**POWER ELECTRONICS**
**B.E., VII Semester, Electronics & Communication Engineering**
**[As per Choice Based Credit System (CBCS) Scheme]**
**Course Code 17EC73 CIE Marks 40**

| | |
|---|---|
| **Number of Lecture Hours/Week: 04** | **SEE Marks 60** |
| **Total Number of Lecture Hours: 50 (10 Hours / Module)** | **Exam Hours 03** |
| | **CREDITS – 04** |

***RNS INSTITUTE OF TECHNOLOGY***

***DEPARTMENT OF ELECTRONICS AND COMMUNICATION***

***POWER ELECTRONICS NOTES:***

# MODULE-1

Course objectives:

- understand the construction and working of various power devices
- Study and analysis of thyristor circuits with different triggering conditions
- Learn the applications of power devices in controlled rectifiers, converters and inverters.
- Study of power electronics circuits under various load conditions.

## COURSE OUTCOMES

- Describe the Characteristics of different power devices and identify the various applications associated with it.
- Illustrate the working of power Circuit as DC - DC Converter
- Illustrate the operation of inverter circuit and static switches.
- Determine the output response of a thyristor circuit with various triggering options
- Determine the response of Controlled rectifier with resistive and inductive loads.

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# MODULE - 1.

TOT: 10 Hrs.

## SYLLABUS

| SL NO. | HEADING | TEXT | CH. | REMARKS |
|---|---|---|---|---|
| 01. | INTRODUCTION: Applications of PE | T-1. | 1.1. | Theory Que. |
| 02. | Power Semiconductor Devices. | T-1 | 1.2 | OLD Syllab Unit-1 |
| 03. | Control Ch of Power Devices. | T-1 | 1.3 | |
| 04. | Types of PE Circuits | T-1 | 1.5 | |
| 05. | Peripheral effects | T-1 | 1.8 | |
| 06. | Power Transistors: Power BJT | T-1 | 4.1<br>4.2 | UNI. |
| 07. | Steady State ch. | T-1 | 4.2.1 | Theory Derivati |
| 08. | Power MOSFETs<br>Device operation | T-1<br>T-1 | 4.3<br>4.3.1 | Proble. OLD Syllabu |
| 09. | Switching Ch. | T-1 | 4.3.2 | Unit-2 |
| 10. | IGBTs Device operation o/p & Transfer ch. | T-1 | 4.6 | |
| 11. | di/dt & dv/dt Limitation | T-1 | 4.8 | |

Started :

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## INTRODUCTION

### Definitions :

Power = Voltage * Current . in Watts

Energy = Power * Time : in W hrs.

**Power Electronics :**

The applications of Solid State electronics for the Control and Conversion of electric power.

Power deals with Static & rotating power equipment for
Generation ; Transmission and distribution.

Electronics deals with Solid State devices and Circuits for Signal processing to meet the desired Control objectives.

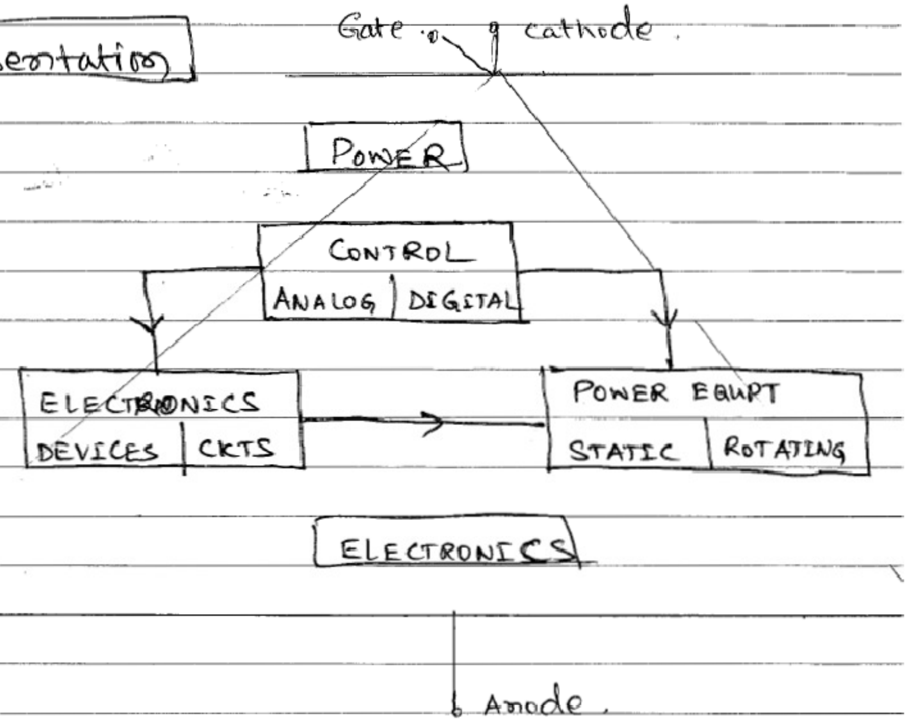
### IEEE PE Society definition of Power Electronics

" Power electronics encompasses the use of electronic devices, the application of Circuit theory and design techniques and the development of analytical tools towards efficient electronic Conversion, Control and Condition of electric power.

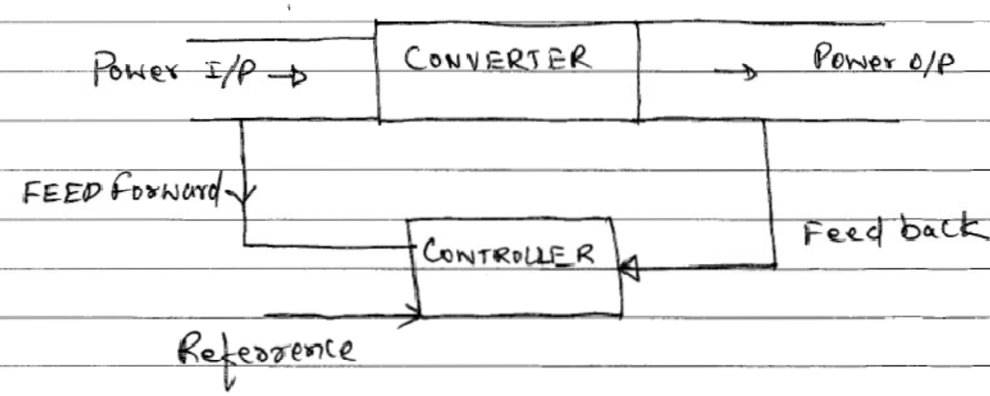
Simpler definition:

" use of electronics for the control of large power is known as Power Electronics

Representation




BLOCK DIAGRAM OF A POWER PROCESSOR :



# APPLICATIONS OF PE.

## COMMERCIAL

1. Air Con
2. Central refrigeration
3. UPS
4. Elevators
5. Emergency Lamps
6. Heating sys

## DOMESTIC

1. Cooking equipt
2. Lighting/heating ckts
3. Air Con
4. Refrigerators
5. Freezers
6. PCs.

## TELECom

1. Battery Chargers
2. DC power Supply & UPS
3. Mobile Cell phone battery chargers.

## TRANSPORTATION

1. Traction Control of electric vehicles.
2. Battery Chargers for electrical vehicle
3. Electric locomotives
4. Street Cars and trolley buses.

## Utility SYSTEMS

* High voltage DC Transmission (HVDC)

8/Nov/21 :



* Static VAR Compensation

* Fuel cells

* Energy Storage Systems

* Boiler feed Systems.

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## POWER SEMICONDUCTOR DEVICES

* Power devices are of major two types. Silicon and Silicon Carbide devices.

In Silicon devices

Power Diodes — TRANSISTORS — THYRISTORS

TRANSISTORS ↓

1) BJTs
2) MOSFETs
3) IGBTs
4) SITs.

Note: 1) BJT → Power Bipolar Junction Transistor

2) Power MOSFETs → Power Metal oxide semiconductor field-effect Transistors

3) Power IGBT : Power Insulated gate Bipolar Transistors

4) Power SITs : Static Induction Transistors.

# CLASSIFICATION OF POWER DEVICES

Based on material.

## POWER SEMICONDUCTORS

- SILICON
  - DIODES
    - Schottky
    - Epitaxial Diode (PIN
    - Double Diffused Diode. PIN.
  - TRANSISTORS
    - BJT
      - NPN
      - PNP
    - MOSFET
      - N-Channel
        1. Enhancement
        2. Conventional
        3. S-FET
        4. Cool MOS
      - P Ch E-MOS
    - IGBT
      - NPT (Non Punch Thr')
      - PT
        - Low $V_c$ sat
        - High speed.
      - Conventional
      - Trench IGBT
  - THYRISTOR
    - Thy For Ph Control
    - Fast Thy
      - Symmetric
      - Asymmetric
      - Reverse Conducting
    - GTO
      - Symmetric
      - Asymmetric
      - Rev Cond
    - IGCT
      - Asym
      - Rev. Cond
    - MCT
      - P Type
      - N Type
    - MTO
- SILICON CARRBIDE
  - DIODES
    - Schottky
    - JBS
    - PIN
  - TRANSISTOR
    - MOSFET

JBS = JN Barrier Schottky.

MCT → Metal oxide Controlled ~~MOCo~~ Thyristor.

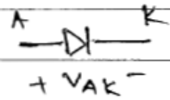
MTO: MOS Turn off

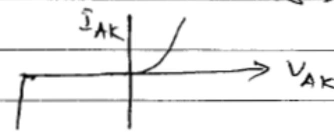
IGCT: Integrated Gate Controlled Thy.

# CONTROL CHARACTERISTICS OF DEVICES

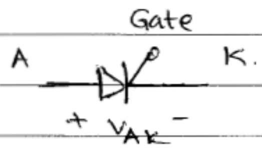
Device | Symbol | Characteristics

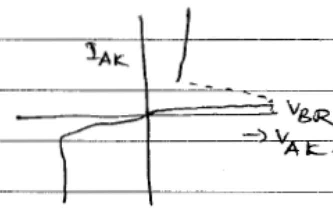
1. Diode



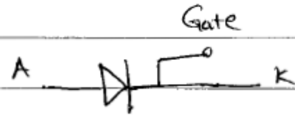




2. Thyristor.




3. SITH

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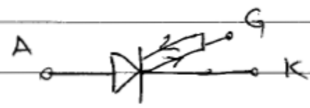
4. GTO

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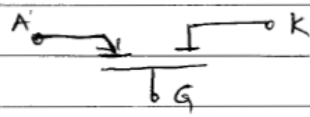
5. MCT

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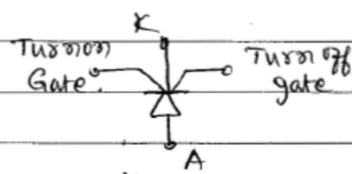
6. MTO

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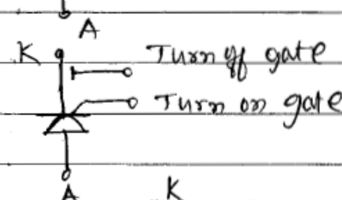
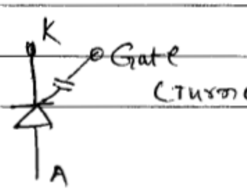
7. ETO




(MOS-GTO Hybrid)
EMOSFET-GTO.

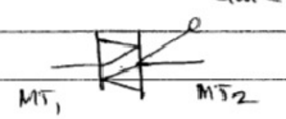
8. IGCT

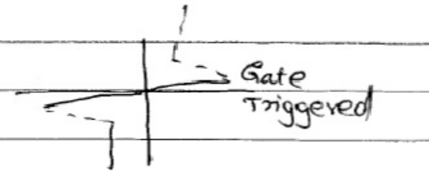



(Turn on & off.

