ELECTRONIC SYSTEM

SEMICONDUCTOR DEVICE

GADAFFI OMAR

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SEMICONDUCTOR DEVICES

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PREFACE

This books aims for students of mechatronic engineering with the explanation of the basic concepts of semiconductor devices to diode, transistor, thyristor, rectifier, triac, and diac.

The whole book is presented in a straightforward manner to assist students in rapidly grasping the topics and subject matter. This book will impart knowledge of the theory, idea, and application of formulas, as well as the ability to solve problems pertaining to the aforementioned procedures.

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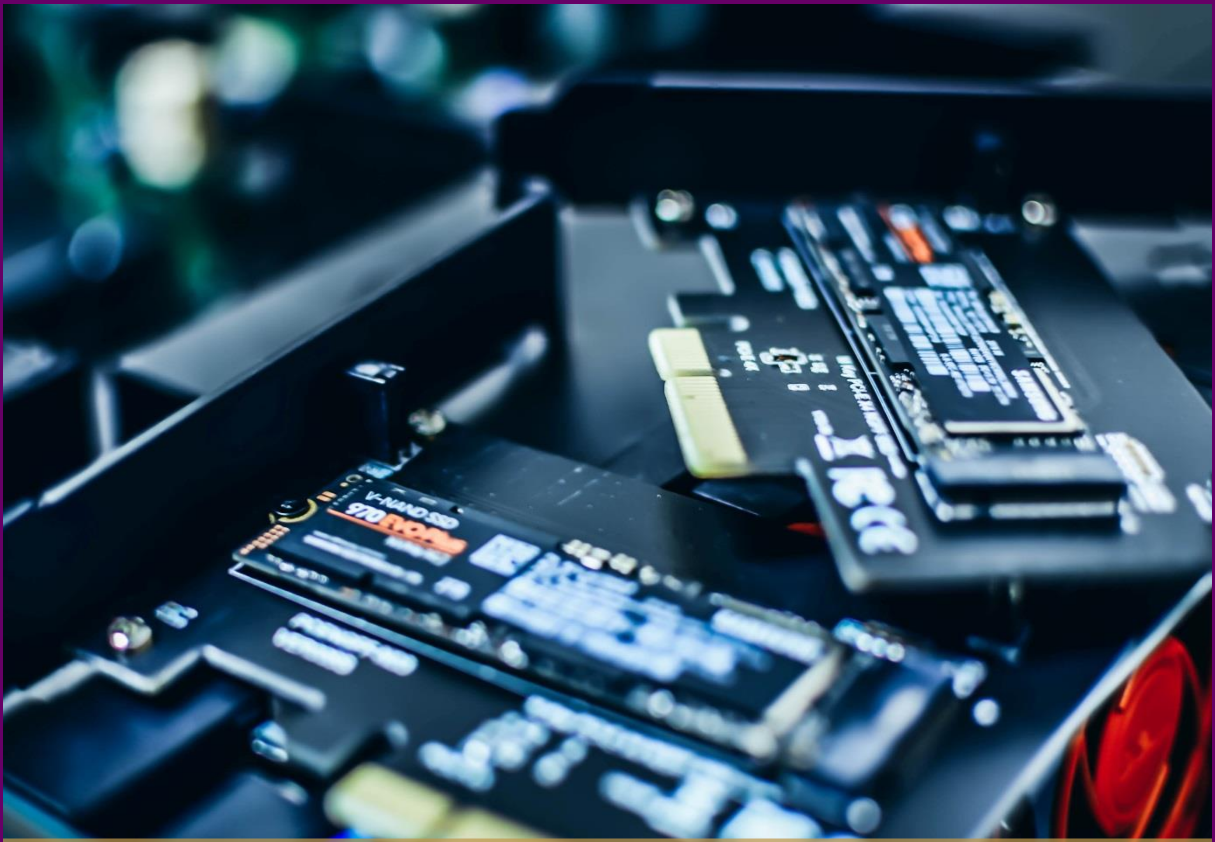
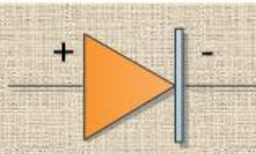
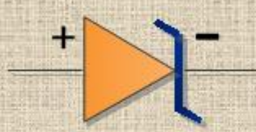


SEMICONDUCTOR DEVICES

The semiconductor industry is made up of firms that develop and manufacture semiconductors and semiconductor devices such as integrated circuits. It was founded about 1960, when semiconductor device manufacture became a viable enterprise. Since then, the semiconductor industry's yearly revenue has expanded to nearly $481 billion, as of 2018. The semiconductor industry drives the broader electronics industry, with annual power electronics sales of £135 billion ($216 billion) in 2011, annual consumer electronics sales expected to reach $2.9 trillion by 2020, technology industry sales expected to reach $5 trillion in 2019, and e-commerce sales exceeding $29 trillion in 2017.

The MOSFET (metal-oxide-semiconductor field-effect transistor, or MOS transistor) is the most frequently used semiconductor device, having been created in 1959 at Bell Labs by Mohamed M. Atalla and Dawon Kahng. MOSFET scaling and shrinking have been the key drivers of semiconductor technology's remarkable exponential development since the 1960s. The MOSFET, which accounts for 99.9% of all transistors, is the semiconductor industry's driving force and the most commonly produced device in history, with an estimated 13 sextillion (1.3 1022) MOSFETs made between 1960 and 2018.

SEMICONDUCTOR DEVICES – 2 LAYER DEVICES

DEVICE	BUILDING STRUCTURE / SCHEMATIC DIAGRAM	SCHEMATIC SYMBOL
DIODE		
ZENER DIODE		
LED		
	2 EXTRINSIC MATERIALS	

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DIODE

- A PN Junction Diode is one of the most fundamental types of semiconductor device.
- Consist of 2 pins which is anode and cathode (anode represented P material and cathode represented N material)
- It is characterised by the ability to conduct electricity in just one way.
- Its can be operated if connected with a bias voltage which is;
  - Forward biased
  - Reverse biased

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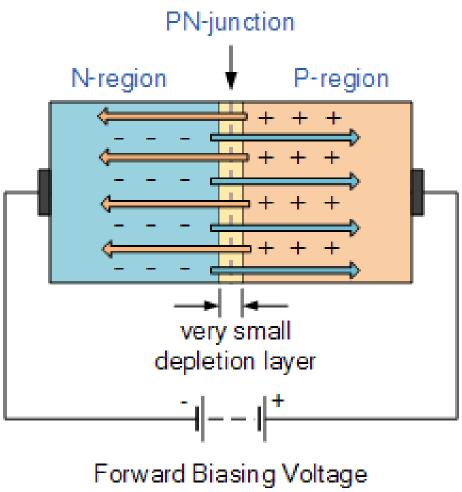
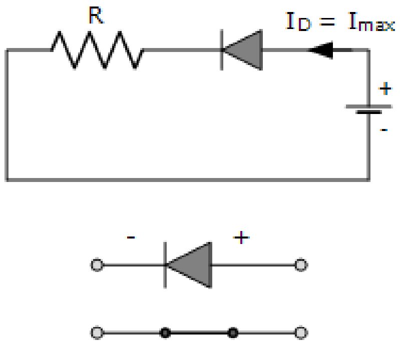
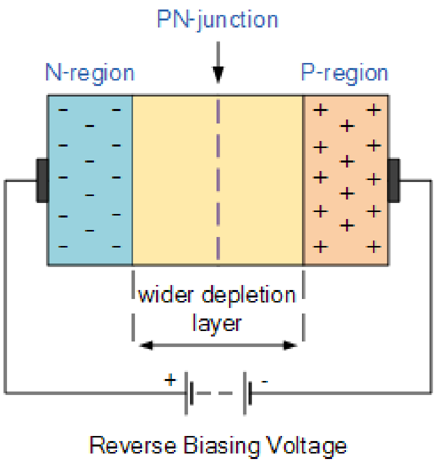
DIODE

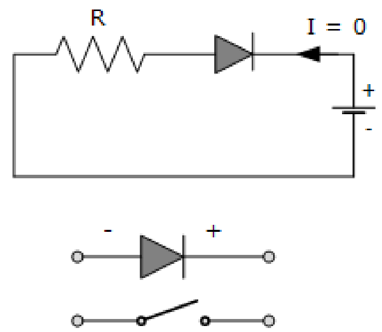




- **Forward Biased**
  - To the N-type material, a negative voltage is applied; to the P-type material, a positive voltage is applied.
  - When the external voltage exceeds the potential barrier value (0.7 volts for silicon and 0.3 volts for germanium), the depletion layer becomes very thin and narrow, allowing for substantial current flow.

