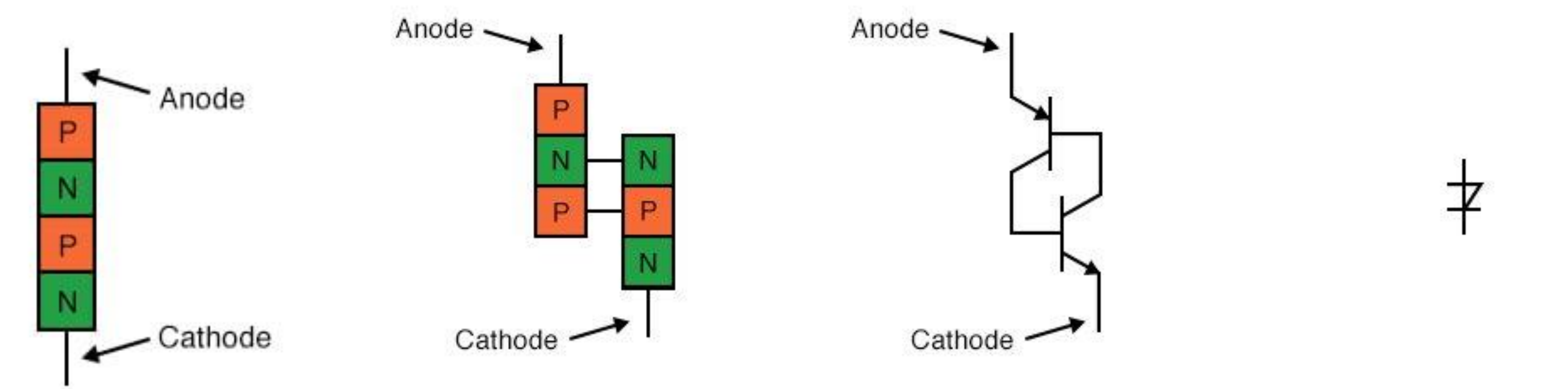
ELECTRONICS

22/6/2021

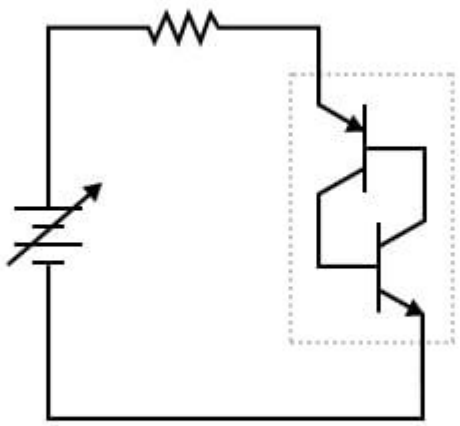
Shockley Diode

- A device called the four-layer diode, also known as a PNPN diode, or a Shockley diode after its inventor, William Shockley.
- Shockley diode - a four-layer sandwich of P-N-P-N semiconductor material.
- Transistor equivalent of Shockley diode.



Physical diagram Equivalent schematic Schematic symbol

- With no voltage applied, there will be no current.
- As the voltage is initially increased, there will still be no current because neither transistor is able to turn on: both will be in cut-off mode.
- How to turn a bipolar junction transistor on?

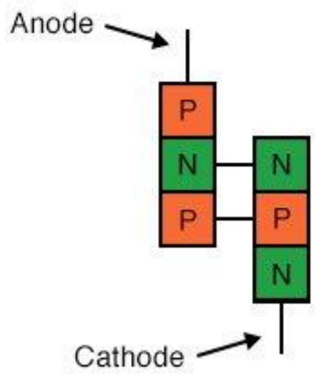


- From the diagram, base current through the lower transistor is controlled by the upper transistor, and the base current through the upper transistor is controlled by the lower transistor. Neither transistor can turn on until the other transistor turns on.

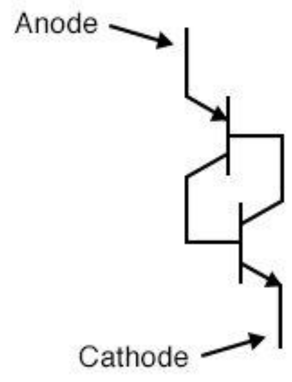
Turning the Shockley Diode On and Off

- Two real transistors connected to form a Shockley diode – each will conduct if sufficient voltage is applied by the battery between anode and cathode to cause one of them to break down.

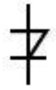
- Once one transistor breaks down and begins to conduct, it will allow the base current through the other transistor, causing it to turn on with both transistors will be saturated, keeping each other turned on instead of off.



Physical diagram



Equivalent schematic



Schematic symbol

Turning the Shockley Diode On and Off

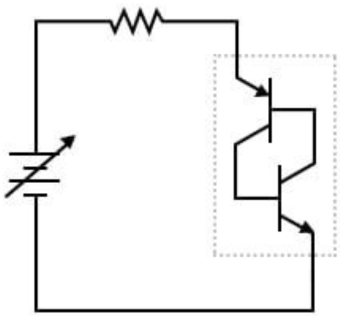
- To Turn On - Apply sufficient voltage between anode and cathode.
- Latching both transistors on where each will tend to remain.
- The Shockley diode will continue to conduct and will remain conducting because both transistors now have base current to maintain regular, controlled conduction.
- By reducing the applied voltage to a much lower point where too little current flows to maintain transistor bias, at which point one of the transistors will cut-off, sealing both transistors in the “off” state as each one was before any voltage was applied at all.