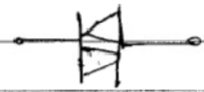
—"—

9. TRIAC

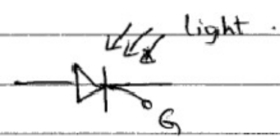


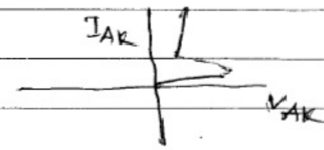




10. DIAC

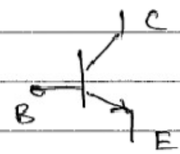


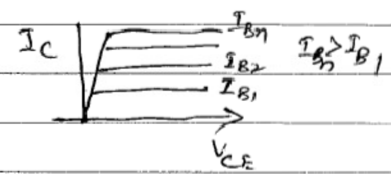
11 LASCR



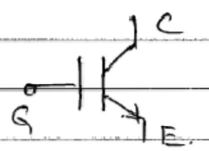




12. BJT (NPN)

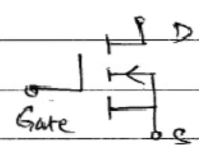


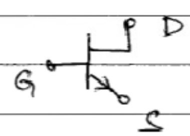

13. IGBT




14 MOSFET

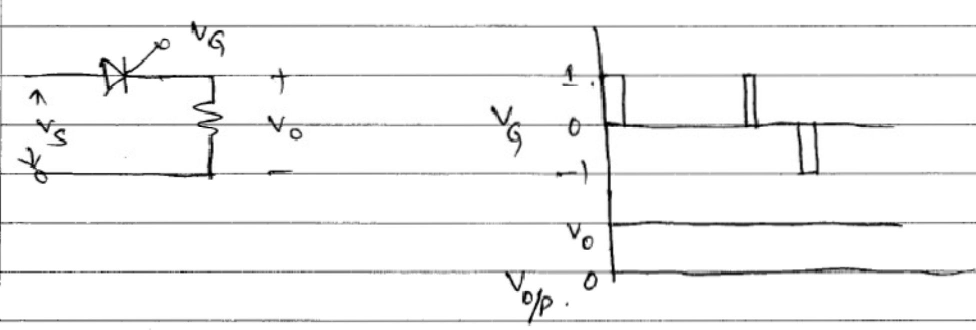


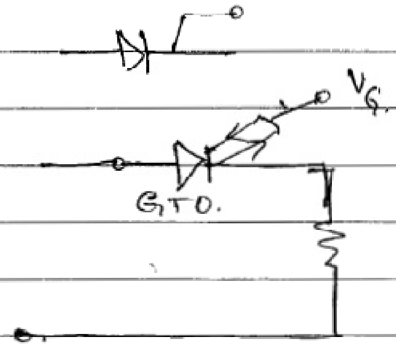

15. SIT



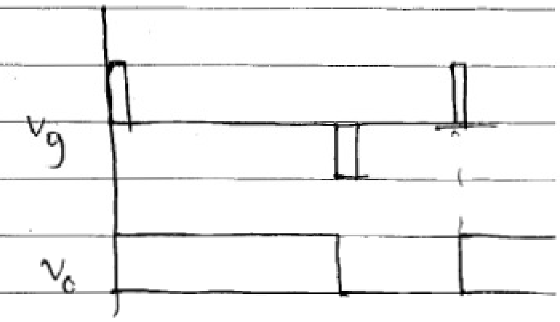

Static Induction Transitor.

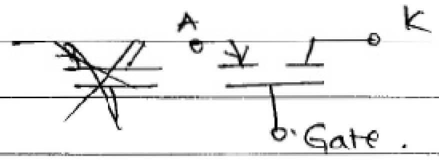
FOR CONTROL CH OF DEVICES
REFER PPT ALSO.





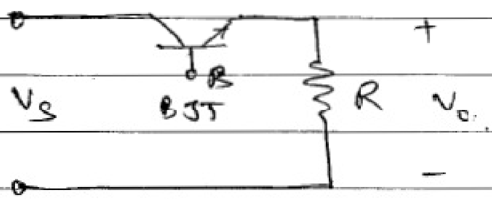

GTO.

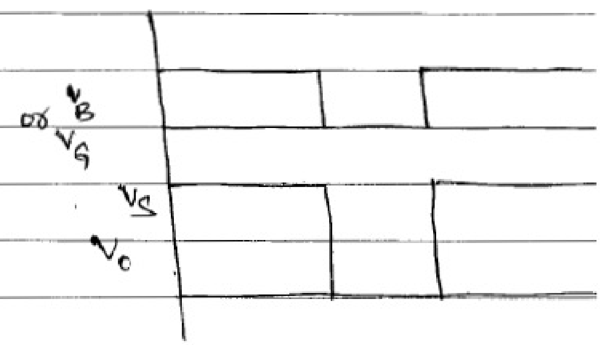


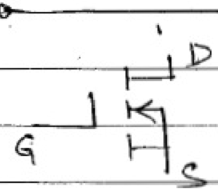




MCT

For all three devicel.





MOSFET IGBT.

TYPES OF PE CIRCUITS

OR

TYPES OF POWER CONVERTERS

1. AC-DC Rectifiers < Diode rectifiers / Controlled rectifiers

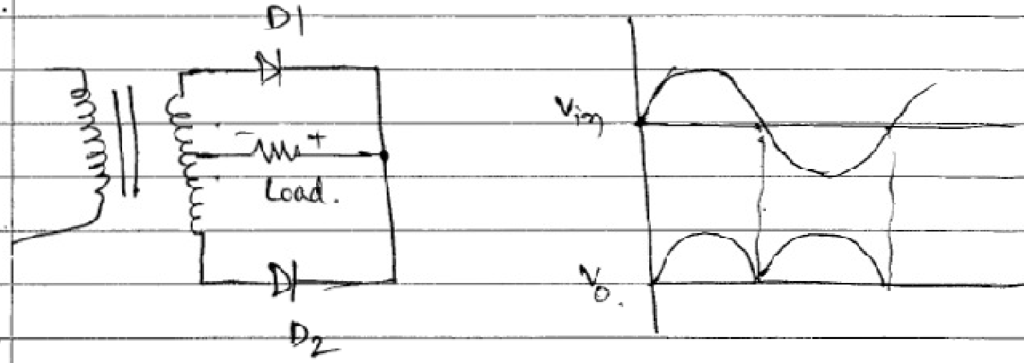
2. AC-AC Converters (ACVC)

3. DC-DC Converters (DC CHOPPERS)

4. DC-AC Converters (Inverters)

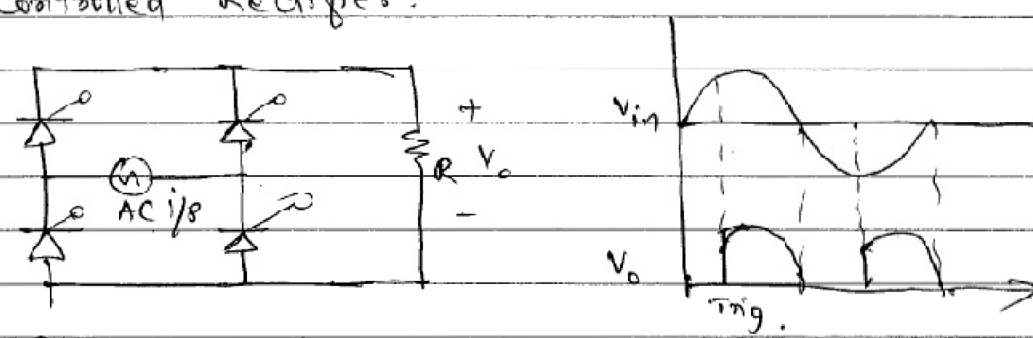
5. Static Switches.

1.



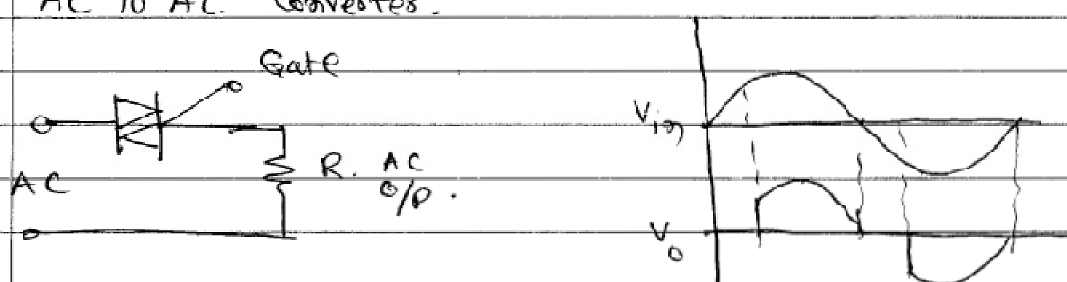

Diode rectifier.
Explain the working. Converts AC i/p to fixed DC.

2. Controlled Rectifier.



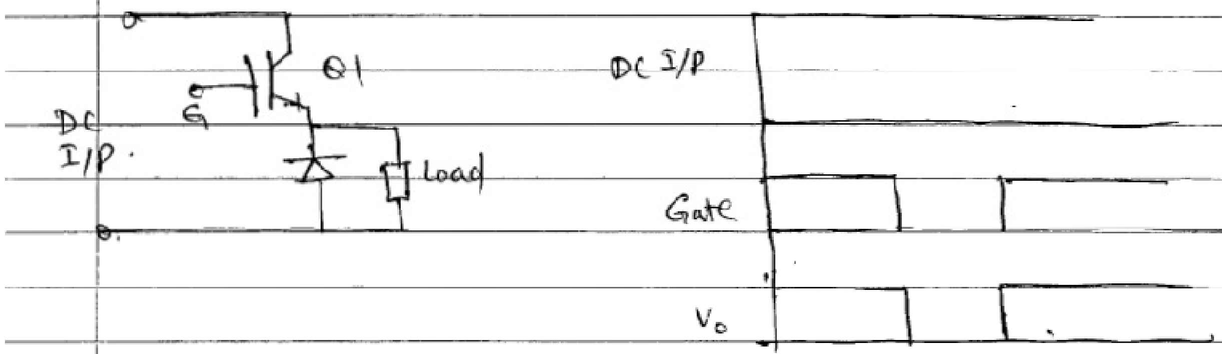

Converts Fixed AC TO Var DC.

3. AC TO AC Converter.



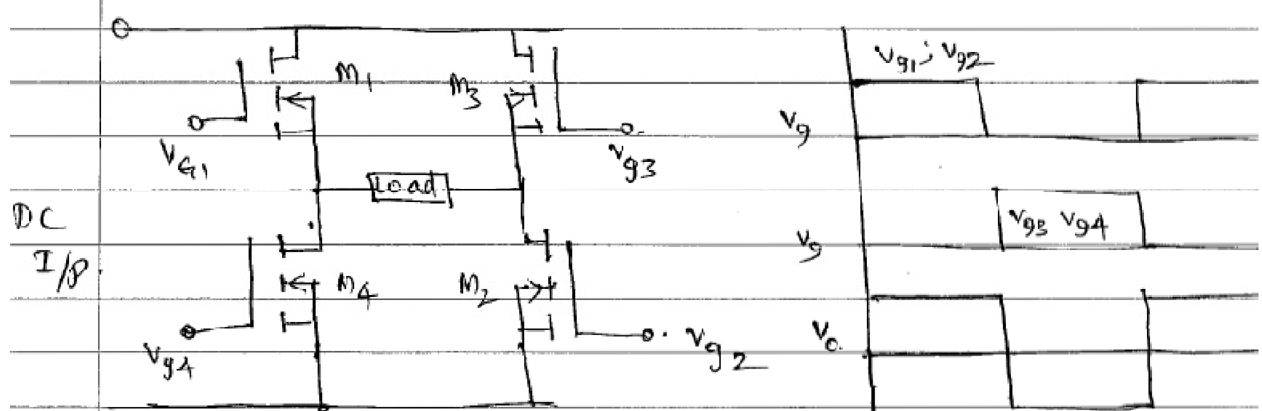

Converts Fix AC to Var AC.

