Unit 1st & 4th 6th sem electronics

Date 13-01-14
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Lecture - 01

INTRODUCTION

POWER ELECTRONICS

Before:

- Circuit theory & Network
- Electrical M/C & Power System.
- Power semiconductor Devices.

} Power Electronics is Multidisciplinary course.

Outline of this course is divided in to 6 parts:

1. Introduction
2. Power semiconductor devices → Heart of Power Electronics.
3. AC - DC Converters
4. DC - DC Converters
5. DC - AC Converters
6. AC - AC Converters.

} Various Circuits in PE Can be divided in to four categories.

Reference Book:

1. M.H. Rashid (IIIrd Edition)
2. Ned Mohan "Power Elec. App. & design" (IIIrd Ed)
3. Cyril Lander "Power Electronics".
4. B.K. Bose "Modern Power Electronics & AC Drives".
5. Paper Published in IEEE Journals.

Quotes from IEEE Journal:

We now live in truly global society. In the highly automated industrial front with economic competitiveness of nation, in future two technologies will dominate:

1. Computer
2. Power Electronics.

→ The computer providing intelligence as to "What to do" and the power electronics "the means to do it".

1) Energy scenario
2) Fan speed $T \propto N^2$, $P \propto N^3$
3) Speed of an I.M. $N_s = 120f/p$, voltage, frequency converter
4) To make Iron loss = Cu loss when M/C is lightly loaded
5) Transmission line to make V constant
6) Transmission line DC converter for transmit power to reduce reactive power drop

→ Solar : output is DC,
Expensive but decreasing day by day.

→ Wind : cheapest, environment clean.

Wind energy now provides more than 31000MW of power around the world. In India, installed capacity 1900MW (2008) till Now = 7000MW.

It is estimated that the wind could supply 12% of the world's electrical demand by 2020.

Disadvantage:

Unreliable (seasonal in Nature).

As wind speed changes, turbine speed also ~~change~~ changes.

POWER ELECTRONICS

Def:

"Power electronics is the technology associated with efficient conversion and control of electric power by Power Semiconductor devices".

Goal of PE:

The Goal of Power electronics is to control the flow of energy from electric Source to electric Load.

→ The Success of any technology depends on following:

1) It should be highly efficient
2) It should be Reliable
3) Size, weight & Cost should be low.

If efficiency ↑, low power loss, cooling requirement comes down. So, we can package various element densely. Therefore size comes down. So High efficiency can be achieved by PE devices.

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*** How can the circuit change the voltage level, yet dissipate low power?

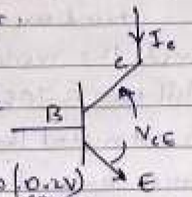
We know that circuit element R, L, C is passive element while transistor is an active element.

L & C do not dissipate power.

Power loss in BJT when it is ON = $V_{CE} \times I_C$

In active region V_{CE} is high while

In saturation region V_{CE} is ~~low~~ very low (0.2V approx.)



So the power loss in transistor can be reduce if it operates in saturation region.

So, in power electronic circuit, we use (1) L & C

(2) Transistor (in saturation region or cutoff.)

Conclusion:

→ Resistor and active element (operated in active region) results in power dissipation.

→ For high efficiency, active element should be operated either in saturation or cut-off region. In addition, use only L & C element.

→ ~~These~~ There are three ways to change the voltage level:

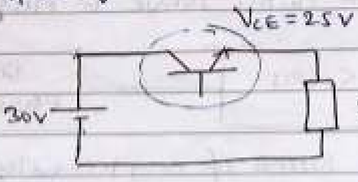
(a) Use of potential divider (Resistor) so power loss.

(b) Operate transistor in active region.

For Ex: Input = 30V, output = 5V

$V_{CE} = 25V$

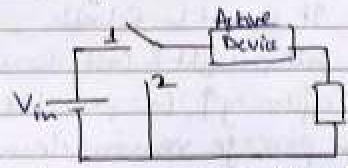
Power dissipated in transistor $= 25 \times I$ ✓



(c) Close the switch to position 1 for some time & then transfer it to 2.

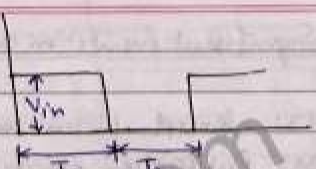
Then,

$$V_{out} = V_{in} \frac{T_1}{T_1 + T_2}$$



Power loss = 0 (b/coz voltage drop across device during ON = 0V)

$V_{out} = \frac{V_{in} T_1}{T_1 + T_2}$



In this case the Active device is connected in saturation region. So, $V_{CE} \approx 0V$. Thatiswhy Powerloss is approx. 0 watt. This is the principle used in Power electronic equipment.

Application of Power Electronics:

→ Power electronic is used in almost all the equipment wherever the efficient power conversion is required. few Applications are:

(a) In motor drives (to control the speed in an efficient way)
(b) Power Supplies (both AC & DC)
(c) Lighting
(d) High efficiency Induction Heating
(e) Electric welding.
(f) Active Filters (to filter the harmonics, we use Active filter)
(g) Bulk power transmission.
(h) Electric vehicles
(i) To process power from non-conventional source.

What is the reason for progress in power electronics?

The Progress in PE is primarily due to the advances in PE devices.

Ex:

(a) Small Diode → (0.5A, 50V)
Power Diode → (40A, 1200V)

(b) Small Transistor → (500mA, 50V)
Power Transistor → (50A, 1200V)

Significant events in the Past history of Power Electronics

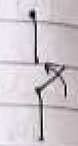
1783: Concept of semiconductor came by VOLTA.
1830: Rectification effect of CuO was observed by OHM.
1876: Selenium Rectifier by SIEMENS.
1896: Single phase bridge rectifier ckt by POLLACK.
1897: 3ϕ Bridge circuit
1901: Invension of glass bulb Mercury arc rectifier
1948: Invension of transistor
1953: Germanium power diode
1954: Silicon power diode
1957: Thyristor (SCR) : Blocking Voltage Capability.
(In 1957, SCR could block 500V
Today, it block approx 7000V)

That's completes the introductory lecture in Power Electronic.

POWER SEMICONDUCTOR DEVICES

→ Power Semiconductor devices are the heart & soul of modern power electronic equipment. These are used as switches.

Properties of an ideal switch:



→ (a) I=0 (OFF) open circuit
It should be able to withstand any V across it
$-\infty \leq V \leq \infty$

→ (b) when it is ON
$V_{switch} = 0V$
It is able to pass any current from it.
$-\infty \leq I \leq \infty$

So, power dissipated in these two cases = 0 watt.

→ Switch should be turned ON/OFF instantaneously i.e.
$t_{on} = t_{off} = 0$.
turn ON/OFF loss i.e. switching loss = 0

Transition time b/w ON & OFF of Switch should be 0 for an ideal Switch. So, Power loss = 0.

In an ideal switch have.

→ 0 conduction losses (case(a))

→ 0 Blocking loss. (case (b))

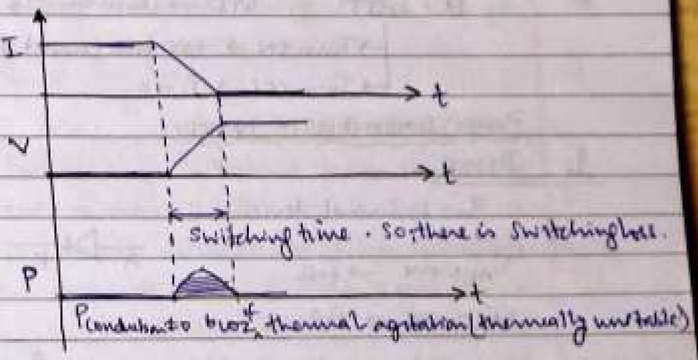
→ 0 Switching loss

However in practical switch, this is not the case.

In ~~an~~ a Non-ideal switch,

Current ≠ 0 in OFF condition

So there is some blocking ~~so~~ loss conduction loss & Switching loss.



Various types of Switches used in PE :

(a) Uncontrolled Switch: It is called uncontrolled switch because ON & OFF is determined by the ckt in which the device is connected. Ex: Diode (ON & OFF depends on F.B. & R.B).

$$I = \left(\frac{10-0.7}{10}\right) A.$$

If we apply AC then

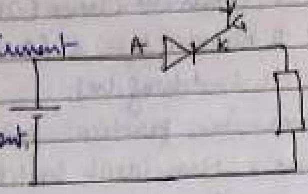
during +ve half cycle → ON
during ~~of~~ -ve half cycle → OFF } ON & OFF of diode is determined by the circuit (Power Supply).

(b) Semi-controlled switch

It is Semicontrolled switch because switch may be turn to one of its state using a controlled terminal and other state is reachable to the circuit only. That's why it is Semicontrolled

Ex: SCR.

Turned ON → by supplying gate current but turned off cannot be done by supplying gate current.



(c) fully-controlled switch:

Ex: BJT , GTO → (turn on - $+I_g$, turnoff - $-I_g$)

↳ Turn ON → +ve base current I_b

↳ Turn OFF → $I_b = 0$.

POWER SEMICONDUCTOR DEVICES:

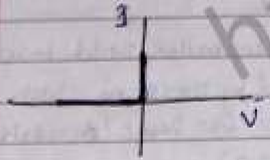
1. DIODE

Two terminal device.

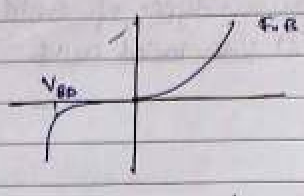
$V_{AK} = +ve$ → F.B.

$V_{AK} = -ve$ → R.B.

Ideal characteristics



Practical characteristics



The maximum reverse voltage should be less than V_{BD}.

If it is greater than V_{BD} then it will get damaged.

