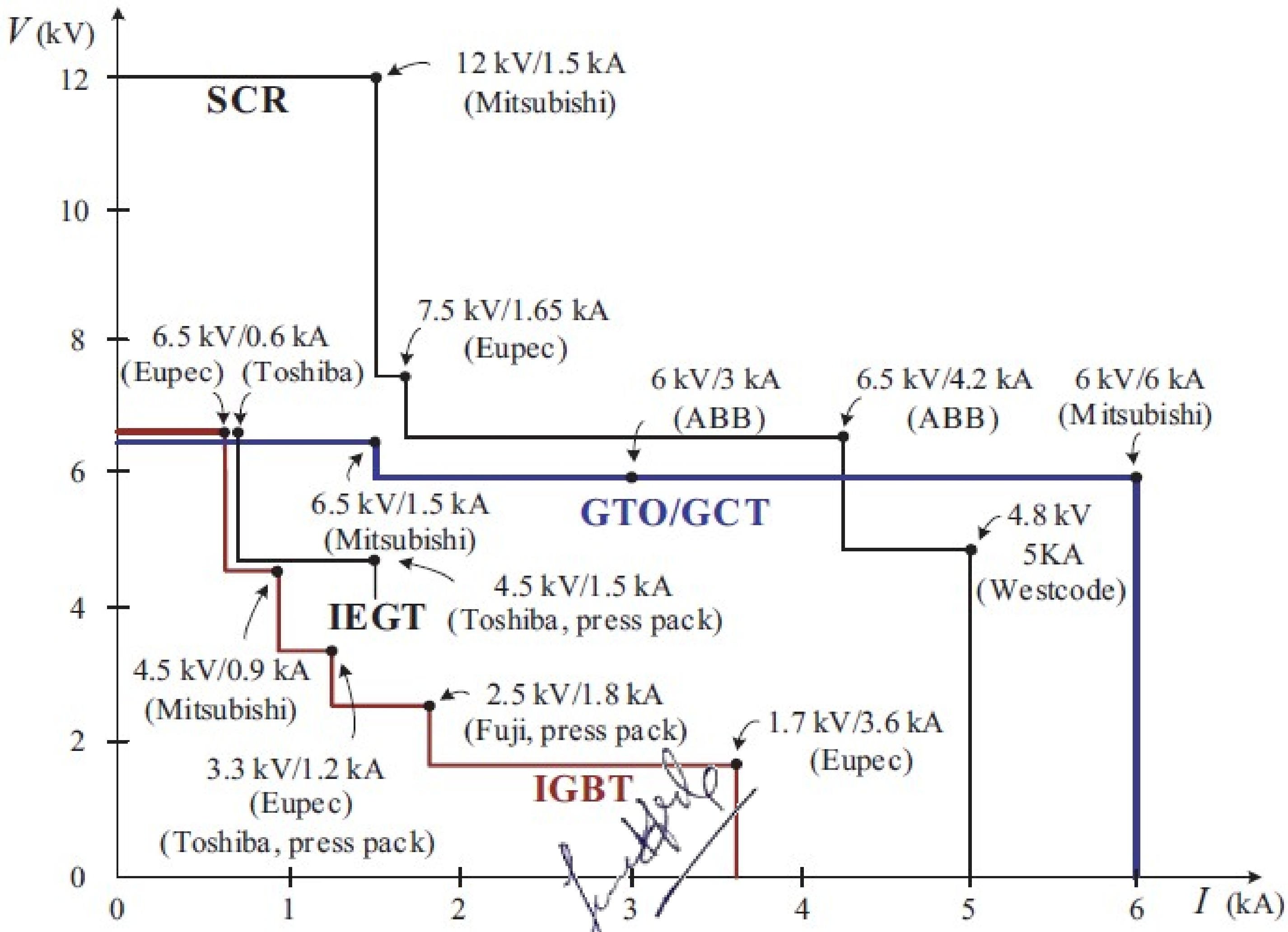
CONT….