4. DC - DC ( Static S/W) Also.




① Converts Fixed DC to var DC ② Q1 acts as Static S/W.

④ $\boxed{\text{INVERTER}}$




Converts DC to var AC.

$\boxed{\text{PERIPHERAL EFFECTS}}$

* Power Converters ~~operate~~ mainly operate by Switching of Power devices.

* Hence Converters introduce Current and

Voltage harmonics into the Supply System

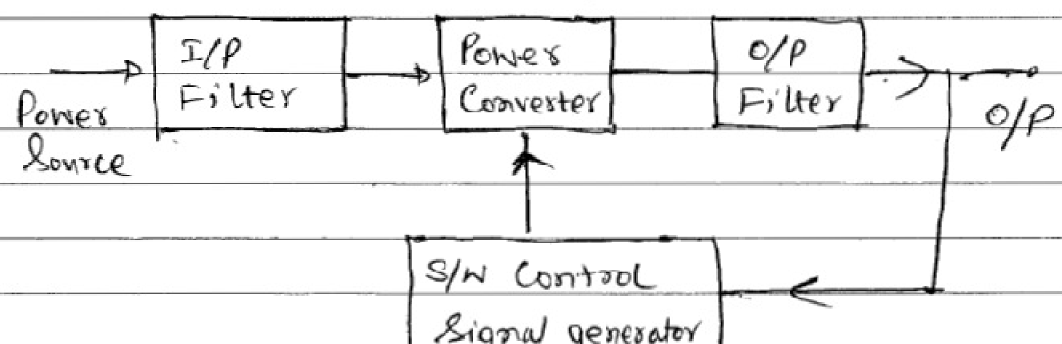
* Problems because of this are :
  - Distortion in o/p voltage.
  - Harmonic generation into Supply System
  - Interference with Communication or Signalling equipment (EMI)

Solution to the problem :
Introduce i/p and o/p filters in the Converter.

Important measuring factors are.

THD : Total Harmonic Distortion
DF : Displacement factor.
IPF : I/P Power factor.

Further EMI Can Cause erroneous signals generated by gating Circuits.
EMI Can be reduced by grounded Shielding.



## Power modules :

Power devices are available as a single module or unit.

Power converters require 2 or 4 or 6 devices depending on application.

Utilising power modules offer lower on state losses, high voltage and current switchings ch higher speed than that of conventional devices.

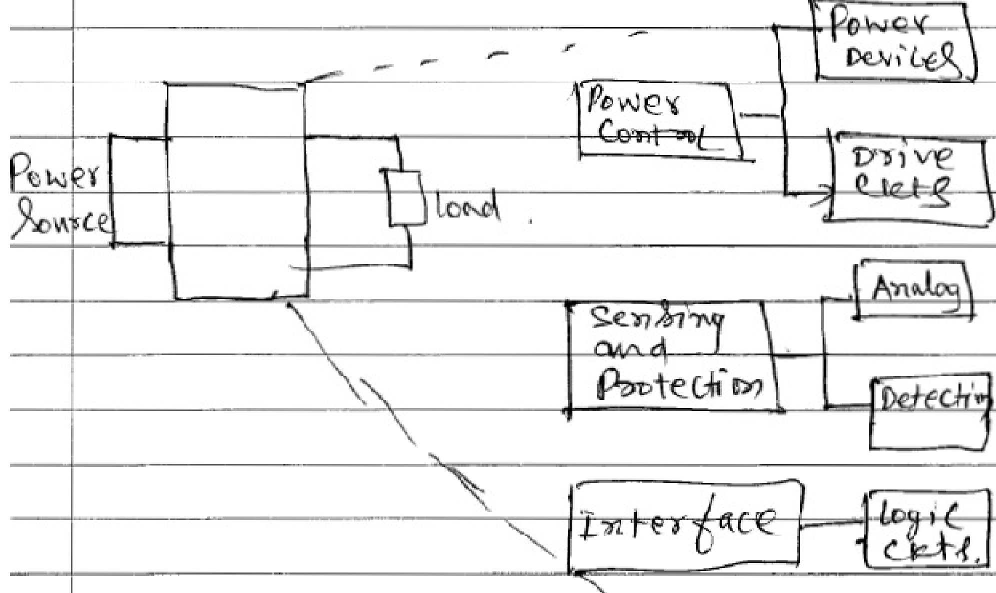
Some modules include transient protection and drive circuitry.

## INTELLIGENT MODULES

These integrate the power module and the peripheral ~~unit~~ circuit.

Peripheral ckt consists of i/p or o/p isolation, interface with signal & high voltage system, a drive ckt, protection and diagnostic ckt.

This is also known as Smart power Technology.



# MODULE - 1.

## PART - 2

## POWER TRANSISTORS

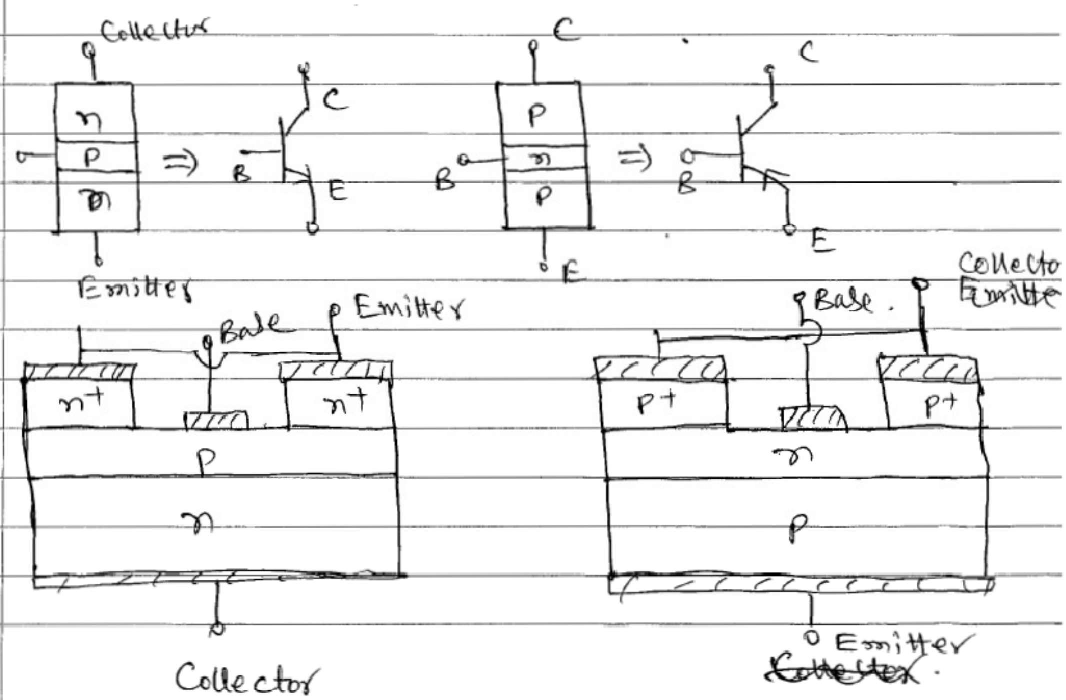
### Power BJT. :

- A switching device operated in saturation and cut off region to reduce on time power loss
- Faster than SCR but power rating is lower than SCR.

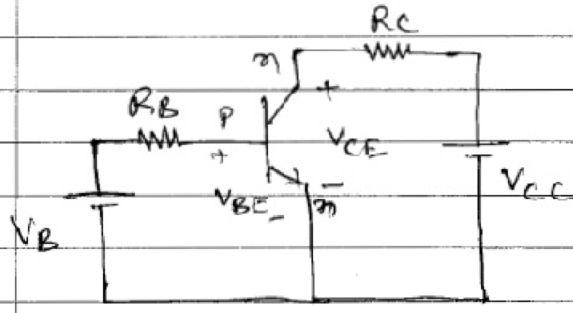
Classification :

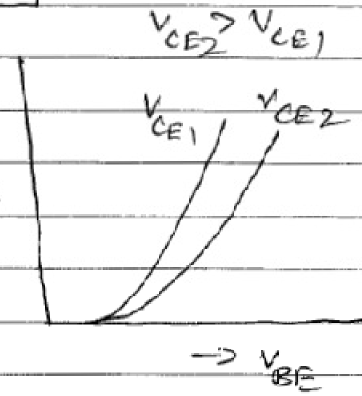
1. BJT (NPN & PNP)
2. Metal oxide semiconductor field effect Transistor (MOSFETS)
3. Static Induction Transistors (SITS)
4. Insulated Gate Bipolar transistor (IGBT)
5. COOLMOS

1. BJT

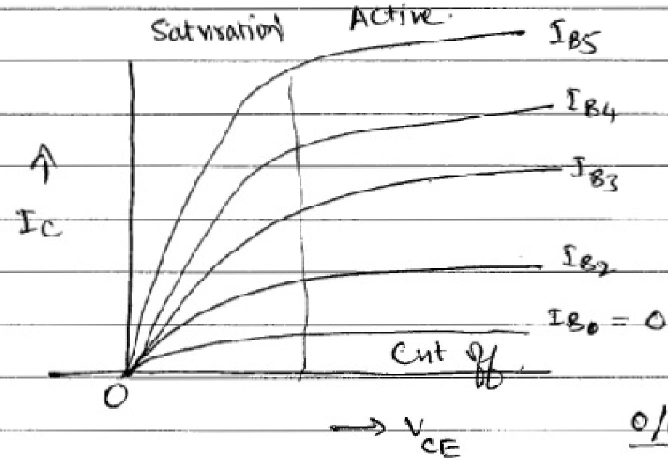


# STEADY STATE CHARACTERISTICS



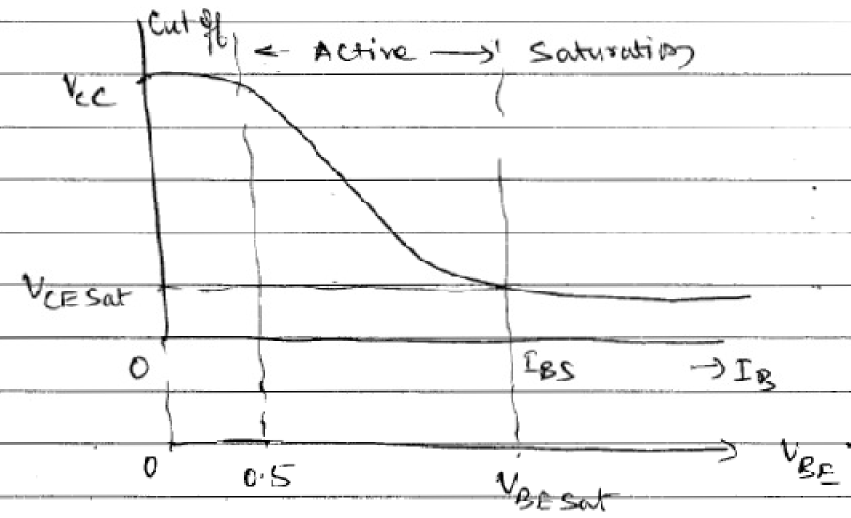




I/P ch



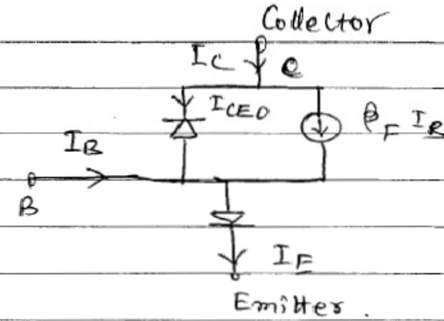

$I_{Bn} > I_{B1} > I_{B0}$

O/P Characteristics




Transfer ch

Transistor model:




$I_C = \beta_F I_B + I_{CEO}$.