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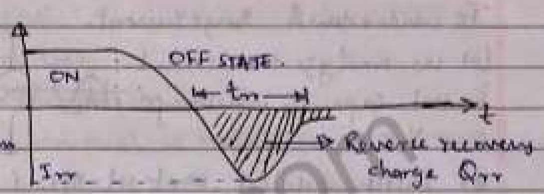
Power Diode

The off state is important. When switch is closed then it takes some time to



comes to 0 but the diode continues to conduct i.e. the reverse current starts flowing till sometime (say t_{rr}) because the minority carrier require certain time to recombine with the opposite charge and to get neutralize. This time is known as reverse recovery time denoted by "t_{rr}".
The Area covered in t_{rr} is the reverse recovery charge.
To find reverse recovery charge. Assuming it is a triangle

$$\boxed{Q_{rr} = \frac{I_{rr}\, t_{rr}}{2}}$$

So, Q_{rr} and t_{rr} is very important parameter. Why?
→ Even the current becomes 0, it continues to conduct for t_{rr}. So if the circuit in which the frequency of operation is very high, this t_{rr} will determine the upper frequency of operation.
→ And I_{rr}, flowing in the opposite direction (from cathode to Anode) i.e. to the source or flow through other switches which have their own current carrying capacity may have to carry this reverse recovery current.

Important specification of DIODE:

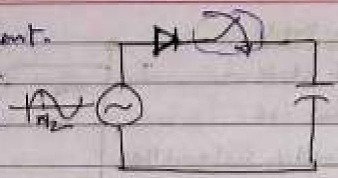
1. Average forward current (depends up on duty cycle)
2. Reverse blocking voltage (should be less than V_{BR})
3. ON state voltage drop (required for knowing conduction loss)
4. t_{rr}
5. Surge current rating
6. I^2t rating (short time surge energy that the diode can withstand)

To understand Surge Current.

Let us analyze this circuit.

Initial capacitor is discharge

$V_c = 0$.



Let Switch is closed at $\omega t = \pi/2$ i.e. $V = V_{max}$ at this instant

~~[illegible]~~, $V_{in} = V_{max}$ but $V_c = 0$

we know capacitor oppose the voltage change. So, there will be Large inrush current has to flow through diode ([illegible]) and this current is much higher than avg. forward current. This is known as Surge Current.

Various type of DIODE:

(a) Rectifier Diode or Slow DIODE

- Suitable for line frequency application.
- t_{rr} more
- Maximum voltage rating : 6kV [can block this much voltage]
- Current Rating : 4500A

(b) fast recovery DIODE

- Generally used in high frequency application.
- 6kV rating
- 1.1KA Current rating
- t_{rr} could be order of 0.1 μs.

(c) ~~Shottky~~ Schottky Diode [8' M]

- Very Low ON state voltage drop. Current flows only due to majority carriers
- Low voltage rating : 100V
- Current rating : 300A.

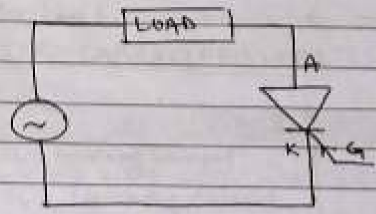
(d) Silicon Carbide DIODE

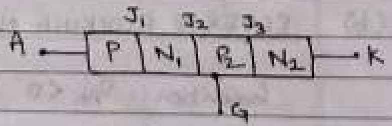
→ They have ultra power loss
→ Ultra fast switching behaviour.
→ Highly reliable i.e. no temperature influence on the switching behaviour.
→ Limitation is they are very expensive to make.

2. SILICON CONTROLLED RECTIFIER or THYRISTOR.

(Semi controlled ~~switch~~ device)

→ Three terminal device : Anode, Cathode, Gate





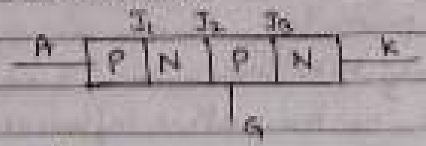
(Can be turned ON by giving +ve gate current)

→ There are four layers P,N,P,N and three junction J_1, J_2, & J_3.
→ N_2 → Layer is very thin and highly doped
P_2 → thicker than N_2 & less highly doped
N_1 → (Blocking layer) is the thickest of all layer & less doped.
P_1 → Similar to P_2.
→ ~~So~~ Junction J_3 have very low breakdown voltage due to highly doped of P_2 and N_2. (Similar to base emitted junction of transistor). Therefore J_3 cannot support very high reverse voltage.

Characteristics:

(a) FORWARD BLOCKING MODE ($V_{AK} > 0$)
(b) REVERSE BLOCKING MODE ($V_{AK} < 0$)
(c) ~~REVERSE~~ FORWARD CONDUCTING MODE. → $V_{AK} > 0$, $i_g \neq 0$.
→ $V_{AK} > V_{..}$ $i_g = 0$

(a) FORWARD BLOCKING MODE



Condition: $V_{AK} > 0$.

→ Current flowing in this mode is very small due to minority charge carrier.

→ In forward blocking mode,

$V_{AK} > 0$.

J_1 & J_3 = F.B.

J_2 = R.B.

So the entire voltage appears across J_2.

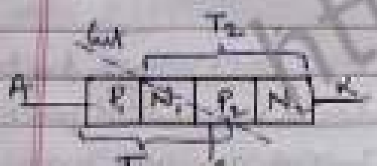
(b) REVERSE BLOCKING MODE

Condition: $V_{AK} < 0$

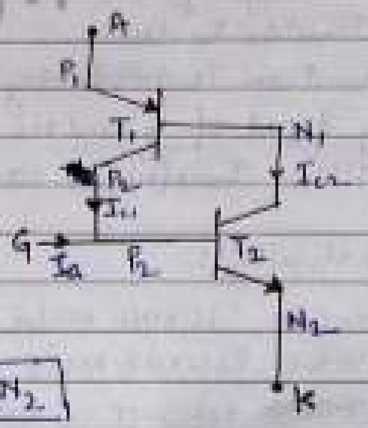
→ J_1 & J_3 = R.B.

J_2 = F.B.

But we know that J_3 cannot support high reverse voltage because N_2 is very thin & highly doped. i.e., when J_3 is reverse biased, entire voltage should be blocked by J_1.



PNP & NPN Transistor



Two transistor,

$P_1 N_1 P_2$, $N_1 P_2 N_2$

(a) Base of T_1 is same as Collector of T_2

(b) Collector of T_1 is same as the base of T_2

SCR CHARACTERISTICS

Notes:

Assume $I_G = 0$ in forward blocking mode,

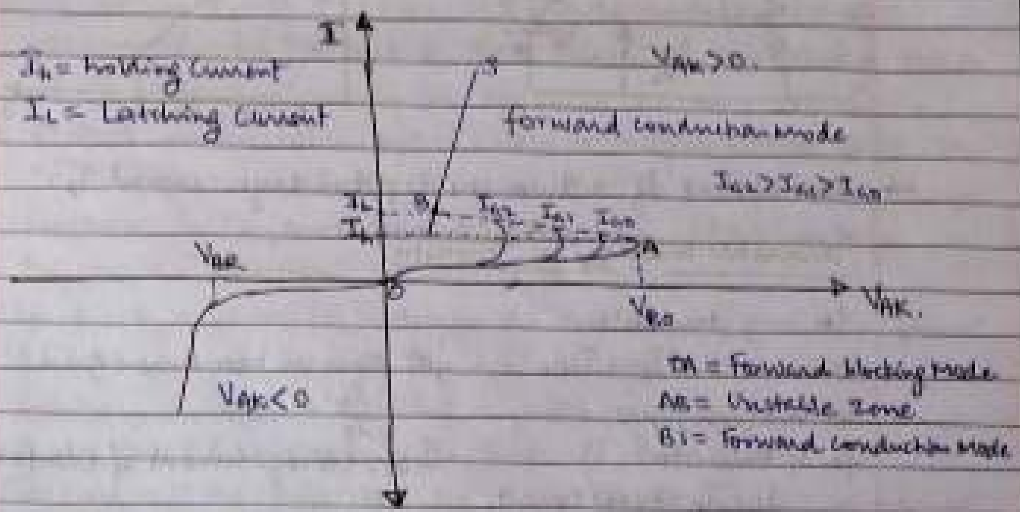
$J_2 = R.B$ i.e. entire voltage appears across J_2.

If the applied voltage is higher than breakdown voltage across J_2 i.e. V_{BO} (forward breakover) then the device goes into conduction mode. The moment when it goes to conduction mode, the voltage will drop to very low value (it could be order of 1-2V).

Till 0V to V_{BO} (current will be very small i.e. forward leakage current)

Once the device is in conduction mode, current is limited by the load.

SCR CHARACTERISTICS:



Dotted line shows the -ve resistance which is unstable line.

→ For finite gate current the voltage at which it goes to conduction mode (V_{BO}) will reduce due to decrease in depletion layer around J_2.

(c) FORWARD CONDUCTING MODE:

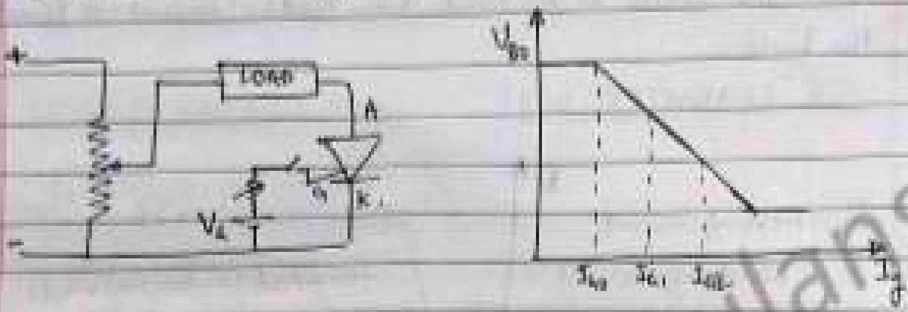
Conditions: ⓐ $V_{AK} > 0$ ⓑ $I_g \neq 0$ } or { ⓐ $V_{AK} > V_{BO}$ ⓑ $I_g = 0$ }

It will go on in both condition.

Note:

- Once the thyristor goes to conduction mode, we should make $i_g = 0$ because it is advantageous to make $i_g = 0$. If there is constant I_g is flowing, definately there is going to be the dissipation in that junction.
  So, it is advantageous to make $i_g = 0$ once the current through the device is higher than the Latching.
- To turn the device off, current should be decrease to a value which is less than the holding current.

Graph b/w V_{BO} & I_g



- Gate current I_g reduces the depletion layer around J_2.

Transistor Analogy for Thyristor

for any transistor,

$$I_C = \alpha I_E + I_{CBO}$$

, α = common base current gain $= \frac{I_C}{I_E}$

I_{CBO} = Leakage current of collector base J^n

See figure,

for T_1 transistor

$I_E = I_A$ = Anode current

$\therefore I_{C1} = \alpha_1 I_A + I_{CBO1}$

for T_2 transistor.