DIODE





- **Reverse Biased**
  - When a positive voltage is supplied to the N-type material, electrons are drawn toward the positive electrode and away from the junction, while holes in the P-type end are likewise attracted away from the junction and toward the negative electrode. As a result, the depletion layer becomes broader.
  - However, a negligible leakage current flows via the connection, measured in microamperes (A).
  - If the diode's reverse bias voltage Vreverse is elevated to a sufficiently high value, the diode's PN junction will overheat and burn (damage).
  - This may result in the diode being shorted, allowing the maximum circuit current to flow.

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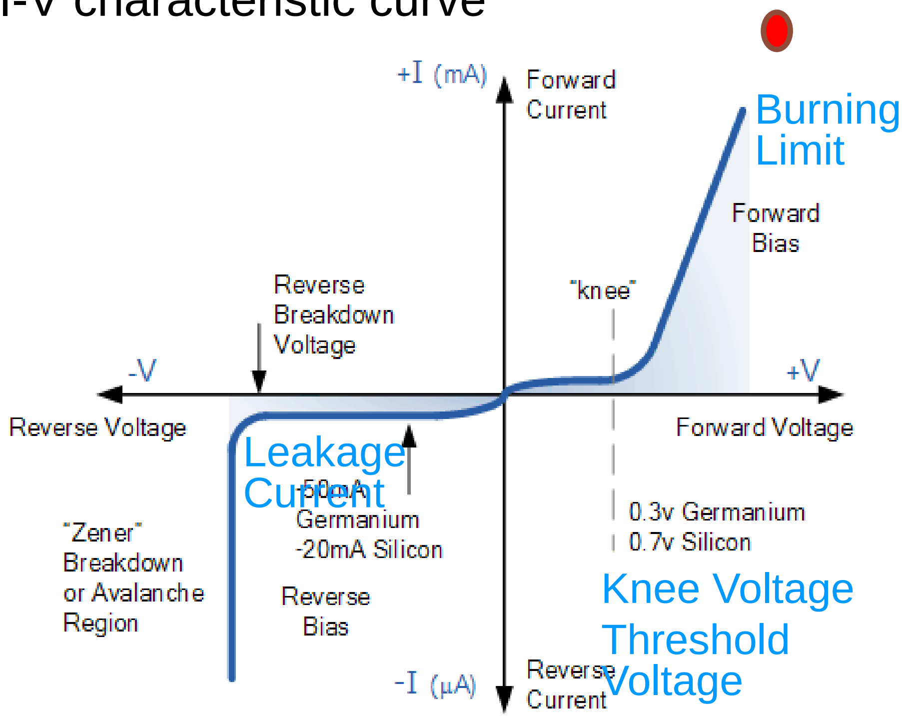
DIODE

Diode I-V characteristic curve



- Knee Voltage (Threshold voltage)
  - Level of voltage when sudden increase in forward current takes place.
  - Si = 0.7 V, Ge = 0.3 V
- Forward current
  - current flowing through the diode during forward biased.
  - usually measured in mA
- Reverse current
  - a very small current (leakage current) flowing through the diode in reverse biased connections.
  - usually measured in µA
- Breakdown voltage
  - Level of voltage when sudden increase of reverse current takes place.
  - This will burned and damaged the diode.
- Burning level
  - A point when forward current or forward voltage rise and exceeds maximum power rating.

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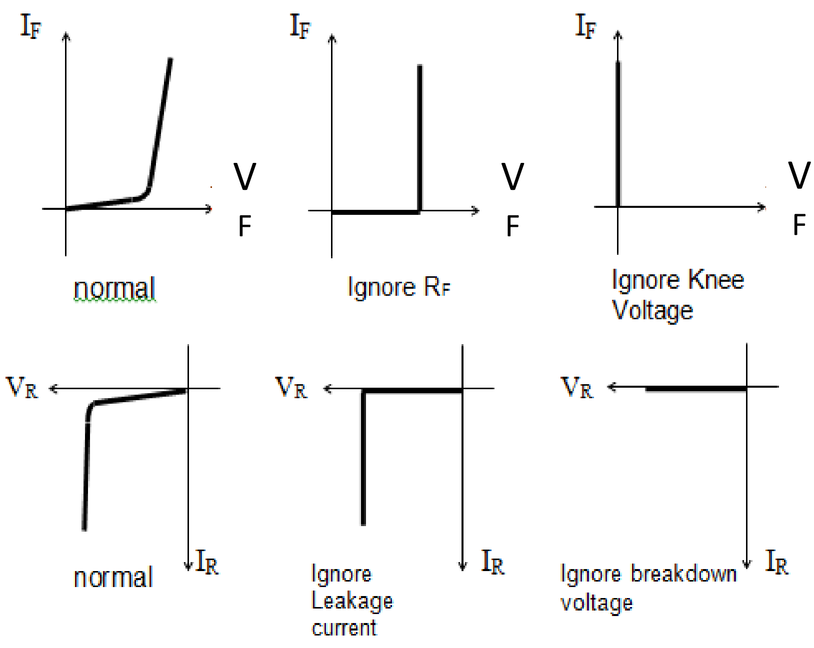
DIODE

FOR CALCULATIONS AND ANALYSIS PURPOSE

- **Ideal diode concepts;**
  - No knee voltage
  - No forward resistances
  - No leakage current
  - No breakdown voltage.

- ***The concept of ideal diode is when the forward biased is given, the diode is acting like a closed switch (ON) with zero resistance and no voltage drop***
- ***When a reverse biased voltage is given, the diode is acting like an open switch (OFF) with no leakage current.***

Ideal diode characteristic curve



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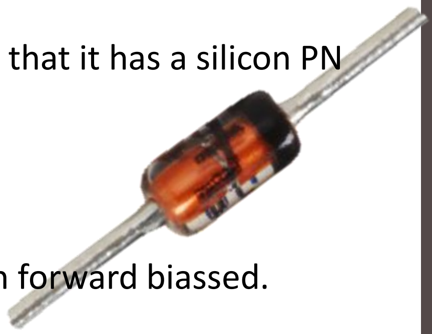
DIODE ZENER



- The Zener diode is similar to a regular diode in that it has a silicon PN junction.

- It performs just like a conventional diode when forward biassed.

- When the reverse voltage placed across the Zener Diode surpasses the device's rated voltage, the diode's breakdown voltage is attained (Avalanche Breakdown) and current begins to flow.

- Over a wide range of applied voltages, the current climbs rapidly to its maximum and then remains relatively constant (saturated).

- The "Zener voltage" is the value at which the voltage across the zener diode becomes stable. This voltage can range from less than one volt to hundreds of volts for Zener diodes.