$I_E = I_C + I_B = I_B(1+\beta_F) + I_{CEO}$.

$I_B = \dfrac{V_B - V_{BE}}{R_B}$ — ①  $I_{BS} = \dfrac{V_B - V_{BES}}{R_B}$

$I_{CS} = I_{CM} = \dfrac{V_{CC} - V_{CES}}{R_C}$ — ②

$I_{BS} = \dfrac{I_{CS}}{\beta}$

$I_B > I_{BS}$ ∴ $\beta_{Forced} < \beta$

$$\boxed{\beta_{Forced} = \frac{I_{CS}}{I_B}}$$

Over drive factor $\boxed{ODF = \dfrac{I_B}{I_{BS}}}$

$$\boxed{\text{Power Loss } P_T = V_{BES} I_B + V_{CES} I_{CS}.}$$

Prob ① : In the BJT circuit shown above transistor has $\beta_F = 8$ to $40$. The load resistance is $R_C = 11\,\Omega$. The dC supply $V_{CC} = 200V$ and input voltage to the base circuit is $V_B = 10$ V. If $V_{CEsat} = 1.0V$

$V_{BES} = 1.5V$ find (a) value of $R_B$ that results in saturation with an ODF of 5 (b) Forced $\beta$ (c) Power Loss.

If ODF = 10 Compare power loss.

Ans: $I_{CS} = \frac{V_{CC} - V_{CES}}{R_C} = \frac{200-1}{11} = \boxed{18.1\ A}$

$I_{BS} = \frac{I_{CS}}{\beta_{min}} = \frac{18.1}{8} = \boxed{2.2625\ A}$

$ODF = \frac{I_B}{I_{BS}}$ $\therefore I_B = ODF * I_{BS}$

$= 5 * 2.2625$

$\boxed{I_B = 11.3125\ A.}$

$\therefore R_B = \frac{V_{BB} - V_{BES}}{I_B} = \frac{10-1.5}{11.3125} = \boxed{0.7514\ \Omega}$

(ii) Forced $\beta = \frac{I_{CS}}{I_B} = \frac{18.1}{11.3125} = \boxed{1.6}$

(iv) Power Loss = $P_T = V_{BES} I_B + V_{CES} I_{CS}$

$= 1.5 * 11.3125 + 1 * 18.1 = \boxed{35.07\ W}$

(v) If ODF = 10 $\boxed{I_B = 22.625\ A}$

$\therefore P_T = 1.5 * 22.625 + 1 * 18.1 = \boxed{51.5\ W}$

Note: Increasing ODF will not give any benefit in $I_{CS}$ and also power loss increased to double Transistor is likely to burn.

Further reducing ODF more than 5 is likely to make transistor to go to active region and power loss will be more.

It is Compromise betn S/w Speed, Saturation and Power loss

**Prob 2:** (4.1) The β of BJT varies from 10 to 60. The load resistance is $R_C = 5\Omega$. The DC Supply voltage is 100V and i/p voltage $V_B = 8V$. If $V_{CEsat} = 2.5V$ and $V_{BES} = 1.75V$ find (a) $R_B$ which will result in Saturation with ODF of 20 (ii) Forced β and Power Loss in Transistor.

**Ans:**

$$I_{CS} = \frac{V_{CC} - V_{CES}}{R_C} = \frac{100 - 2.5}{5} = 19.5A.$$

$$I_{BS} = \frac{I_{CS}}{\beta_{min}} = \frac{19.5}{10} = \boxed{1.95A}.$$

$$I_B = ODF * I_{BS} = 20 * 1.95 = 39 A.$$

$$R_B = \frac{V_B - V_{BES}}{I_B} = \frac{8 - 1.75}{39} = \boxed{0.160\,\Omega}$$

(ii) $$\text{Forced } \beta = \frac{I_{CS}}{I_B} = \frac{19.5}{39} = \boxed{0.5}$$

(iii) $$P_T = V_{BES} I_B + I_{CS} * V_{CES} = 1.75 * 39 + 19.5 * 2.5$$
$$= \boxed{117 W}$$

Prob ③: The $\beta$ of BJT varies from 12 to 75. The load resistance is $R_C = 1.5\,\Omega$. The DC Supply voltage is $V_{CC} = 40V$ and input voltage to the base Circuit is $V_B = 6V$. If $V_{CES} = 1.2V$ $V_{BES} = 1.6V$ and $R_B = 0.7\,\Omega$ Find ODF Forced $\beta$ and Power Loss $P_T$

Ans

$$I_{CS} = \frac{V_{CC} - V_{CES}}{R_C} = \frac{40 - 1.2}{1.5} = \boxed{25.87\,A}$$

$$I_{BS} = \frac{I_{CS}}{\beta_{min}} = \frac{25.87}{12} = \boxed{2.16\,A}$$

$$I_B = \frac{V_B - V_{BES}}{R_B} = \frac{6 - 1.6}{0.7}$$

$$= \boxed{6.28\,A}$$

$$ODF = \frac{I_B}{I_{BS}} = \frac{6.28}{2.16} = \boxed{2.91} \simeq \boxed{3}$$

$$\text{Forced } \beta = \frac{I_{CS}}{I_B} = \frac{25.87}{6.28} = \boxed{4.12}$$

$$P_T = V_{BES} I_B + V_{CES} I_{CS} = 1.6 * 6.28 + 1.2 * 25.87$$

$$= \boxed{41.09\,W}$$

—o—

Prob ④ For the BJT Circuit if $V_{BES} = 1.5V$ $V_{CES} = 1.2V$ $\beta = 25$, $V_{CC} = 100V$, $R_C = 10\,\Omega$ and $R_B = 20\,\Omega$ find (a) The min value of $V_B$ required to ensure saturation

(b) on State power loss of the transistor.

**ANS** $I_{CS} = \frac{V_{CC} - V_{CES}}{R_C} = \frac{100-1.2}{10} = \boxed{9.88\,A}$

$I_{BS} = \frac{I_{CS}}{\beta_{min}} = \frac{9.88}{25} = \boxed{0.395\,A}$

$I_{BS} = I_B$ with ODF = 1 as it is not given.

$V_{BB} = I_{BS} R_B + V_{BEsat} = (0.395 * 20) + 1.5 = \boxed{9.4\,V}$

(b) Power loss $P_T = V_{CES} I_{CS} + V_{BES} * I_B$  Note $I_B = I_{BS}$

$= 1.2 * 9.88 + 1.5 * 0.395$

$\boxed{P_T = 12.44\,W}$

Prob ⑤: The power BJT connected as a switch has $V_{CES} = 1.2V$ and $\beta$ in the range of 8 to 20. If $V_{CC} = 200V$, ODF = 5, $R_C = 15\Omega$ compute
(a) value of the base cur required to move the transistor into saturation

**ANS** $I_{CS} = \frac{V_{CC} - V_{CES}}{R_C} = \frac{200-1.2}{15} = \boxed{13.25\,A}$

$I_{BS} = \frac{I_{CS}}{\beta_{min}} = \frac{13.25}{8} = \boxed{1.66\,A}$

$I_B = ODF * I_{BS} = 5 * 1.66 = \boxed{8.30\,A}$

Forced $\beta = \frac{I_{CS}}{I_B} = \frac{13.25}{8.3} = \boxed{1.596}$

Prob ⑥: In the above prob if $V_{BB} = 10V$ and $V_{BES} = 1.5V$

Compute $R_B$.

ANS: $R_B = \frac{V_{BB} - V_{BES}}{I_B} = \frac{10 - 1.5}{8.3} = \boxed{1.024\ \Omega}$

Prob (7): A Power BJT used as Switch has $\beta$ range of 10 to 25. If $V_{CC} = 230V$, $R_C = 12\ \Omega$ $V_{BB} = 15V$ $V_{CES} = 1.2V$ and $V_{BES} = 1.8V$

Find: (a) value of $R_B$ required to move the transistor into Saturation with ODF of 6.
(b) Forced $\beta$
(c) Power dissipated in the transistor.

ANS) $I_{CS} = \frac{V_{CC} - V_{CES}}{R_C} = \frac{230 - 1.2}{12} = \boxed{19.067A}$

$I_{BS} = \frac{I_{CS}}{\beta_{min}} = \frac{19.067}{10} = \boxed{1.9067A}$

$I_B = ODF * I_{BS} = 6 * 1.9067 = \boxed{11.44A}$

$R_B = \frac{V_{BB} - V_{BES}}{I_B} = \frac{15 - 1.8}{11.44} = \boxed{1.154\ \Omega}$

(b) Forced $\beta = \frac{I_{CS}}{I_B} = \frac{19.067}{11.44} = \boxed{1.667}$

(c) $P_T = V_{CES} I_{CS} + V_{BES} I_B$
$= 1.2 * 19.067 + 1.8 * 11.44 = \boxed{43.47W}$

Prob (8): A Power BJT used as a S/W in the ckt has $V_{CE\,sat} = 1.8V$ $V_{BE} = 1.2V$ $\beta_{min} = 12$.
Given $R_C = 12\,\Omega$ and $R_B = 6\,\Omega$ and $V_{CC} = 220V$

Calculate: (i) Min value of $V_{BB}$ required to drive max Cur thr' $R_C$. Also find power dissipated in transistor in this Condition.

(ii) If $V_{BB}$ is reduce to 75% of the value calculated in part (i)
Find power dissipated in transistor

Comment on the result.

ANS $I_{CM} = I_{CS} = \dfrac{V_{CC} - V_{CES}}{R_C} = \dfrac{220 - 1.8}{12} = \boxed{18.18A}$

$$I_{BS} = \frac{I_{CS}}{\beta_{min}} = \frac{18.18}{12} = \boxed{1.515A}$$

With ODF = 1 as not given

$$V_{BB} = I_{BS} R_B + V_{BES} = 1.515 * 6 + 1.2 = \boxed{10.29V}$$

$P_{T\,ON} = I_{CS} V_{CES} + V_{BES} I_B$ Note $I_B = I_{BS}$

$$= \cancel{12}\ 18.18 * 1.8 + 1.2 * 1.515 = \boxed{34.54W}$$

Part (2): $V_{BB\,NEW} = V_{BB} * 0.75 = 0.75 * 10.29 = \boxed{7.72V}$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{7.75 - 1.2}{6} = \boxed{1.087A}$$

$I_{C_{New}} = \beta_{min} I_B = 12 * 1.087 = \boxed{13.044\,A}$.

$V_{CE} = V_{CC} - I_C R_C = 220 - 13.044 * 12$

$\boxed{V_{CE} = 63.472\,V}$

$P_T = V_{BE} * I_B + V_{CE} I_C$

$= 1.2 * 1.087 + 63.472 * 13.044$

$\boxed{P_{T_{New}} = 829.21\,W}$

Note: As $V_{BB}$ is reduced $I_B$ reduces and transistor comes to active region. Hence power loss increases extensively which may damage transistor.
This is one of the reason of ODF. which will avoid this scenario.

