Power Electronics

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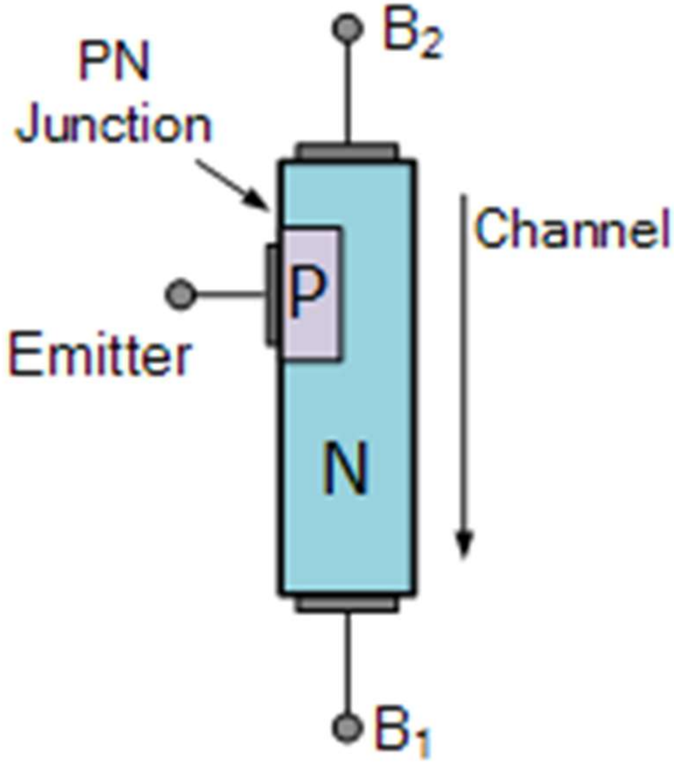
Unijunction Transistor (UJT)

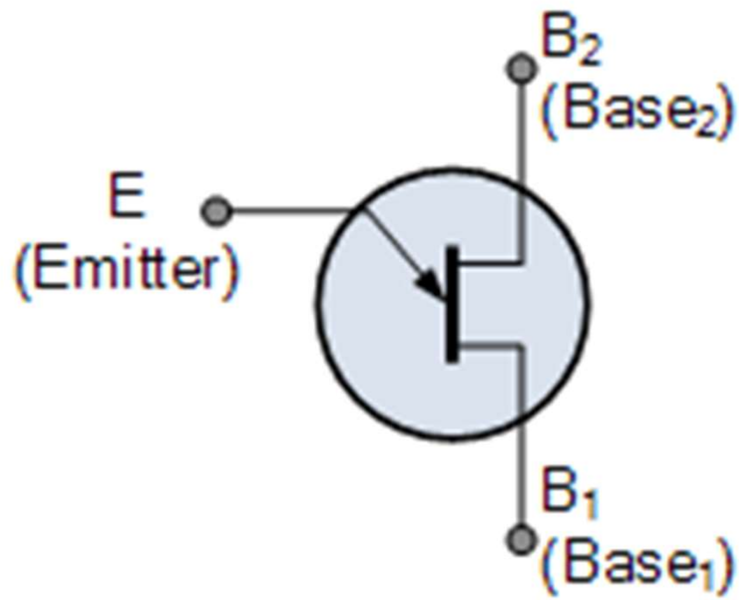
- A unijunction transistor (UJT) is a three terminal semiconductor switching device.
- This device has a unique characteristics that when it is triggered, the emitter current increases re-generatively until it is limited by emitter power supply.
- Due to this characteristics, the unijunction transistor can be employed in a variety of applications e.g., switching, pulse generator, saw-tooth generator etc.

Construction of UJT

- It consists of an n-type silicon bar with an electrical connection on each end.
- The leads to those connections are called base leads, i.e., base-one B_1 and base-two B_2.
- Part way along the bar between the two bases, nearer to B_2 than B_1, a pn junction is formed between a p-type emitter and the bar.
- The lead to this junction is called the emitter lead E.
- Next figure shows the symbol of unijunction transistor. Note that emitter is shown closer to B_2 than B_1.

Construction of UJT



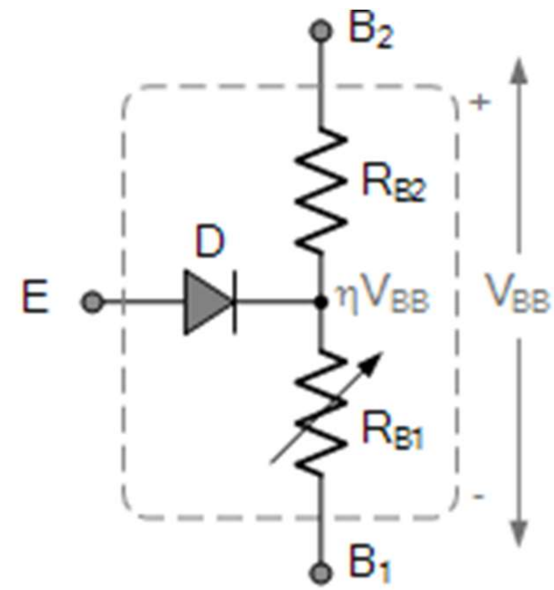


Unijunction Transistor (UJT)

- The following points may be noted about the UJT:
  - Since the device has one pn junction and three leads, it is commonly called a unijunction transistor.
  - With only one pn junction, the device is really a form of **diode**. Because the two base terminals are taken from one section of the diode, this device is also called **double-based diode**.
  - The emitter is heavily doped having many holes. The n-region, however, is lightly doped. For this reason, the resistance between the base terminals is very high when emitter lead is open.

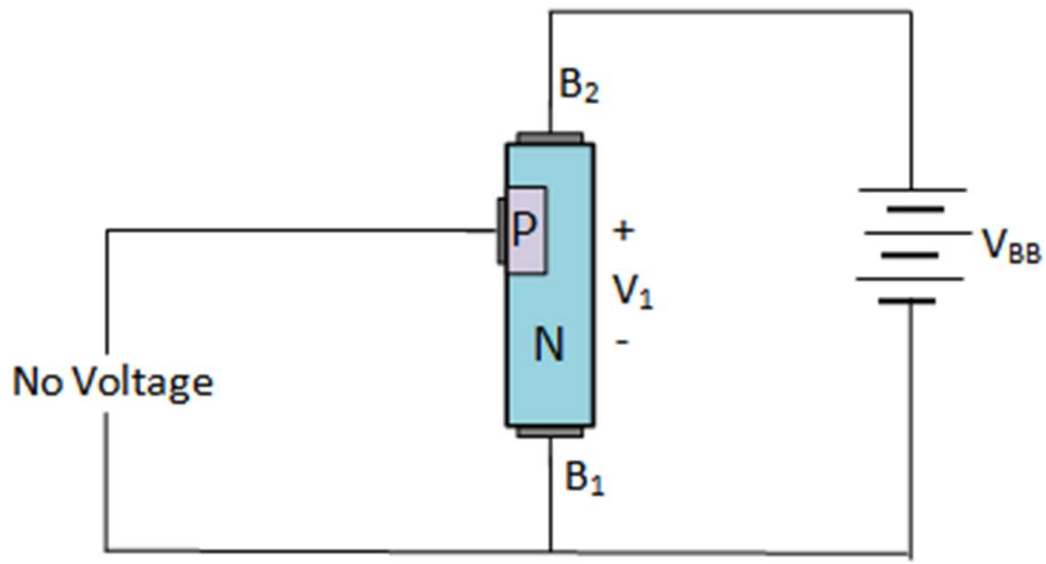
Equivalent Circuit of a UJT

- The resistance of the silicon bar is called the **inter-base resistance R_{BB}**. It is represented by two resistors in series such as:
  - R_{B2} is the resistance of silicon bar between B_2 and the point at which the emitter junction lies.
  - R_{B1} is the resistance of the bar between B_1 and emitter junction. This resistance is shown variable because its value depends upon the bias voltage across the pn junction.
- The pn junction is represented in the emitter by a diode D.



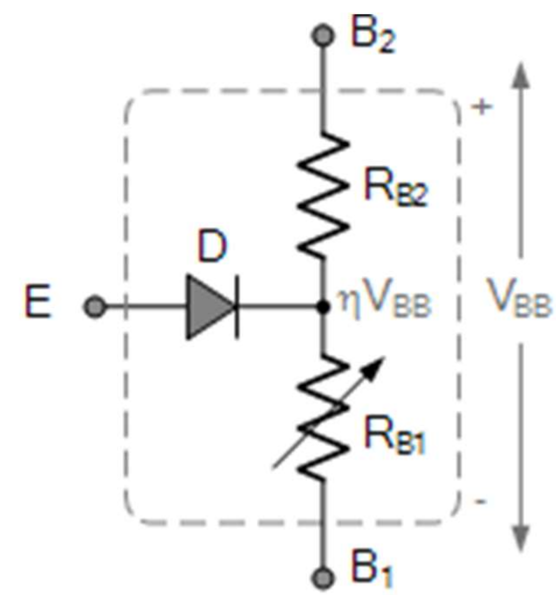
Operation of UJT

- The device has normally B_2 positive with respect to B_1.
- If voltage V_{BB} is applied between B_2 and B_1 with emitter open, a voltage gradient is established along the n-type bar.



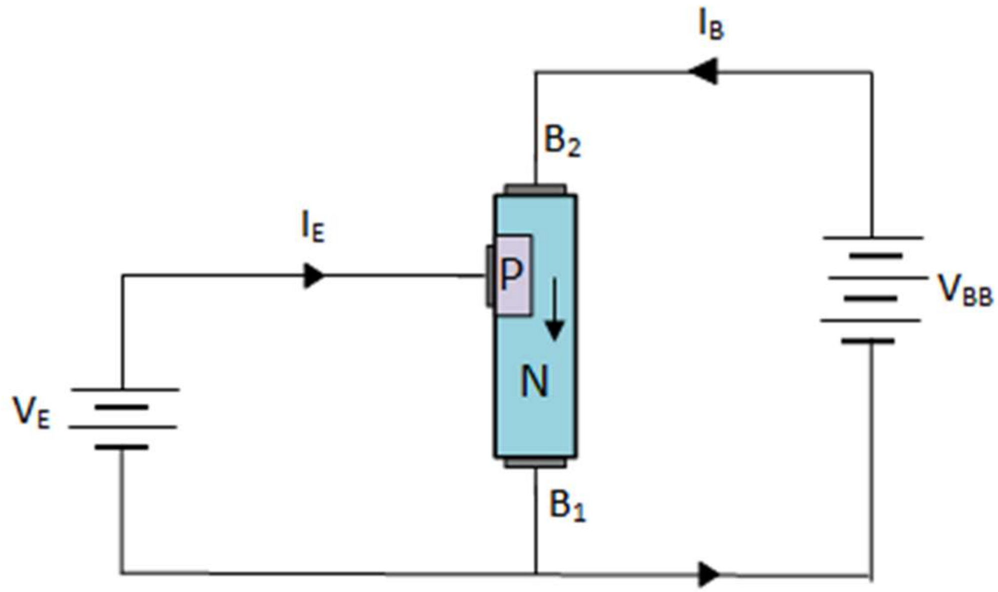
Operation of UJT

- Since the emitter is located nearer to B_2, more than half of V_{BB} appears between the emitter and B_1.
- The voltage V_1 between emitter and B_1 establishes a reverse bias on the pn junction and the emitter current is cut off.
- Of course, a small leakage current flows from B_2 to emitter due to minority carriers.



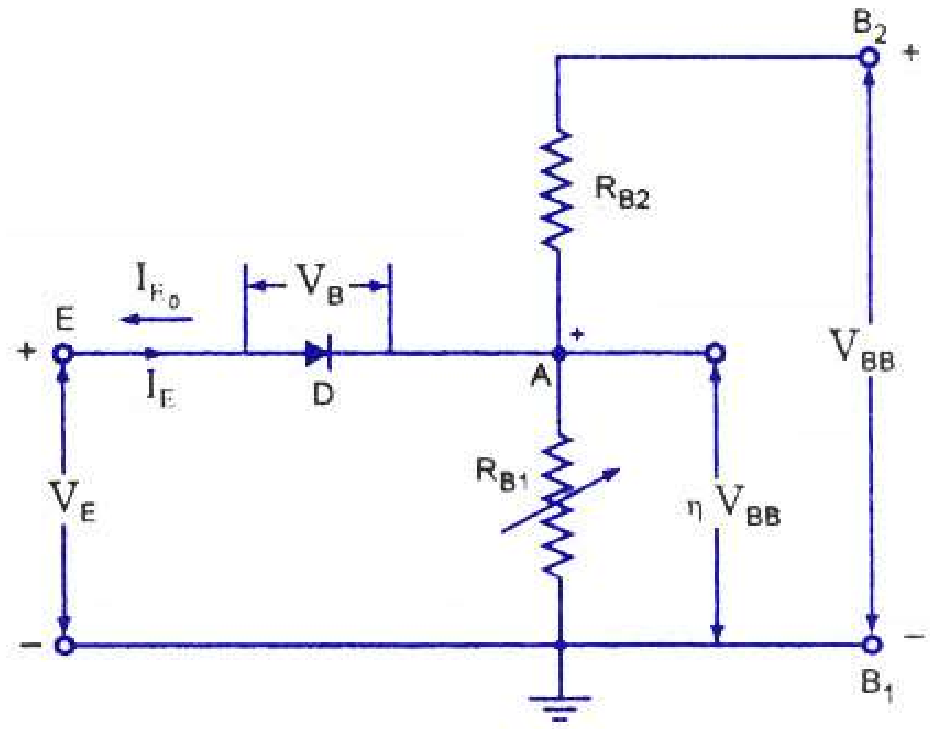
Operation of UJT

- If a positive voltage is applied at the emitter, the pn junction will remain reverse biased so long as the input voltage is less than V_1.
- If the input voltage to the emitter exceeds V_1, the pn junction becomes forward biased.
- Under these conditions, holes are injected from p-type material into the n-type bar.