$I_E = I_K$ = cathode current.

$\therefore I_{C2} = \alpha_2 I_K + I_{CBO2}$

Now, we know,

$$I_E = I_C + I_B.$$

$\therefore I_{c1} + I_{c2} = I_A = \alpha_1 I_A + I_{CBO1} + \alpha_2 I_K + I_{CBO2}$ — (I)

for T_2,

$I_K = I_{B2} + I_{C2}$

for finite I_G, $I_{B2} = I_G + I_{C1}$

$\therefore I_K = I_G + I_{C1} + I_{C2}$

$= I_A + I_G$

$$\boxed{I_K = I_A + I_G} \quad \text{— (II)}$$

$\therefore$ Using (I) & (II) we get:

Anode Current →
$$I_A = \frac{\alpha_2 I_G + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$
Note: $\alpha \uparrow$ with I_E

Note:

If $I_G \uparrow$, I_A also $\uparrow$ and

If $I_A \uparrow$, $\alpha_1 \uparrow$ (bcoz $\alpha \uparrow$ with I_E i.e. I_A) Also $\alpha_2 \uparrow$

So, increase in α_1 and α_2 will further $\uparrow I_A$. This results in +ve feedback. Only in oscillators we use +ve feedback, Almost all the other system we use -ve feedback to stabilize it.

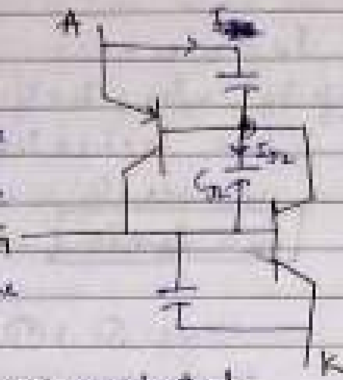
→ So, Due to the +ve feedback, small $\uparrow$ in I_G will results in Large increase in I_A (Anode current). This is one of the ways to trigger the thyristor.

→ If there is finite I_G to trigger the thyristor, I_G should be present till the current through the device is equal to or greater than the Latching Current I_L. If the thyristor gone in to conduction mode, gate has no control to turn off the thyristor.

→ To turn-off the thyristor, the device current should be reduced to a value which is less than the Holding Current (I_H). And I_H is always less than I_L.

Another way to turn on the Thyristor

We can turn on the Thyristor by making Large $\frac{dv}{dt}$



If $\frac{dv}{dt}$ is Large, I_{S2} would be Large and this may increase I_{CBO1} and I_{CBO2} and this Current gets amplified by the transistor action.

If they amplified & $\alpha_1 + \alpha_2$ approaches to 1 then the device will turn ON.

So, Not only the I_G will trigger the thyristor but also by applying Large $\frac{dv}{dt}$ across the device, it will go in to the <u>Conduction mode</u> <u>without I_G</u> (bcoz of the junction Capacitor)

<u>Summarizing</u> Various ways of triggering thyristor

<u>FOR CONDUCTION MODE</u>:

→ It is forward biased & Any one of these case makes the device turn ON.

(a) $V_{AK} > V_{BO}$, $I_G = 0$

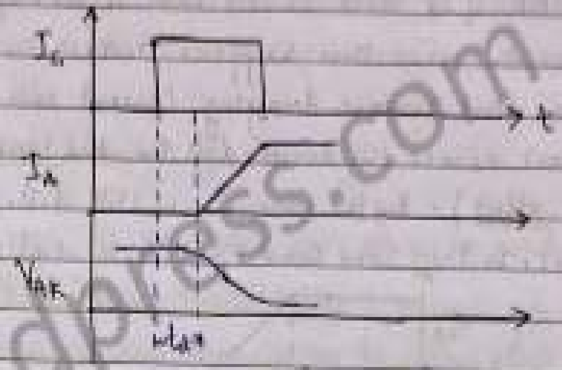
(b) $V_{AK} > 0$, $I_G \neq 0$

(c) $\frac{dV_{AK}}{dt}$ must be higher.

(d) Increase in temperature leads to ↑ in I_{CBO1} & I_{CBO2} which results ↑ in α_1 & α_2 & further ↑ in I_A

(e) <u>By direct Light radiation</u> to the junction leads to ↑ in junction temperature - So leakage Current I_{CBO1} & I_{CBO2} will ↑ & they get amplified & thyristor goes in to the Conduction mode. This method is used in High voltage application. Because of High voltage, it may be difficult to give I_G - So, this method is used in HVDC transmission.

SWITCHING CHARACTERISTICS OF THYRISTOR.



→ In forward blocking mode, when I_G starts flowing, there is finite delay time (t_d) before anode current I_A buildsup.
The increase in Anode (di/dt) current depends up on load.
And V_{AK} starts decreasing (approximately equal to (1.5-2V)).

→ If $\frac{dI}{dt}$ is very high then there will be an overheating of junction J_2 and hence the device may gets damaged.
Therefore, during turn-on dI/dt has to be control. How to control it we will see sometime later.

→ When device turn-on, J_2 will break and gets saturated with minority carrier and therefore Gate has no further control.
That's why it is semicontrolled device.

How to TURN-OFF ?

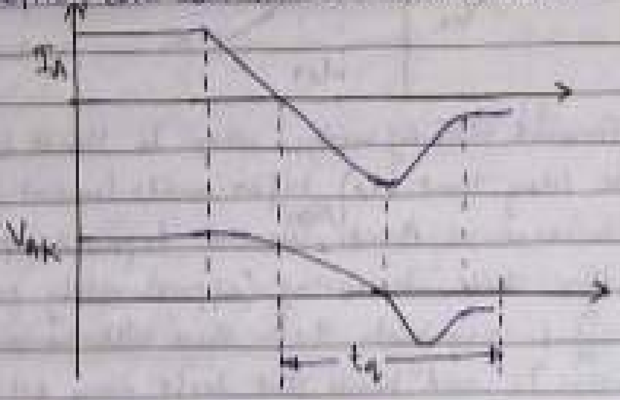
for turning off the current through the device should be reduced below the holding value. So,

If Input is AC there may be chance for -ve half cycle the current may reduced to 0 value.

If Input is DC then it will not turnoff.

So, for turning off the device, we apply the -ve voltage temporarily with other L & C elements. Current I_A becomes zero and then reverses its direction as seen in diode.

→ When reverse current I_r attain peak value then J_1 & J_3 will block. (J_3 block earlier than J_1 bcoz of highly doped). ~~and grant~~ When this happens, reverse current starts decaying. Now, this fast reverse decaying current will cause a voltage overshoot across the device due to the leakage inductance effect. ($L\,di/dt$ effect). By the way, J_2 is still F.B. bcoz of minority carriers. So, they take some time to neutralize it.



Therefore, Positive voltage should not appear across the thyristor till Junction J_2 has attain the forward blocking mode. If we apply the voltage then the device will go into the conduction mode & it will never turn off.

→ t_q → It is defined as the minimum time interval between on state (I_A) current becomes 0 & the instant when the thyristor is capable of withstanding forward voltage without turning on.

Important Parameters of Thyristor:

(a) Average Forward current (to assess its suitability with the Power ckt)
(b) Reverse Blocking voltage
(c) ON state voltage drop (to determine the heat sink size)
(d) di/dt during turn ON & turn Off } for designing Protection ckt (Snubber ckt)
(e) Reapplied dv/dt
Off state current (to determine the heat sink size)

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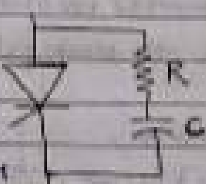
(g) SCR rating (same as diode)
(h) Device turn-off time t_q (to access high frequency switching capability)

How do we limit $\frac{di}{dt}$ and $\frac{dv}{dt}$?

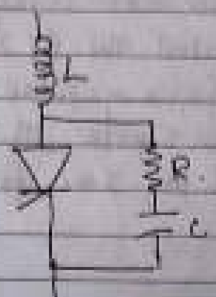
If there is large $\frac{dv}{dt}$, the device will go in to conduction mode.
If there is large di/dt then $L\,di/dt$ = voltage appear across the thyristor which may damage the thyristor if it goes above the rating value.

→ So, to control the $\frac{dv}{dt}$, we use a capacitor with small resistor

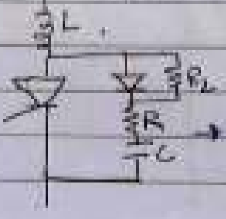


(connect RC ckt (Snubber) across the thyristor. Suppose initially it is ON current flowing & voltage is very less. When it gets turn off all the current flows through the RC ckt and capacitor starts charging up to the voltage across the thyristor (say 1.5V)
So by choosing the suitable R & C value, we can control the rate of voltage across the thyristor. Resistor is used to discharge the capacitor when the thyristor gets on again. So discharging current can be controlled by resistor R.

→ So, to control di/dt we use an inductor. This will not allow a fast rise in current.



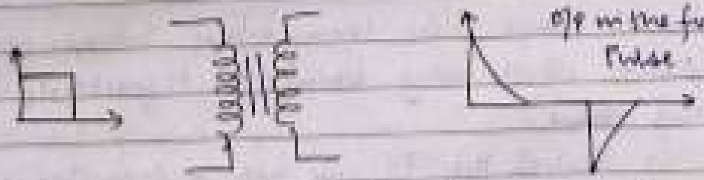
So, this two circuit will control the $\frac{di}{dt}$ & $\frac{dv}{dt}$



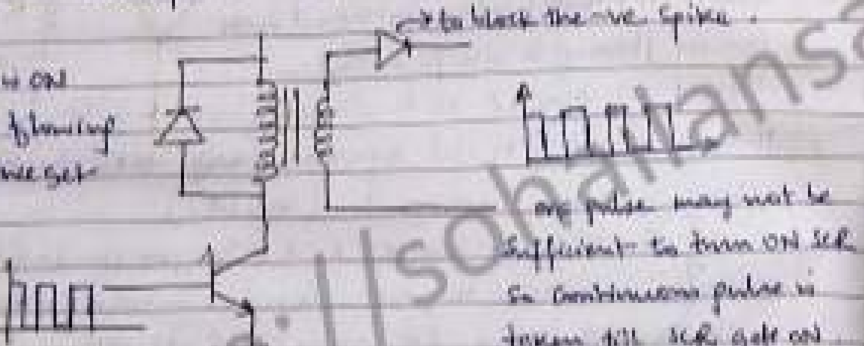
→ This circuit is also used as a (feedback) to discharge the capacitor quickly than the previous figure.