—>o—

Prob ⑨: Jul Aug 2006 VTU 7 mks

A power BJT is connected as a switch with following data:
$R_B$ that will result in saturation with ODF 20
$V_{CC} = 100V$, $V_B = 8V$, $V_{CES} = 2.5V$, $V_{BES} = 1.75V$

$\beta = 10$ to $60$, $R_C = 10\,\Omega$

$I_{CS} = \frac{V_{CC} - V_{CES}}{R_C} = \frac{100 - 2.5}{10} = 9.75\,A$

$I_{BS} = \frac{I_{CS}}{\beta_{min}} = \frac{9.75}{10} = \boxed{0.975\,A}$

$I_B = ODF * I_{B sat} = 20 * 0.975 = \boxed{19.5A}$

$R_B = \frac{V_B - V_{BES}}{I_B} = \frac{8 - 1.75}{19.5} = \boxed{0.32 \Omega}$

$\text{Forced } \beta = \frac{I_{CS}}{I_B} = \frac{9.75}{19.5} = \boxed{0.5}$

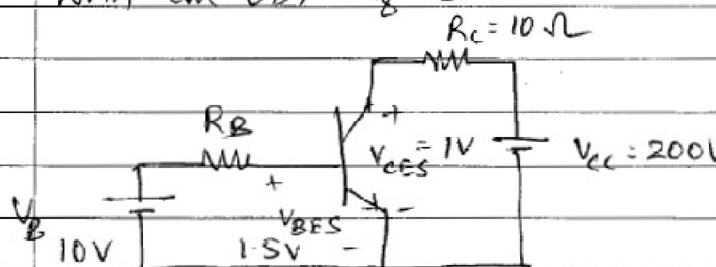
Power loss $P_T = V_{BES} I_B + I_{CS} V_{CES}$

$= 1.75 * 19.5 + 2.5 * 9.75$

$\boxed{P_T = 58.5W}$.

Prob 10 Jan Feb 2007, 8 Mks 2008 7 mks VTU.

A transistor S/W has $\beta$ in the range of 8 to 40 find value of $R_B$ that results in saturation with an ODF of 5




Ans: (i) $I_{CS} = \frac{V_{CC} - V_{CES}}{R_C} = \frac{200 - 1}{10} = \boxed{19.9A}$.

(ii) $I_{BS} = \frac{I_{CS}}{\beta_{min}} = \frac{19.9}{8} = \boxed{2.4875A}$

(iii) $I_B = ODF * I_{BS} = \boxed{12.4375A}$

$$R_B = \frac{V_B - V_{BES}}{I_B} = \frac{10-1.5}{12.4375} = \boxed{0.68348\,\Omega}$$

$$\beta_f = \frac{I_{CS}}{I_B} = \frac{19.9}{12.4375} = \boxed{1.6}$$

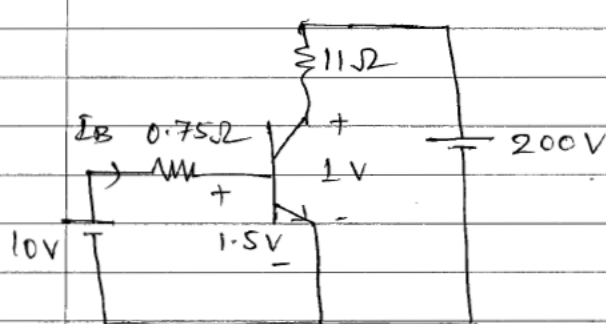
$$P_T = V_{BES} I_B + V_{CES} I_{CS}$$

$$= 1.5 * 12.4375 + 1 * 19.9 = \boxed{38.55\,W}$$

—o—

Prob (11): Aug 04, Dec 10, 2009, 2017 8 Mks.

Calculate force $\beta$, If manufacturer Specified $\beta$ is in range of 8 to 40 Calculate min ODF obtain powerloss of transistor.




Ans: $$I_{CS} = \frac{V_{CC} - V_{CES}}{R_C} = \frac{200-1}{11} = \boxed{18.09\,A}$$

$$V_B = I_B R_B + V_{BES} =$$

$$I_B = \frac{V_B - V_{BES}}{R_B} = \frac{10-1.5}{0.75} = \boxed{11.33\,A}$$

$$\text{Forced } \beta = \frac{I_{CS}}{I_B} = \frac{18.09}{11.33} = \boxed{1.596}$$

$$I_{BS} = \frac{I_{CS}}{\beta_{min}} = \frac{18.9}{8} = \boxed{2.261\,A.}$$

$$ODF = \frac{I_B}{I_{BS}} = \frac{11.33}{2.261} = \boxed{5}$$

$$P_T = V_{BES}\, I_B + V_{CES}\, I_{CS}$$

$$= 1.5 * 11.33 + 1 * 18.09 = \boxed{35\,W}$$

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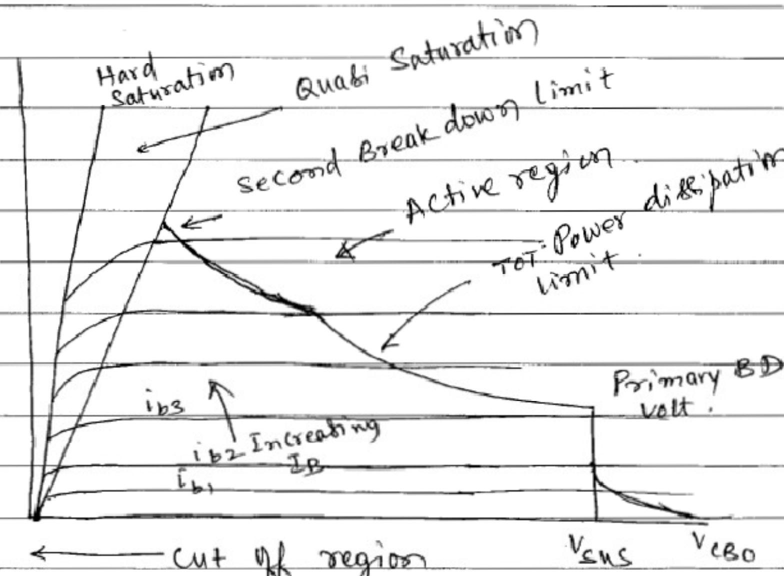
## DIFFERENT OPERATING REGIONS OF BJT




Regions of opⁿ :

1. Cut off region  2. Active region

3. Saturation ( Hard Saturation & Quasi Saturation)

Second Break down : As the BJT is in hard Saturation $I_{CE}$ is high but takes time to Spread in Junction. This Creates high Current intensity at small areas of operation. This forms hot Spots and likely to burn the transistor.

Total power dissipation: The power to be dissipated by transistor based on area of the junction.

Primary break down: Avalanche break down of reverse biased CB junction.

FBSOA: Forward bias Safe operating area.

IMPORTANT FEATURES OF POWER BJT

1. Power BJTs are high power versions of normal BJT

2. Both NPN & PNP are available

3. NPN are relatively of higher rating typically 1200V 800A, with max Switching Speed of 10 KHz

4. Compared to SCR they are faster and fully Controlled that ON and Off both are Controlled.

5. For medium power applications of < 500V MOSFETS are preferred

6. IGBT and MCT have replaced BJT in higher power applications also.

## Types of BJT devices.

- Power BJT
- MOSFET
- IGBT
- SIT

## MERITS OF BJT.

1. Small turn on and turn off time, hence higher switching frequencies.
2. Small turn on losses
3. Base drive has full control on operation of BJT
4. BJTs do not require commutation circuits.
5. BJT is a Bipolar device.
6. Less expensive.

## DEMERITS / DIS ADV of BJT.

1. The DC current gain $h_{FE}$ is as low as 20 or 10 and varies with collector current and temperature
2. Increase in $h_{FE}$ by multiple stages is not possible due to reduction in switching speed.

4. Device Can be damaged due to Secondary break down.

5. BJT require Complex expensive base drive Circuits and isolation Circuits.

6. BJT parallel Configuration is difficult due to -ve temperature Coefficient.

## APPLICATIONS OF BJT :

1. As main Switching device in Inverter & Chopper

2. In SMPS

3. In the linear power Supplies as a Series pass transistor.

4. In UPS and AC Motor applications.

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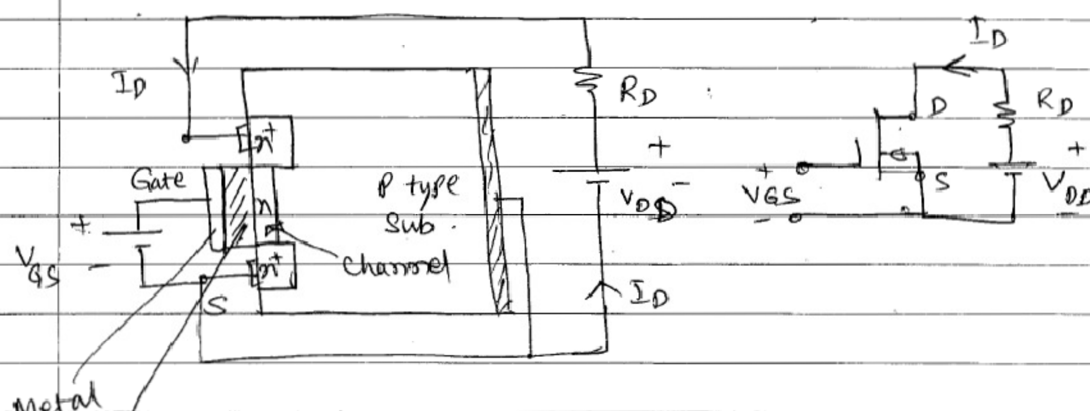
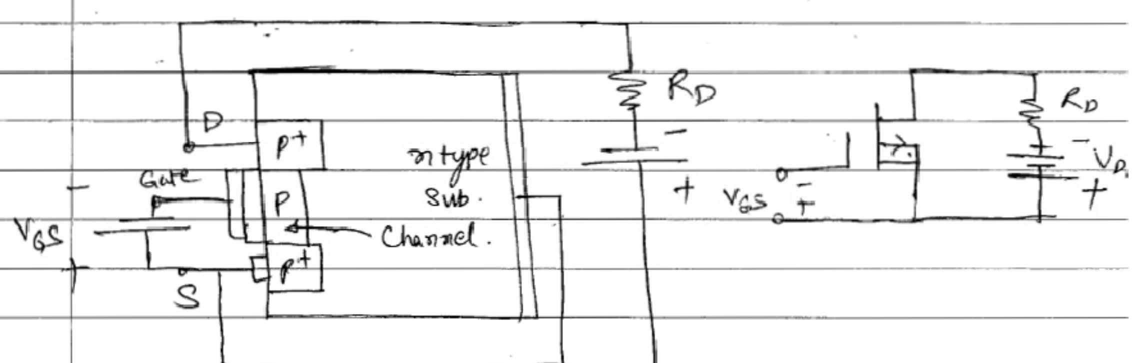
Start

# POWER MOSFETS

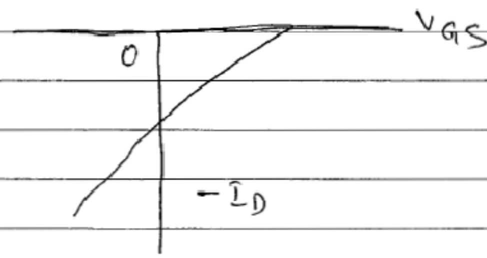
## Construction :