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DIODE ZENER

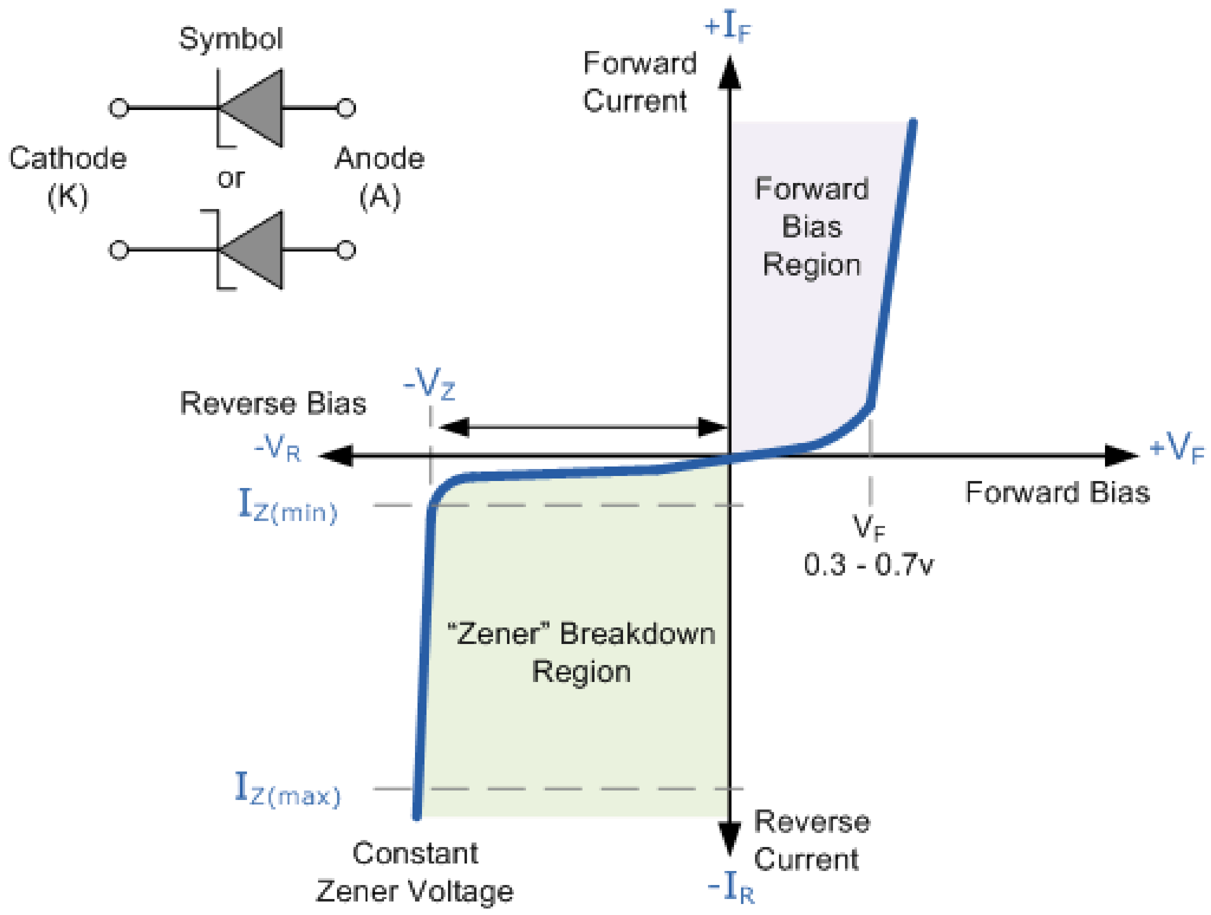
- Zener diodes are classified by the point at which they fail. The breakdown value of a diode having a Zener voltage (VZ) of 5V is -5V.
- The simplest sort of voltage regulator is the Zener diode.

- **Advantages**
  - Can operate in forward and reverse bias voltage.
  - Able to conduct high inverse current without damaging the diode.
  - When a reverse voltage applied across the Zener Diode reach and exceed the Zener Voltage, the voltage drop across Zener diode will remains fairly constant (same as Zener Voltage rating) – can act as voltage regulator.
  - The zener diode can be made from range of 2.4V to 200V.

- **Ideal Zener Diode concept**
  - Voltage drop across Zener diode are equal to Zener voltage ($V_D = V_Z$)

DIODE ZENER

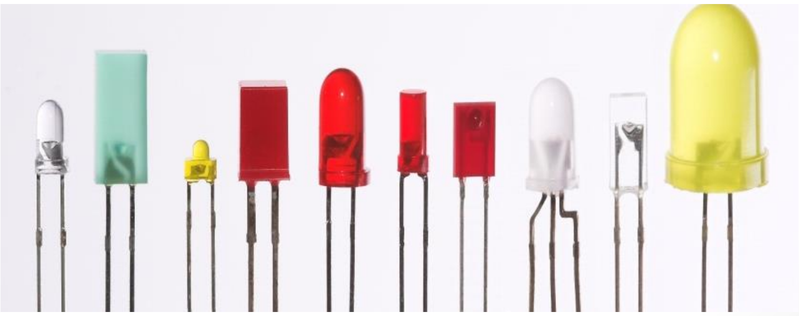
Zener Diode I-V Characteristics



Diode Zener can operated in forward and reverse biased

LIGHT EMITTING DIODE (LED)

- When given a forward bias, a Light-Emitting Diode (LED) is a semiconductor PN junction diode that produces visible light.
- They are current-dependent sources, and the intensity of their light output is proportional to the forward current flowing through the LED.
- When given a bias voltage, typical semiconductor materials such as silicon and germanium create heat, while semiconductor materials such as gallium arsenide (GaAs), gallium phosphide (GaP), and gallium ardenide phosphide (GaAsP) emit light.
- The colour of emits light depent on the types of semiconductor combination material as shown in Table 1(slide 12)



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LIGHT EMITTING DIODE (LED)

TABLE 1: LED COLOUR BASED ON SEMICONDUCTOR MATERIALS

Typical LED Characteristics			
Semiconductor Material	Wavelength	Colour	V_F @ 20mA
GaAs	850-940nm	Infra-Red	1.2v
GaAsP	630-660nm	Red	1.8v
GaAsP	605-620nm	Amber	2.0v
GaAsP:N	585-595nm	Yellow	2.2v
AlGaP	550-570nm	Green	3.5v
SiC	430-505nm	Blue	3.6v
GaInN	450nm	White	4.0v

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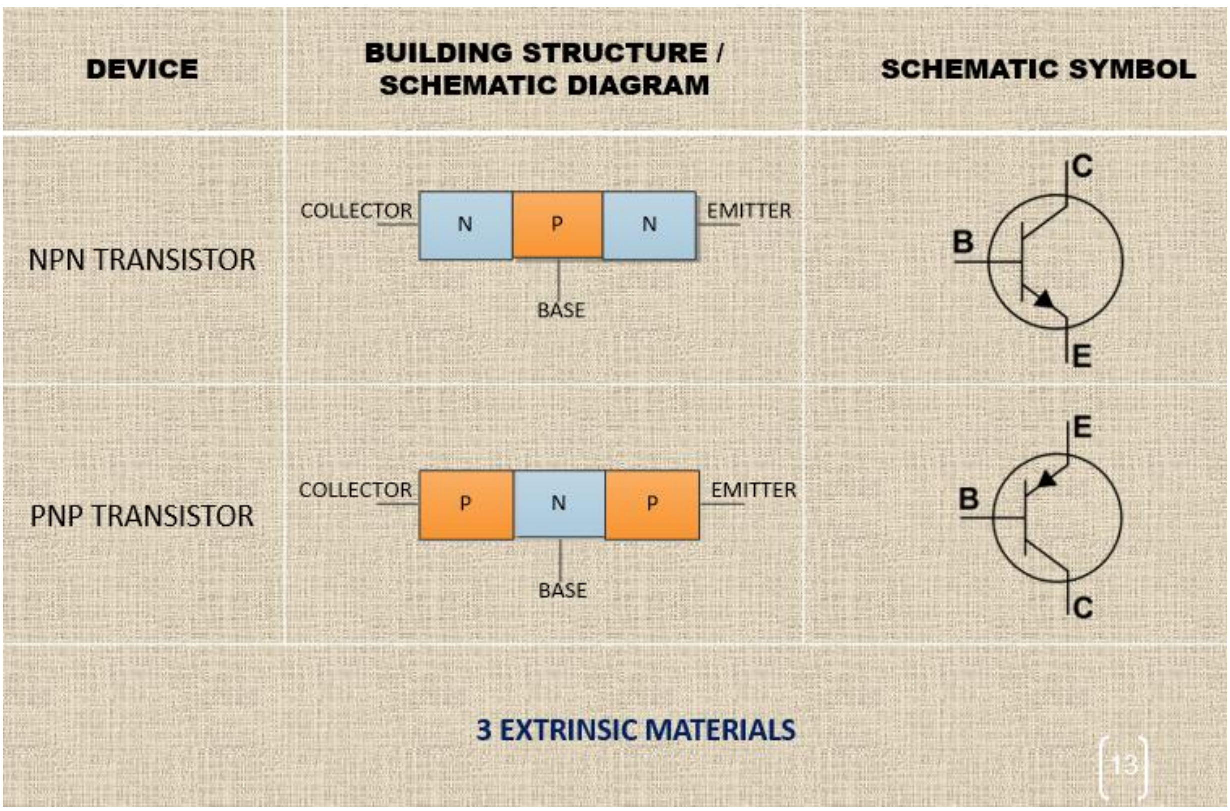
SEMICONDUCTOR DEVICES – 3 LAYER DEVICES

There are 2 types of BJT transistor which is NPN and PNP.