Electrical Characteristics

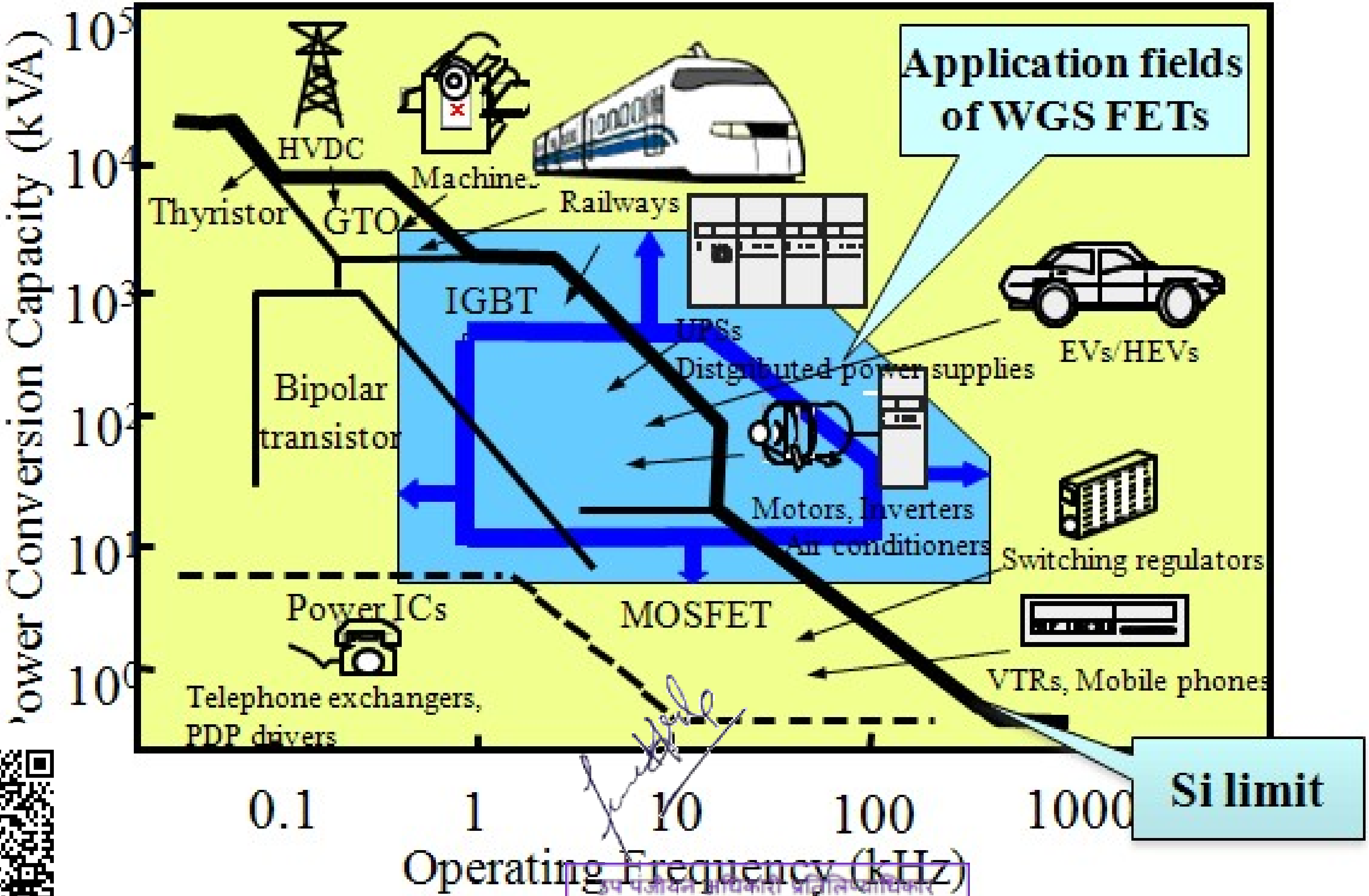
($T_j = 25°C$)

Item	Symbol	Min	Typ	Max	Unit	Test Conditions
Zero gate voltage collector current	I_{CES}	—	—	100	μA	V_{CE} = 600V, V_{GE} = 0
Gate to emitter leak current	I_{GES}	—	—	±1	μA	V_{GE} = ±30 V, V_{CE} = 0
Gate to emitter cutoff voltage	$V_{GE(off)}$	4	—	8	V	V_{CE} = 10V, I_C = 1 mA
Collector to emitter saturation voltage	$V_{CE(sat)}$	—	1.35	1.75	V	I_C = 50 A, V_{GE} = 15V Note3
	$V_{CE(sat)}$	—	1.6	—	V	I_C = 90 A, V_{GE} = 15V Note3
Input capacitance	Cies	—	4700	—	pF	V_{CE} = 25 V
Output capacitance	Coes	—	198	—	pF	V_{GE} = 0 V
Reverse transfer capacitance	Cres	—	83	—	pF	f = 1 MHz
Switching time	$t_{d(on)}$	—	63	—	ns	I_C = 30 A,
	t_r	—	81	—	ns	V_{CE} = 400 V, V_{GE} = 15 V
	$t_{d(off)}$	—	142	—	ns	Rg = 5 Ω Note3
	t_f	—	74	—	ns	Inductive load
C-E diode forward voltage	V_{ECF1}	—	1.2	2.1	V	I_F = 20 A Note3
	V_{ECF2}	—	1.5	—	V	I_F = 40 A Note3
C-E diode reverse recovery time	t_{rr}	—	90	—	ns	I_F = 20 A di_F/dt = 100 A/μs