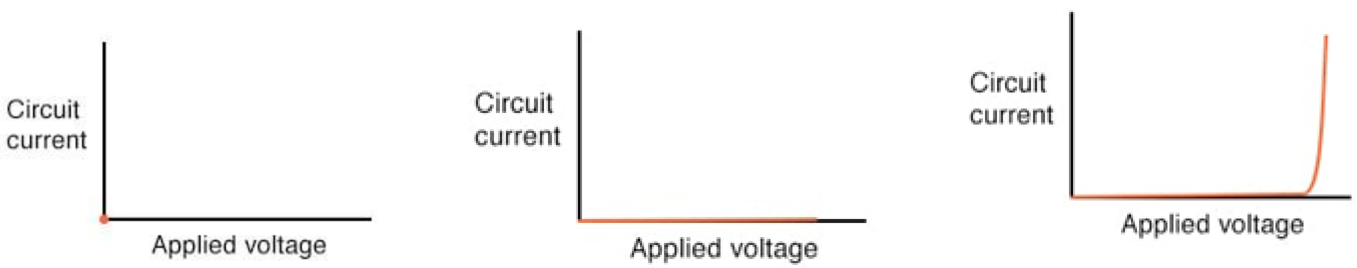
Voltage vs Current Plot in a Shockley Diode's Circuit

a) Observe the circuit as the DC voltage source (battery) is set to zero voltage.

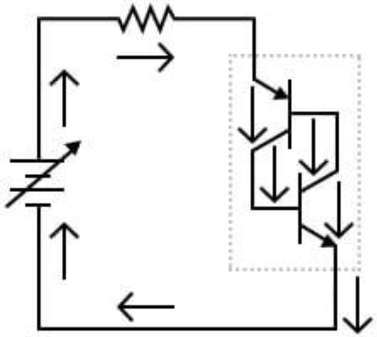
b) Next, steadily increase the DC voltage. Current through the circuit is at or nearly at zero, as the breakdown limit has not been reached for either transistor.
(Some applied voltage; still no current)

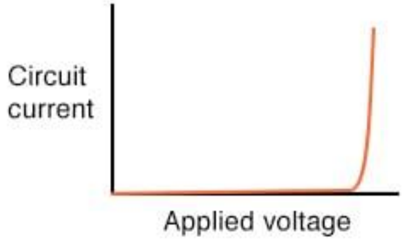
c) When the voltage breakdown limit of one transistor is reached, collector current conducted even though no base current has gone through it yet. A Shockley diode is similar to a Zener diode built to handle reverse breakdown without sustaining damage.





(a) (b) (c)

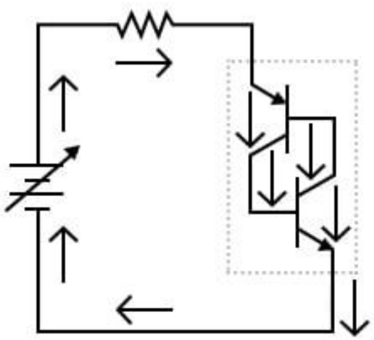


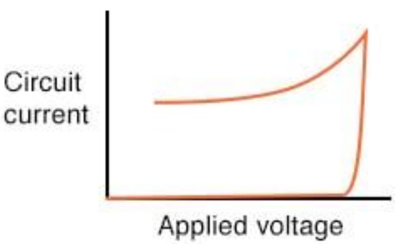


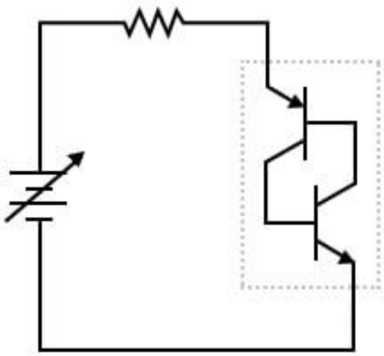
The upper transistor receives base current and turns **ON** and allow the lower transistor to conduct normally, the two transistors "sealing" themselves in the "on" state **(Transistors are now fully conducting).**

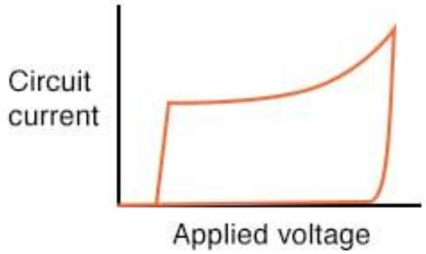
Continuation of a substantial output current known as the output current "feeds back" positively to the input (transistor base current) to keep both transistors in the "on" state, thus reinforcing (or regenerating) itself.

The effect of positive feedback is to keep both transistors in a state of saturation despite the loss of input stimulus **(the original, high voltage needed to break down one transistor and cause a base current through the other transistor)**





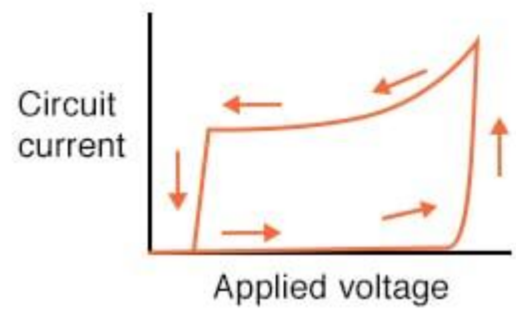




As one transistor passes less and less collector current, it reduces the base current for the other transistor, thus reducing base current for the first transistor. **The vicious cycle continues rapidly until both transistors fall into cut-off.**

Based on positive feedback - positive relationship between output (controlled current) and input (controlling current through the transistors' bases).