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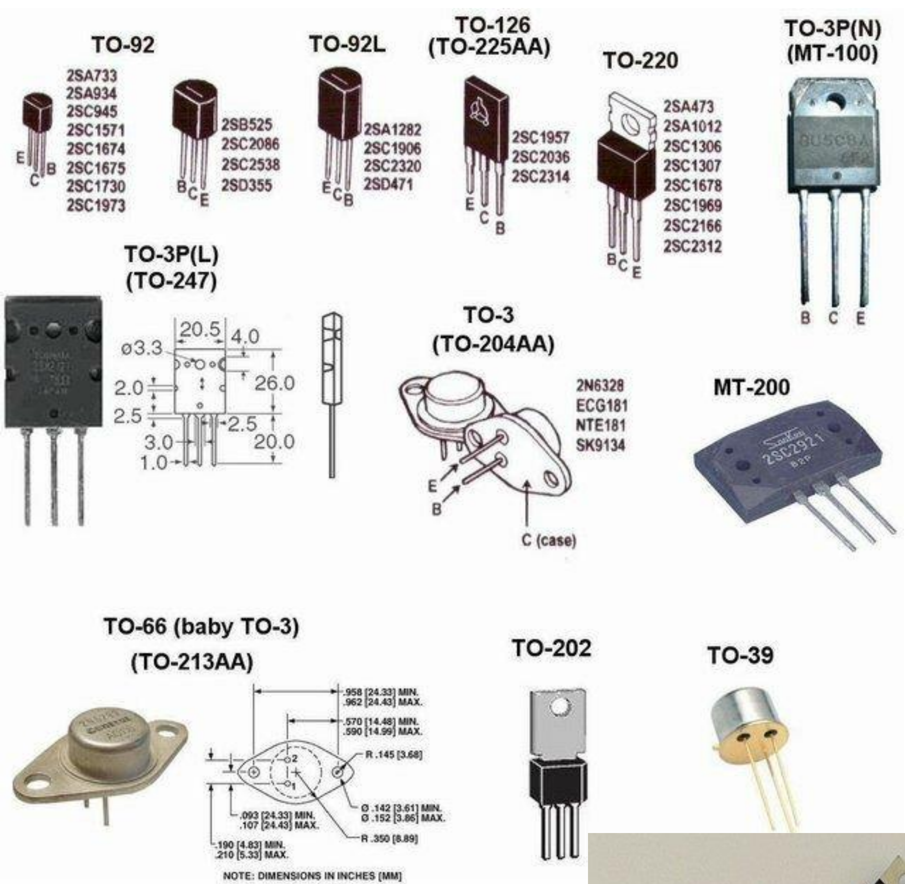
TRANSISTOR PACKAGING



TRANSISTOR

- BJT is another name for BJT (bipolar junction transistor). The use of both holes and electrons in the current flow is referred to as bipolar.

- Three doped semiconductor regions are separated by two PN junctions in a bipolar junction transistor (BJT).

- Emitter (E), base (B), and collector (C) are the three types of regions (C)

    - Emitter (E) has a lot of doping. Its function is to inject or emit electrons into the base (B)

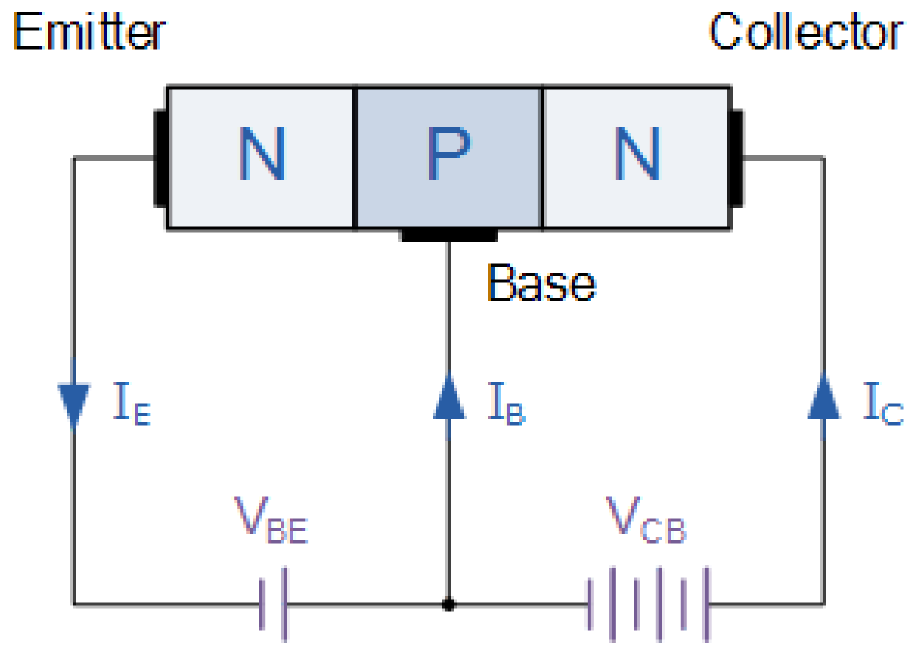
    - The base (B) region is very thin and does not have much doping. The collector receives the majority of the current carriers injected into the base from the emitter. The current flow from the collector to the emitter terminal is controlled by the base.

    - The collector (C) region is the largest of the three and is moderately doped (it must dissipate more heat than the emitter or base). Its job is to collect electrons from the base (B) so that they can be used in the circuit.

- Transistor can be used as a switch and as an amplifier.

TRANSISTOR BIASING

- Conditions for transistor to operate



- Pin EB (Emitter Base) – **Forward Biased** (+ve battery connect to P material while –ve battery connect to N material)

- Pin CB (Collector Base) – **Reverse Biased** (-ve battery connect to P material while +ve battery connect to N material)

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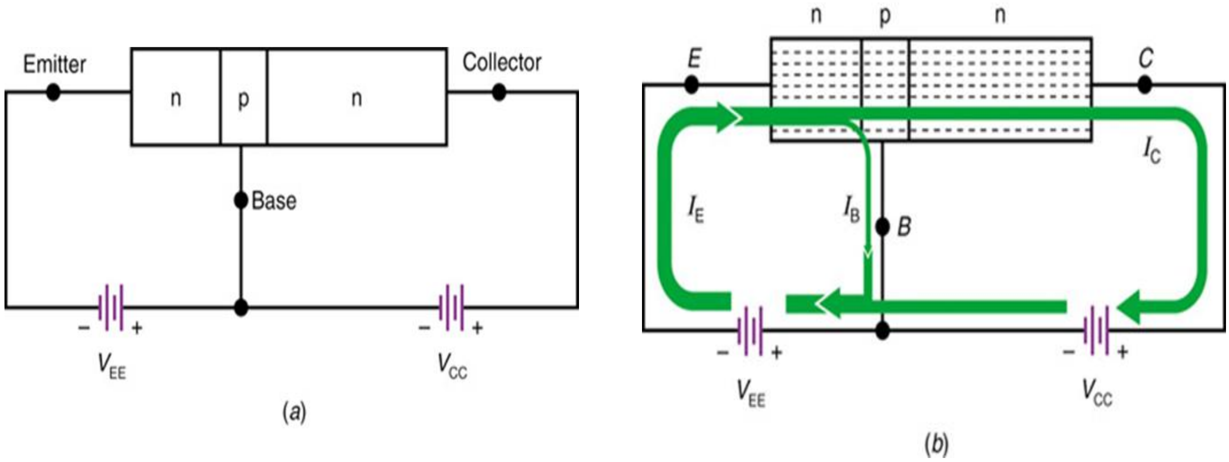
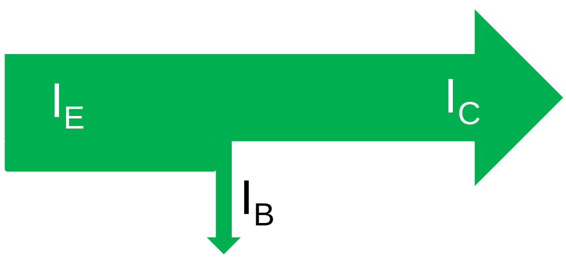
TRANSISTOR BIASING