Voltage and Current Rating of High power Switching devices



APPLICATIONS



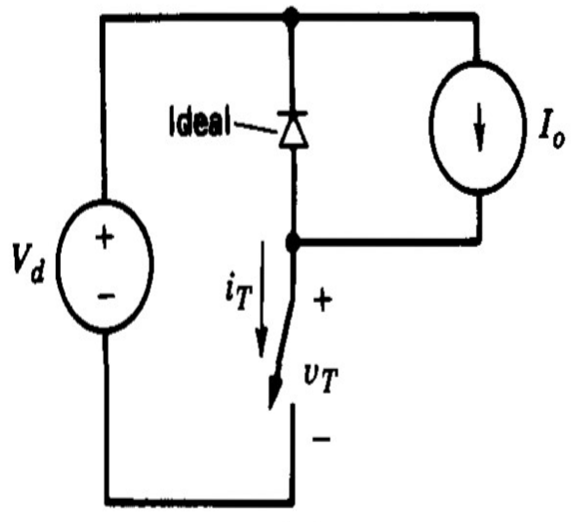
Comparison

Device	*Power Capability*	*Switching Speed*
BJT/MD	Medium	Medium
MOSFET	Low	Fast
GTO	High	Slow
IGBT	Medium	Medium
MCT	Medium	Medium

DESIRED CHARACTERISTICS IN CONTROLLABLE SWITCHES

The ideal controllable switch has the following characteristics:

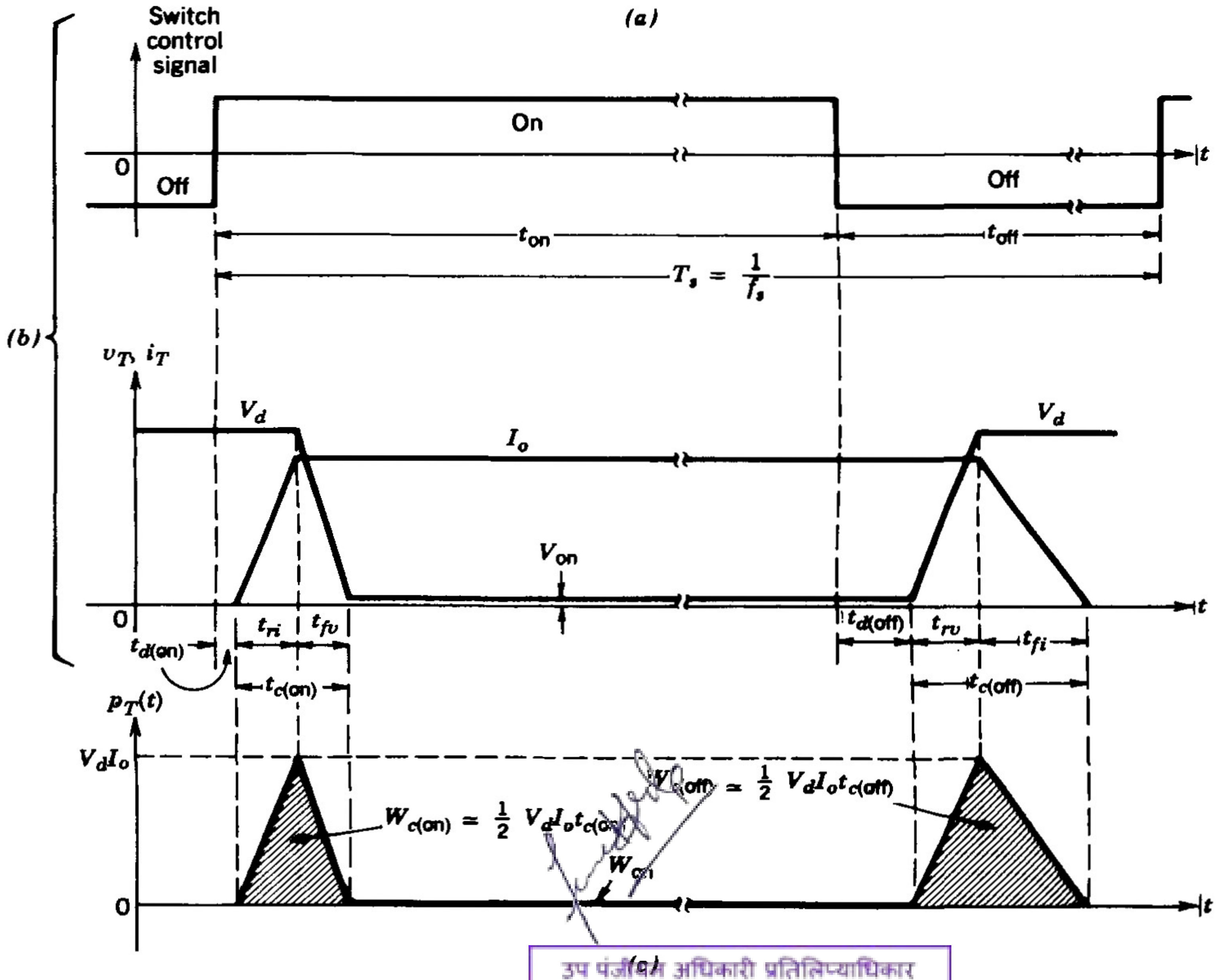
1. Block arbitrarily large forward and reverse voltages with zero current flow when OFF.
2. Conduct arbitrarily large currents with zero voltage drop when ON.
3. 3. Switch from on to off or vice versa instantaneously when triggered.
4. Vanishingly small power required from control source to trigger the switch.