Resulting curve known as **hysteretic:** as the input signal (voltage) is increased and decreased, the output (current) does not follow the same path.



Recap – Shockley Diode

- A four-layer PNPN semiconductor devices - a pair of interconnected PNP and NPN transistors.
- Shockley diodes tend to stay on once turned on (latched), and stay off once turned off.
- Latch a Shockley diode - exceed the anode-to-cathode breakover voltage, or exceed the anode-to-cathode critical rate of voltage rise.
- Shockley diode stop conducting - reduce the current going through it to a level below its low-current dropout threshold.

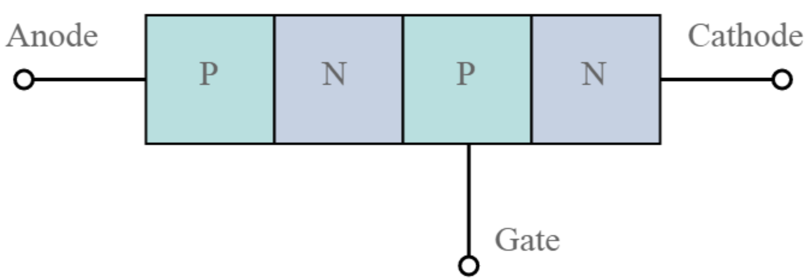
What is a Thyristor, SCR?

- Thyristors of silicon Controlled rectifiers, SCRs are semiconductor devices that can act as electronic switches sometimes controlling circuits with high voltage and current levels.

- Thyristors or SCRs are used for many power control applications, often where current and voltage levels are relatively high. Thyristors may also be used in lower power applications including light control, as well as for power supply protection and many other applications. Thyristors are simple to use and cheap to buy, making them an ideal option for many circuits.

What is a thyristor?

- The thyristor may be considered an unusual form of electronics component because it consists **of four layers of differently doped silicon** rather than the three layers of the conventional bipolar transistors.
- Whereas conventional bipolar transistors may have a p-n-p or n-p-n structure with the electrodes named collector, base and emitter, the **thyristor** has a **p-n-p-n structure** with the **outer layers electrodes referred to as the anode (n-type) and the cathode (p-type)**. The control terminal of the SCR is named the gate and it is connected to the p-type layer that adjoins the cathode layer.



Thyristor applications

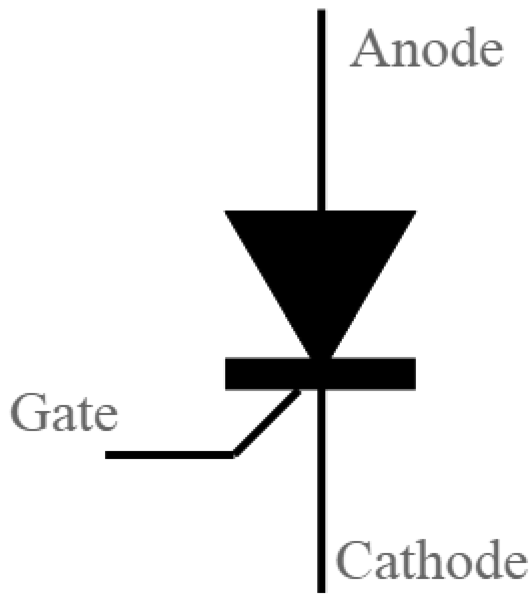
Thyristors, or SCRs are used in many areas of electronics and some of the more common applications for them are outlined below:

- AC power control (including lights, motors,etc).
- AC power electronic switching.
- Overvoltage protection crowbar for power supplies.
- Control elements in phase angle triggered controllers.
- Within photographic flash lights where they act as the electronic switch to discharge a stored voltage through the flash lamp, and then cut it off at the required time.
- Thyristors are able to switch high voltages and withstand reverse voltages making them ideal for electronic switching applications, especially within AC scenarios.

Thyristor symbols & basics

- The thyristor or, SCR is a semiconductor device that has a number of unusual characteristics.
- It has three terminals: Anode, cathode and gate, reflecting thermionic valve / vacuum tube technology. The gate is the control terminal while the main current flows between the anode and cathode.
- The device is a "one way device“ known as the silicon controlled rectifier. Therefore when the device is used with AC, it will only conduct for a maximum of half the cycle.
- In operation, the thyristor or SCR will not conduct initially - requires a certain level of current to flow in the gate to "fire" it. Once fired, the thyristor will remain in conduction until the voltage across the anode and cathode is removed. The next half cycle will be blocked as a result of the rectifier action.