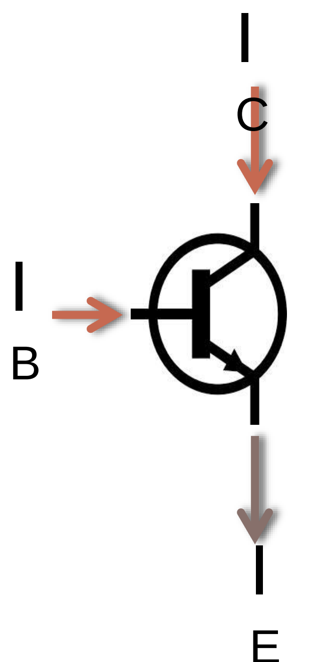


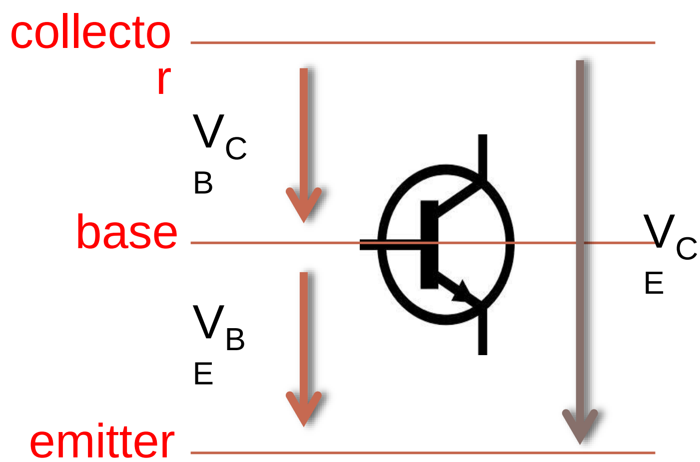


- As indicated in diagram (a), the EB lead is provided a forward biassed supply, and a high number of majority carriers (N-type electrons) diffuse across the junction (b).
- The electrons injected by the emitter become minority carriers once they reach the base.
- The base is manufactured from very thin material and is just mildly doped. As a result, only a small percentage of electrons moving from the emitter to the base area recombine with holes.
- Most electrons are driven into the collector layer and subsequently flow into the external collector lead because the collector is reverse biassed (N is linked to positive supply). These electrons exit the collection and flow into the voltage source's positive terminal.
- As a result, electrons leave the negative source terminal and enter the emitter area in a continuous stream.

TRANSISTOR BASIC FORMULA

- **K**irchoff **C**urrent **L**aw and **K**irchoff **V**oltage **L**aw





$I_E = I_B + I_C$

$V_{CE} = V_{CB} + V_{BE}$

$$V_{BE} = 0.7V\ (silicon)$$
$$V_{BE} = 0.3V\ (germanium)$$

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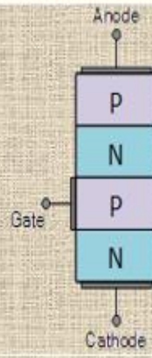
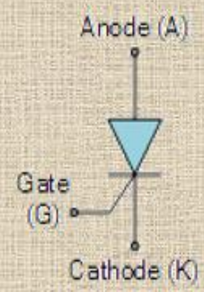
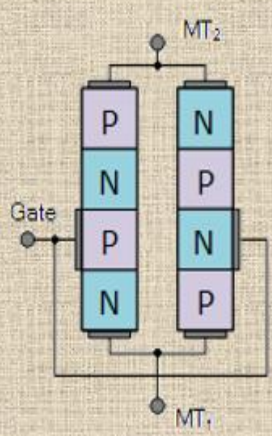
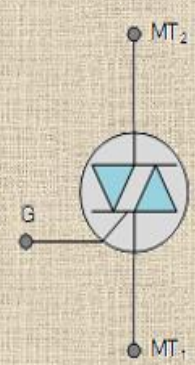
SEMICONDUCTOR DEVICES – 4 LAYER DEVICES

DEVICE	BUILDING STRUCTURE	SCHEMATIC SYMBOL
SCR		
TRIAC		

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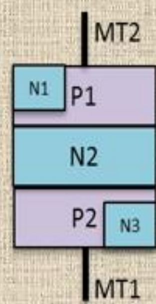
SEMICONDUCTOR DEVICES – 4 LAYER DEVICES

DEVICE	BUILDING STRUCTURE	SCHEMATIC SYMBOL
DIAC		
(4 EXTRINSIC MATERIALS)		

MT1 = MAIN TERMINAL 1 , MT2 = MAIN TERMINAL2

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THYRISTOR

- Thyristors are a class of semiconductor devices characterized by at least 4 layers of extrinsic materials (Example: SCR, TRIAC and DIAC).
- Some sources define SCR as thyristors. (SCR = Thyristors)
- Thyristors can control a relatively large amount of power and voltage.

Silicon Control Rectifier (SCR)

- SCR is a three-terminal device labelled: “Anode”, “Cathode” and “Gate” .
- Consist of three PN junctions which may be turned “ON” and “OFF” at an exceptionally quick pace.
- It requires a gate signal to turn it “ON” and once in “ON” state, it operates as a rectifying diode.
- As it need a signal at gate to triggered it “ON”, SCR can be described as a controlled rectifying diode.

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Silicon Control Rectifier (SCR)

- The SCR is a power electronic device as it can handle large amount of current and voltage.
- Generally the SCR are used in many applications such as switches, power control, conversion mode, motor speed control, phase control and surge protector.
  - Static Switch:
    Used as a switch for power-switching in various control circuits.
  - Power Control:
    Used to regulate the amount of power delivered to a load.
  - Surge Protection:
    When the voltage rises beyond the threshold value, the SCR is turned on to dissipate the charge or voltage quickly.
  - Power Conversion:
    Conversion of power source from ac to ac, ac to dc and dc to ac.

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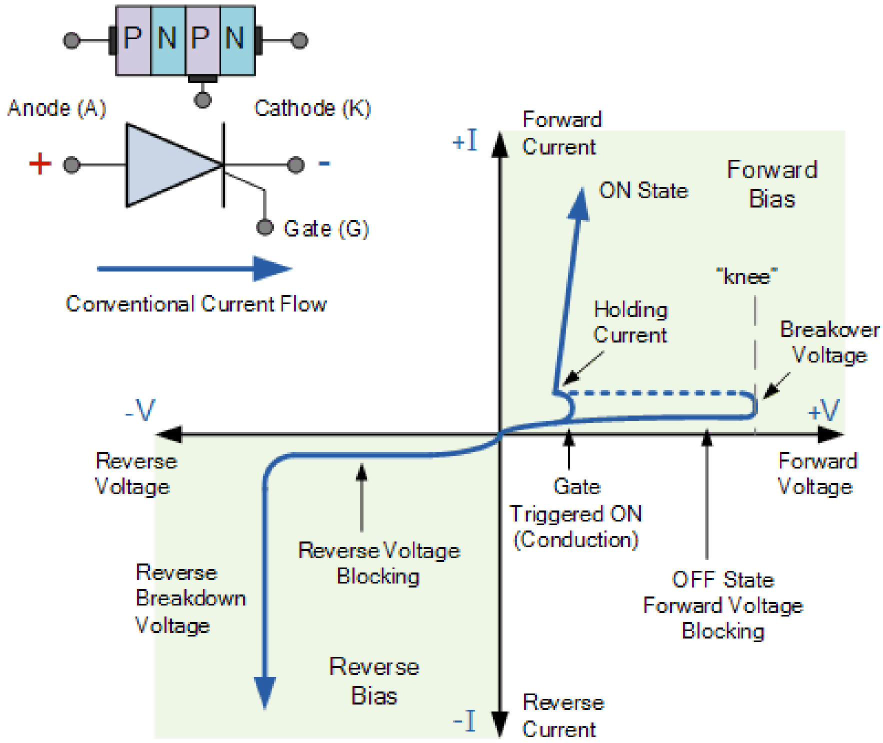
Silicon Control Rectifier (SCR)

SCR I-V Characteristic Curve



- Reverse blocking voltage
  - Voltage is applied in the direction that would be blocked by a SCR.
  - a very small current (leakage current) flowing through the SCR in reverse biased connections.
- Forward blocking voltage
  - Voltage is applied in the direction that would cause a SCR to conduct, but the voltage still not exceed breakdown voltage (not yet been triggered into conduction).
  - a very small current (leakage current) flowing through the SCR in forward biased connections.
- Holding current
  - The point/level where the state of current flow changes from blocking to conduction region and vice-versa.
- Breakdown / Breakover voltage
  - Level of voltage when sudden increase of forward current takes place.
  - SCR will remain conducting until forward current drops below holding current level.