GATING REQUIREMENT:

- → I_g should be present till $I_A > I_L$
- → One of the requirement is control ckt should be isolated from power circuit because we require very low voltage to trigger on.
- → By using Pulse transformer we isolate the control circuit



I_g must be +ve but here -ve pulse also. So, we have to block -ve pulse. So, the circuit is shown below:



When transistor is ON current starts flowing from Xmer and set the o/p.

o/p pulse may not be sufficient to turn ON SCR so continuous pulse is taken till SCR gets on.

Note:

- → Snubber ckt is required for the protection of thyristor i.e. to control the dv/dt & di/dt
- → High frequency pulse signal is required at gate to trigger the thyristor. This pulse signal is generated by Pulse Xmer. for high freq. Xmer, ferrite core is used.

Lecture-06

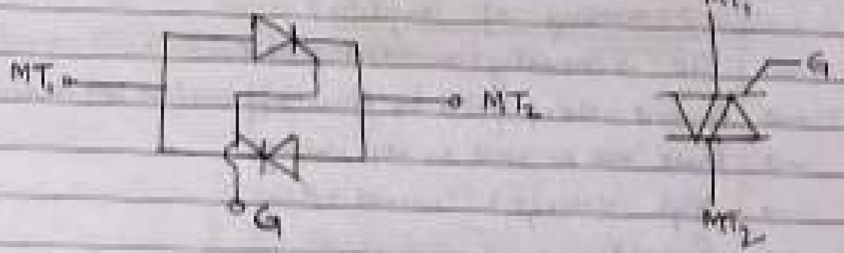
VARIOUS TYPES OF SCR

1. Converter grade SCR → Slow devices
→ used in ckt where frequency could be 50Hz
2. Inverter grade SCR → fast devices
→ Suitable for high frequency application.

→ If we want input = AC & o/p = AC just like a fan regulator, then we have to connect two thyristor in antiparallel. Instead of connecting the two thyristor, there is a separate device for the conversion of AC-AC known as TRIAC.

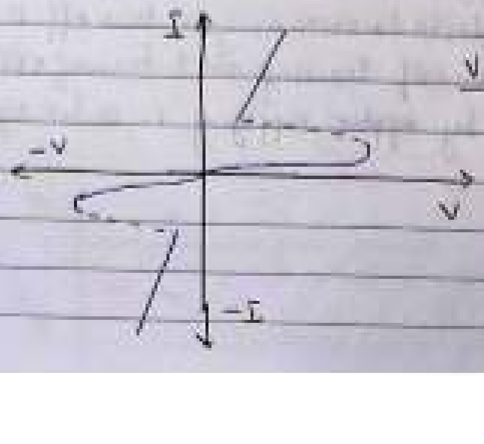
3. TRIAC (1964 by General Electric)

→ It has a complicated structure but functionally it is equivalent to two thyristors connected in antiparallel.



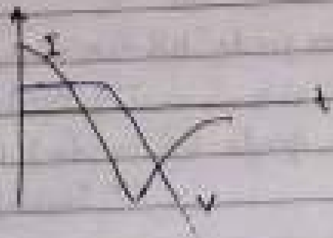
→ Bidirectional device (two power terminal & only one Gate terminal)
→ Can be triggered when MT_2 is +ve w.r.t. MT_1 & supplying a +ve I_g w.r.t. MT_1
→ It can also be triggered when MT_2 is -ve w.r.t. MT_1 and supplying a -ve I_g w.r.t. MT_1.

V-I characteristics.



used in fan Regulator, Light intensity controller, temperature controller.

Limitation of Triac



→ In case of thyristor, there is only one device to block in the reverse direction, but in a Triac, two thyristor is connected back to back. So when a reverse voltage is applied to one of them, forward voltage appears across the another thyristor. So, another thyristor may get triggered bcoz of this $\frac{dv}{dt}$. In another words, TRIAC has less time than thyristor to recover its blocking power.

Summary of Thyristor:

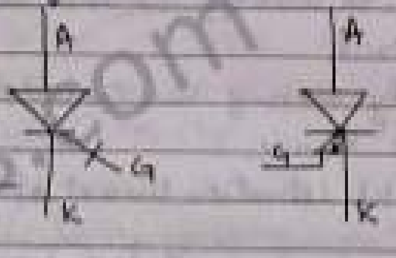
→ SCR is nearly an ideal switch.
→ Require sharp pulse to ~~turn-off~~ on (no continuous gate drive)
→ Block +ve as well as -ve voltage
→ High voltage & current rating.
→ Rugged
→ Limitation: Only one limitation
Inability to turn off by application of control signal at the thyristor gate.

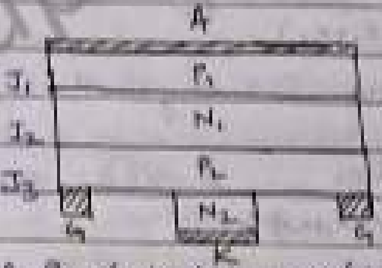
→ We can modify this device to turn off through gate by using ~~another~~ device known as gate turn off thyristor GTO which is capable of turning on & turning off through gate terminal by ~~appers~~ applying a control signal.

4. GATE TURN-OFF Thyristor (GTO)

1961 - Small Power GTO by General Electrical
1981 - 2.5KV, 1KA by Hitachi, Toshiba.
Now - 6KV, 6KA by MITSUBISHI

→ Can be Turn-ON by +ve I_G
→ Can be Turn-off by -ve I_G
→ four layer similar to SCR P_1, N_1, P_2, N_2. It is different in structure with SCR.





Small-small Blocks of N_2 layer is placed separated by a gap. & all are connected with Heatsink & makes a cathode.

→ Thickness of P_2 < that in SCR (to make them more)
→ N_2 Layer is removed by itching in place where gate contacts are situated.
→ It speeds up the turn-off process.
→ GTO can be brought in to conduction very rapidly because a very high di/dt is possible in GTO.

Turn-ON characteristics:

→ Similar to SCR but here it is recommended that +ve I_G is maintained throughout the conduction period because in GTO I_L is higher than that one in SCR. So in some case if I_A drops momentarily then GTO will get turn-off. So there must be +ve I_G always for conduction period we can reduce the I_G once it turn ON.

Turn-off characteristics:

When Thyristor (or GTO) is ON, both transistor T_1 & T_2 are in saturation (see SCR transistor model)

So, to turn-off, we have to bring transistor T_2 out of saturation

How?

By making base current of $T_2 = 0$.

We know,

Total saturation current of GTO

$$I_A = \frac{\alpha_2 I_G + I_{CBO}}{1-(\alpha_1+\alpha_2)} \quad \text{--- (I)} \qquad I_{CBO} = I_{CBO1} + I_{CBO2}$$

When GTO is in ON state I_G is very small. So, we can neglect

$$\therefore I_A = \frac{I_{CBO}}{1-(\alpha_1+\alpha_2)} \quad \text{--- (II)}$$

This amount of current we have to turn-off

from eqn (I) $I_A = 0$ when $I_{CBO} = -\alpha_2 I_G$ i.e. $I_G = -\frac{I_{CBO}}{\alpha_2}$ --- (III)

$$\therefore \boxed{\frac{I_A}{I_G} = \frac{\alpha_2}{(\alpha_1+\alpha_2)-1}} \quad \text{--- [using (II) \& (III)]}$$

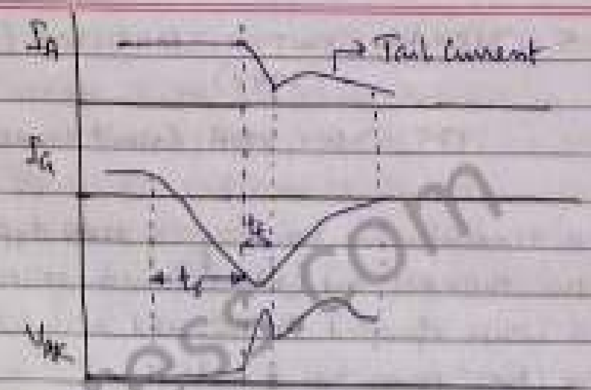
How do I make this as high as possible?

By making α_2 as high as possible.

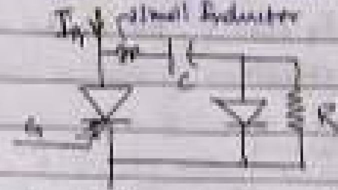
α_2 is for T_2 (N_1, P_2, N_2)

To make α_2 high, make thickness of P_2 layer less.

During Turn-off, I_G is -ve (flowing out of terminal). So, holes are extracted from P_2 due to which voltage are developed in P_2 region and thus reverse bias the J_2 and goes to cutoff mode. As holes extraction continues P_2 gets further depleted, so conducting area dropped.



→ Suppose we want to turn-off, I_G is reversed. Though I_G has reversed I_A still remains constant for t_s duration. This is known as storage time. During storage time, Anode current remains approximately constant. For turning off the GTO, we take snubber circuit in to an account. Since di/dt is very high for GTO so very small inductor is taken in snubber ckt.



→ From t_s onwards Anode current falls at a very fast rate. Also because of the small inductance & turn-on time of diode (connected in snubber ckt) I_A cannot start flowing through snubber ckt immediately and because of this there is going to be a <u>voltage spike</u>. Therefore the snubber ckt layout is very important in case of GTO. Voltage peak time is t_f which is fall time & is very small. After t_f, a tail current starts flowing through the snubber circuit. Now the voltage across GTO is governed by dv/dt.

→ This tail current corresponds to the free charges exist with the N_1 Layer. (blocking layer or lightly doped Layer)

→ Turn-off loss is more than SCR. To reduce this, tail current must be minimize which can be done by <u>Anode Shorting</u> (produces a short circuit b/w Anode & N_1) so that the minority carrier trapped in N_1 recombine more quickly. And finally tail current time ↓.