Operation of UJT

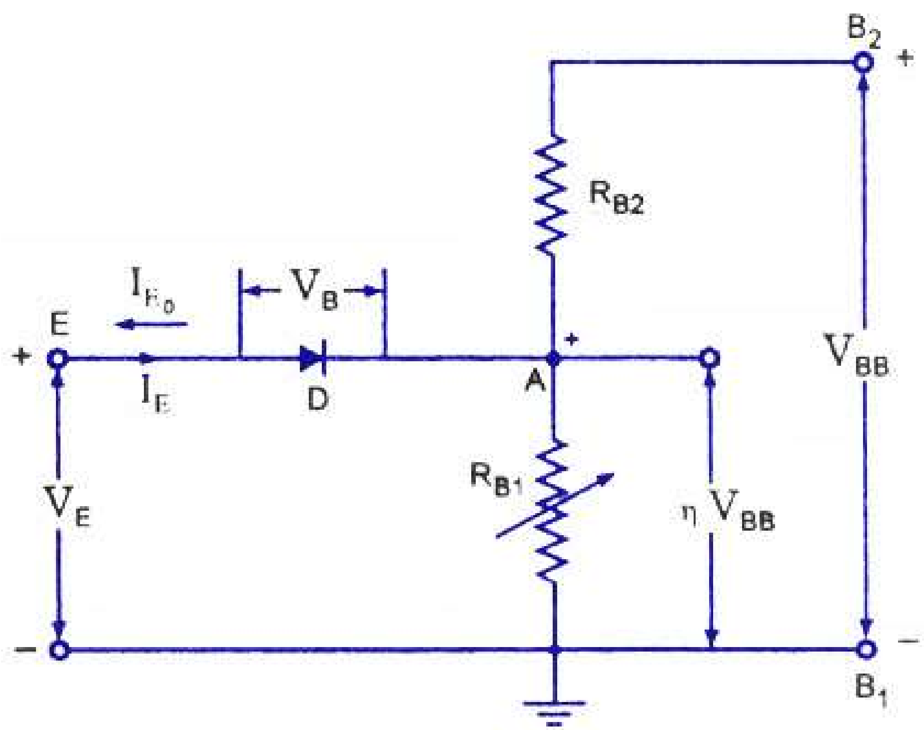
- These holes are repelled by positive B_2 terminal and they are attracted towards B_1 terminal of the bar.
- This accumulation of the holes in the emitter to B_1 region results in the decrease of resistance in this section of the bar.
- The result is that internal voltage drop from emitter to B_1 is decreased and hence the emitter current I_E increases.



Equivalent Circuit of a UJT

Operation of UJT

- As more holes are injected, a condition of saturation will eventually be reached.
- At this point, the emitter current is limited by emitter power supply only. The device is now in the **ON sate**.
- If a negative pulse is applied to the emitter, the pn junction is reverse biased and the emitter current is cut off. The device is then said to be in the **OFF state**.



Equivalent Circuit of a UJT

Explanation - Equivalent Circuit

- The circuit action of a UJT can be explained more clearly from its equivalent circuit.
- With no voltage applied to the UJT, the inter-base resistance is given by ;

$$R_{BB} = R_{B1} + R_{B2}$$

- If a voltage V_{BB} is applied between the bases with emitter open, the voltage will divide up across R_{B1} and R_{B2}.
- Voltage across R_{B1},

$$V_1 = \frac{R_{B1}}{R_{B1} + R_{B2}} V_{BB}$$

- or

$$\eta = \frac{V_1}{V_{BB}} = \frac{R_{B1}}{R_{B1} + R_{B2}}$$

Explanation - Equivalent Circuit

- The ratio V_1/V_{BB} is called **intrinsic stand-off ratio** and is represented by η. The value of η lies between 0.51 and 0.82.
- So voltage across R_{B1}, $V_1 = \eta V_{BB}$
- The voltage ηV_{BB} appearing across R_{B1} reverse biases the diode. Therefore, the emitter current is zero.

Explanation - Equivalent Circuit

- If now a progressively rising voltage is applied to the emitter, the diode will become forward biased when input voltage exceeds ηV_{BB} by V_D, the forward voltage drop across the silicon diode, i.e.

$$V_p = \eta V_{BB} + V_D$$

where V_P = Peak point voltage

V_D = forward voltage drop across silicon diode (≈0.7 V)

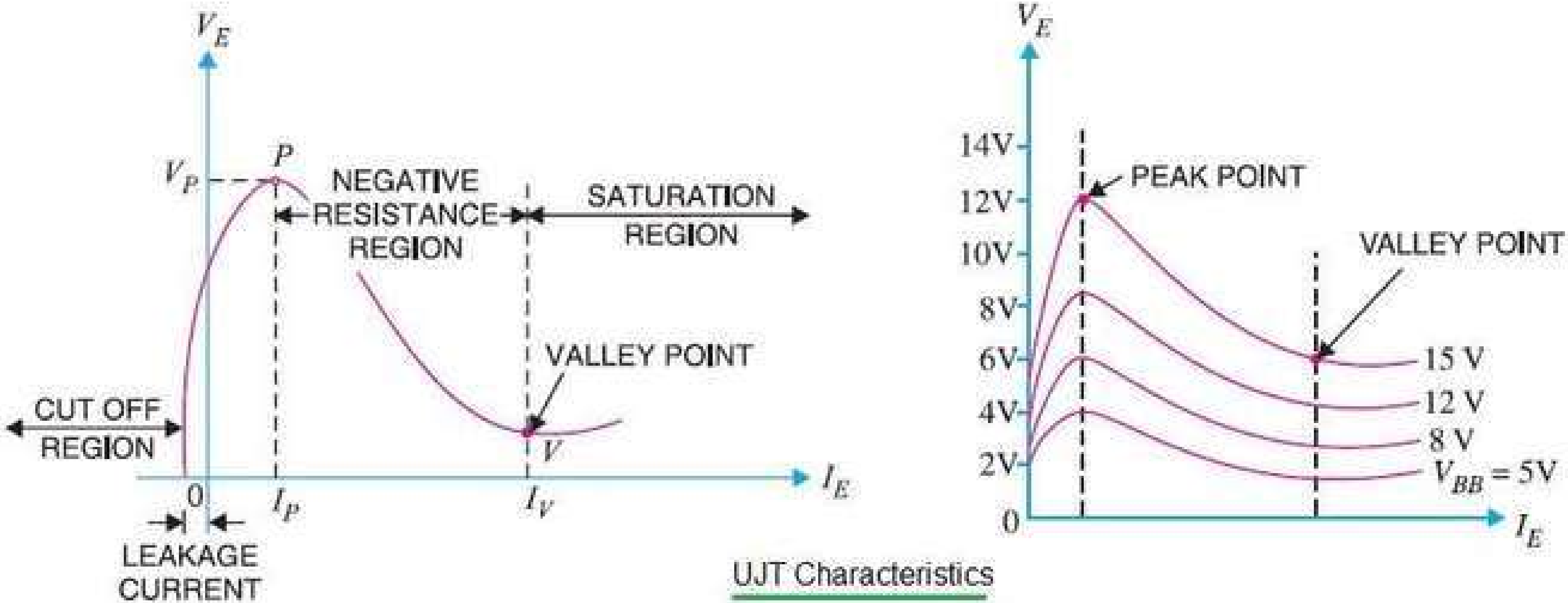
Explanation - Equivalent Circuit

- When the diode D starts conducting, holes are injected from p-type material to the n-type bar. These holes are swept down towards the terminal B_1.
- This decreases the resistance between emitter and B_1 (indicated by variable resistance R_{B1}) and hence the internal resistance drop from emitter to B_1.
- The emitter current now increases regeneratively until it is limited by the emitter power supply.

Conclusion

- When the input positive voltage to the emitter is less than peak-point voltage V_P, the pn junction remains reverse biased and the emitter current is practically zero.
- However, when the input voltage exceeds V_P, R_{B1} falls from several thousand ohms to a small value. The diode is now forward biased and the emitter current quickly reaches to a saturation value limited by R_{B1} and forward resistance of pn-junction.