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Silicon Control Rectifier (SCR)

- **SCR operations**
  - Like normal diode, in order for current to flow through the SCR, the anode and cathode terminal must be given the forward bias voltage.
  - However, forward bias voltage alone is still not enough to triggered the SCR.
  - The SCR only can be triggered by applying a sufficient positive voltage pulse at gate terminal.
  - Once it starts conducting no more gate voltage is required to maintain it in ON state (latch).

- **How to stop SCR from conducting**
  - Removing the supply voltage
  - Change to polarity of supply voltage
  - Shorted the anode and cathode pin
  - Reducing its anode to cathode current by cutting of their current path using circuit breaker such as switch.

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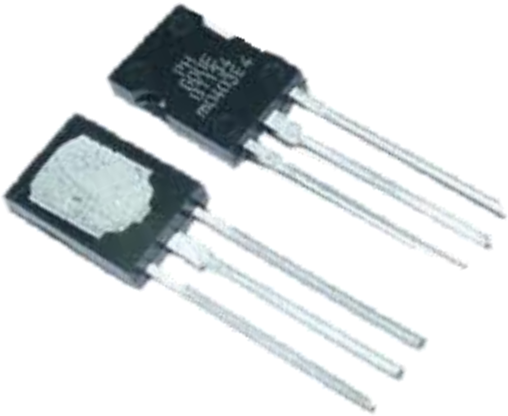
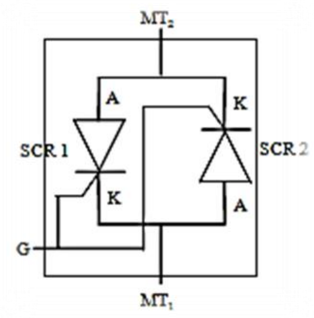
Triode for Alternating Current (TRIAC)



- One of the problems of using a SCR for controlling purposed is that like a diode, the SCR is a unidirectional device, meaning that it passes current in one direction only, from Anode to Cathode.



- The triac works in the same way as two SCRs linked in reverse parallel, but with a single gate connection.
- This allows the triac to be triggered into conduction while having a voltage across it of either polarity.
- Like SCR, triac is a three-terminal device but it is a “bidirectional” device.

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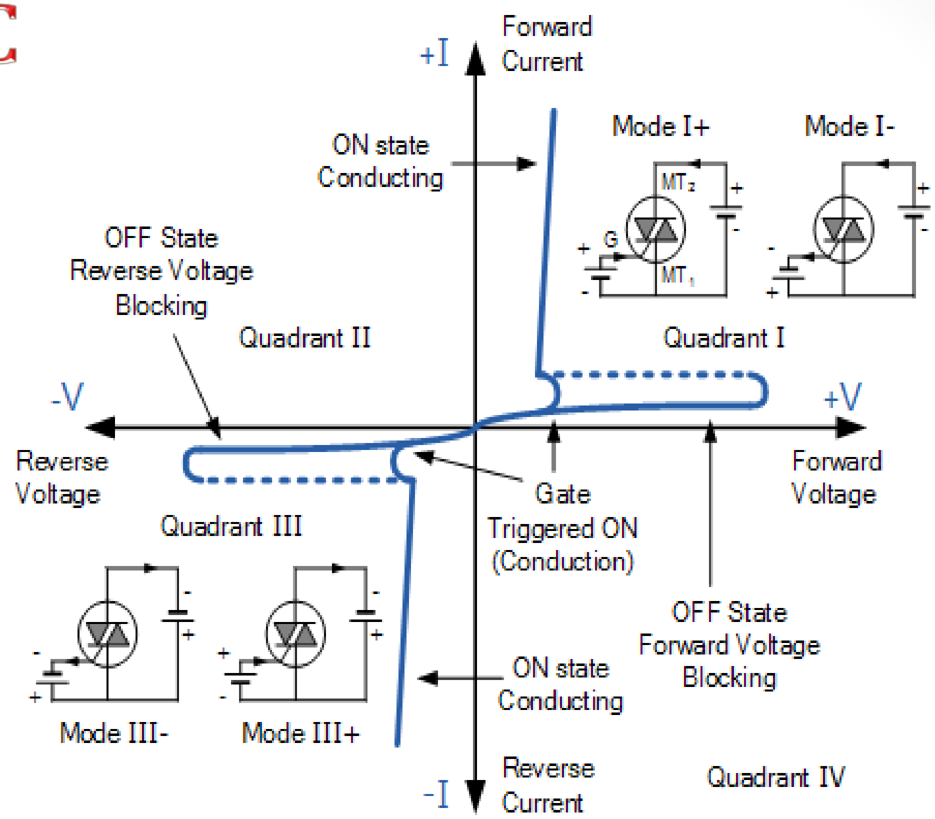
Triode for Alternating Current (TRIAC)

- Because a triac conducts in both directions of a sinusoidal waveform, the idea of an anode and cathode terminal used to identify the main power terminals of an SCR is substituted with the identifications MT1, Main Terminal 1, and MT2, with the Gate terminal G referred the same.
- Triac Applications
  - for switching and power control of AC systems

TRIAC

Triac I-V Characteristic Curve

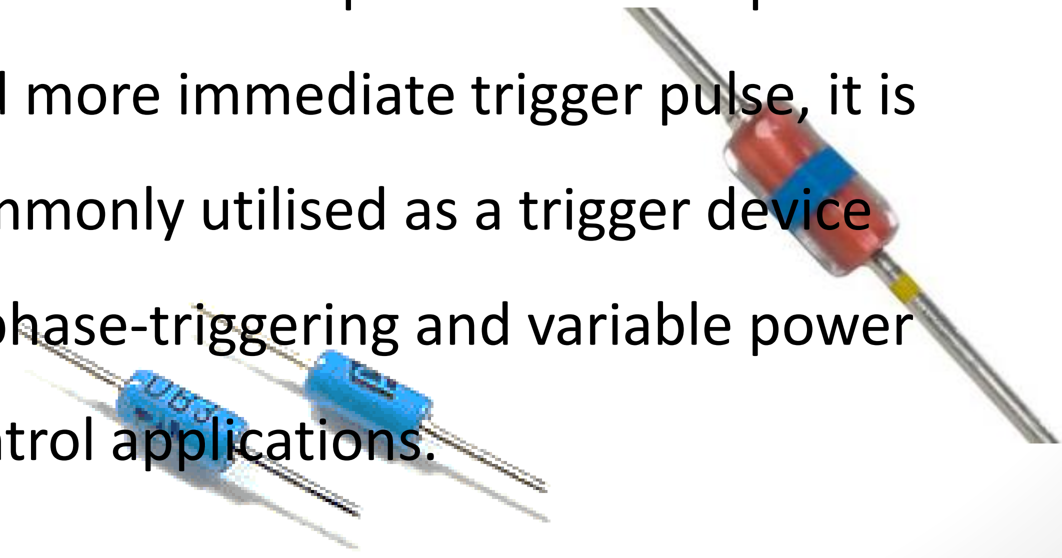


- Triac characteristic curve is very similar to the SCR characteristic curve except during reverse bias.
- During the reverse bias, the characteristic curve is similar to a forward bias curve except it is in a opposite directions.
- Triac can conduct current in either direction when triggered by a single gate pulse.
- Just like silicon controlled rectifiers (SCR's), triac's also require a minimum holding current (I_H) to maintain conduction.

Diode for Alternating Current (DIAC)

- A Diac is a bi-directional device with two terminals and four layers that may be switched from its off state for either polarity of applied power.

- Because diac helps create a sharper and more immediate trigger pulse, it is commonly utilised as a trigger device in phase-triggering and variable power control applications.