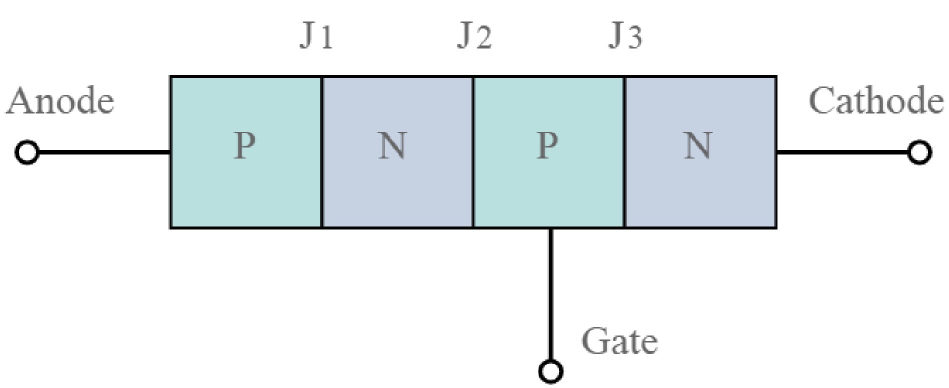
- The SCR or thyristor symbol seeks to emphasis its rectifier characteristics while also showing the control gate.



SCR Thyristor Structure & Fabrication

- The thyristor or SCR has a structure that consists of four layers: it contains a PNPN sandwich.

- The thyristor consists of a four layer PNPN structure with the outer layers are referred to as the anode (P-type) and cathode (N-type). The control terminal of the thyristor is named the gate and it is connected to the P-type layer located next to the cathode.

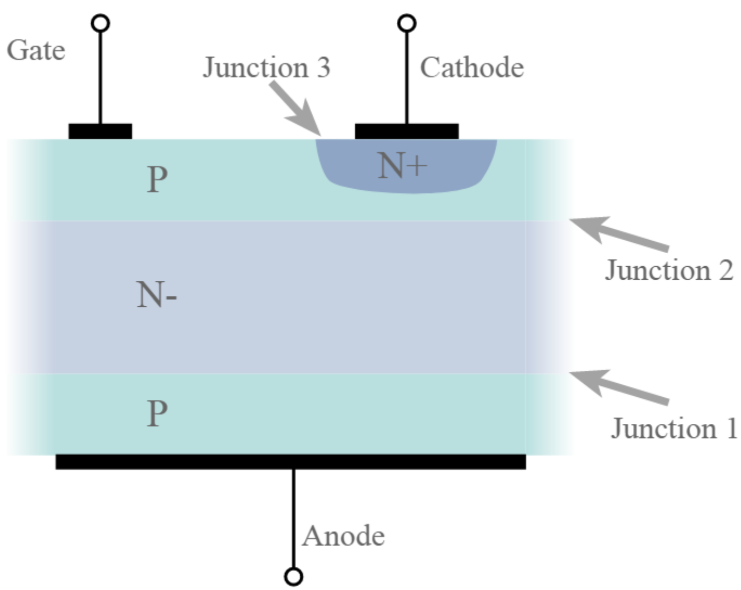


The thyristor has **three junctions** rather than the one junction of a diode, and two within transistors.
The three junctions are normally denoted as J_1, J_2, and J_3, serially with J_1 being nearest to the anode.

Thyristor semiconductor structure and fabrication

- The level of doping varies between the different layers of the thyristor. The cathode is the most heavily doped. The gate and anode are the next heavily doped. The lowest doping level is within the central N type layer. This is also thicker than the other layers and these two factors enable a large blocking voltage to be supported. Thinner layers would mean that the device would break down at lower voltages.

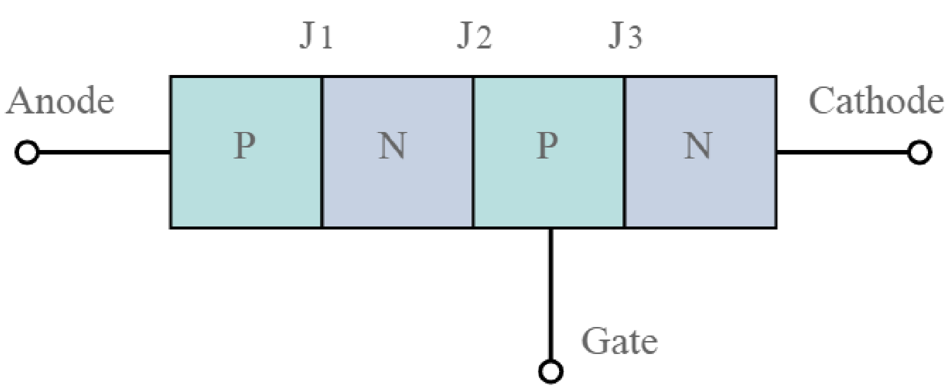
- Thyristors are used to switch, thermal considerations are of paramount importance. The anode of the SCR or silicon controlled rectifier is usually bonded to the package since the gate terminal is near the cathode and needs to be connected separately.

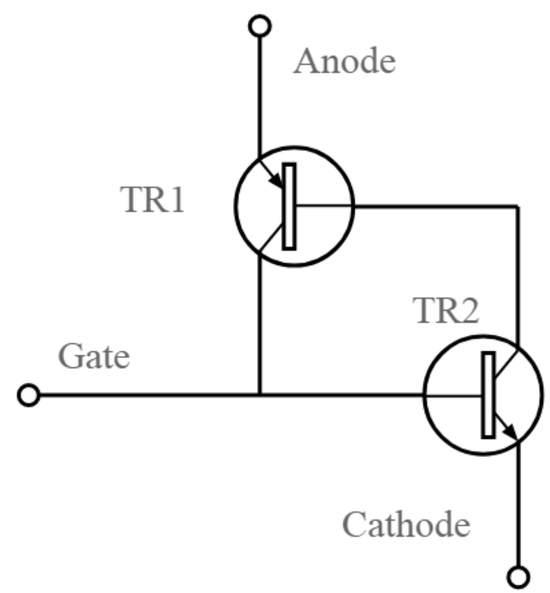


How does a thyristor work?