Unit 2nd

Photodetector

Photodetectors, also called **photosensors**, are sensors of light or other electromagnetic radiation.[1] A photo detector has a p–n junction that converts light photons into current. The absorbed photons make electron–hole pairs in the depletion region. Photodiodes and photo transistors are a few examples of photo detectors. Solar cells convert some of the light energy absorbed into electrical energy

TYPES OF PHOTODETECTORS

Photodetectors may be classified by their mechanism for detection:[2][*unreliable source?*][3][4]

- Photoemission or photoelectric effect: Photons cause electrons to transition from the conduction band of a material to free electrons in a vacuum or gas.
- Thermal: Photons cause electrons to transition to mid-gap states then decay back to lower bands, inducing phonon generation and thus heat.
- Polarization: Photons induce changes in polarization states of suitable materials, which may lead to change in index of refraction or other polarization effects.
- Photochemical: Photons induce a chemical change in a material.
- Weak interaction effects: photons induce secondary effects such as in photon drag[5][6] detectors or gas pressure changes in Golay cells.

Photodetectors may be used in different configurations. Single sensors may detect overall light levels. A 1-D array of photodetectors, as in a spectrophotometer or a Line scanner, may be used to measure the distribution of light along a line. A 2-D array of photodetectors may be used as an image sensor to form images from the pattern of light before it.

A photodetector or array is typically covered by an illumination window, sometimes having an anti-reflective coating.

PROPERTIES OF PHOTODETECTORS

There are a number of performance metrics, also called figures of merit, by which photodetectors are characterized and compared[2][3]

- Spectral response: The response of a photodetector as a function of photon frequency.
- Quantum efficiency: The number of carriers (electrons or holes) generated per photon.
- Responsivity: The output current divided by total light power falling upon the photodetector.
- Noise-equivalent power: The amount of light power needed to generate a signal comparable in size to the noise of the device.
- Detectivity: The square root of the detector area divided by the noise equivalent power.
- Gain: The output current of a photodetector divided by the current directly produced by the photons incident on the detectors, i.e., the built-in current gain.
- Dark current: The current flowing through a photodetector even in the absence of light.
- Response time: The time needed for a photodetector to go from 10% to 90% of final output.

- Noise spectrum: The intrinsic noise voltage or current as a function of frequency. This can be represented in the form of a noise spectral density.
- Nonlinearity: The RF-output is limited by the nonlinearity of the photodetector[7]

PHOTODIODES

A **photodiode** is a semiconductor device that converts light into an electrical current. The current is generated when photons are absorbed in the photodiode. Photodiodes may contain optical filters, built-in lenses, and may have large or small surface areas. Photodiodes usually have a slower response time as their surface area increases. The common, traditional solar cell used to generate electric solar power is a large area photodiode.

Photodiodes are similar to regular semiconductor diodes except that they may be either exposed (to detect vacuum UV or X-rays) or packaged with a window or optical fiber connection to allow light to reach the sensitive part of the device. Many diodes designed for use specially as a photodiode use a PIN junction rather than a p–n junction, to increase the speed of response. A photodiode is designed to operate in reverse bias

PRINCIPLE OF OPERATION

A photodiode is a p–n junction or PIN structure. When a photon of sufficient energy strikes the diode, it creates an electron–hole pair. This mechanism is also known as the inner photoelectric effect. If the absorption occurs in the junction's depletion region, or one diffusion length away from it, these carriers are swept from the junction by the built-in electric field of the depletion region. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced. The total current through the photodiode is the sum of the dark current (current that is generated in the absence of light) and the photocurrent, so the dark current must be minimized to maximize the sensitivity of the device.[2]

To first order, for a given spectral distribution, the photocurrent is linearly proportional to the irradiance

Photovoltaic mode

When used in zero bias or ***photovoltaic mode***, photocurrent flows out of the anode through a short circuit to the cathode. If the circuit is opened or has a load impedance, restricting the photocurrent out of the device, a voltage builds up in the direction that forward biases the diode, that is, anode positive with respect to cathode. If the circuit is open or the impedance is high, a forward current will consume all or some of the photocurrent. This mode exploits the photovoltaic effect, which is the basis for solar cells – a traditional solar cell is just a large area photodiode. For optimum power output, the photovoltaic cell will be operated a voltage that causes only a small forward current compared to the photocurrent.[3]

Photoconductive mode

In this mode the diode is reverse biased (with the cathode driven positive with respect to the anode). This reduces the response time because the additional reverse bias increases the width of the depletion layer, which decreases the junction's capacitance and increases the region with an electric field that will cause electrons to be quickly collected. The reverse bias also reduces the dark current without much change in the photocurrent.

Although this mode is faster, the photoconductive mode can exhibit more electronic noise due to dark current or avalanche effects.[4] The leakage current of a good PIN diode is so low (<1 nA) that the Johnson–Nyquist noise of the load resistance in a typical circuit often dominates.

Avalanche Photodiode

An **avalanche photodiode** (**APD**) is a highly sensitive semiconductor electronic device that exploits the photoelectric effect to convert light to electricity. From a functional standpoint, they can be regarded as the semiconductor analog of photomultipliers. By applying a high reverse bias voltage (typically 100–200 V in silicon), APDs show an internal current gain effect (around 100) due to impact ionization (avalanche effect). However, some silicon APDs employ alternative doping and beveling techniques compared to traditional APDs that allow greater voltage to be applied (> 1500 V) before breakdown is reached and hence a greater operating gain (> 1000). In general, the higher the reverse voltage, the higher the gain. Among the various expressions for the APD multiplication factor (*M*), an instructive expression is given by the formula

$$M = \frac{1}{1 - \int_0^L \alpha(x)\, dx},$$

where *L* is the space-charge boundary for electrons, and is the multiplication coefficient for electrons (and holes). This coefficient has a strong dependence on the applied electric field strength, temperature, and doping profile. Since APD gain varies strongly with the applied reverse bias and temperature, it is necessary to control the reverse voltage to keep a stable gain. Avalanche photodiodes therefore are more sensitive compared to other semiconductor photodiodes.

If very high gain is needed (10^5 to 10^6), certain APDs (single-photon avalanche diodes) can be operated with a reverse voltage above the APD's breakdown voltage. In this case, the APD needs to have its signal current limited and quickly diminished. Active and passive current-quenching techniques have been used for this purpose. APDs that operate in this high-gain regime are in Geiger mode. This mode is particularly useful for single-photon detection, provided that the dark count event rate and afterpulsing probability are sufficiently low.

Typical applications for APDs are laser rangefinders, long-range fiber-optic telecommunication, and quantum sensing for control algorithms. New applications include positron emission tomography and particle physics. APD arrays are becoming commercially available, also lightning detection and optical SETI may be a future application.

APD applicability and usefulness depends on many parameters. Two of the larger factors are: quantum efficiency, which indicates how well incident optical photons are absorbed and then used to generate primary charge carriers; and total leakage current, which is the sum of the dark current and photocurrent and noise. Electronic dark-noise components are series and parallel noise. Series noise, which is the effect of shot noise, is basically proportional to the

APD capacitance, while the parallel noise is associated with the fluctuations of the APD bulk and surface dark currents. Another noise source is the excess noise factor, ENF. It is a multiplicative correction applied to the noise that describes the increase in the statistical noise, specifically Poisson noise, due to the multiplication process. The ENF is defined for any device, such as photomultiplier tubes, silicon solid-state photomultipliers, and APDs, that multiplies a signal, and is sometimes referred to as "gain noise".

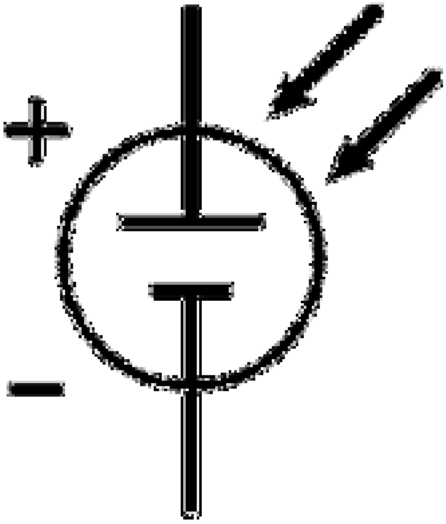
The noise term for an APD may also contain a Fano factor, which is a multiplicative correction applied to the Poisson noise associated with the conversion of the energy deposited by a charged particle to the electron-hole pairs, which is the signal before multiplication. The correction factor describes the decrease in the noise, relative to Poisson statistics, due to the uniformity of conversion process and the absence of, or weak coupling to, bath states in the conversion process. In other words, an "ideal" semiconductor would convert the energy of the charged particle into an exact and reproducible number of electron hole pairs to conserve energy; in reality, however, the energy deposited by the charged particle is divided into the generation of electron hole pairs, the generation of sound, the generation of heat, and the generation of damage or displacement. The existence of these other channels introduces a stochastic process, where the amount of energy deposited into any single process varies from event to event, even if the amount of energy deposited is the same.

The underlying physics associated with the excess noise factor (gain noise) and the Fano factor (conversion noise) is very different. However, the application of these factors as multiplicative corrections to the expected Poisson noise is similar.

Solar cell

For convection cells on the sun's surface, see Granule (solar physics).

A conventional crystalline silicon solar cell (as of 2005). Electrical contacts made from busbars (the larger silver-colored strips) and fingers (the smaller ones) are printed on the silicon wafer.



Symbol of a Photovoltaic cell.

A **solar cell**, or **photovoltaic cell**, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon.[1] It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Individual solar cell devices can be combined to form modules, otherwise known as solar panels. In basic terms a single junction silicon solar cell can produce a maximum open-circuit voltage of approximately 0.5 to 0.6 volts.[2]

Solar cells are described as being photovoltaic, irrespective of whether the source is sunlight or an artificial light. They are used as a photodetector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity.

The operation of a photovoltaic (PV) cell requires three basic attributes:

- The absorption of light, generating either electron-hole pairs or excitons.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.

In contrast, a solar thermal collector supplies heat by absorbing sunlight, for the purpose of either direct heating or indirect electrical power generation from heat. A "photoelectrolytic cell" (photoelectrochemical cell), on the other hand, refers either to a type of photovoltaic cell (like that developed by Edmond Becquerel and modern dye-sensitized solar cells), or to a device that splits water directly into hydrogen and oxygen using only solar illumination.