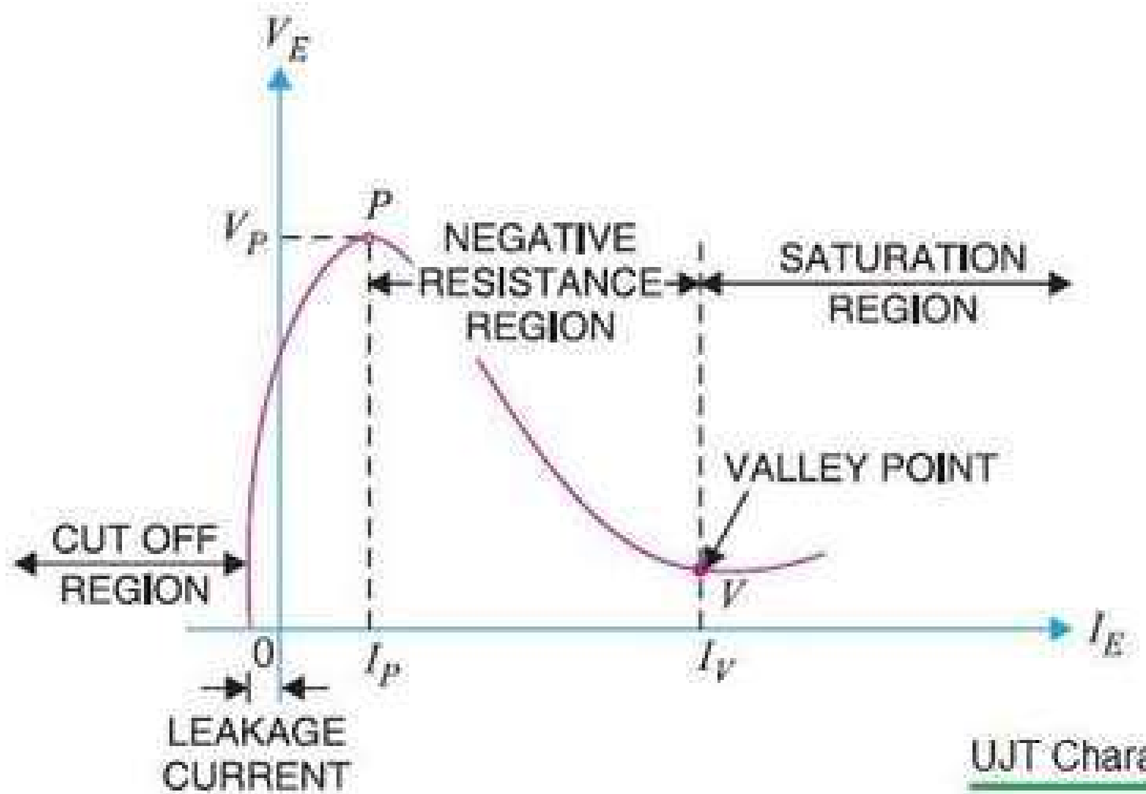
UJT Characteristics



UJT Characteristics

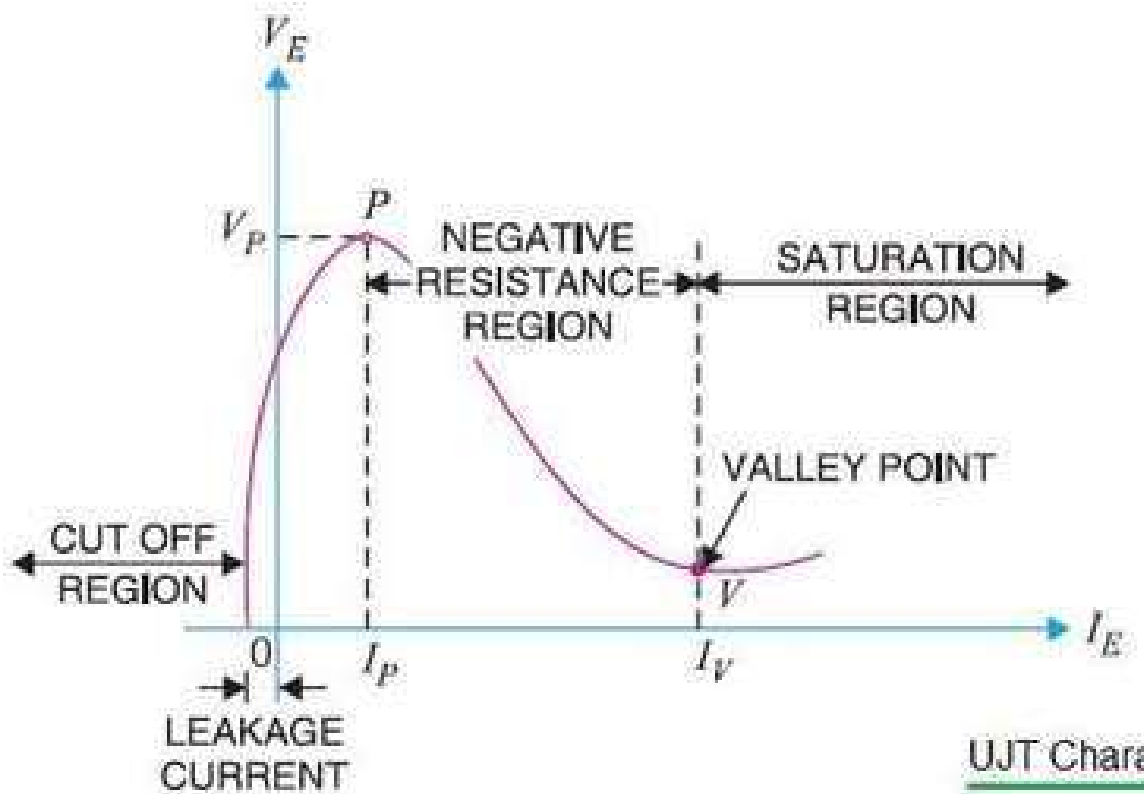
Characteristic of UJT

- First curve shows the curve between emitter voltage (V_E) and emitter current (I_E) of a UJT at a given voltage V_{BB} between the bases. This is known as the emitter characteristics of UJT.
- The following points may be noted from the characteristics.



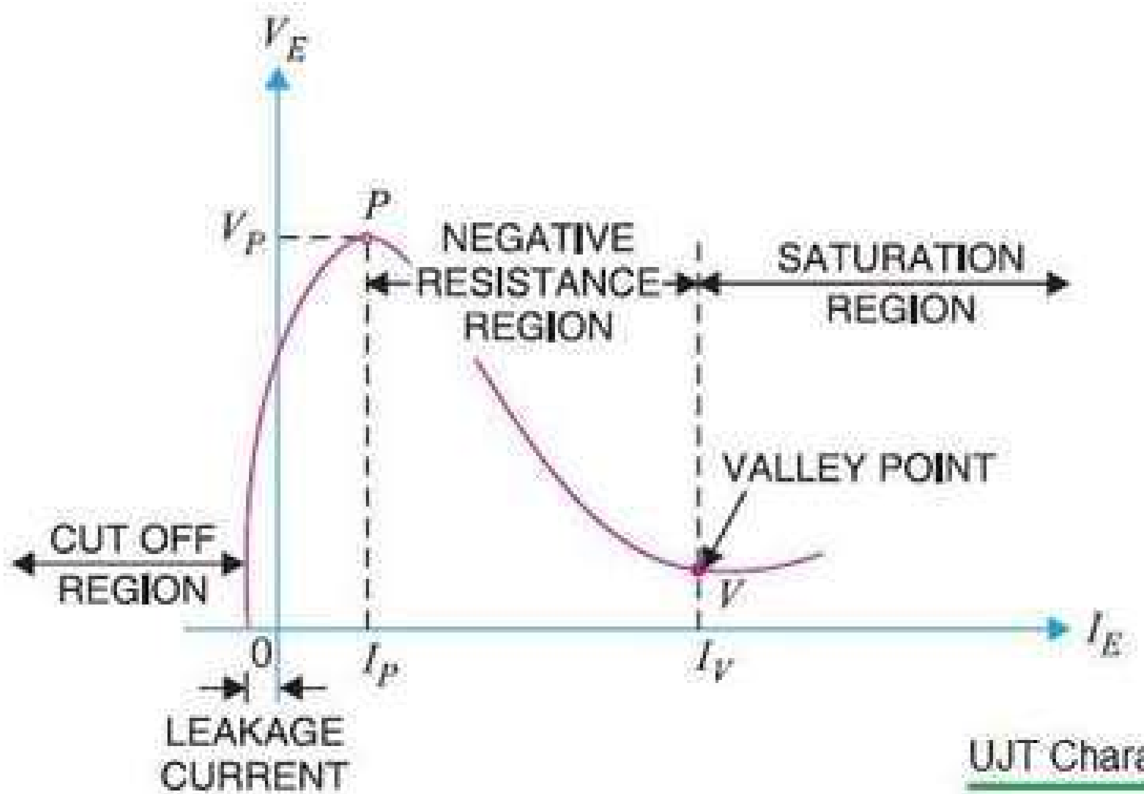
Characteristic of UJT

- Initially, in the cut-off region, as V_E increases from zero, slight leakage current flows from terminal B_2 to the emitter.
- This current is due to the minority carriers in the reverse biased diode.



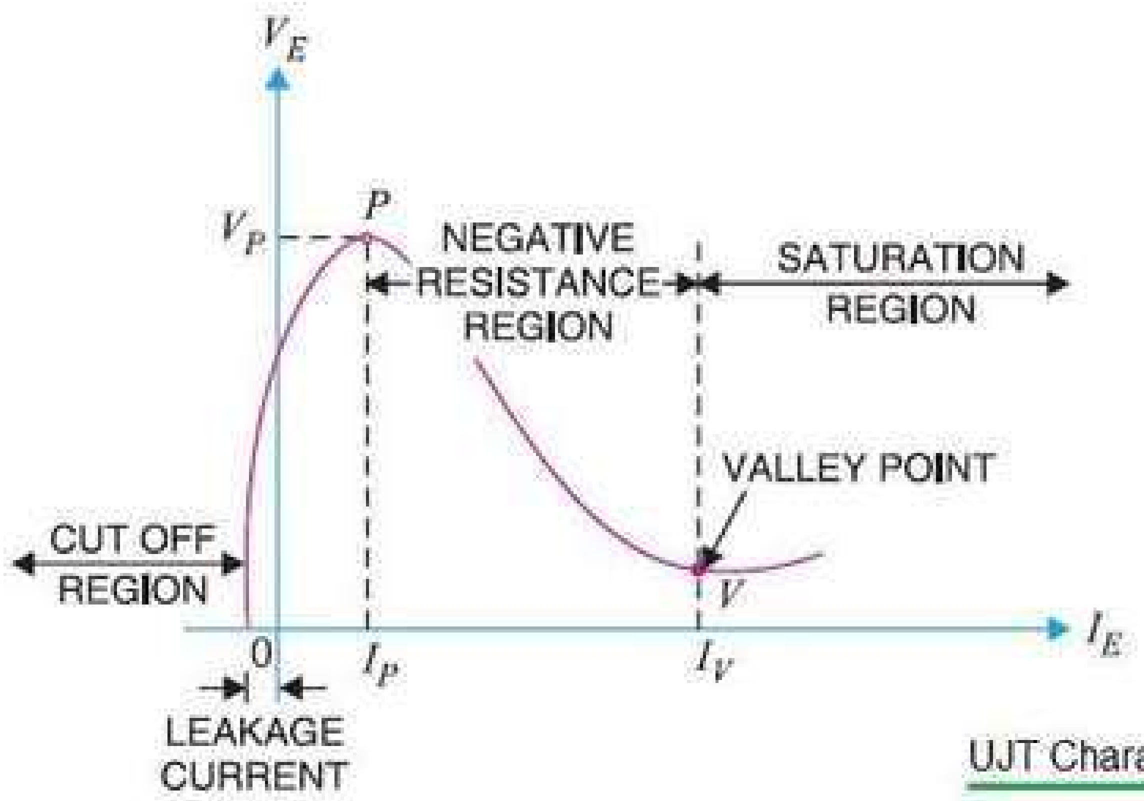
Characteristic of UJT

- Above a certain value of V_E, forward I_E begins to flow, increasing until the peak voltage V_P and current I_P are reached at point P.
- After the peak point P, an attempt to increase V_E is followed by a sudden increase in emitter I_E with a corresponding decrease in V_E.
- This is negative resistance portion of the curve.



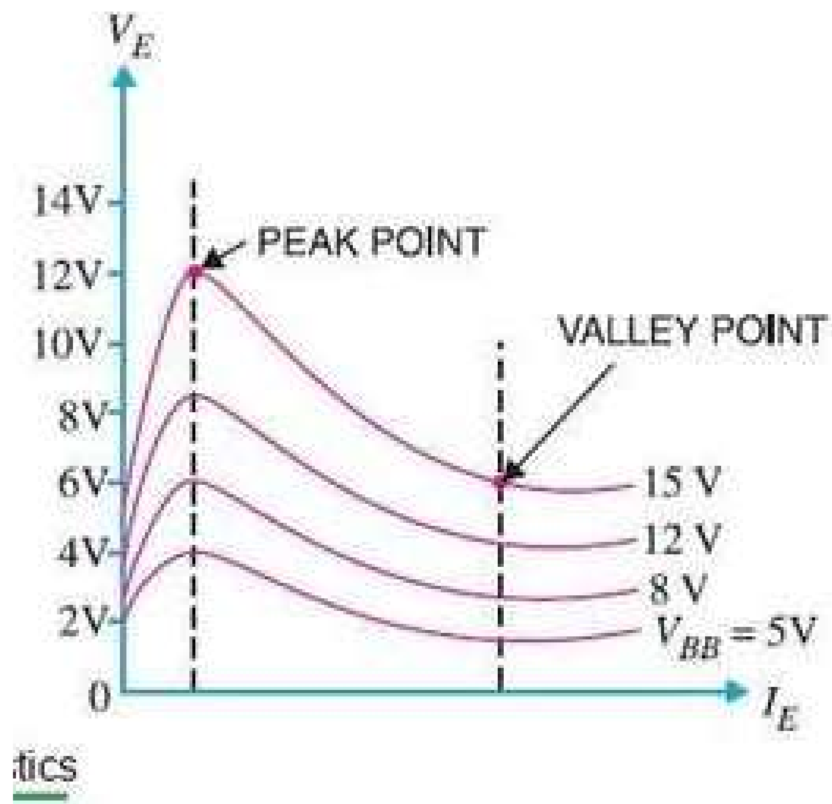
Characteristic of UJT

- The negative portion of the curve lasts until the valley point V is reached with valley-point voltage V_V and valley-point current I_V.
- After the valley point, the device is driven to saturation.



Characteristic of UJT

- The figure shows the typical family of V_E vs I_E characteristics of a UJT at different voltages between the bases.
- It is clear that peak-point voltage V_P falls steadily with reducing V_{BB} and so does the valley point voltage V_V.
- The difference $V_P – V_V$ is a measure of the switching efficiency of UJT and can be seen to fall off as V_{BB} decreases.



Characteristic of UJT

- Three important parameters for the UJT are I_P, V_V and I_V and are defined below:
- **Peak-Point Emitter Current, I_p:** It is the emitter current at the peak point. It represents the minimum current that is required to trigger the device (UJT). It is inversely proportional to the inter-base voltage V_{BB}.
- **Valley Point Voltage, V_V**: The valley point voltage is the emitter voltage at the valley point. The valley voltage increases with the increase in inter-base voltage V_{BB}.
- **Valley Point Current, I_V:** The valley point current is the emitter current at the valley point. It increases with the increase in inter-base voltage V_{BB}.