- A thyristor / SCR can be considered as two back to back transistors to explain its operation and how it works. When designing and using thyristor or SCR circuits it helps to understand how the thyristor works.

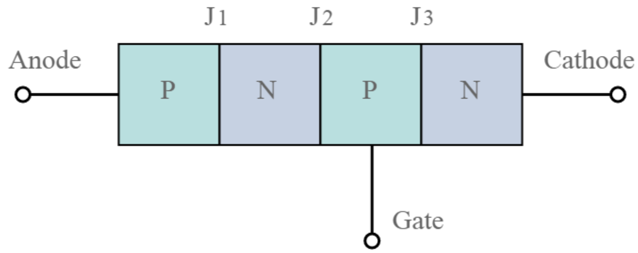
- Essentially the operation of the thyristor / SCR can be explained in terms of a latching switch. Once tuned on by a current at the gate, it requires the voltage across the cathode and anode to be removed before it stops conducting.





Thyristor operation: the basics

- In operation, the thyristor / SCR has three states:
- **Reverse blocking**: In this mode or state the thyristor blocks the current in the same way as that of a reverse biased diode. The thyristor / SCR can only conduct in one direction and blocks in the reverse direction.
- **Forward blocking:** In this mode or state the thyristor operation is such that it blocks forward current conduction that would normally be carried by a forward biased diode. In this state the thyristor / SCR is not in its “turn-on” state as the gate has not fired.
- **Forward conducting:** In this mode the thyristor / SCR has been triggered into conduction by a current on the gate. It will remain conducting regardless of the state of the gate. Current only needs to be applied to the gate to fire the thyristor / SCR, and it will remain conducting. The device will stop conducting when the forward current drops below a threshold value known as the "holding current.“
- The thyristor consists of four semiconductor regions: P N P N. The outer P region forms the anode, and the outer n region forms the cathode as shown below.

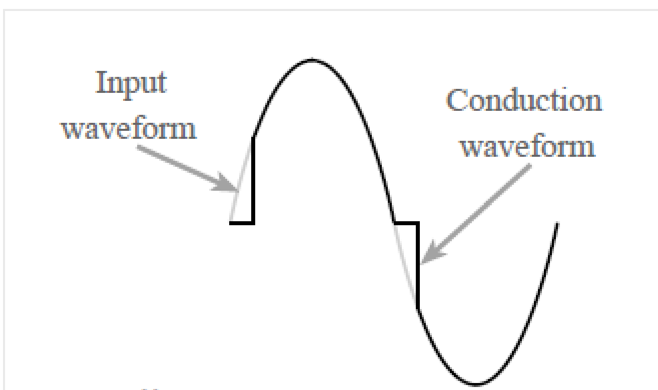


What is a Triac?

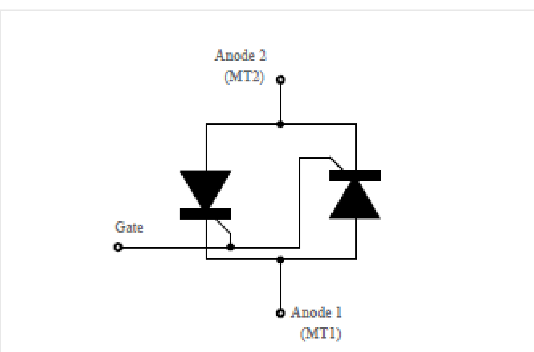
- Triacs are electronic components that are widely used in AC power control applications. They are able to switch high voltages and high levels of current, and over both parts of an AC waveform. This makes triac circuits ideal for use in a variety of applications where power switching is needed.
- One particular use - light dimmers for domestic lighting, and many other power control situations including motor control and electronic switches.
- Triacs tend to be used for low to medium power electronic switching applications, leaving thyristors to be used for the very heat duty AC power switching applications.

Triac basics

- The triac is a development of the thyristor. While the thyristor can only control current over one half of the cycle, the triac controls it over two halves of an AC waveform.
- The triac - a pair of parallel but opposite thyristors with the two gates connected together and the anode of one device connected to the cathode of the other.
- Triac switching action occurs on both halves of an AC waveform - complete cycle can be used.
- For basic thyristor circuits - only half the waveform is used. **Triac** only requires one device to control both halves of the AC waveform and in many respects it is an ideal solution for an electronic switch for AC.