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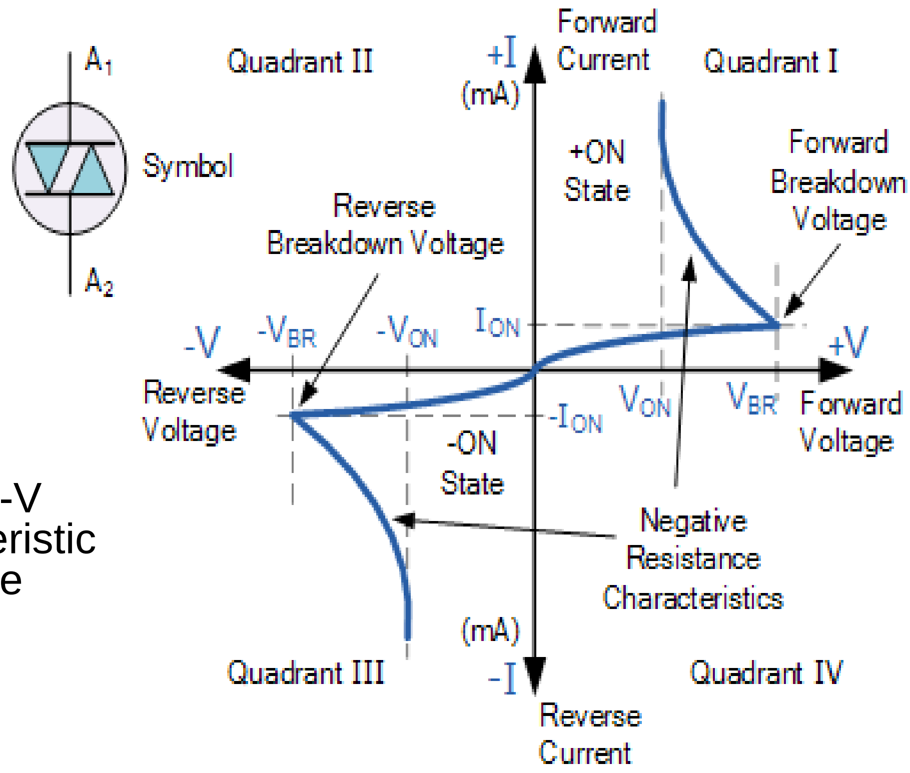
Diode for Alternating Current (DIAC)



Diac I-V Characteristic Curve

- Until the applied voltage is greater than the breakdown voltage, the diac prevents current flow in both directions.
- When the device fails, the diac conducts heavily in the same way that a zener diode does when it passes a sudden voltage pulse.
- Diacs breakdown voltage is the name given to this voltage point.
- The voltage across a standard zener diode would remain constant as the current increased. The voltage in the diac, on the other hand, decreases as the current increases.

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DIFFERENCES BETWEEN SCR AND TRIAC

SCR	TRIAC
- Passes current in one direction only	- Passes current in bi-direction
- Need a positive triggered voltage to operate	- Can be triggered using positive and negative triggered voltage in order to operate

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DIFFERENCES BETWEEN SCR AND DIAC

SCR	DIAC
- Passes current in one direction only	- Passes current in bi-direction
- Can be operate only by applying a sufficient positive voltage pulse at gate terminal	- Can be operate only when the applied voltage is greater than breakdown voltage

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DIFFERENCES BETWEEN SCR AND DIODE

SCR	DIODE
- Has 3 pin (gate, anode & cathode)	- Has 2 pin (anode & cathode)
- Can be operate only by applying a sufficient positive voltage pulse at gate terminal	- Can be operate when the applied forward biased voltage is equal or greater than threshold voltage

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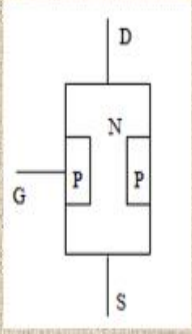
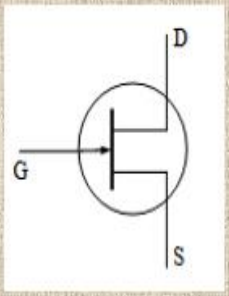
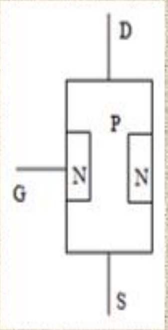
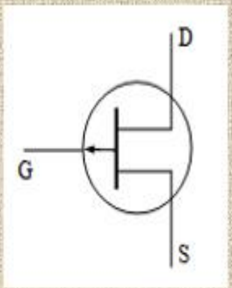
UNIPOLAR SEMICONDUCTOR DEVICES

DEVICE	BUILDING STRUCTURE	SCHEMATIC SYMBOL
JFET N-TYPE CHANNEL		
JFET P-TYPE CHANNEL		

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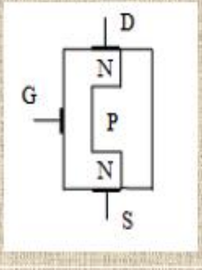
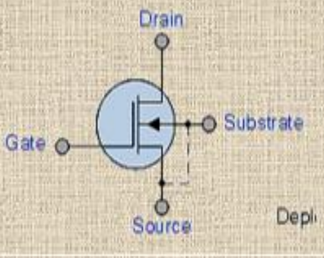
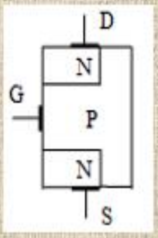
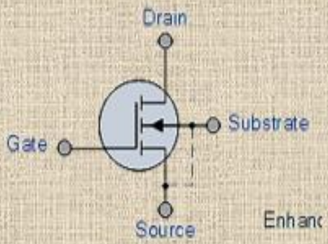
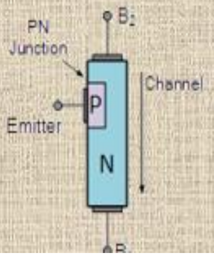
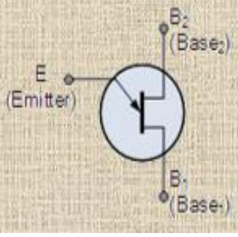
UNIPOLAR SEMICONDUCTOR DEVICES

DEVICE	BUILDING STRUCTURE	SCHEMATIC SYMBOL
DE-MOSFET N-TYPE		
E-MOSFET N-TYPE		
UJT		

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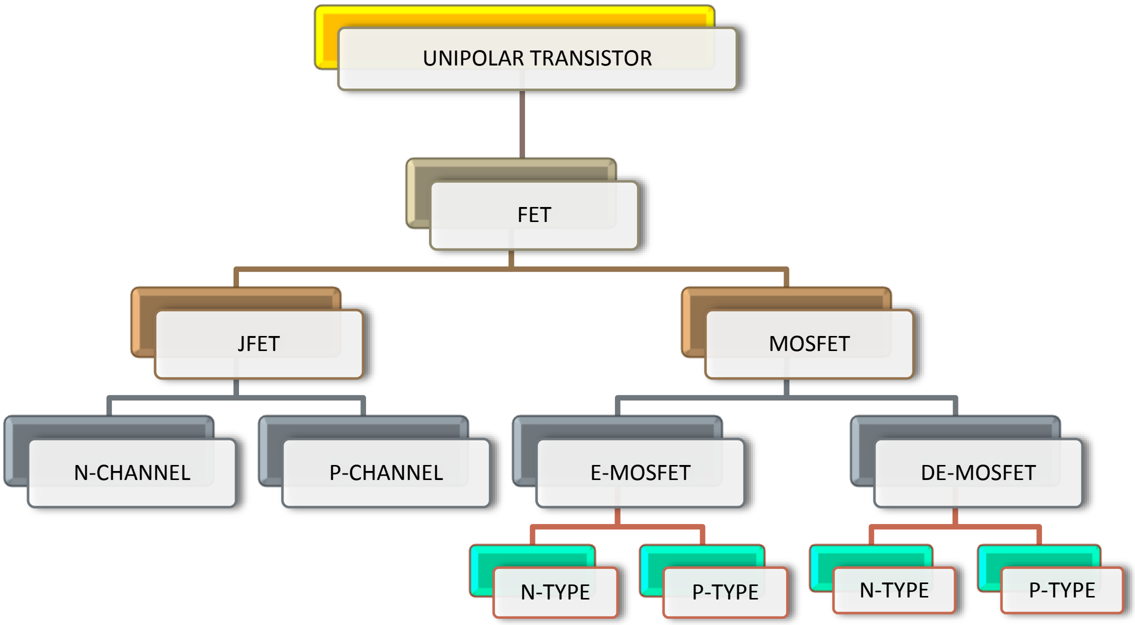
UNIPOLAR TRANSISTOR DEVICES



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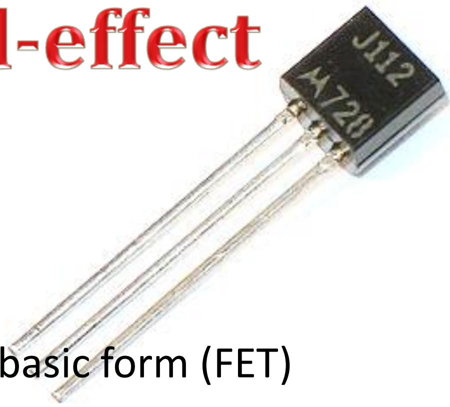
Junction Gate Field-effect Transistor (JFET)



- A field-effect transistor in its most basic form (FET)
- JFETs, unlike bipolar transistors, are only voltage-controlled and do not require a biassing current.
- Between the source and drain terminals, an electric charge travels across a semiconducting channel.
- When there is no potential difference between the gate and source terminals of a JFET, it is normally ON.
- They're three-terminal semiconductor devices that can be employed as switches, amplifiers, or voltage-controlled resistors that can be controlled electronically.