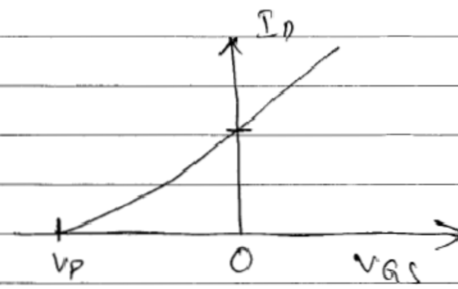



n channel depletion MOSFET




P Channel depletion MOSFET

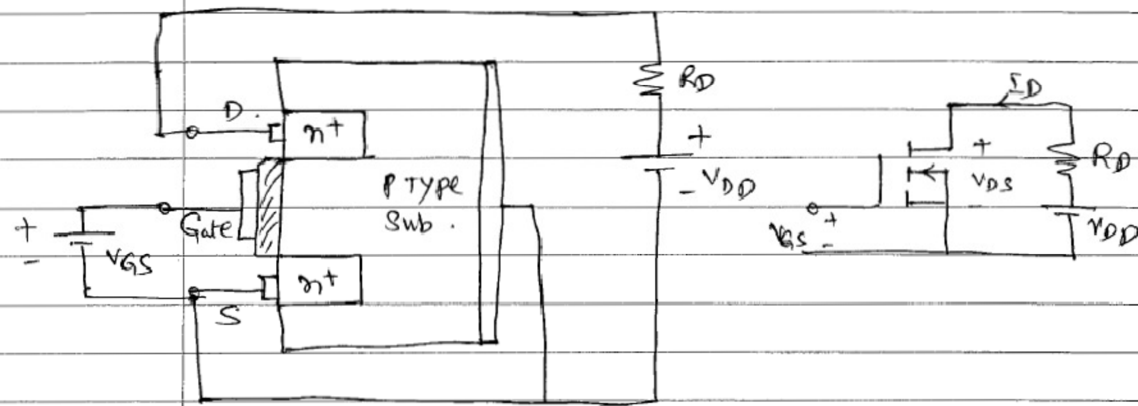


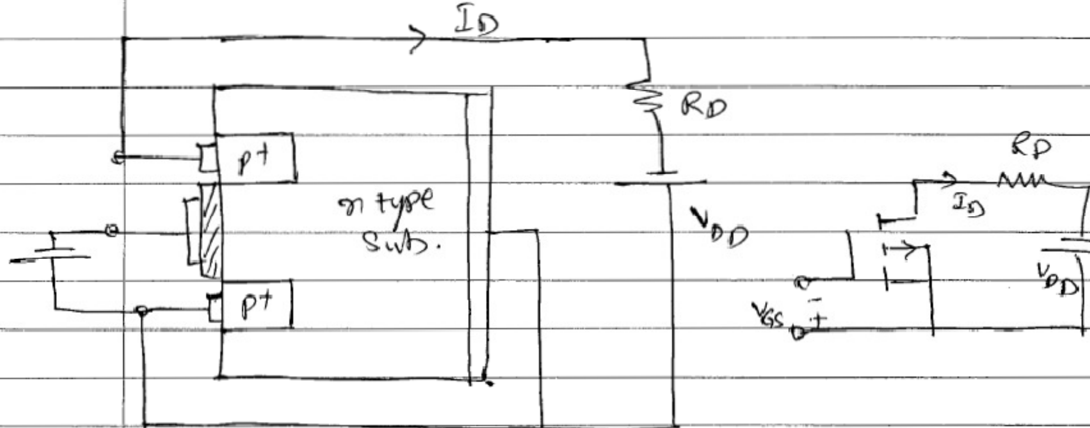

P channel $I_D$ v/s $V_{GS}$ Ch

n- channel. $I_D$ (Cur) Ch

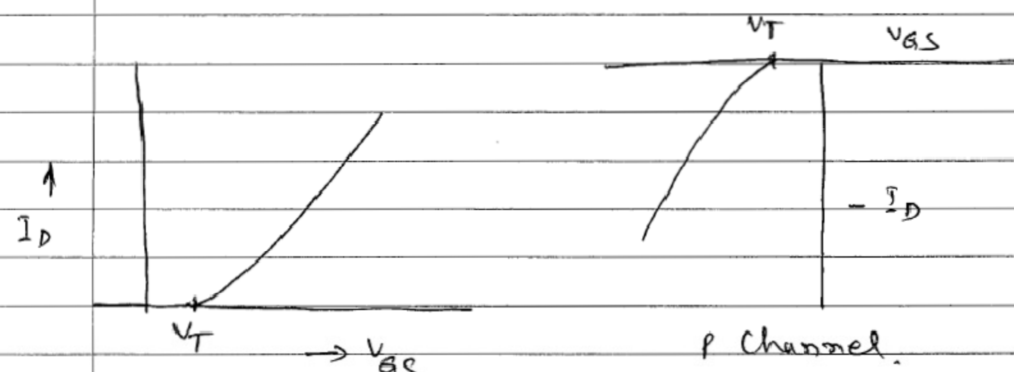
# Enhancement MOSFET. (E-MOSFET)




n- Channel e- MOSFET




P- Channel e- MOSFET.

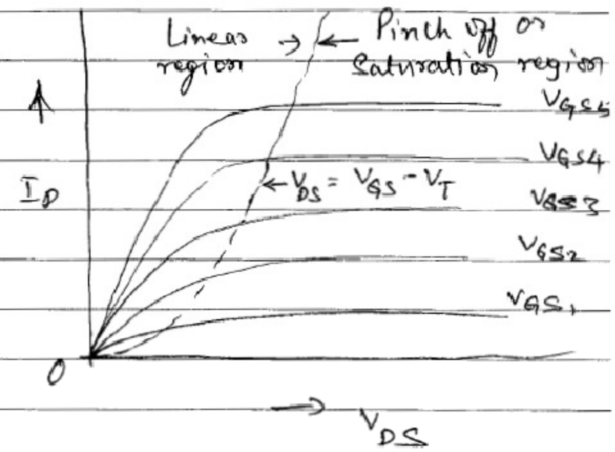



P Channel.

n Channel.

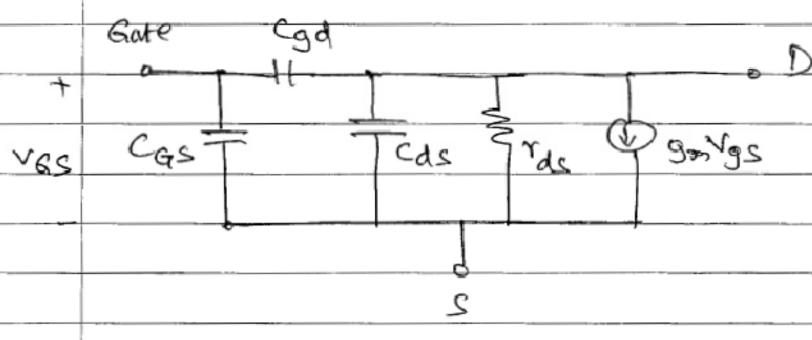
## STEADY STATE CHARACTERISTICS

$V_{GS4} > V_{GS3} > V_{GS2} > V_{GS1} > V_T$

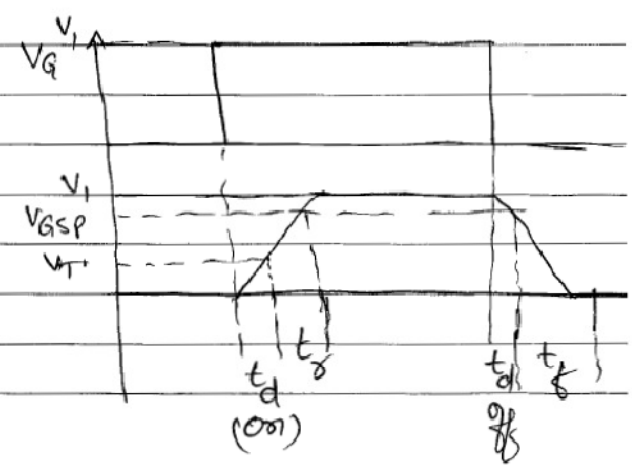



$$R_{DS} = \frac{\Delta V_{DS}}{\Delta I_D}$$

## SWITCHING CHARACTERISTICS




Switching model.



$t_{ON} = t_{d_{ON}} + t_r$.

$t_{off} = t_{d_{off}} + t_f$

$t_d$ = delay time  $t_r$ = rise time  $t_f$ = fall time.

$t_{d_{ON}}$ = time taken to charge input Capacitor to threshold voltage.

$t_r$ = rise time is the time taken to take o/p voltage to full gate voltage.

$t_{d_{off}}$ = time taken to discharge i/p capacitor.

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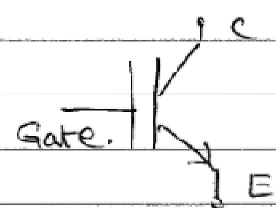
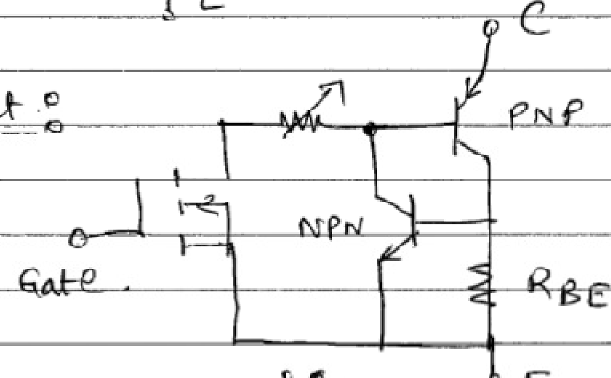
## $\boxed{\text{INSULATED GATE BIPOLAR TRANSISTOR.}}$

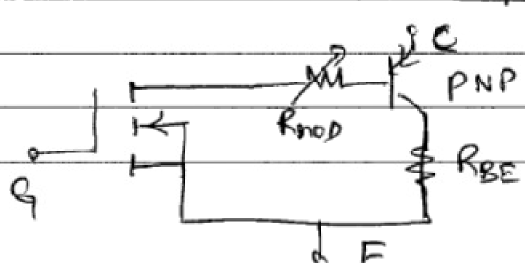
## $\boxed{\text{IGBT}}$

Symbol:

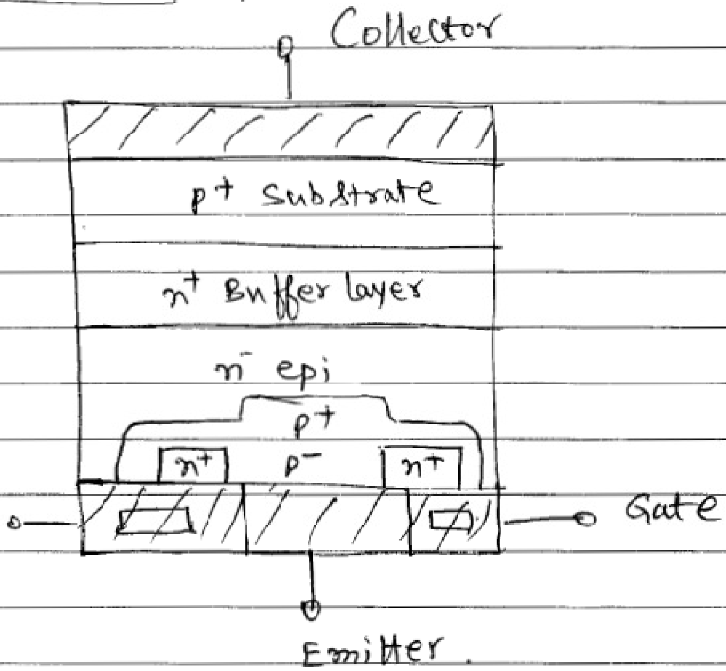



Equivalent Ckt:



Construction :




FEATURES

- Low on state voltage drop
- Low on state Power Loss
- Higher Switching Speed as Compared to BJT
- High input impedance because of isolation of gate by $SiO_2$
- Combines Adv of BJT & MOSFET

- BJT has lower on state power loss but slower switching speed

- MOSFET has higher on state power loss but higher switching speed.

- IGBT Combines both advantages.

- other names for IGBT : COMFET (Conductivity Modulated MOSFET)

IGT : Insulated gate Transistor.

Bipolar MOS Transistor.

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Types of IGBT.

NON - PUNCH THROUGH IGBT.

$n^+$ Buffer layer is absent, causing symmetrical blocking ie Both +VCE & −VCE are blocked equally.

+ve or −ve $V_{CE}$ blocked equally.

PUNCH THROUGH IGBT :

$n^+$ Layer or buffer present.

This has Assymmetrical blocking

+ VCE Blocked successfully But

not − VCE.