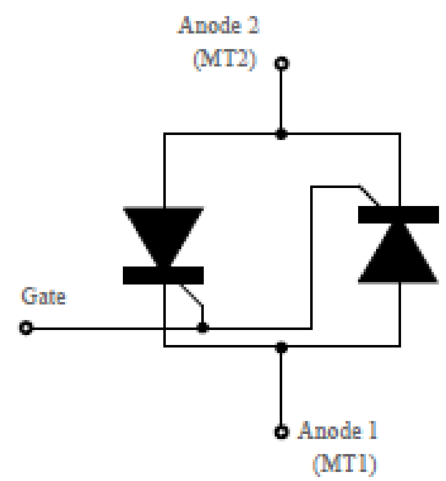
Triac switching waveform



Triac equivalent circuit

Triac symbol

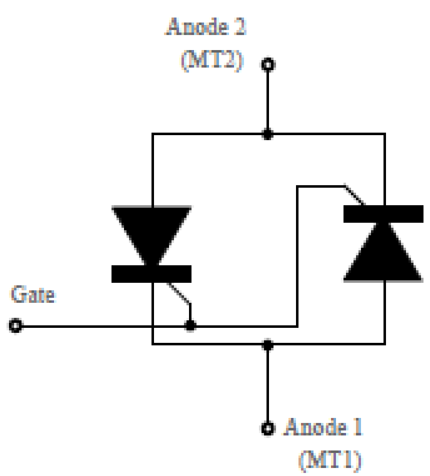
- Triac - indicates its bi-directional properties. Can be seen to be a couple of thyristor symbols in opposite senses merged together.
- Like a thyristor, a triac has three terminals.
- There is a gate which acts as a trigger to turn the device on, the other terminals are both called Anodes, or Main Terminals These are usually designated Anode 1 and Anode 2 or Main Terminal 1 and Main Terminal 2 (MT1 and MT2). When using triacs it is both MT1 and MT2 have very similar properties.



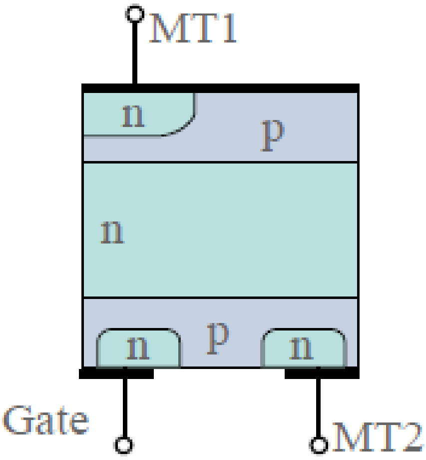
Triac equivalent circuit

How does a triac work?

- Triac structure - several areas of N-type and P-type material that form what is effectively a pair of back to back thyristors.
- Can conduct current irrespective of the voltage polarity of terminals MT1 and MT2 and triggered by either positive or negative gate currents, irrespective of the polarity of the MT2 current.



Triac equivalent circuit



Triac basic structure

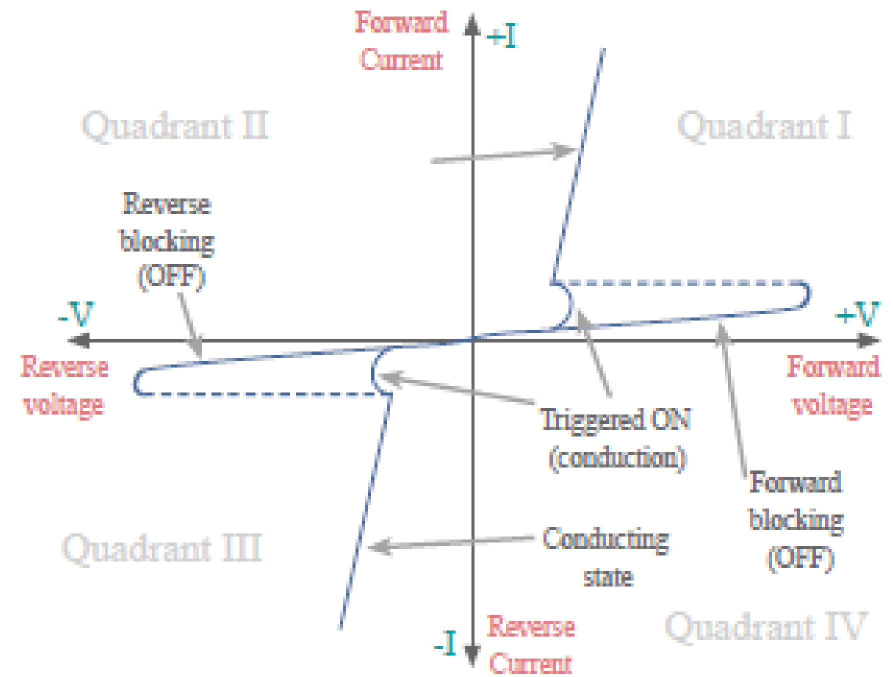
This means that there are four triggering modes or quadrants:

I+ Mode MT2 current is +ve, gate current is +ve;

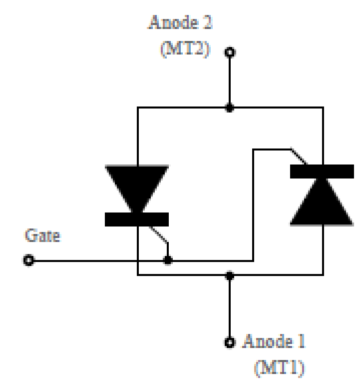
I- Mode MT2 current is +ve, gate current is –ve;

III+ Mode: MT2 current is -ve, gate current is +ve;

III- Mode: MT2 current is -ve, gate current is –ve;



Triac IV characteristic



Triac equivalent circuit

Typical IV characteristic of a triac with the four different quadrants

Triac applications

- Lighting control - especially domestic dimmmers.
- Control of fans and small motors.
- Electronic switches for general AC switching and control
- There are naturally many other triac applications, but these are some of the most common.
- Modules called solid state relays.
- LED light or infrared source and the optical triac are contained within the same package, sufficient isolation being provided to withstand high voltages which may extend to hundreds of volts or possibly even more.
- Solid state relays come in many forms, but those used for AC switching may use a triac.