Unijunction Transistor Applications

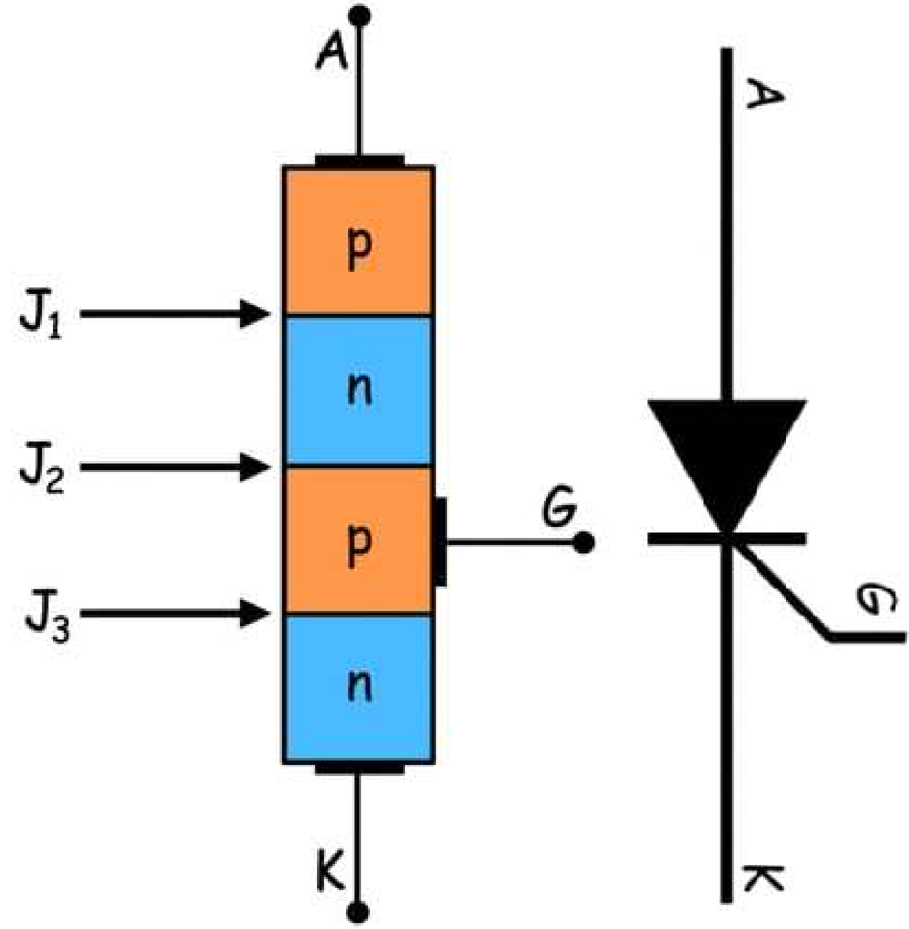
- The most common application of a unijunction transistor is as a triggering device for *SCR's* and *TRIACs* but other UJT applications include saw-toothed generators, simple oscillators, phase control, and timing circuits.
- The simplest of all UJT circuits is the Relaxation Oscillator producing non-sinusoidal waveforms and overvoltage detector.

Silicon Controlled Rectifier (SCR)

- Silicon Controlled Rectifier (SCR) is a unidirectional semiconductor device made of silicon.
- This device is the solid state equivalent of thyratron and hence it is also referred to as thyristor.
- In fact, SCR (Silicon Controlled Rectifier) is a trade name given to the thyristor by General Electric Company.
- SCRs are mainly used in electronic devices that require control of high voltage and power.
- This makes them applicable in medium and high AC power operations such as motor control function.
- An SCR conducts when a gate pulse is applied to it, just like a diode.

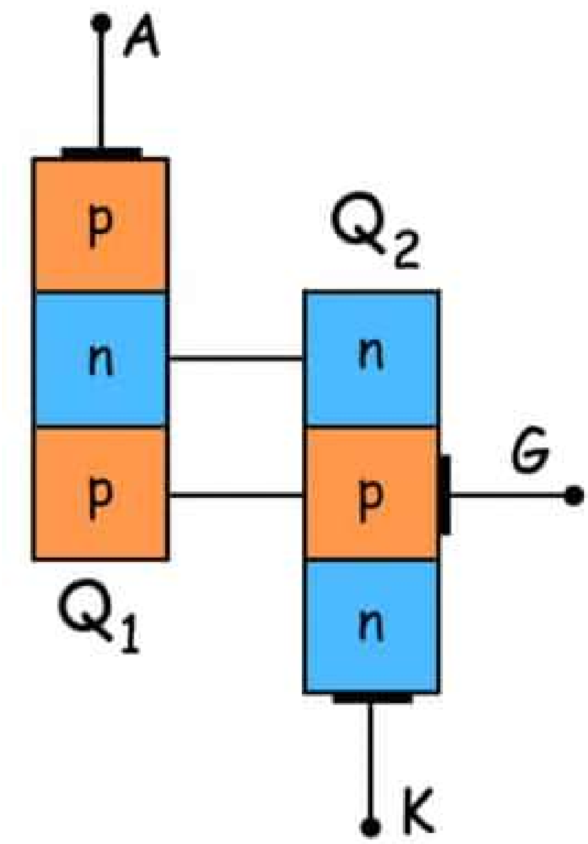
Silicon Controlled Rectifier (SCR)

- Basically SCR is a three-terminal, four-layer semiconductor device consisting of alternate layers of p-type and n-type material.
- Hence it has three pn junctions J1, J2 and J3. The figure shows an SCR with the layers p-n-p-n.
- The device has terminals Anode (A), Cathode (K) and the Gate (G).
- The Gate terminal (G) is attached to the p-layer nearer to the Cathode (K) terminal.

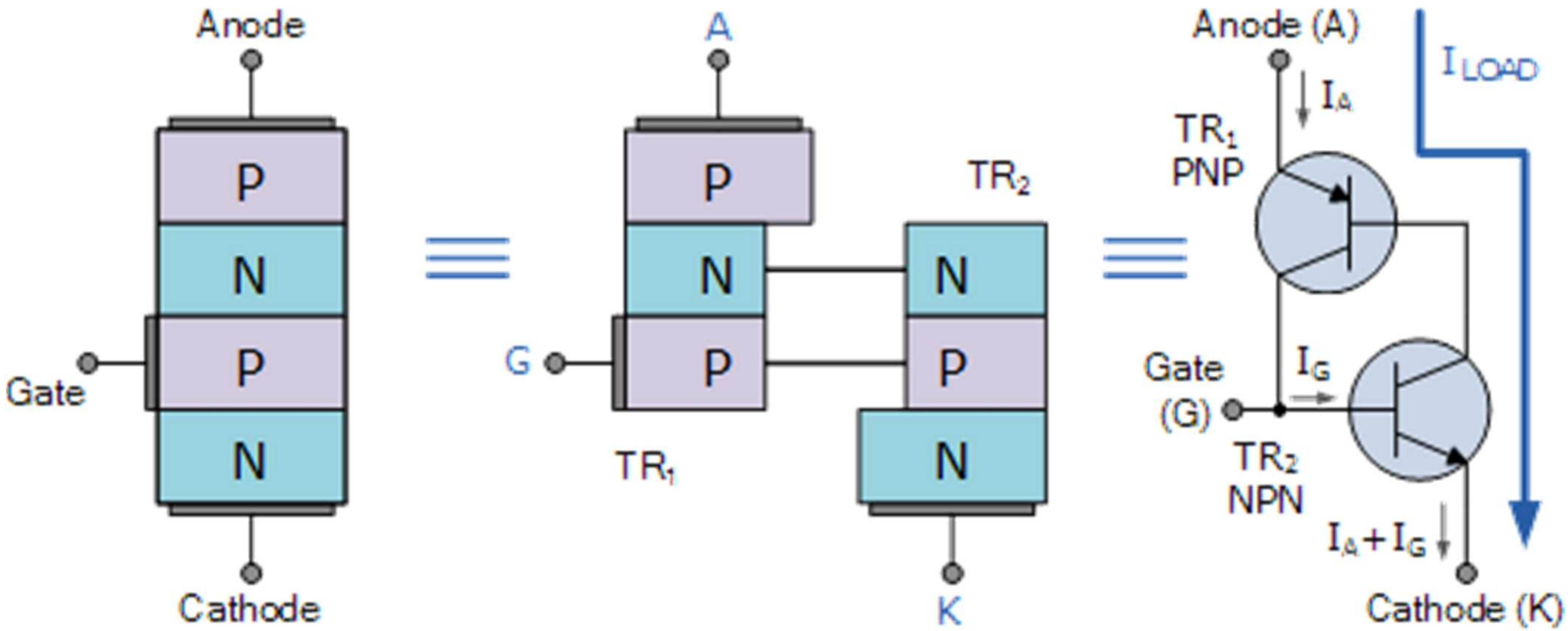


Silicon Controlled Rectifier (SCR)

- An SCR can be considered as two inter-connected transistors.
- It is seen that a single **SCR** is the combination of one pnp transistor (Q_1) and one npn transistor (Q_2).
- Here, the emitter of Q_1 acts as the anode terminal of the SCR while the emitter of Q_2 is its cathode.
- Further, the base of Q_1 is connected to the collector of Q_2 and the collector of Q_1 is connected to the base of Q_2.
- The gate terminal of the SCR is connected to the base of Q_2, too.

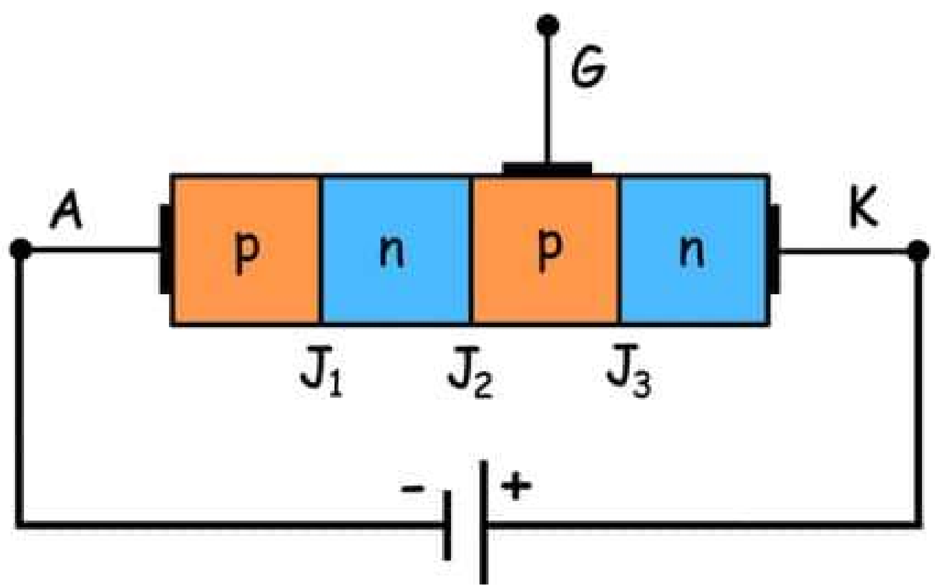


Silicon Controlled Rectifier (SCR)



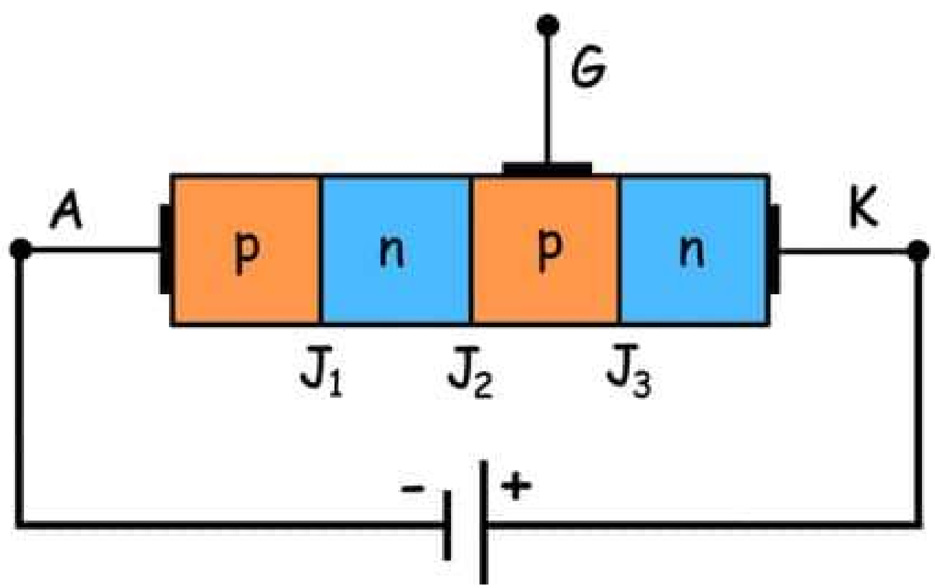
Reverse Blocking Mode of SCR

- In this mode, the SCR is reverse biased by connecting its anode terminal (A) to negative end and the cathode terminal (K) to the positive end of the battery.
- This leads to the reverse biasing of the junctions J1 and J3, which in turn prohibits the flow of current through the device, in spite of the fact that the junction J2 remains in forward biased condition.