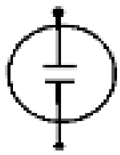
Solar cells are typically named after the semiconducting material they are made of. These materials must have certain characteristics in order to absorb sunlight. Some cells are designed to handle sunlight that reaches the Earth's surface, while others are optimized for use in space. Solar cells can be made of only one single layer of light-absorbing material (single-junction) or use multiple physical configurations (multi-junctions) to take advantage of various absorption and charge separation mechanisms.

Solar cells can be classified into first, second and third generation cells. The first generation cells—also called conventional, traditional or wafer-based cells—are made of crystalline silicon, the commercially predominant PV technology, that includes materials such as polysilicon and monocrystalline silicon. Second generation cells are thin film solar cells, that include amorphous silicon, CdTe and CIGS cells and are commercially significant in utility-scale photovoltaic power stations, building integrated photovoltaics or in small stand-alone power system. The third generation of solar cells includes a number of thin-film technologies often described as emerging photovoltaics—most of them have not yet been commercially applied and are still in the research or development phase. Many use organic materials, often organometallic compounds as well as inorganic substances. Despite the fact that their efficiencies had been low and the stability of the absorber material was often too short for commercial applications, there is a lot of research invested into these technologies as they promise to achieve the goal of producing low-cost, high-efficiency solar cells.

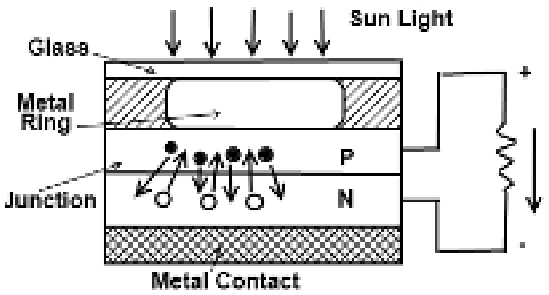
Construction and working of Solar Cell

It essentially consists of a silicon PN junction diode with a glass window on top surface layer of P material is made extremely thin so, that incident light photon's may easily reach the PN junction. When these photons collide with valence electrons'. They comport them sufficient energy as to leave their parent atoms. In this way free electrons and holes are generated on both sides of the junction. Due to these holes and electrons current are produces. This current is directly proportional to the illumination's (mw/cm2) and also depends on the size of the surface area being illuminated.

The open circuit voltage is a function of illumination. The symbol is shown below.



Solar Cell
Symbol



Solar Cell Construction

As shown in the given diagram the Solar cell is like an ordinary diode. It consist of silicon, germanium PN junction with a glass windows on the top surface layer of P-Type, the P-Type material is made very thin and wide so that the incident light photon may easily reach to PN junction.

The P nickel plated ring around the P layer acts as the positive output terminal's (anode) and the metal contact at the bottom acts as a Cathode.

Silicon and germanium are the most widely used semiconductors materials for solar cells although gallium arsenide, Indium arsenide and Cadmium arsenide are also being used nowadays.

LCD DISPLAY

A **liquid-crystal display** (**LCD**) is a flat-panel display or other electronically modulated optical device that uses the light-modulating properties of liquid crystals. Liquid crystals do not emit light directly, instead using a backlight or reflector to produce images in color or monochrome.[1] LCDs are available to display arbitrary images (as in a general-purpose computer display) or fixed images with low information content, which can be displayed or hidden, such as preset words, digits, and seven-segment displays, as in a digital clock. They use the same basic technology, except that arbitrary images are made up of a large number of small pixels, while other displays have larger elements. LCDs can either be normally on (positive) or off (negative), depending on the polarizer arrangement. For example, a character positive LCD with a backlight will have black lettering on a background that is the color of the backlight, and a character negative LCD will have a black background with the letters being of the same color as the backlight. Optical filters are added to white on blue LCDs to give them their characteristic appearance.

LCDs are used in a wide range of applications, including LCD televisions, computer monitors, instrument panels, aircraft cockpit displays, and indoor and outdoor signage. Small LCD screens are common in portable consumer devices such as digital cameras, watches, calculators, and mobile telephones, including smartphones. LCD screens are also used on consumer electronics products such as DVD players, video game devices and clocks. LCD screens have replaced heavy, bulky cathode ray tube (CRT) displays in nearly all applications. LCD screens are available in a wider range of screen sizes than CRT and plasma displays, with LCD screens available in sizes ranging from tiny digital watches to very large television receivers. LCDs are slowly being replaced by OLEDs, which can be easily made into different shapes, and have a lower response time, wider color gamut, virtually infinite color contrast and viewing angles, lower weight for a given display size and a slimmer profile (because OLEDs use a single glass or plastic panel whereas LCDs use two glass panels; the thickness of the panels increases with size but the increase is more noticeable on LCDs) and potentially lower power consumption (as the display is only "on" where needed and there is no backlight). OLEDs, however, are more expensive for a given display size due to the very expensive electroluminescent materials or phosphors that they use. Also due to the use of phosphors, OLEDs suffer from screen burn-in and there is currently no way to recycle OLED displays, whereas LCD panels can be recycled, although the technology required to recycle LCDs is not yet widespread. Attempts to increase the lifespan of LCDs are quantum dot displays, which offer similar performance as an OLED display, but the Quantum dot sheet that gives these displays their characteristics can not yet be recycled.

Since LCD screens do not use phosphors, they rarely suffer image burn-in when a static image is displayed on a screen for a long time, e.g., the table frame for an airline flight schedule on an indoor sign. LCDs are, however, susceptible to image persistence.[2] The LCD screen is more energy-efficient and can be disposed of more safely than a CRT can. Its low electrical power consumption enables it to be used in battery-powered electronic equipment more efficiently than CRTs can be. By 2008, annual sales of televisions with LCD screens exceeded sales of CRT units worldwide, and the CRT became obsolete for most purposes

Advantages of lcd

- Very compact, thin and light, especially in comparison with bulky, heavy CRT displays.

- Low power consumption. Depending on the set display brightness and content being displayed, the older CCFT backlit models typically use less than half of the power a CRT monitor of the same size viewing area would use, and the modern LED backlit models typically use 10–25% of the power a CRT monitor would use.[102]
- Little heat emitted during operation, due to low power consumption.
- No geometric distortion.
- The possible ability to have little or no flicker depending on backlight technology.
- Usually no refresh-rate flicker, because the LCD pixels hold their state between refreshes (which are usually done at 200 Hz or faster, regardless of the input refresh rate).
- Sharp image with no bleeding or smearing when operated at native resolution.
- Emits almost no undesirable electromagnetic radiation (in the extremely low frequency range), unlike a CRT monitor.[103][104]
- Can be made in almost any size or shape.
- No theoretical resolution limit. When multiple LCD panels are used together to create a single canvas, each additional panel increases the total resolution of the display, which is commonly called stacked resolution.[105]
- Can be made in large sizes of over 80-inch (2 m) diagonal.
- Masking effect: the LCD grid can mask the effects of spatial and grayscale quantization, creating the illusion of higher image quality.[106]
- Unaffected by magnetic fields, including the Earth's.
- As an inherently digital device, the LCD can natively display digital data from a DVI or HDMI connection without requiring conversion to analog. Some LCD panels have native fiber optic inputs in addition to DVI and HDMI.[107]
- Many LCD monitors are powered by a 12 V power supply, and if built into a computer can be powered by its 12 V power supply.
- Can be made with very narrow frame borders, allowing multiple LCD screens to be arrayed side-by-side to make up what looks like one big screen.

Disadvantages OF lcd

- Limited viewing angle in some older or cheaper monitors, causing color, saturation, contrast and brightness to vary with user position, even within the intended viewing angle.
- Uneven backlighting in some monitors (more common in IPS-types and older TNs), causing brightness distortion, especially toward the edges ("backlight bleed").
- Black levels may not be as dark as required because individual liquid crystals cannot completely block all of the backlight from passing through.
- Display motion blur on moving objects caused by slow response times (>8 ms) and eye-tracking on a sample-and-hold display, unless a strobing backlight is used. However, this strobing can cause eye strain, as is noted next:
- As of 2012, most implementations of LCD backlighting use pulse-width modulation (PWM) to dim the display,[108] which makes the screen flicker more acutely (this does not mean visibly) than a CRT monitor at 85 Hz refresh rate would (this is because the entire screen is strobing on and off rather than a CRT's phosphor sustained dot which continually scans across the display, leaving some part of the display always lit), causing severe eye-strain for some people.[109][110] Unfortunately, many of these people don't know that their eye-strain is being caused by the invisible strobe effect of PWM.[111] This problem is worse on many LED-backlit monitors, because the LEDs switch on and off faster than a CCFL lamp.
- Only one native resolution. Displaying any other resolution either requires a video scaler, causing blurriness and jagged edges, or running the display at native resolution using 1:1 pixel mapping, causing the image either not to fill the screen (letterboxed display), or to run off the lower or right edges of the screen.
- Fixed bit depth (also called color depth). Many cheaper LCDs are only able to display 262,000 colors. 8-bit S-IPS panels can display 16 million colors and have significantly better black level, but are expensive and have slower response time.

- Low refresh rate. All but a few high-end monitors support no higher than 60 or 75 Hz; while this does not cause visible flicker due to the LCD panel's high internal refresh rate, the low input refresh rate limits the maximum frame-rate that can be displayed, affecting gaming and 3D graphics.
- Input lag, because the LCD's A/D converter waits for each frame to be completely been output before drawing it to the LCD panel. Many LCD monitors do post-processing before displaying the image in an attempt to compensate for poor color fidelity, which adds an additional lag. Further, a video scaler must be used when displaying non-native resolutions, which adds yet more time lag. Scaling and post processing are usually done in a single chip on modern monitors, but each function that chip performs adds some delay. Some displays have a video gaming mode which disables all or most processing to reduce perceivable input lag.[112]
- Dead or stuck pixels may occur during manufacturing or after a period of use. A stuck pixel will glow with color even on an all-black screen, while a dead one will always remain black.
- Subject to burn-in effect, although the cause differs from CRT and the effect may not be permanent, a static image can cause burn-in in a matter of hours in badly designed displays.
- In a constant-on situation, thermalization may occur in case of bad thermal management, in which part of the screen has overheated and looks discolored compared to the rest of the screen.
- Loss of brightness and much slower response times in low temperature environments. In sub-zero environments, LCD screens may cease to function without the use of supplemental heating.
- Loss of contrast in high temperature environments

LCD Display Types

There are many LCD display types to choose from. Some are new cutting edge technology and other are older legacy types of displays. Although even some of the legacy type of LCD displays make use of cutting edge technology. The goal of this article is to provide the reader with a brief overview of the uses, advantages and disadvantages of each type of display.