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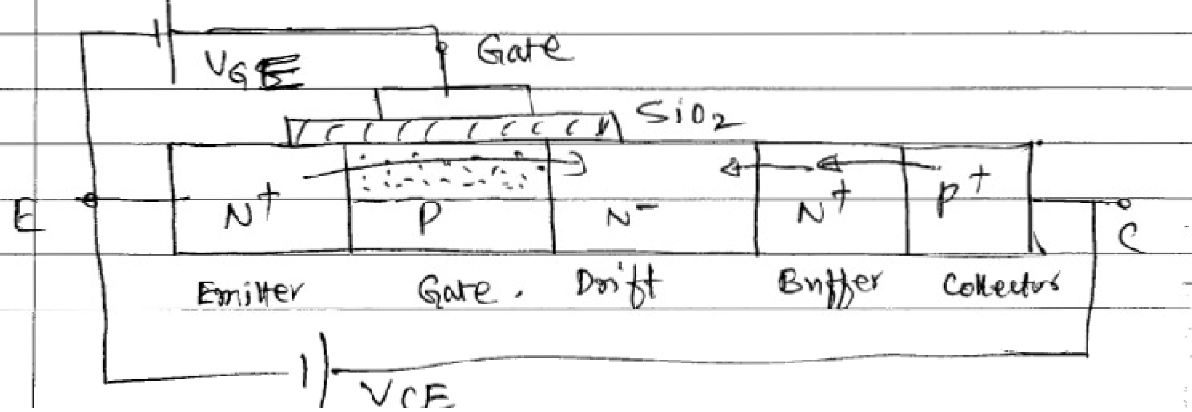
OPERATION OF IGBT.



1. Formation of Inversion Layer :

Forward biasing Gate to ~~Source~~ Emitter $V_{GE}$ will attract minority Carriers from P region to form a Conduction path.

Minimum $V_{GE}$ to formulate this electron layer is Called as Threshold voltage which is similar to MOSFET.

2. CONDUCTIVITY MODULATION :

Holes from $P^+$ region are pushed towards drift region due to $V_{CE}$.

Electrons are pumped from $n^+$ region through inversion layer.

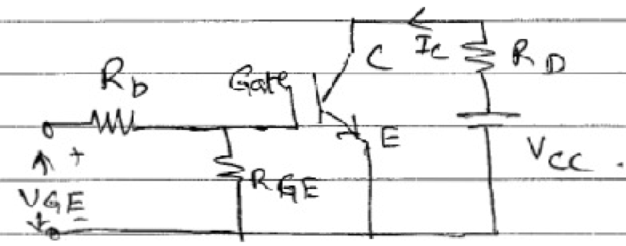
A Small amount of recombination takes place but most of Charge Carriers both electrons and holes travel in opposite direction.

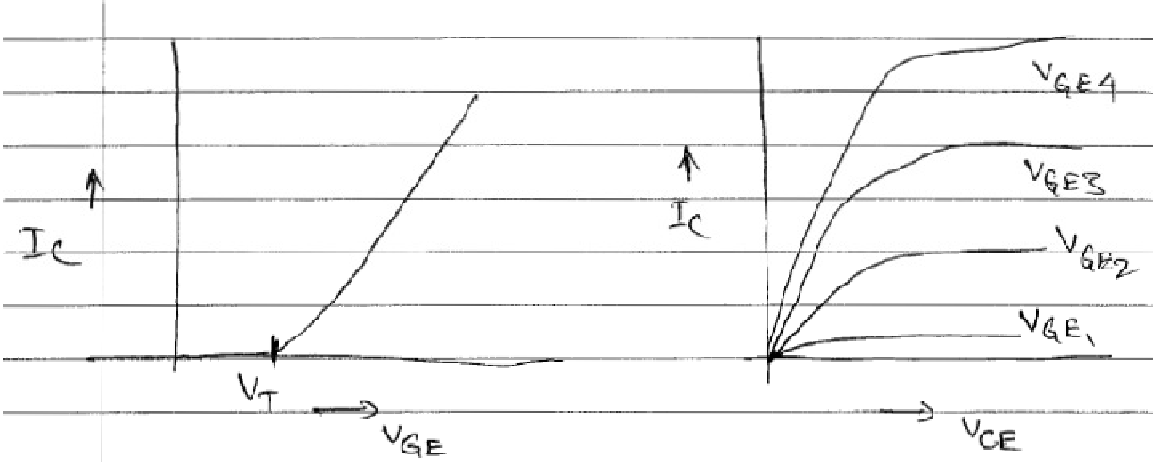
The Collector Current is due to both Carrier movement that is holes and electrons.

This process is Called as Conductivity modulation which is not there in MOSFET.
In MOSFET Current is due to one type of charge Carrier only.

This results in higher Cur in IGBT hence lower ON State resistance

## STATIC CHARACTERISTICS

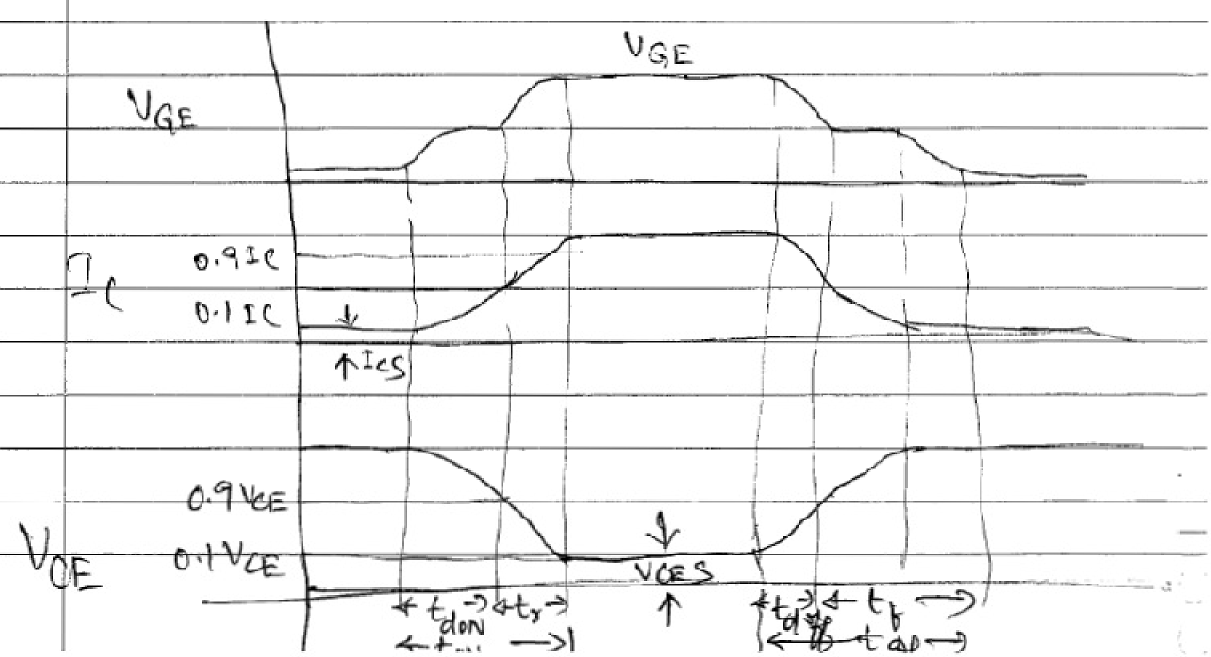



$V_{GE4} > V_{GE3} > V_{GE2} > V_{GE1} > V_T$

Explain Ch llr to mosfet.

## SWITCHING CHARACTERISTICS



$t_{ON} = t_{d_{ON}} + t_r$ delay time + rise time.

$t_{off} = t_{d_{off}} + t_f$ delay time + fall time.

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## ADVANTAGES OF IGBT :

1. Combines advantages of BJT and MOSFET
2. High input impedance like MOSFET
3. Voltage Controlled device like MOSFET
4. Simple gate drive and lower Switching loss.
5. Low on State Conduction powerloss like BJT
6. Higher Current Capability and higher Switching Speed than BJT.

## DIS ADVANTAGE OF IGBT :

1. Asymmetric blocking
2. Switching frequency lesser than MOSFET
3. Problem of latch up.
4. Power dissipation during turn off due to current tail in Switching Characteristic

## APPLICATIONS OF IGBT :

1. AC & DC motor Controls
2. General purpose inverters
3. UPS
4. Welding equipment

5. Numerical Control Cutting tools

6. Robotics and Induction heating.

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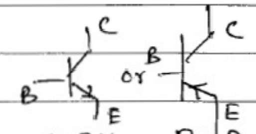
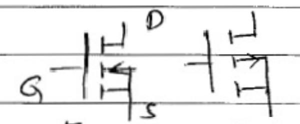
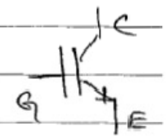
## COMPARE SCR AND BJT

| SL No. | SCR | BJT |
|---|---|---|
| 1. | Four layer device | 1. Three layer device |
| 2. | Turns on by regeneration | 2. No regeneration. |
| 3. | Gate looses Control after S/W on | 3. Gate or base has full Control. |
| 04. | Commutation or Circuit for S/W off required | 04. No external Circuit for Switching off. |
| 05 | Switching freq are low. | 05 S/W freq, high. |
| 06. | $\frac{dv}{dt}$ protection required to avoide false switching | 06. BJT will be damaged due to excessive dv/dt |
| 07. | used in Controlled rectifiers, AC regulators, DC drives | 07. used in Inverters, UPS, AC drives, SMPS |

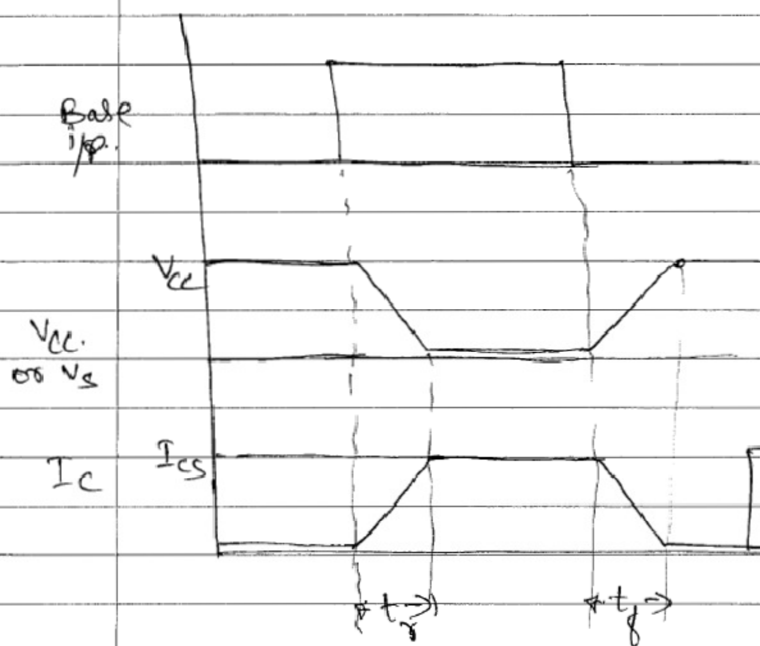
# COMPARISON OF POWER DEVICES

| Sl No. | Parameter | Power BJT | MOSFET | IGBT |
|---|---|---|---|---|
| 1. | Symbol |  NPN or PNP |  E-MOSFET N Channel, P-Ch. |  |
| 2. | Type of device | Minority Carrier device | Majority Carrier device | Majority Carrier Device |
| 3. | Tempr Coefft | −ve | +ve | Flat. |
| 4. | Volt Blocking | Asymmetric | Asymmetric | Asymmetr or Symmetr |
| 5. | operating freq | 10 KHz | 100 KHz | 10 KHz |
| 6. | Trigger Circuit | Cur Controlled Needs Continuous base drive | Volt Controlled needs Continuous base drive | Volt Contro-lled needs Cont. base drive. |
| 07. | on State volt drop | < 2V | 4-5V | 3 Volts |
| 08. | Snubbers | Required | May be eliminated | May be eliminate |
| 9 | VI rating | 2KV/1KA | 600V/200A | 1500V/400A |
| 10. | Appns | UPS, SMPS Static VAR Sys AC Motor Control | AC motor Control SMPS | SMPS BLDC drives AC motor UPS |