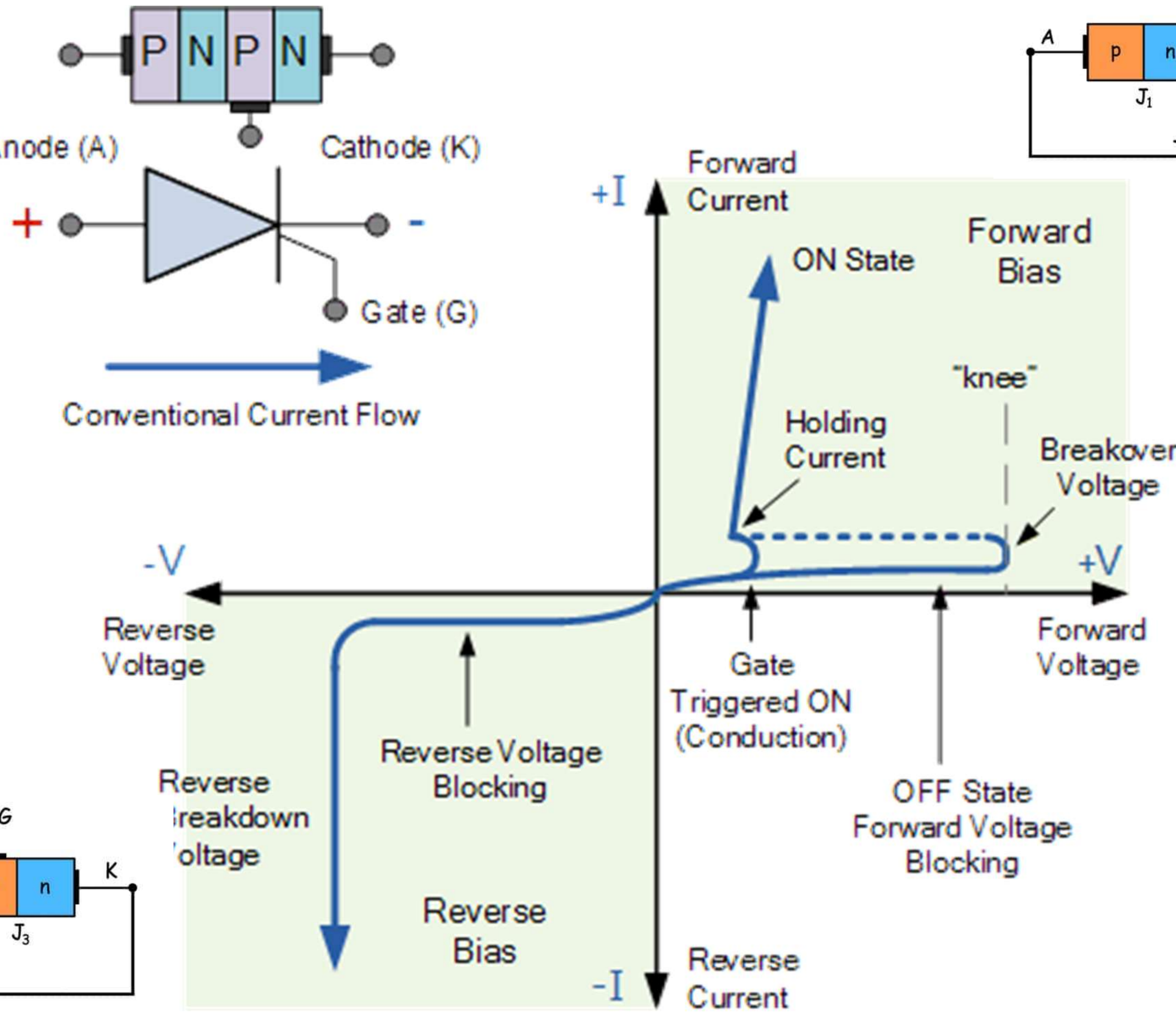


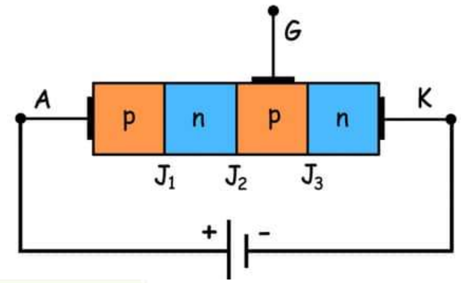
Reverse Blocking Mode of SCR

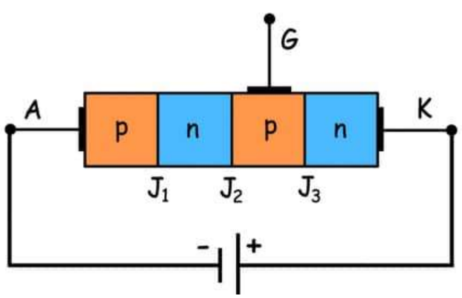
- In this state, the SCR behaves as a typical diode.
- In this reverse biased condition, only reverse saturation current flows through the device as in the case of the reverse biased diode which is shown in the characteristic curve.
- The device also exhibits the reverse breakdown phenomenon beyond a reverse safe voltage limit just like a diode.



Characteristics of SCR

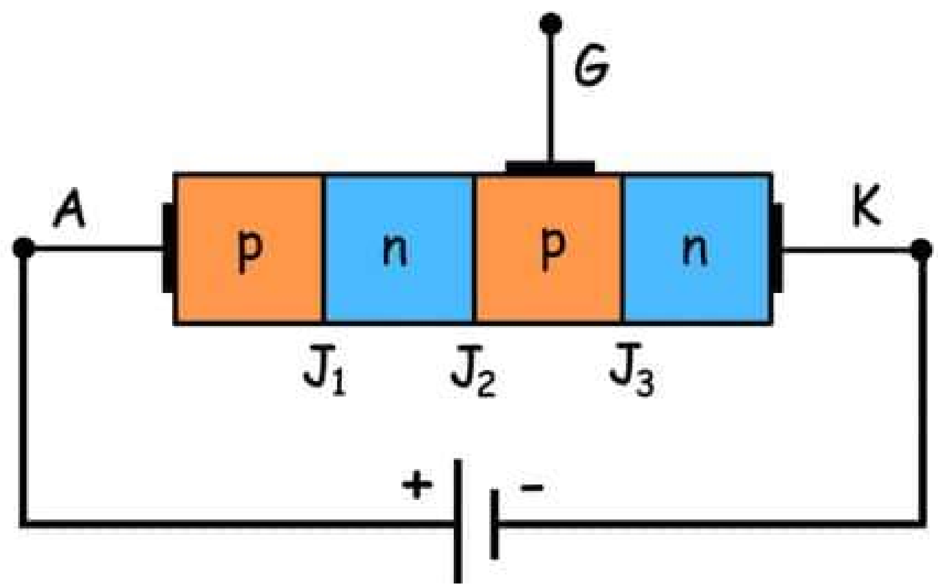






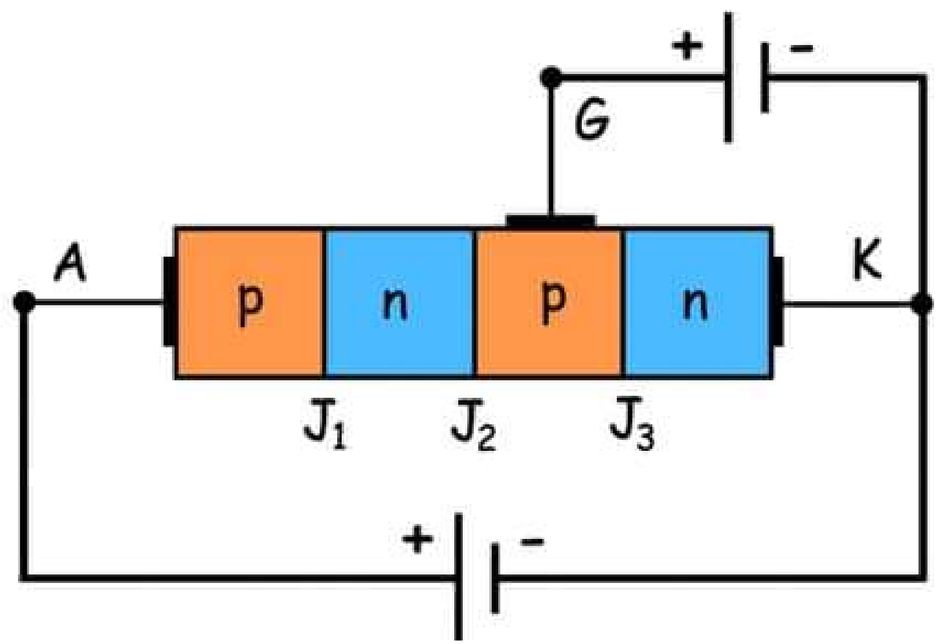
Forward Blocking Mode of SCR

- Here a positive bias is applied to the SCR by connecting anode terminal (A) to the positive and cathode terminal (K) to the negative terminal of the battery, as shown in the figure below.
- Under this condition, the junction J_1 and J_3 get forward biased while junction J_2 gets reverse biased.
- Here also current cannot pass through the SCR except the tiny current flowing as saturation current as shown in the characteristics curve.



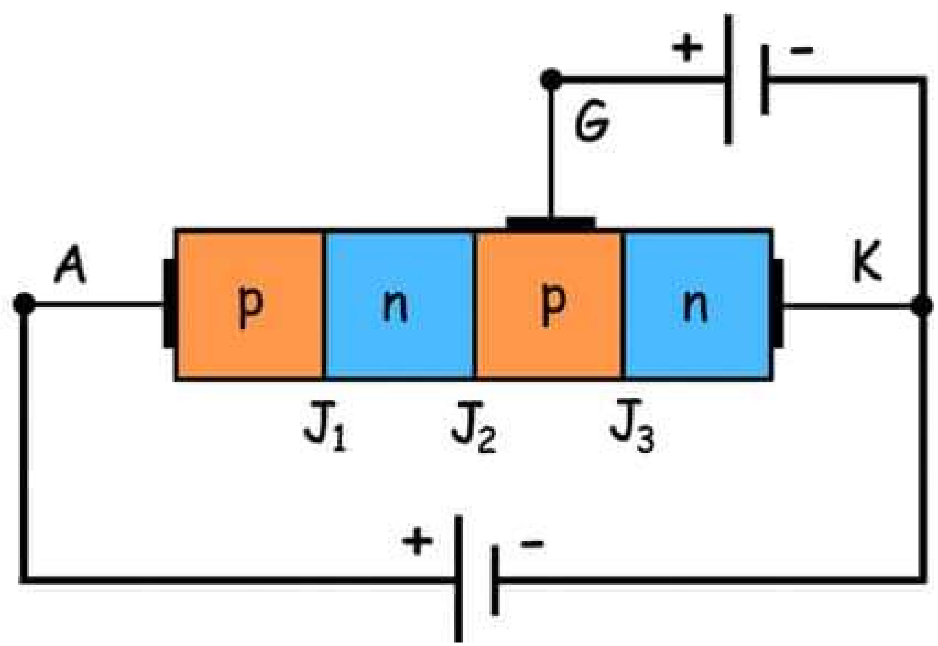
Forward Conduction Mode of SCR

- The SCR can be made to conduct either.
  - By increasing the positive voltage applied at anode terminal (A) beyond the Break Over Voltage, V_B or.
  - By applying positive voltage at the gate terminal (G) as shown in the figure below.



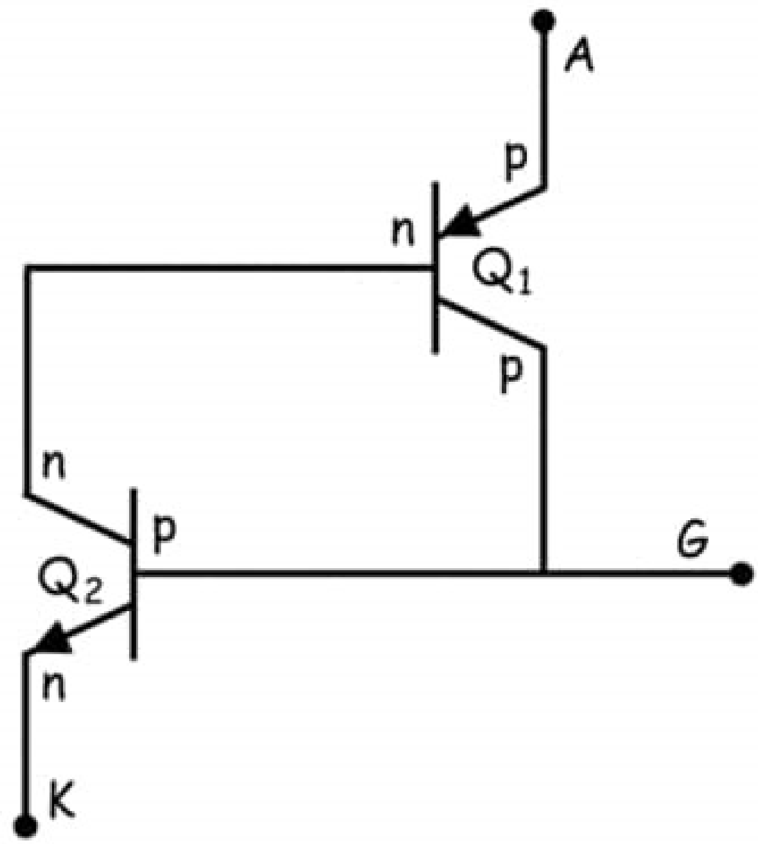
Forward Conduction Mode of SCR

- In the first case, the increase in the applied bias causes the initially reverse biased junction J_2 to break down at the point corresponding to forward Break Over Voltage, V_B.
- This results in the sudden increase in the current flowing through the SCR as shown in the characteristic curve, although the gate terminal of the SCR remains unbiased.