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JFET VS BJT

- Differences between Field Effect Transistor (FET) and Bipolar Junction Transistor (BJT).
  - High input impedance
  - Voltage controlled device
  - Not sensitive to heat
  - Only used electron as current carrier

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Metal Oxide FET (MOSFET)

- The "Metal Oxide" Gate electrode of a MOSFET is electrically insulated from the primary semiconductor N-channel or P-channel by a very thin layer of insulating material, often silicon dioxide, also known as glass.

- NO current flows into the gate since the Gate terminal is isolated from the main current carrying channel, and the MOSFET, like the JFET, serves as a voltage regulated resistor.

- MOSFETs are three-terminal devices featuring a Gate, Drain, and Source, and are available in both P-channel (PMOS) and N-channel (NMOS) configurations (NMOS).

- MOSFETs are available in two basic forms:

  - **The Gate-Source voltage (VGS) is required to turn the device "OFF" in a depletion type transistor. A "Normally Closed" switch is equivalent to a depletion mode MOSFET.**

  - **To turn the device "ON," the transistor requires a Gate-Source voltage (VGS). A "Normally Open" switch is equivalent to an enhancement mode MOSFET.**

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Uni-junction transistor (UJT)

- Gate pulse, timing circuits, and control of thyristors and triacs for AC power control applications are all possible with this three-terminal device.
- Unijunction transistors, like diodes, are made up of separate P-type and N-type semiconductor materials that come together to form a single junction (hence its name Uni-Junction).
- Although the Unijunction Transistor is called a transistor, its switching characteristics are substantially different from those of a standard bipolar or field effect transistor since it is utilised as an ON-OFF switching transistor rather than a signal amplifier.

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FINAL EXAM QUESTIONS (1)

JUNE 2014

1. Explain the operation of ideal diode. **(3M)**
2. Explain TWO main conditions in biasing a transistor. **(6M)**
3. Explain the following terms based on the characteristic curves of SCR. **(12M)**
   i. Forward Blocking Current
   ii. Reverse Blocking Current
   iii. Holding Current
   iv. Break over Voltage
4. Differentiate between SCR and TRIAC. **(4M)**

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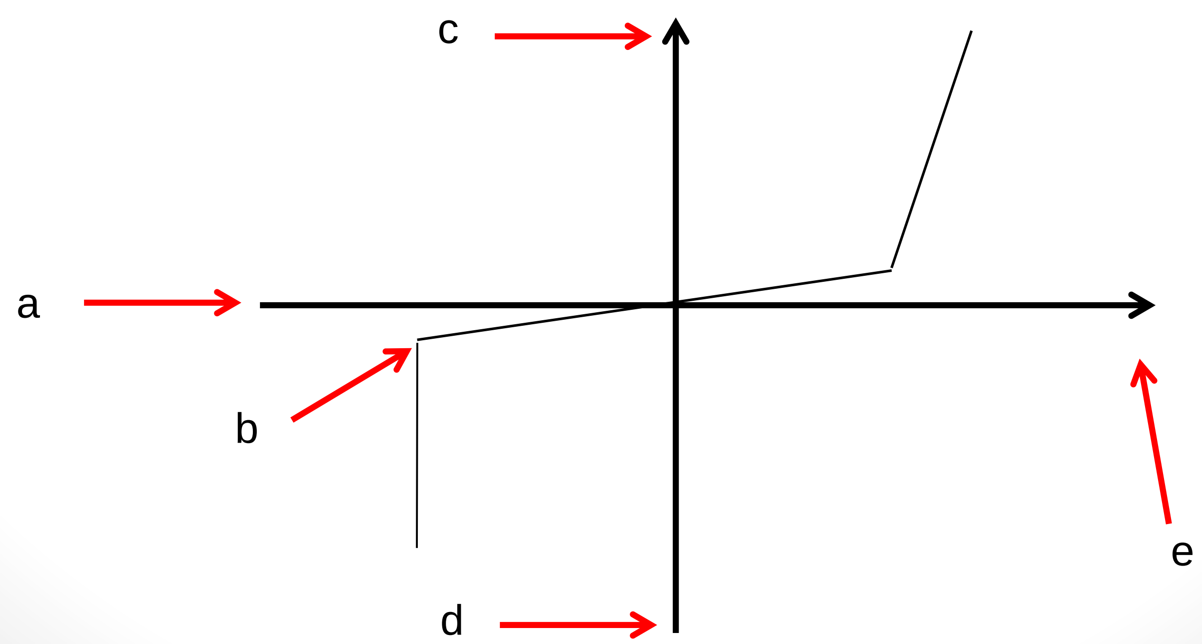
FINAL EXAM QUESTIONS (2)

JUNE 2013

1. Draw and label the schematic symbol of diode. **(1M)**
2. Explain the operation of diode when in forward bias and reverse bias. **(4M)**
3. Draw the schematic of a LED and state 3 characteristic of a LED. **(5M)**
4. Draw and label the structure and schematic symbol of transistor NPN and PNP. **(7M)**
5. Based on figure below; **(8M)**
   i. Label the I-V characteristic curve for zener diode.
   ii. Explain the advantages between zener diode and normal diode.



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FINAL EXAM QUESTIONS (3)

DEC 2012

1. Draw and label the schematic symbol of component below; **(15M)**
   i. LED
   ii. FET
   iii. TRIAC
   iv. NPN Transistor
   v. PNP Transistor

2. State 3 differences between Field Effect Transistor (FET) and Bipolar Junction Transistor (BJT).
   (6M)

3. Explain the concept of ideal diode during forward bias and reverse bias. **(4M)**

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FINAL EXAM QUESTIONS (4)

JAN 2010

1. Draw and label the symbol and structure of diode. **(2M)**
2. Sketch and label an I-V curve of silicon diode and define the following terms.
   i. Forward current
   ii. Reverse current
   iii. Knee Voltage
   iv. Breakdown voltage
   v. Burn limit
   (12M)
3. State 2 bias conditions for transistor operation. **(2M)**
4. Transistors have 3 terminals. Describe the function of the following terminals;
   i. Emitter
   ii. Base
   iii. Collector
   (6M)
5. List 3 function of SCR.
   (3M)

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FINAL EXAM QUESTIONS (5)

APR 2007

1. Draw schematic symbol of a LED.
   (3M)
2. Sketch and label an I-V curve of silicon diode and define the following terms.
   i. Forward current
   ii. Reverse current
   iii. Breakdown voltage
   iv. Knee voltage
   (10M)
3. State 2 bias conditions for enable a transistor to operate. **(4M)**
4. Draw a structure diagram and schematic symbol for; **(8M)**
   i. transistor **NPN**
   ii. transistor **PNP**

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FINAL EXAM QUESTIONS (6)

JAN 2007

1. Sketch and label an I-V curve of silicon diode and define the following terms.
   i. Forward current
   ii. Reverse current
   iii. Knee Voltage
   iv. Breakdown voltage
   v. Burn limit
   (8M)
2. State 3 advantages of a zener diode compared to a normal diode. **(3M)**
3. Draw the structure diagram and schematic symbol for a SCR. **(4M)**
4. State 3 method can be used to stop a SCR operation. **(6M)**
5. State 2 differences between DIAC and TRIAC. **(4M)**

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- Irish poet Samuel Beckett

"'Have you ever attempted it? Never have I failed. It doesn't matter. Please try once more. Fail once more. "Fail better,"

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