The categories of the different LCD display types are:

- **Monochrome (single color)**
  - Static
  - Graphic
  - Character
  - Custom
- **Multi-Color**
  - TFT
  - OLED
  - FSC (Field Sequential Color LCD)
  - EBT (Excellent Black Technology) aka VA (Vertical alignment)
  - CSTN

#1 monochrome LCD display type: segment displays

Segment LCD's, also called static or direct drive are an older technology but are still in heavy use today. These displays are reliable and have been in use for many years. They show no signs of going away anytime soon.

The goal of this display is simplicity. Their only job is to display letters, numbers and icons. There is no 3-D effect or range of brilliant colors and most do not contain a touch screen or any other type of human interface. They normally are not equipped wit a controller/driver chip.

In fact, you could reduce the static/direct drive LCD down to the simple formula of one pin equals one segment. If you need a display that contains a 7 segment number, you need 7 pins. The exception to this is if you increase the number of backplanes and convert this to a multiplex display.

Monochrome LCD display type: multiplex LCD displays.

The formula for a multiplex display is a little more complicated. One pin equals 2 or 4 segments. The advantage of multiplexing is that you reduce the number of pins which, in turn, reduces the cost of the display and the amount of time required to mount the display to a PCB.

One disadvantage of multiplex display over direct drive displays is that the refresh rate is slower and this may allow the segments that are ON to 'fade' or not look as sharp. Some times this is referred to as 'ghosting'. This is not a very common occurrence as the technology has improved since the days of pagers and low cost calculators.

When a customer cannot decided what ***LCD display type*** to use we have a general rule: *If the total number of segments is 20 or less, we advise a static (direct drive) display* since a display with 20 pins is low cost to build and to install on the PCB.

Once the number of segments exceed 20, we recommend multiplex. A display with more than 120 segments becomes cost prohibitive.

If your design exceeds 120 segments we would recommend converting your design to a ***graphics type of LCD display*** that makes use of the controller driver chip. The controller driver chip allow the number of connections for multiple segments to be reduced to 14 or 16 pins. This LCD technology is covered later in the article.

Why choose one of these LCD display types?

While monochrome displays are simple and can come across as somewhat boring, there are some key advantages to consider when choosing which of the LCD display types to go with.

Low Power LCD Displays

One key ***advantage of the monochrome LCD display*** is that they are not power hungry. They operate with very little current draw. This becomes an ideal choice when the only power you have is a *battery*. These displays are built to operate at 3.0V, 3.3V (in some case they can operate as low as 1.7V) and 5V. The current draw for a display with no backlight can run as low as 6uA per cm^2. (*Note*: *The lower the operating temperature of the LCD, the greater the power required*).

If all you need to display is what time it is, the current temperature, or the number of gallons, and your customer does not wish to pay for vibrant, flashy power-hungry color, then this display will work perfectly for you.

Customizable LCD Displays

The majority of the static or multiplex displays we offer have been customized to meet the customer's requirements. This is a great advantage to consider when choosing one of the LCD display types you will use in your product.

A customized static or multiplex display allows you to have the display built to the dimensions you require. You can select the following options:

- Temperature range to operate in
- Backlight type and color
- Positive or negative mode
- Viewing angle (6:00 /12:00)

The tooling or NRE (non-recurring engineering cost) of this type of display is much lower than newer technologies and the MOQ (minimum order quantities) are also lower than other types of displays.

If your goal is to display basic information, with a low tooling cost and you need to operate on a low power budget than the ***best type of LCD Display*** is a static or multiplex LCD.

UNIT 3RD

Power semiconductor device

A **power semiconductor device** is a semiconductor device used as a switch or rectifier in power electronics (for example in a switch-mode power supply). Such a device is also called a **power device** or, when used in an integrated circuit, a **power IC**.

A power semiconductor device is usually used in "commutation mode" (i.e., it is either on or off), and therefore has a design optimized for such usage; it should usually not be used in linear operation. Linear power circuits are widespread as voltage regulators, audio amplifiers, and radio frequency amplifiers.

Power semiconductors are found in systems delivering as little as a few tens of milliwatts for a headphone amplifier, up to around a gigawatt in a high voltage direct current transmission line.

The first semiconductor device used in power circuits was the electrolytic rectifier - an early version was described by a French experimenter, A. Nodon, in 1904. These were briefly popular with early radio experimenters as they could be improvised from aluminum sheets, and household chemicals. They had low withstand voltages and limited efficiency.[1]

The first solid-state power semiconductor devices were copper oxide rectifiers, used in early battery chargers and power supplies for radio equipment, announced in 1927 by L.O. Grundahl and P. H. Geiger.[2]

The first germanium power semiconductor device appeared in 1952 with the introduction of the power diode by R.N. Hall. It had a reverse voltage blocking capability of 200 V and a current rating of 35 A.

Germanium bipolar transistors with substantial power handling capabilities (100 mA collector current) were introduced around 1952; with essentially the same construction as signal devices, but better heat sinking. Power handling capability evolved rapidly, and by 1954 germanium alloy junction transistors with 100 watt dissipation were available. These were all relatively low-frequency devices, used up to around 100 kHz, and up to 85 degrees Celsius junction temperature.[3] Silicon power transistors were not made until 1957, but when available had better frequency response than germanium devices, and could operate up to 150 C junction temperature

INTRODUCTION TO FAMILY OF THYRISTORS

The thyristor is a family of three-terminal devices that include SCRs, GTOs, and MCT. For most of the devices, a gate pulse turns the device on. The device turns off when the anode voltage falls below a value (relative to the cathode) determined by the device characteristics. When off, it is considered a reverse voltage blocking device

The thyristor appeared in 1957. It is able to withstand very high reverse breakdown voltage and is also capable of carrying high current. However, one disadvantage of the thyristor in switching circuits is that once it becomes 'latched-on' in the conducting state; it cannot be turned off by external control, as the thyristor turn-off is passive, i.e., the power must be disconnected from the device. Thyristors which could be turned off, called gate turn-off thyristors (GTO), were introduced in 1960.[4] These overcome some limitations of the ordinary thyristor, because they can be turned on or off with an applied signal. Due to improvements in the MOSFET technology (metal oxide semiconductor technology, initially developed to produce integrated circuits), the power MOSFET became available in the late 1970s. International Rectifier introduced a 25 A, 400 V power MOSFET in 1978.[5] This device allows operation at higher frequencies than a bipolar transistor, but is limited to low voltage applications.

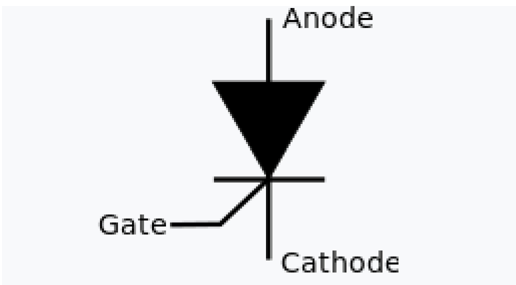
The Insulated-gate bipolar transistor (IGBT) was developed in the 1980s, and became widely available in the 1990s. This component has the power handling capability of the bipolar transistor and the advantages of the isolated gate drive of the power MOSFET.

SILCON CONTROLLED RECTIFIER (SCR)

A **silicon controlled rectifier** or **semiconductor controlled rectifier** is a four-layer solid-state current-controlling device. The principle of four-layer p–n–p–n switching was developed by Moll, Tanenbaum, Goldey and Holonyak of Bell Laboratories in 1956.[1] The practical demonstration of silicon controlled switching and detailed theoretical behavior of a device in agreement with the experimental results was presented by Dr Ian M. Mackintosh of Bell Laboratories in January 1958.[2][3] The name "silicon controlled rectifier" is General Electric's trade name for a type of thyristor. The SCR was developed by a team of power engineers led by Gordon Hall[4] and commercialized by Frank W. "Bill" Gutzwiller in 1957.

Some sources define silicon-controlled rectifiers and thyristors as synonymous,[5] other sources define silicon-controlled rectifiers as a proper subset of the set of thyristors, those being devices with at least four layers of alternating n- and p-type material.[6][7] According to Bill Gutzwiller, the terms "SCR" and "controlled rectifier" were earlier, and "thyristor" was applied later, as usage of the device spread internationally.[8]

SCRs are unidirectional devices (i.e. can conduct current only in one direction) as opposed to TRIACs, which are bidirectional (i.e. current can flow through them in either direction). SCRs can be triggered normally only by currents going into the gate as opposed to TRIACs, which can be triggered normally by either a positive or a negative current applied to its gate electrode.



Modes of operation OF SCR

There are three modes of operation for an SCR depending upon the biasing given to it:

Forward blocking mode (off state)

Forward conduction mode (on state)

Reverse blocking mode (off state)

Forward blocking mode[edit]

In this mode of operation, the anode (+) is given a positive voltage while the cathode (−) is given a negative voltage, keeping the gate at zero (0) potential i.e. disconnected. In this case junction **J1** and **J3** are forward-biased, while **J2** is reverse-biased, allowing only a small leakage current exists from the anode to the cathode. When the applied voltage reaches the breakover value for **J2**, **J2** undergoes avalanche breakdown. At this breakover voltage **J2** starts conducting, but below breakover voltage **J2** offers very high resistance to the current and the SCR is said to be in the off state.

Forward conduction mode[edit]

An SCR can be brought from blocking mode to conduction mode in two ways: Either by increasing the voltage between anode and cathode beyond the breakover voltage, or by applying a positive pulse at the gate. Once the SCR starts conducting, no more gate voltage is required to maintain it in the **ON** state.

There are two ways to turn it **off**:

Reduce the current through it below a minimum value called the holding current, or

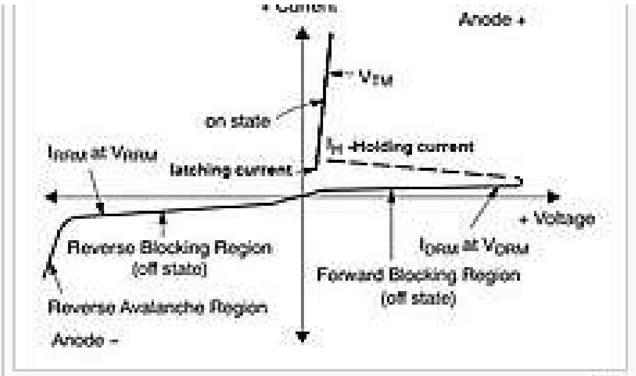
With the gate turned **off**, short-circuit the anode and cathode momentarily with a push-button switch or transistor across the junction.