Forward Conduction Mode of SCR

- However, SCR can also be turned on at a much smaller voltage level by proving small positive voltage at the gate terminal.
- The reason behind this can be better understood by considering the transistor equivalent circuit of the SCR shown in the figure.



Forward Conduction Mode of SCR

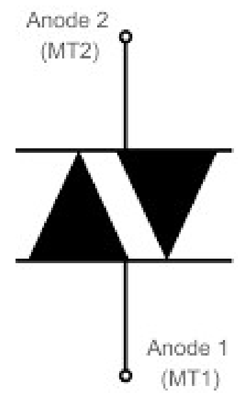
- Here it is seen that on applying a positive voltage at the gate terminal, transistor Q_2 switches ON and its collector current flows into the base of transistor Q_1.
- This causes Q_1 to turn ON which in turn results in the flow of its collector current into the base of Q_2.
- This causes either transistor to get saturated at a very rapid rate and the action cannot be stopped even by removing the bias applied at the gate terminal, provided the current through the **SCR** is greater than that of the Latching current.
- Here the latching current is defined as the minimum current required to maintain the SCR in conducting state even after the gate pulse is removed.

Forward Conduction Mode of SCR

- In such state, the SCR is said to be latched and there will be no means to limit the current through the device, unless by using an external impedance in the circuit.
- This techniques reduces the anode current below the Holding Current.
- Holding current is defined as the minimum current to maintain the SCR in its conducting mode, in presence of gate pulse.

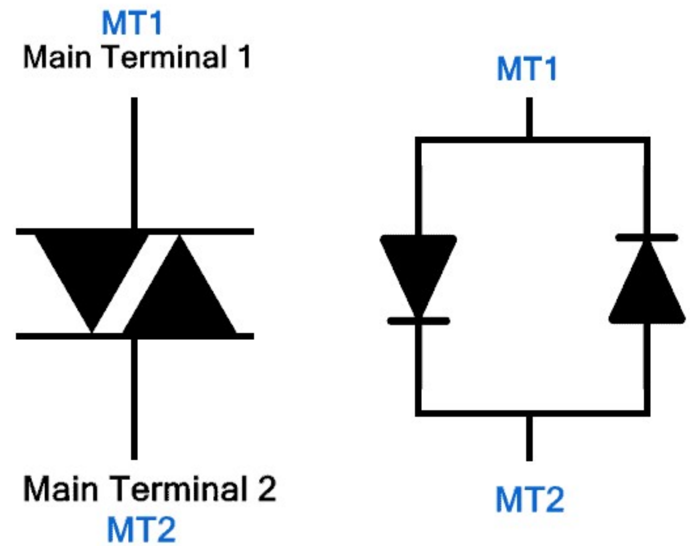
DIAC

- The **Diode AC** switch, or **DIAC** for short, is another solid state, three-layer, two-junction semiconductor device but unlike the transistor the DIAC has no base connection making it a two terminal device, labelled MT_1 and MT_2.
- DIAC's are an electronic component which offer no control or amplification but act much like a bidirectional switching diode as they can conduct current from either polarity of a suitable AC voltage supply.



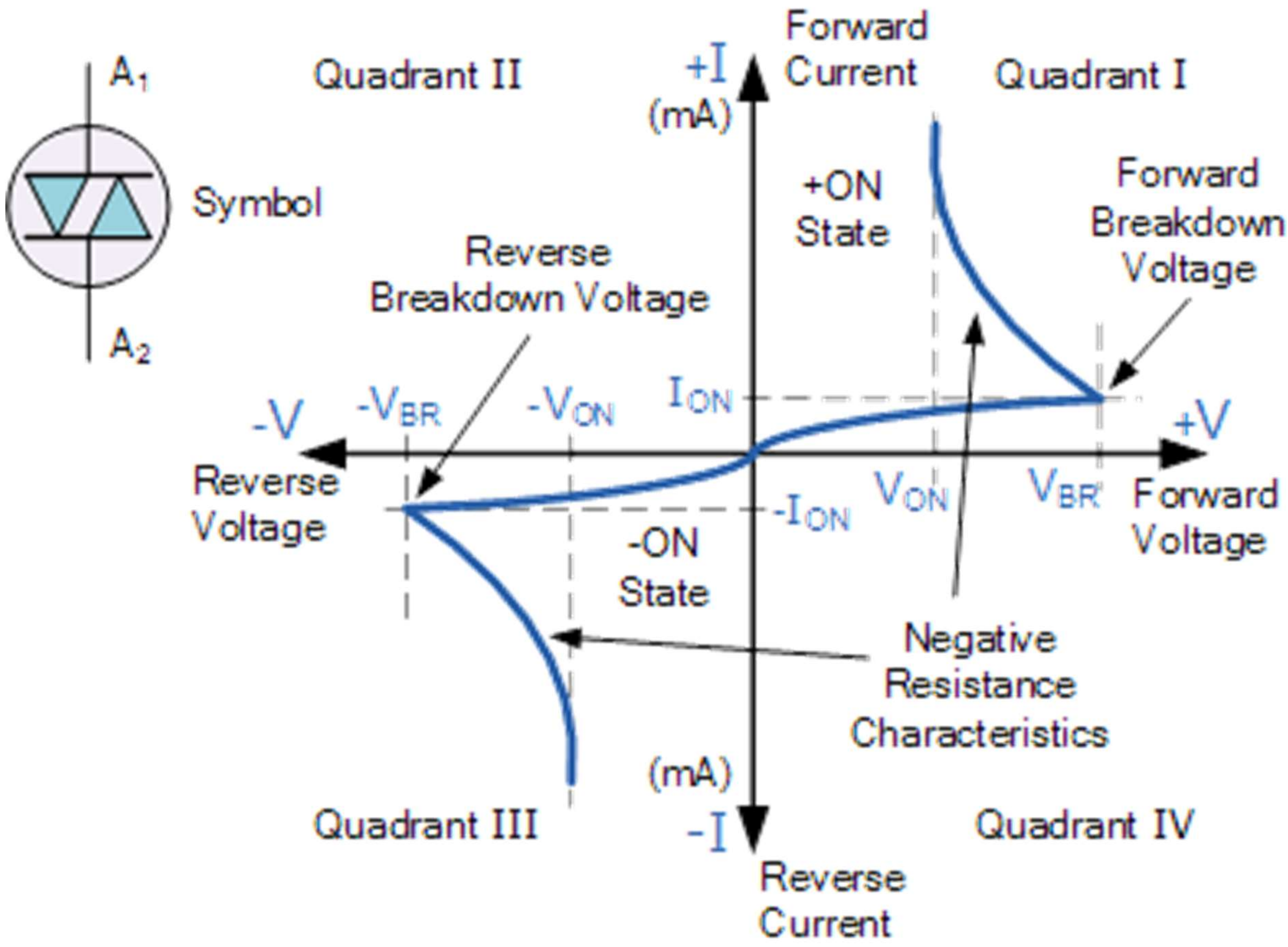
DIAC

- The DIAC is constructed like a transistor but has no base connection allowing it to be connected into a circuit in either polarity.
- DIACs are primarily used as trigger devices in phase-triggering and variable power control applications because a DIAC helps provide a sharper and more instant trigger pulse (as opposed to a steadily rising ramp voltage) which is used to turn "ON" the main switching device.



DIAC Symbol

DIAC


A1
A2
Symbol
Quadrant II
Quadrant I
Quadrant III
Quadrant IV
+I
(mA)
Forward
Current
+ON
State
Forward
Breakdown
Voltage
Reverse
Breakdown Voltage
-V
-VBR
-VON
ION
+V
Reverse
Voltage
-ION
VON
VBR
Forward
Voltage
-ON
State
Negative
Resistance
Characteristics
(mA)
-I
Reverse
Current

DIAC

- The DIAC blocks the flow of current in both directions until the applied voltage is greater than V_{BR}, at which point breakdown of the device occurs and the DIAC conducts heavily in a similar way to the Zener diode passing a sudden pulse of voltage.
- This V_{BR} point is called the DIACs breakdown voltage or breakover voltage.
- In an ordinary Zener diode the voltage across it would remain constant as the current increased. However, in the DIAC the transistor action causes the voltage to reduce as the current increases.

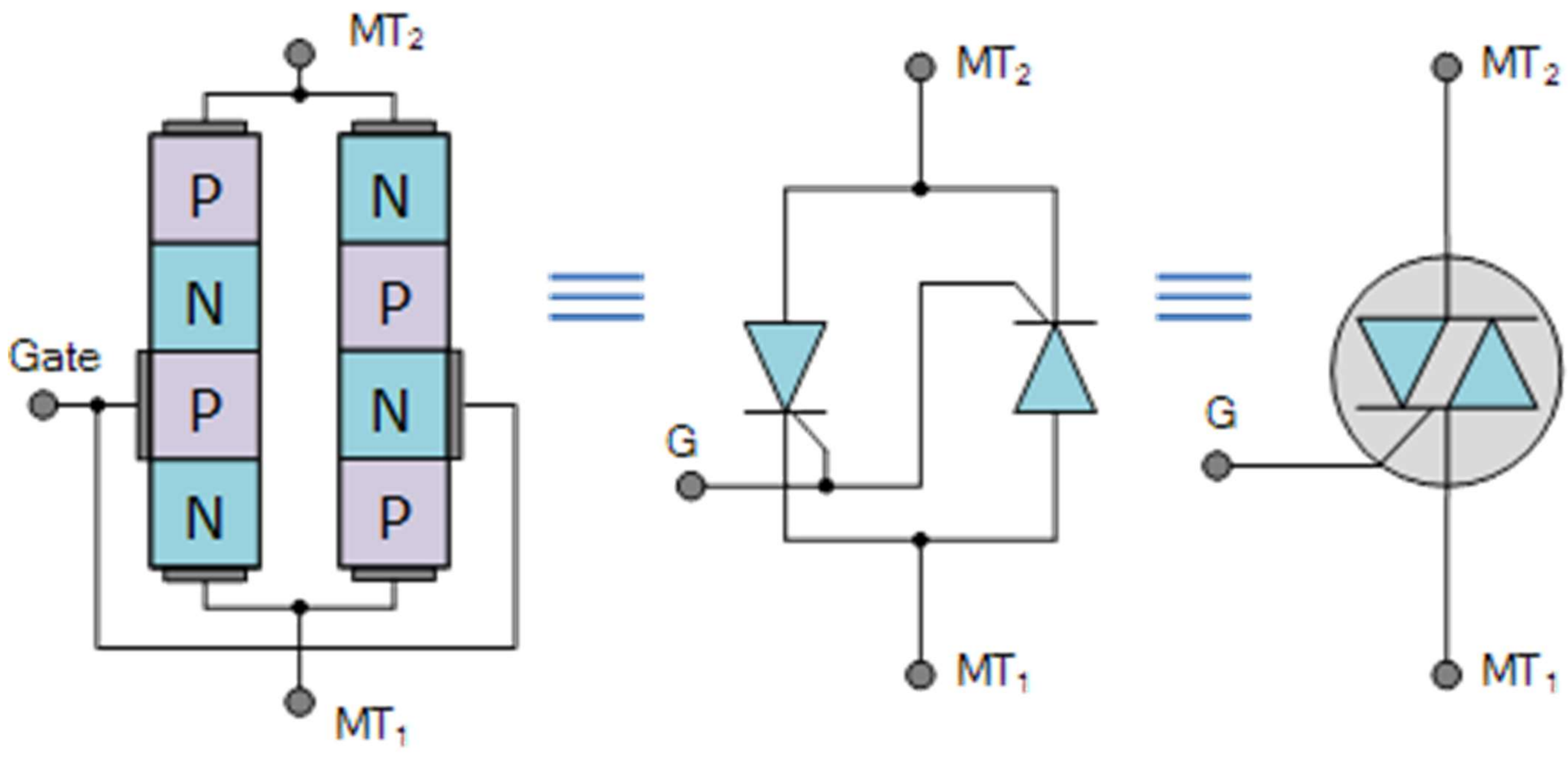
DIAC

- This action gives the DIAC the characteristic of a negative resistance.
- As the DIAC is a symmetrical device, it therefore has the same characteristic for both positive and negative voltages and it is this negative resistance action that makes the DIAC suitable as a triggering device for SCR’s or TRACs.