Using triacs

Understand a few on tips on using triacs.

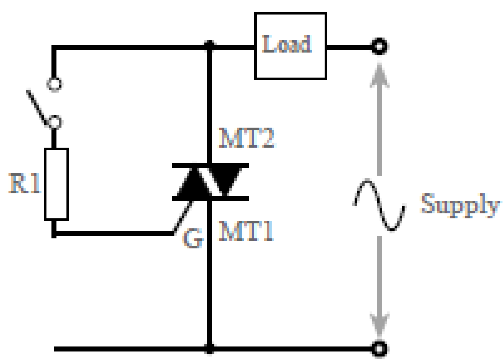
- Due to slight differences between the two halves, these electronic components do not fire symmetrically. This results in harmonics being generated: the less symmetrical the triac fires, the greater the level of harmonics that are produced.

- To overcome the triac non-symmetrical firing, another semiconductor device known as a diac (diode AC switch) is often placed in series with the gate of the triac.

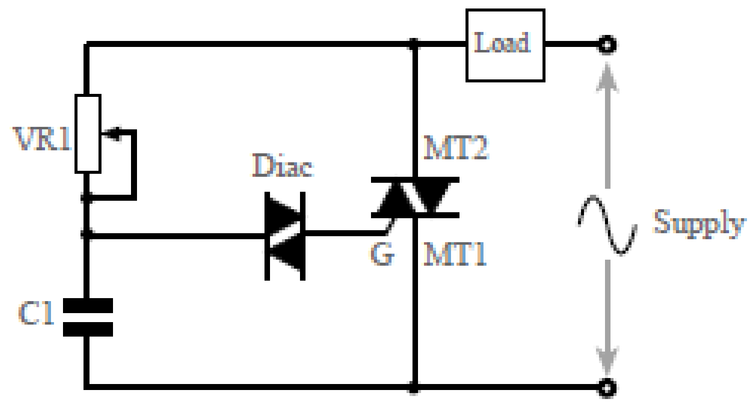
Triac circuit examples

- **Simple triac electronic switch circuit.**

- **Triac variable power or dimmer circuit:** One of the most popular triac circuits varies the phase on the input of the triac to control the power that can be dissipated into load.



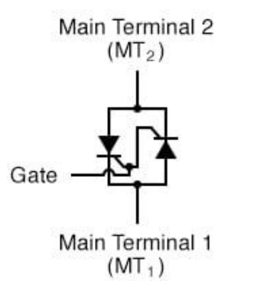
Simple triac switch circuit



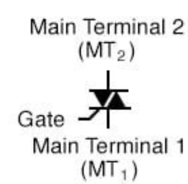
A basic triac circuit using phase of input waveform to control dissipated power in the load

RECAP

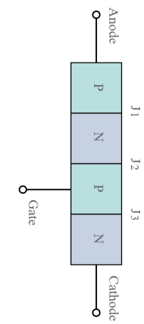
- A TRIAC acts much like two thyristors or SCRs connected back-to-back for bidirectional (AC) operation.
- When used to control AC power to a load, **TRIACs are often accompanied by DIACs connected in series** with their gate terminals. The DIAC helps the TRIAC fire more symmetrically (more consistently from one polarity to another).
- Main terminals 1 and 2 on a TRIAC are not interchangeable.
- To successfully trigger a TRIAC, gate current must come from the main terminal 2 (MT2) side of the circuit!

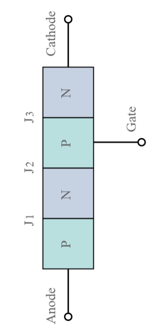


TRIAC equivalent circuit



TRIAC schematic symbol

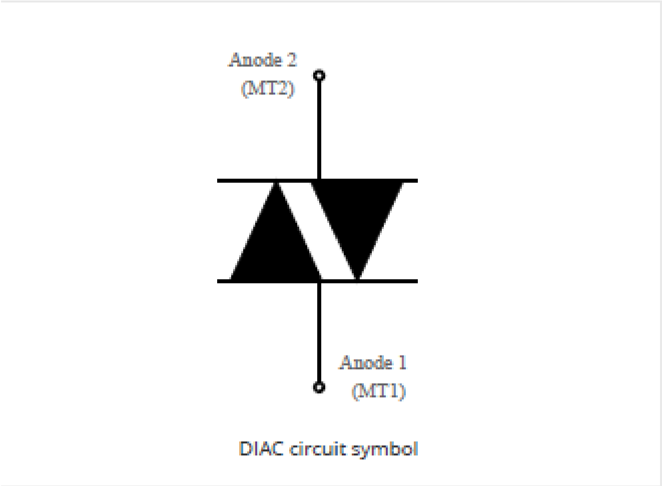




What is a DIAC?

- A DIAC - bi-directional semiconductor switch that can be turned on in both forward and reverse polarities above a certain voltage. It is often used to provide defined switching for a triac.
- A DIAC is a full-wave or bi-directional semiconductor switch that can be turned on in both forward and reverse polarities.
- The **name DIAC comes** from the words **DIode AC switch**.