Reverse blocking mode[edit]

When a negative voltage is applied to the anode and a positive voltage to the cathode, the SCR is in reverse blocking mode, making J1 and J3 reverse biased and J2 forward biased. The device behaves as two reverse-biased diodes connected in series. A small leakage current flows. This is the reverse blocking mode. If the reverse voltage is increased, then at critical breakdown level, called the reverse breakdown voltage (V_{BR}), an avalanche occurs at J1 and J3 and the reverse current increases rapidly. SCRs are available with reverse blocking capability, which adds to the forward voltage drop because of the need to have a long, low-doped P1 region. Usually, the reverse blocking voltage rating and forward blocking voltage rating are the same. The typical application for a reverse blocking SCR is in current-source inverters.

An SCR incapable of blocking reverse voltage is known as an **asymmetrical SCR**, abbreviated **ASCR**. It typically has a reverse breakdown rating in the tens of volts. ASCRs are used where either a reverse conducting diode is applied in parallel (for example, in voltage-source inverters) or where reverse voltage would never occur (for example, in switching power supplies or DC traction choppers).

Asymmetrical SCRs can be fabricated with a reverse conducting diode in the same package. These are known as RCTs, for reverse conducting thyristors.



Characteristic curve of a silicon-controlled rectifier

This semi-controlled device turns on when a gate pulse is present and the anode is positive compared to the cathode. When a gate pulse is present, the device operates like a standard diode. When the anode is negative compared to the cathode, the device turns off and blocks positive or negative voltages present. The gate voltage does not allow the device to turn off

Thyristor turn-on methods

forward-voltage triggering

gate triggering

dv/*dt* triggering

temperature triggering

light triggering

Forward-voltage triggering occurs when the anode–cathode forward voltage is increased with the gate circuit opened. This is known as avalanche breakdown, during which junction J2 will break down. At sufficient voltages, the thyristor changes to its on state with low voltage drop and large forward current. In this case, J1 and J3 are already forward-biased.

In order for gate triggering to occur, the thyristor should be in the forward blocking state where the applied voltage is less than the breakdown voltage, otherwise forward-voltage triggering may occur. A single small positive voltage pulse can then be applied between the gate and the cathode. This supplies a single gate current pulse that turns the thyristor onto its on state. In practice, this is the most common method used to trigger a thyristor

POWER MOSFET

Some common power devices are the power diode, thyristor, power MOSFET, and IGBT. The power diode and power MOSFET operate on similar principles to their low-power counterparts, but are able to carry a larger amount of current and are typically able to withstand a larger reverse-bias voltage in the *off-state*.

Structural changes are often made in a power device in order to accommodate the higher current density, higher power dissipation, and/or higher reverse breakdown voltage. The vast majority of the discrete (i.e., non-integrated) power devices are built using a vertical structure, whereas small-signal devices employ a lateral structure. With the vertical structure, the current rating of the device is proportional to its area, and the voltage blocking capability is achieved in the height of the die. With this structure, one of the connections of the device is located on the bottom of the semiconductor die

The main benefit of the power MOSFET compared to the BJT is that the MOSFET is a depletion channel device and so voltage, not current, is necessary to create a conduction path from drain to source. At low frequencies this greatly reduces gate current because it is only required to charge gate capacitance during switching, though as frequencies increase this advantage is reduced. Most losses in MOSFETs are due to on-resistance, can increase as more current flows through the device and are also greater in devices that must provide a high blocking voltage. BV_{dss}.

Switching times range from tens of nanoseconds to a few hundred microseconds. Nominal voltages for MOSFET switching devices range from a few volts to a little over 1000 V, with currents up to about 100 A or so, though MOSFETs can be paralleled to increase switching current. MOSFET devices are not bi-directional, nor are they reverse voltage blocking

TRIACs

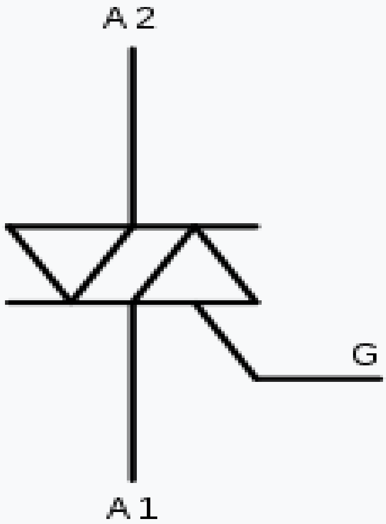
A TRIAC resembles an SCR in that both act as electrically controlled switches. Unlike an SCR, a TRIAC can pass current in either direction. Thus, TRIACs are particularly useful for AC applications. TRIACs have three leads: a gate lead and two conducting leads, referred to as MT1 and MT2. If no current/voltage is applied to the gate lead, the TRIAC switches off. On the other hand, if the trigger voltage is applied to the gate lead, the TRIAC switches on.

TRIACs are suitable for light-dimming circuits, phase-control circuits, AC power-switching circuits, AC motor control circuits, etc.

TRIAC

Type	Passive
Pin configuration	MT1(MAIN TERMINAL1), gate and MT 2(MAIN TERMINAL2

Electronic symbol



TRIAC, from **triode for alternating current**, is a generic trademark for a three terminal electronic component that conducts current in either direction when triggered. Its formal name is **bidirectional triode thyristor** or **bilateral triode thyristor**. A thyristor is analogous to a relay in that a small voltage induced current can control a much larger voltage and current. The illustration on the right shows the circuit symbol for a TRIAC where A1 is Anode 1, A2 is Anode 2, and G is Gate. Anode 1 and Anode 2 are normally termed Main Terminal 1 (MT1) and Main Terminal 2 (MT2) respectively.

TRIACs are a subset of thyristors and are related to silicon controlled rectifiers (SCRs). TRIACs differ from SCRs in that they allow current flow in both directions, whereas an SCR can only conduct current in a single direction. Most TRIACs can be triggered by applying either a positive or negative voltage to the gate (an SCR requires a positive voltage). Once triggered, SCRs and TRIACs continue to conduct, even if the gate current ceases, until the main current drops below a certain level called the holding current.

Gate turn-off thyristors (GTOs) are similar to TRIACs but provide more control by turning off when the gate signal ceases.

TRIACs' bidirectionality makes them convenient switches for alternating-current (AC). In addition, applying a trigger at a controlled phase angle of the AC in the main circuit allows control of the average current flowing into a load (phase control). This is commonly used for controlling the speed of a universal motor, dimming lamps, and controlling electric heaters

DIAC

The **DIAC** is a diode that conducts electrical current only after its breakover voltage, V_{BO}, has been reached momentarily. The term is an acronym of "diode for alternating current".

When breakdown occurs, the diode enters a region of negative dynamic resistance, leading to a decrease in the voltage drop across the diode and, usually, a sharp increase in current through the diode. The diode remains in conduction until the current through it drops below a value characteristic for the device, called the *holding current*, I_H. Below this value, the diode switches back to its high-resistance, non-conducting state. This behavior is bidirectional, meaning typically the same for both directions of current.

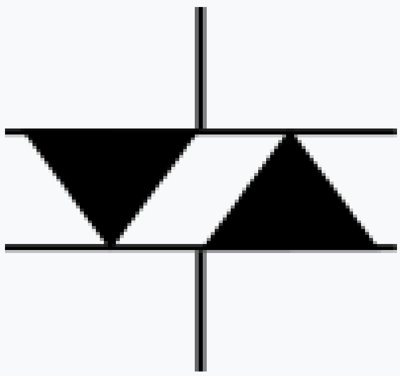
Most DIACs have a three-layer structure with breakover voltage of approximately 30 V. Their behavior is similar to that of a neon lamp, but it can be more precisely controlled and takes place at a lower voltage.

DIACs have no gate electrode, unlike some other thyristors that they are commonly used to trigger, such as TRIACs. Some TRIACs, like Quadrac, contain a built-in DIAC in series with the TRIAC's gate terminal for this purpose.

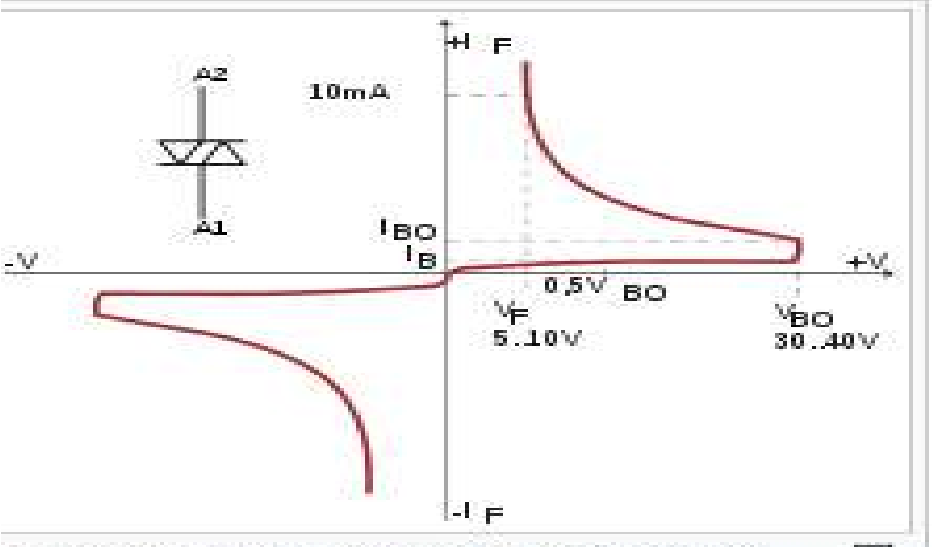
DIACs are also called "symmetrical trigger diodes" due to the symmetry of their characteristic curve. Because DIACs are bidirectional devices, their terminals are not labeled as anode and cathode but as A1 and A2 or main terminal MT1 and MT2.

Type	Passive
Pin configuration	anode, cathode

Electronic symbol



I V CHARISTICS OF TRIAC



Typical DIAC voltage and current relationships. V_{BO} is the breakover voltage.