TRIAC

- another type of semiconductor device called a **Triode AC Switch** or TRIAC, is also a member of the thyristor family which can be used as a solid state power switching device.
- But the biggest advantage that a TRIAC has over a SCR, is that it is a **bidirectional** switching device.
- In other words, a TRIAC can be triggered into conduction by both positive and negative voltages applied to its Anode and with both positive and negative trigger pulses applied to its Gate terminal making it a two-quadrant switching Gate controlled device.

TRIAC

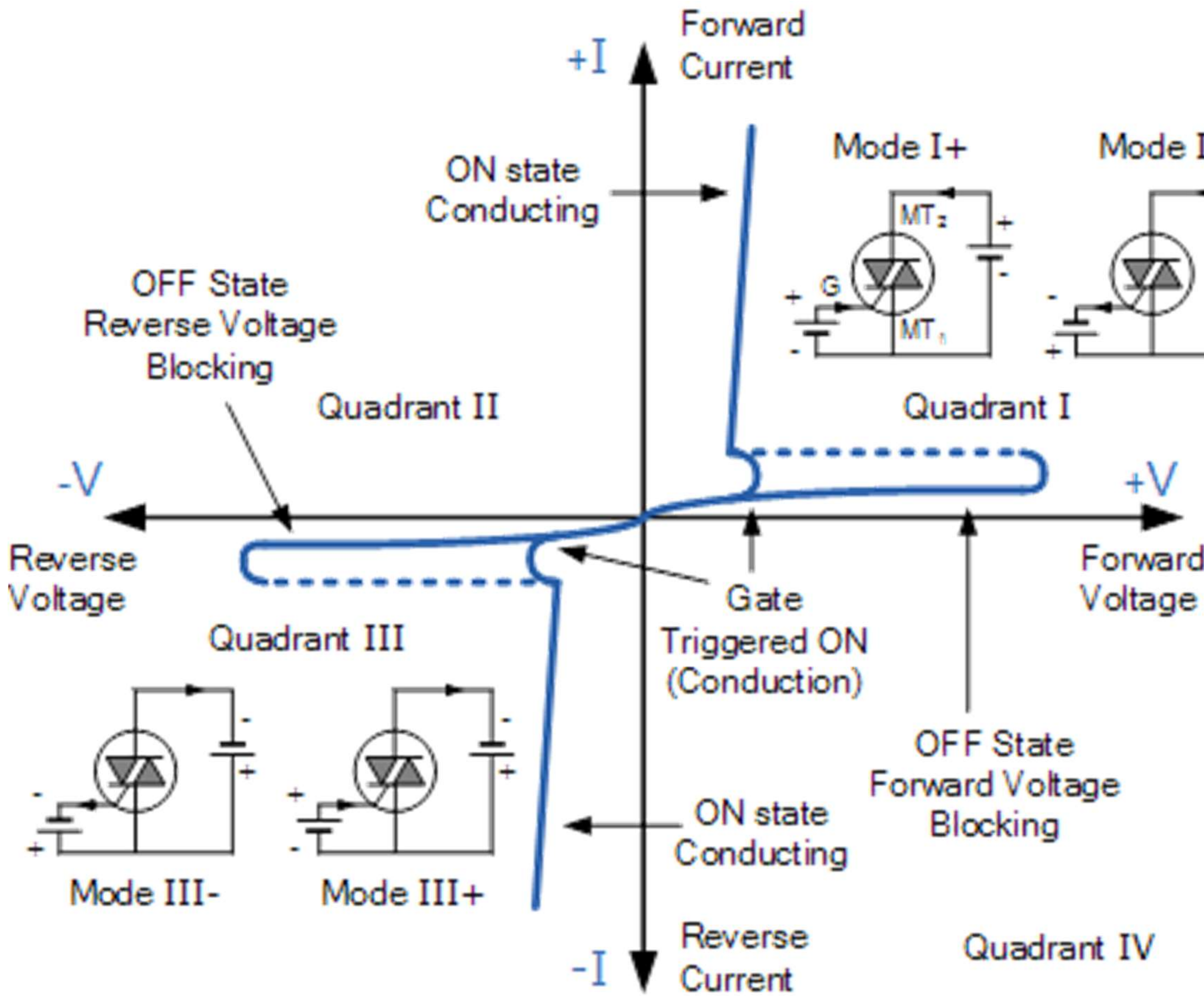


Physical Construction Two-Thyristor Analogy Circuit Symbol

TRIAC

- We now know that a TRIAC is a 4-layer, PNPN in the positive direction and a NPNP in the negative direction, three-terminal bidirectional device that blocks current in its OFF state acting like an open-circuit switch.
- But unlike a conventional thyristor, the TRIAC can conduct current in either direction when triggered by a single gate pulse.
- Then a TRIAC has four possible triggering modes of operation as follows.
  - I + Mode = MT2 current positive (+ve), Gate current positive (+ve)
  - I – Mode = MT2 current positive (+ve), Gate current negative (-ve)
  - III + Mode = MT2 current negative (-ve), Gate current positive (+ve)
  - III – Mode = MT2 current negative (-ve), Gate current negative (-ve)

TRIAC



Forward
Current
+I
ON state
Conducting
Mode I+
Mode I-
MT2
G
MT1
OFF State
Reverse Voltage
Blocking
Quadrant II
Quadrant I
-V
+V
Reverse
Voltage
Forward
Voltage
Gate
Triggered ON
(Conduction)
Quadrant III
OFF State
Forward Voltage
Blocking
ON state
Conducting
Mode III-
Mode III+
Reverse
Current
-I
Quadrant IV

TRIAC

- In Quadrant I, the TRIAC is usually triggered into conduction by a positive gate current, labelled above as mode I+.
- But it can also be triggered by a negative gate current, mode I–.
- Similarly, in Quadrant <III, triggering with a negative gate current, $-I_G$ is also common, mode III– along with mode III+. Modes I– and III+ are, however, less sensitive configurations requiring a greater gate current to cause triggering than the more common TRIAC triggering modes of I+ and III–.

TRIAC

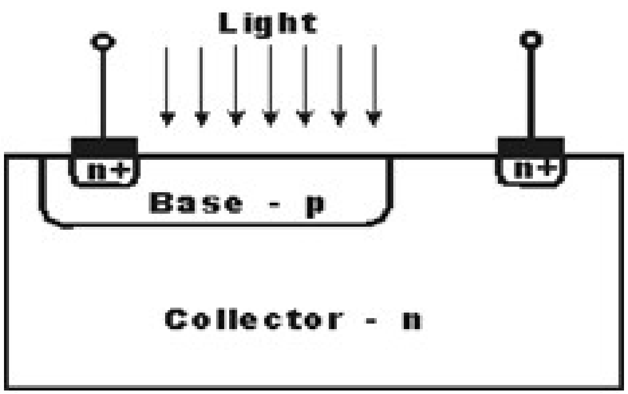
- Also, just like silicon controlled rectifiers (SCR's), TRIAC's also require a minimum holding current I_H to maintain conduction at the waveforms cross over point.
- Then even though the two thyristors are combined into one single TRIAC device, they still exhibit individual electrical characteristics such as different breakdown voltages, holding currents and trigger voltage levels exactly the same as we would expect from a single SCR device.

Phototransistor

- A **Phototransistor** is an electronic switching and current amplification component which relies on exposure to light to operate.
- When light falls on the junction, reverse current flows which is proportional to the luminance.
- Phototransistors are used extensively to detect light pulses and convert them into digital electrical signals.
- These are operated by light rather than electric current.
- Providing large amount of gain, low cost and these phototransistors might be used in numerous applications.

Phototransistor

- **Phototransistors** are transistors with the base terminal exposed to light. Instead of sending current into the base, the photons from striking light activate the transistor.
- This is because a phototransistor is made of a bipolar semiconductor and focuses the energy that is passed through it.
- The structure of the **phototransistor** is specifically optimized for photo applications. These devices can be either homojunction structured or heterojunction structured
- Compared to a normal transistor, a photo transistor has a larger base and collector width and is made using diffusion



Phototransistor

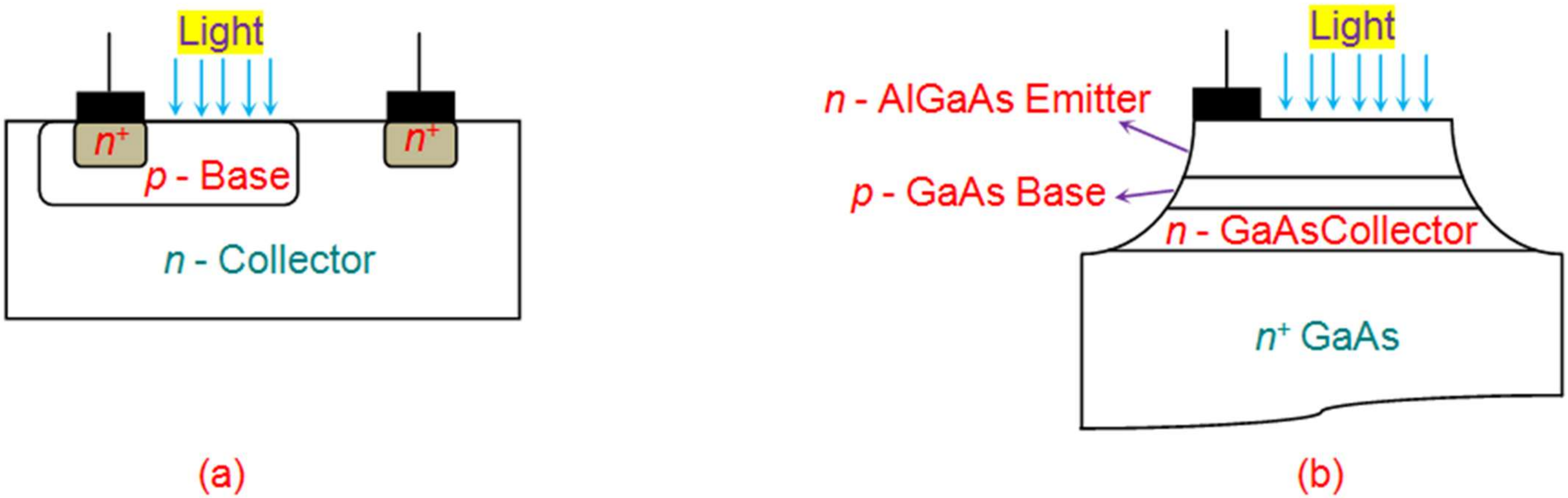


Figure 1 Phototransistor (a) Homojunction Structure (b) Heterojunction Structure

Figure 1 *npn* Phototransistor Symbol with (a) Three Leads (b) Two Leads

Phototransistor

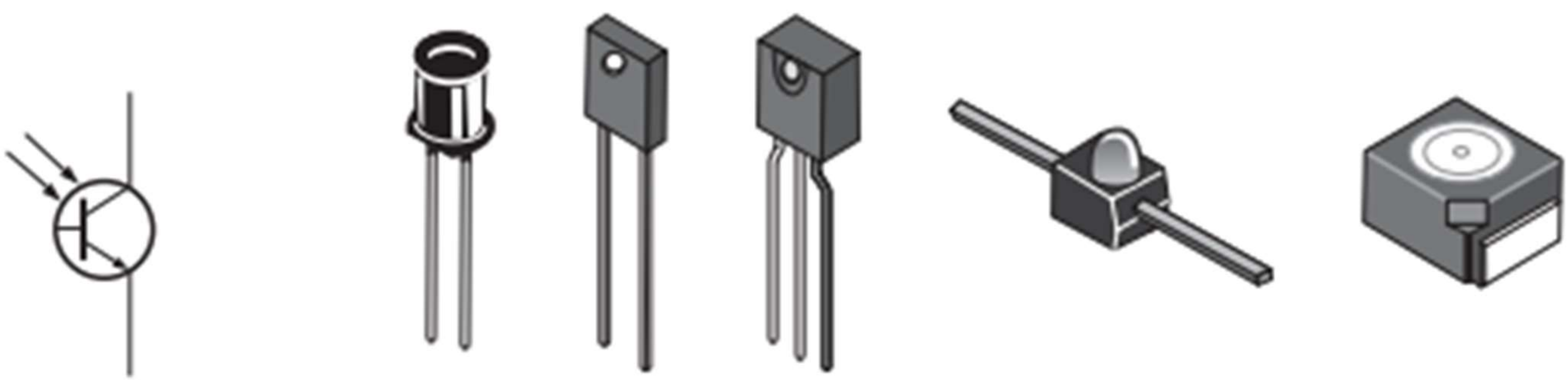
- In a Photo-transistor the base current is produced when light strikes the photosensitive semiconductor base region.
- The collector-base *pn* junction is exposed to incident light through a lens opening in the transistor package.
- When there is no incident light, there is only a small thermally generated collector-to-emitter leakage current, I_{CEO} .
- This **dark current**, I_{λ}, is produced that is directly proportional to the light intensity.
- This action produces a collector current that increases with I_{λ}.
- Except for the way base current is generated, the phototransistor behaves as a conventional BJT. In many cases, there is no electrical connection to the base.