8/3/21

# $\frac{di}{dt}$ and $dv/dt$ Protection OR SNUBBER CKT. Design.

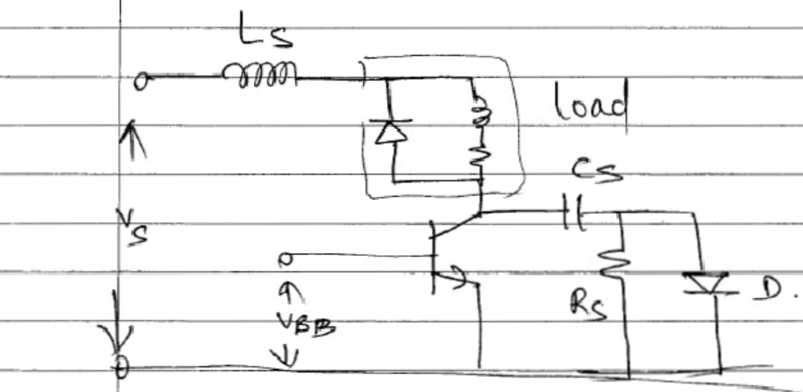
- Consider S/W Characteristics of BJT.
- Assume delay time $t_d$ is very small.




$$\boxed{\frac{dv_s}{dt} = \frac{V_s}{t_f}} \quad -(1)$$

$$\boxed{\frac{di}{dt} = \frac{I_{CS}}{t_r}} \quad -(2)$$

SNUBBER CKT.



While Switching on $L_s \frac{di}{dt} = V_s$

As Comple voltage Comes across $L_s$ and slowly Current increases.

$$\therefore \frac{di}{dt} = \frac{V_s}{L_s} = \frac{I_{cs}}{t_r} \quad \therefore \boxed{L_s = \frac{V_s}{I_{cs}} t_r} \quad - (3)$$

From (2).

While S/w off.

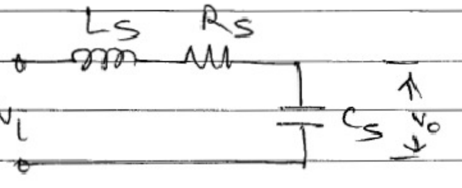
$$C_s \frac{dv_s}{dt} = I_{cs} \quad \therefore \frac{dv}{dt} = \frac{I_{cs}}{C_s} = \frac{V_s}{t_f}$$

$$\therefore \boxed{C_s = \frac{I_{cs}}{V_s} t_f} \quad - (4)$$

Design of $R_s$

Based on resonant circuit and damping ratio

In a series RLC network.




$$\frac{V_o(s)}{V_i(s)} = \frac{1/L_sC_s}{s^2 + \frac{R_s}{L_s}s + \frac{1}{L_sC_s}}$$

$$\therefore \text{In Ch eq}^n \quad \omega_n^2 = \frac{1}{L_sC_s} \quad \text{or} \quad \omega_n = \frac{1}{\sqrt{L_sC_s}}$$

$$2\xi\omega_n = \frac{R_s}{L_s} \quad \text{or} \quad \xi = \frac{R_s}{L_s} * \frac{1}{2\omega_n}$$

$\therefore \quad \zeta = \frac{R_S}{2}\sqrt{\frac{C_S}{L_S}}$

For Critically damped Case $\zeta = 1$.

$$\therefore \quad \boxed{R_S = 2\sqrt{\frac{L_S}{C_S}}} \quad — (5)$$

**II Case : Based on freq of operation.**

Time Constant $R_S C_S = \frac{T_S}{3}$

$$\text{or} \quad \boxed{R_S = \frac{1}{3 f_S C_S}} \quad — (6)$$

**III Case Based on Discharge Cur.**

$$\boxed{I_{discharge} = \frac{V_S}{R_S}}$$

Power dissipated by Snubber neglecting Inductor Loss.

$$\boxed{\frac{1}{2} C_S V_S^2 f_S}$$

Prob (1):

A bipolar transistor is operated as a chopper switch at a freq of $f_s = 10\text{ KHz}$. The DC voltage of chopper is $V_s = 220V$ and the load cur $I_L = 100A$ $V_{CES} = 0V$. The switching times are $t_d = 0$, $t_r = 3\mu s$, $t_f = 1.2\,\mu s$

Find $L_s$, $C_s$, $R_s$ for critically damped case
$R_s$ for discharge time to be limited $\frac{1}{3}$ of switching period. $R_s$ if the peak ~~cur~~ discharge cur limited 10% of load cur. Power loss in RC snubber neglecting $L_s$

Ans:

$$L_s = \frac{V_s}{I_L} t_r = \frac{220}{100} * 3 * 10^{-6} = \boxed{6.6\,\mu H}$$

$$C_s = \frac{I_L}{V_s} t_f = \frac{100}{220} * 1.2 * 10^{-6} = \boxed{0.55\,\mu F}$$

$$R_s\Big|_{\text{Critically damped}} = 2\sqrt{\frac{L_s}{C_s}} = \boxed{6.93\,\Omega}$$

$$R_s = \frac{1}{3 f_s C_s} = \frac{1}{3 * 10 * 10^3 * 0.55 * 10^{-6}} = \boxed{60.6\,\Omega}$$

$$R_s = \frac{V_s}{I_{Disch}} = \frac{V_s}{0.1 * I_L} = \frac{220}{0.1 * 100} = \boxed{22\,\Omega}$$

$$P_s = \frac{1}{2} C_s V_s^2 f_s = \boxed{133.1\text{ W}}$$

Prob (2): A BJT operated as a chopper switch at a freq $f_s = 20\,kHz$. The DC input voltage is $V_s = 400V$, load cur $I_L = 100A$

The switching time $t_r = 1\mu s$ $t_f = 3\mu s$

Find $L_s$, $C_s$ and $R_s$ for critically damped case, for $\frac{1}{3}$ of S/W ~~freq~~ period and if

discharge cur limited to 5% of load cur.

Power loss due to capacitor.

Ans:

$$L_s = \frac{V_s}{I_L} t_r = \frac{400}{100} * 1 * 10^{-6} = \boxed{4\,\mu H}$$

$$C_s = \frac{I_L}{V_s} t_f = \frac{100}{400} * 3 * 10^{-6} = \boxed{0.75\,\mu F}$$

$$R_s = 2\sqrt{\frac{L_s}{C_s}} = 2\sqrt{\frac{4}{0.75}} = \boxed{4.62\,\Omega}$$

$$R_s = \frac{1}{3 C_s f_s} = \frac{1}{3 * 0.75 * 10^{-6} * 20 * 10^{3}}$$

$$= \boxed{22.2\,\Omega}$$

$$R_s = \frac{V_s}{0.05\, I_L} = \frac{400}{0.05 * 100} = \boxed{80\,\Omega}$$

$$P_s = \frac{1}{2} C_s V_s^2 f_s = \frac{1}{2} * 0.75 * 10^{-6} * 400^2 * 20 * 10^3$$
$$= \boxed{1200W}$$

Stamp Σ1:



Jan Feb 2006 7 Mks

Prob (3): A MOSFET is operated as a Chopp Switch at a frequency of $f_s = 50\,KHz$. The DC input voltage is 30V, and the load Cur $I_L = 40A$. The switching times $t_r = 60\,nS$ $t_f = 25\,nS$ Find Snubber parameters including power loss $I_{disch} = 5\%$.

Ans: $L_S = \frac{V_S}{I_L} t_r = \frac{30}{40} * 60 * 10^{-9} = \boxed{45\,nH}$

$$C_S = \frac{I_L}{V_S} t_f = \frac{40}{30} 25 * 10^{-9} = \boxed{33.33\,nF}$$

$$R_S = 2\sqrt{\frac{L_S}{C_S}} = \boxed{2.32\,\Omega}$$

$$R_S = \frac{1}{3 C_S f_S} = \frac{1}{3 * \underset{33.33}{\cancel{0.33}} * 10^{-9}\ 50 * 10^{3}} = \boxed{200\,\Omega}$$

$$R_S = \frac{V_S}{0.05 * 40} = \boxed{15\,\Omega}$$

$$P_S = \frac{1}{2} C_S V_S^2 f_S = \frac{1}{2} * 33.33 * 10^{-9} * 30^2 * 50 * 10^{3}$$

$$= \boxed{0.75\,W}$$

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Stamp 1:

Jul Aug 2005 VTU 6 Mks

Prob (4): In the circuit shown the BJT is acting as a chopper switch at a freq of 15 KHz $E_{DC} = 240V$, load cur is 100A

The switching times are $t_r = 1.5\mu S$

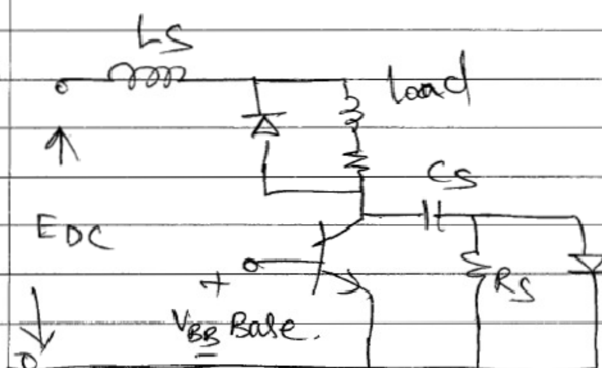
$t_f = 0.7\mu S$ Calculate snubber values

Also $R_S$ for ~~5%~~ of disch cur of 5% of load cur.

Find Power loss neglecting inductor loss

Take $V_{CES} = 0$

Ans:




Ans: $L_S = \frac{V_S}{I_L} t_r = \boxed{3.6 \mu H.}$

$C_S = \frac{I_L}{V_S} t_f = \boxed{0.29 \mu F}.$

Sol:

$$R_s = 2\sqrt{\frac{L_s}{C_s}} = \boxed{7\,\Omega}$$

Critically damped

$$R_s = \frac{1}{3 C_s f_s} = \frac{1}{3 * 0.29 * 10^{-6} * 15 * 10^{3}}$$

$$= \boxed{76.66\,\Omega}$$

$$R_s = \frac{V_s}{0.05\, I_L} = \frac{240}{0.05 * 100} = \boxed{48\,\Omega}$$

Power loss $P_s = 0.5\, C_s V_s^2 f_s = \boxed{125.28\,W}$

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Prob ⑤: A BJT is used as chopper switch at a freq of $f = 12$ KHz in the circuit shown in fig. The DC input voltage to the ckt is 230V, load cur $I_L = 100A$, The transistor switching times are $t_d = 0$, $t_r = 2.5\,\mu s$, $t_f = 1\,\mu s$ compute the values of snubber circuit.
Chose discharge cur to be limited to 10% of $I_L$
Assume $V_{CES} = 0$

Ans: $L_s = \frac{V}{I_L} t_r = 5.75\,\mu H$

$C_s = \frac{I_L}{V} t_f = 0.435\,\mu F$

$$R_s \Big|_{\text{Critically damped}} = 2\sqrt{\frac{L_s}{C_s}} = 7.27\,\Omega$$

$$R_s = \frac{1}{3 f C_s} = 63.86\,\Omega$$

$$R_s = \frac{V}{I_{disch}} = \frac{230}{0.1 * 100} = \boxed{23\,\Omega}$$

Power dissipated $\overline{P_s} = \frac{1}{2} C_s V^2 f_s$

$$= \boxed{138.07\ W}$$

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