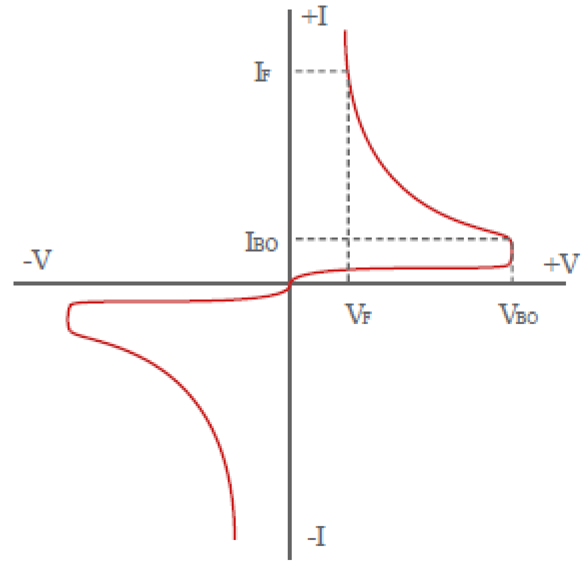
The DIAC symbol used to depict this electronic component in circuit diagrams can be remembered as a combination of what may appear to be two diodes in parallel with each other but connected in opposite directions.



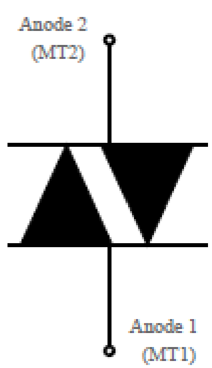
DIAC circuit symbol

DIAC operation

- DIAC conducts current only after a certain breakdown voltage has been exceeded.
- When the DIAC breakdown voltage occurs, the resistance of the component decreases abruptly and this leads to a sharp decrease in the voltage drop across the DIAC, and a corresponding increase in current. The DIAC will remain in its conducing state until the current flow through it drops below a particular value known as the holding current.
- Most DIACs have a breakdown voltage of around 30V, although the exact specifications will depend upon the particular type of device.



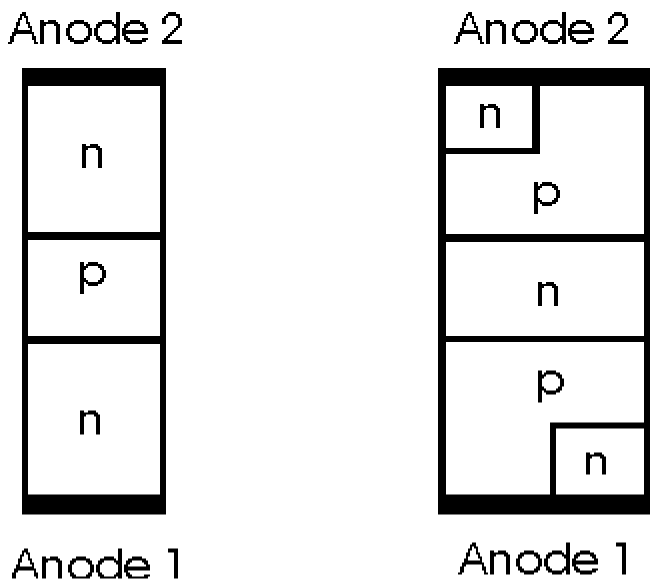
DIAC voltage- current characteristic



DIAC circuit symbol

Diac structure

- DIAC - fabricated as either a three layer or a five layer structure. In the three layer structure the switching occurs when the junction that is reverse biased experiences reverse breakdown. The three layer version of the device is the more common and can have a break-over voltage of around 30 V. Operation is almost symmetrical owing to the symmetry of the device.
- A five layer DIAC structure is also available. This does not act in quite the same manner, although it produces an I-V curve that is very similar to the three layer version. It can be considered as two break-over diodes connected back to back.
- For most applications a three layer version of the DIAC is used. It provides sufficient improvement in switching characteristics. For some applications the five layer device may be used.

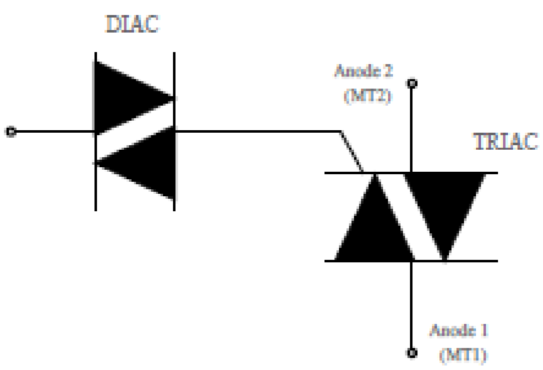


3 layer structure 5 layer structure

The structure of a DIAC

DIAC applications

- One of the major uses of DIACs within TRIAC circuits. TRIACs do not fire symmetrically as a result of slight differences between the two halves of the device.
- The non-symmetrical firing and resulting waveforms give rise to the generation of unwanted harmonics – the less symmetrical the waveform the greater the level of harmonic generation.
- To resolve the issues resulting from the non-symmetrical operation, a DIAC is often placed in series with the gate. This device helps make the switching more even for both halves of the cycle. This results from the fact that the DIAC switching characteristic is far more even than that of the TRIAC.



DIAC TRIAC combination

Other types of thyristor or SCR- Assignment

There is a number of different types thyristor - these are variants of the basic component, but they offer different capabilities that can be used in various instances and may be useful for certain circuits.

- Reverse conducting thyristor, RCT.
- Gate Assisted Turn-Off Thyristor, GATT
- Gate Turn-Off Thyristor, GTO.
- Asymmetric Thyristor.


Thank
You!