Phototransistor

- The relationship between the collector current and the light-generated base current in a phototransistor is:

$$I_C = \beta_{DC} I_\lambda$$

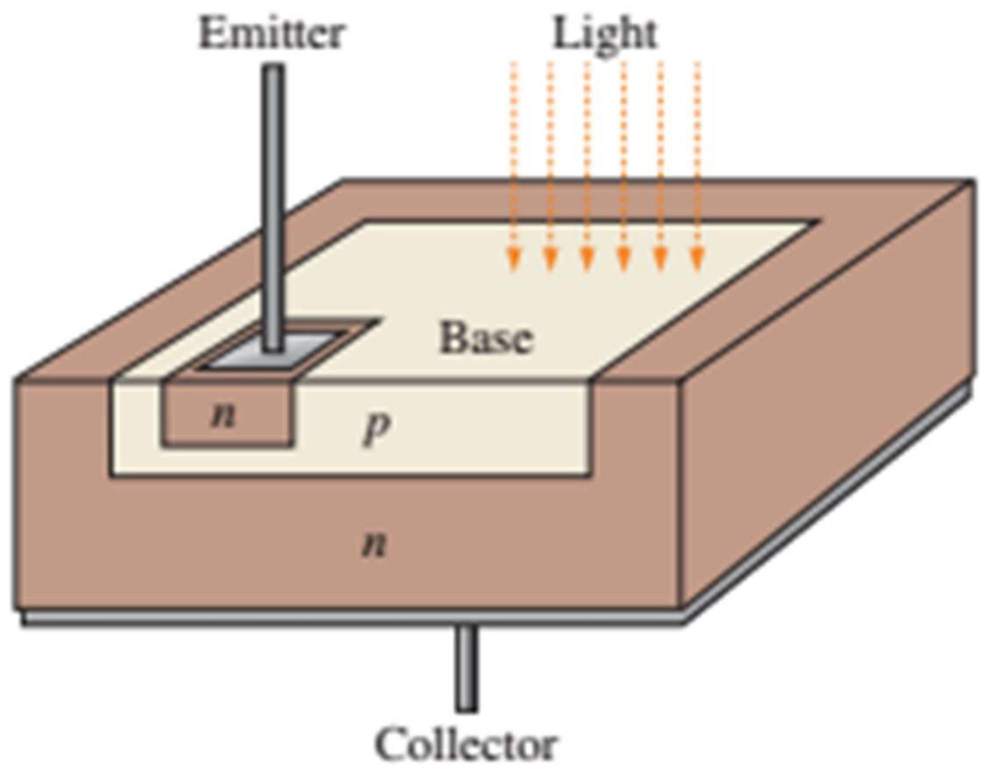
- The schematic symbol and some typical photo-transistors are shown.



(a) Schematic symbol (b) Typical packages

Phototransistor

- Since the actual photo-generation of base current occurs in the collector-base region, the larger the physical area of this region, the more base current is generated.
- Thus, a typical photo-transistor is designed to offer a large area to the incident light



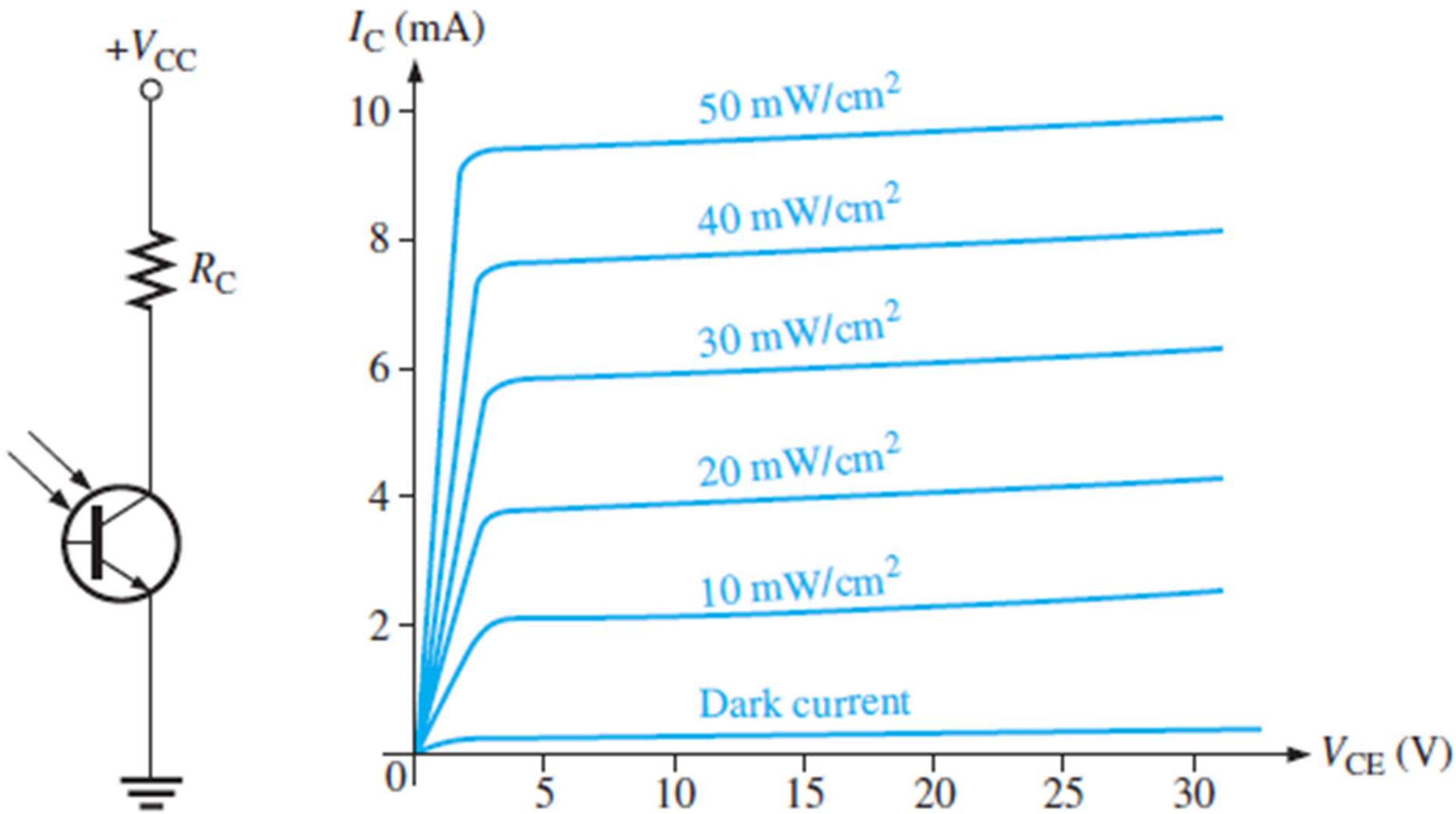
Phototransistor

- Phototransistors are either tri-terminal (emitter, base and collector) or bi-terminal (emitter and collector) semiconductor devices which have a light-sensitive base region.
- In the three-lead configuration, the base lead is brought out so that the device can be used as a conventional BJT with or without the additional light-sensitivity feature.
- In the two-lead configuration, the base is not electrically available, and the device can be used only with light as the input.
- In many applications, the phototransistor is used in the two-lead version.

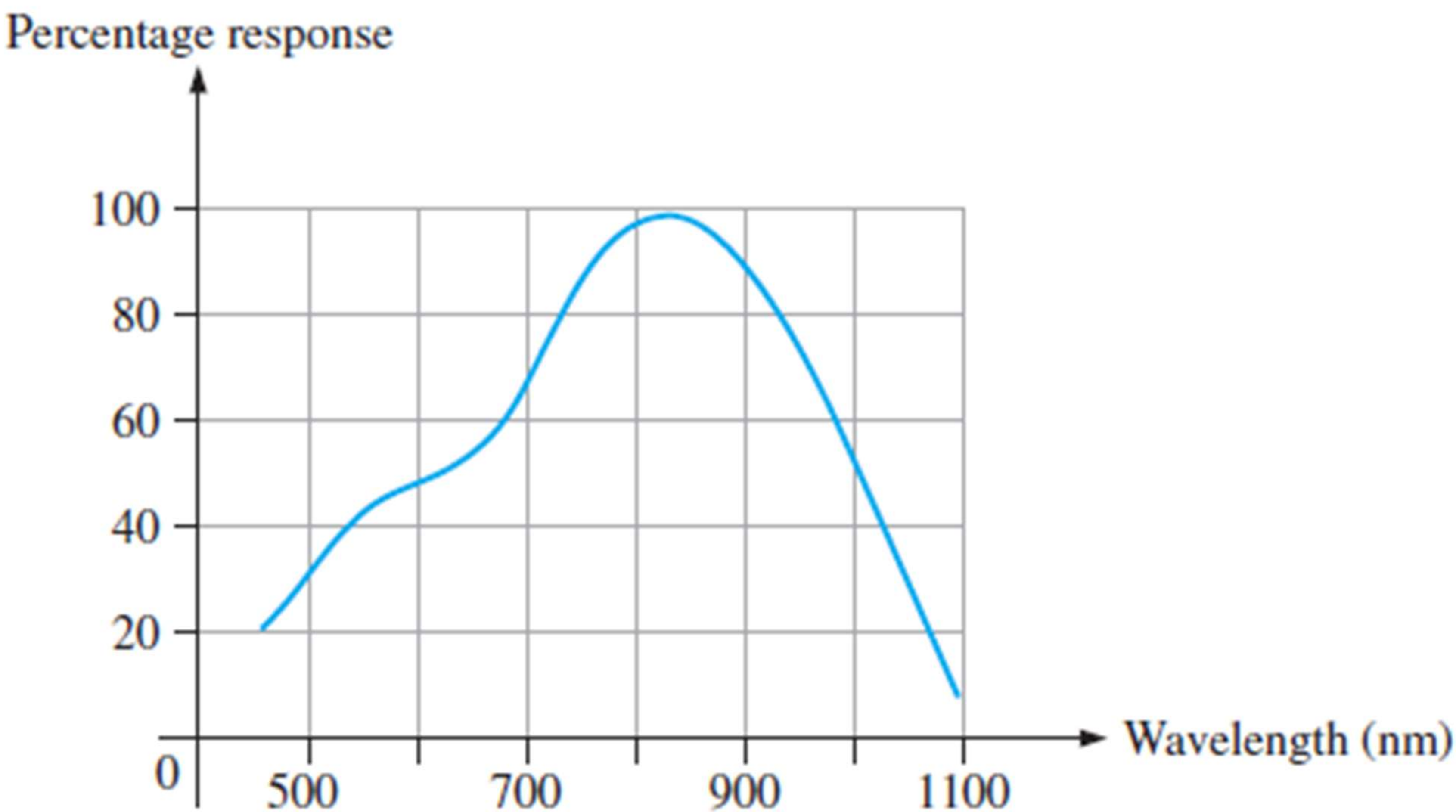
Phototransistor

- A phototransistor with a biasing circuit and typical **collector characteristic** curves.
- Each curve on the graph corresponds to a certain value of light intensity and that the collector current increases with light intensity.
- Phototransistors are not sensitive to all light but only to light within a certain range of wavelengths.
- They are most sensitive to particular wavelengths in the red and infrared part of the spectrum, as shown by the peak of the infrared **spectral response curve**.

Collector Characteristic



Spectral Response Curve



Applications of Phototransistor

- Object detection
- Encoder sensing
- Automatic electric control systems such as in light detectors
- Security systems
- Punch-card readers
- Relays
- Computer logic circuitry
- Counting systems
- Smoke detectors
- Laser-ranging finding devices

Applications of Phototransistor

- Optical remote controls
- CD players
- Astronomy
- Night vision systems
- Infrared receivers
- Printers and copiers
- Cameras as shutter controllers
- Level comparators

Power Electronics

END