(a)

In order to consider power dissipation in a semiconductor device, a controllable switch is connected in the circuit shown in fig

Generic-switch switching characteristics



SAFE OPERATING AREA

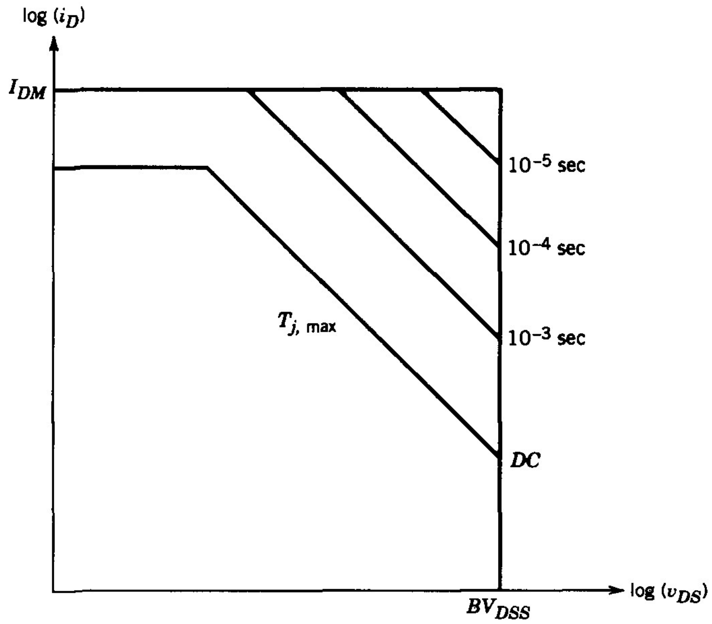


Figure 22-18 The SOA of an *n*-channel enhancement mode MOSFET. Note the absence of second breakdown.

Three factors determine the SOA of the MOSFET,

- The maximum drain current I_{DM}
- The internal junction temperature Tj (which is governed by the power dissipation in the device)
- The breakdown voltage BV_{DSS}.

At small anode-cathode voltages, the maximum controllable anode current is the limiting boundary of the SOA

PROTECTION OF SWITCHING DEVICES AND CIRCUITS:

Switching devices and circuit components may fail due to the following reasons.

1. Overheating –thermal failure
2. Over current
3. Overvoltage –usually happens during turn-off
4. Excessive *di/dt*
5. *Excessive dv/dt6. Switching loss –excessive switching loss is a major contributing factor ofoverheating*

❑Power electronic circuits and their switching devices and components can be protected from over current by placing fuses at suitable locations.

❑Heat sinks, fins and fans are used to take the excess heat away from switching devices and other components.

Snubber circuits are required to limit *di/dt, dv/dt and ervoltage during turn-on and turnoff.*

References

- NPTEL Video Lectures
- Rashid, M. H. (Ed.). (2017). *Power electronics handbook*. Butterworth-Heinemann.
- Mohan, Ned, Tore M. Undeland, and William P. Robbins. *Power electronics: converters, applications, and design*. John wiley & sons, 2003.