

Fundamentals of Electronics and Communication Engineering

1BECE105

Module 1

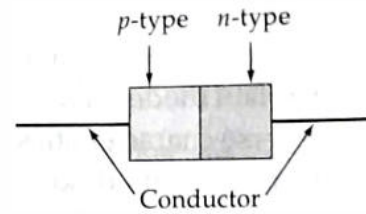
Diodes and Their Application: Introduction, Characteristics and Parameters, Diode Approximation, DC Load Line Analysis, Half Wave Rectifier, Full Wave Bridge Rectifier, Capacitor Filter Circuit (Only Qualitative Approach), Zener Diode and Its Use in Voltage Regulation, Diode Logic Circuit.

Prepared By

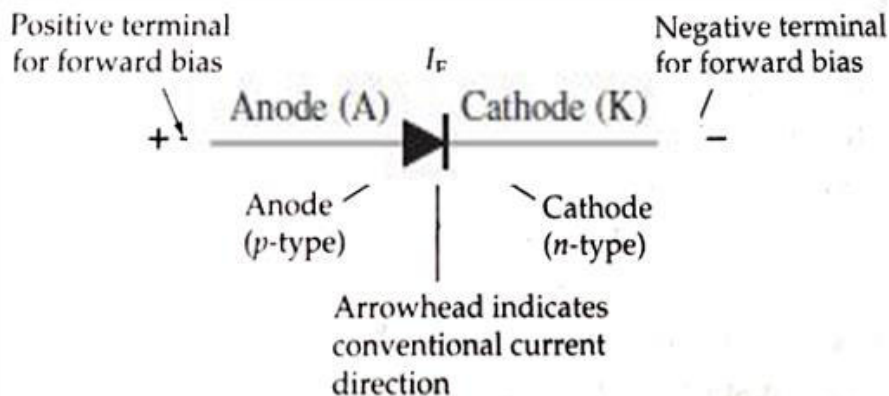
Dr. Shalini Hanok
Associate Professor
Dept. of ECE
ATMECE, Mysore

PN Junction Diode

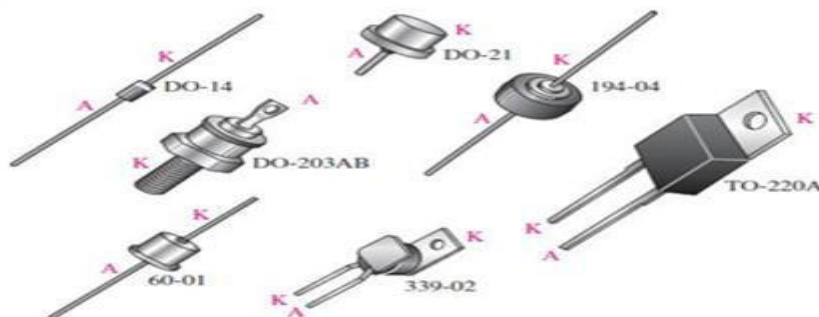
- A PN junction diode is a two terminal unidirectional device with a *p*-type anode and an *n*-type cathode.
- A PN junction provided with copper wire (conductor) connecting leads becomes an electronic device known as a *diode*.
- Diodes are used in a wide range of applications like rectification, voltage regulation, protection against high voltage and wave shaping.



A semiconductor diode is a PN junction with conductors on each side of the junction for connecting the device to a circuit



Symbol of a diode

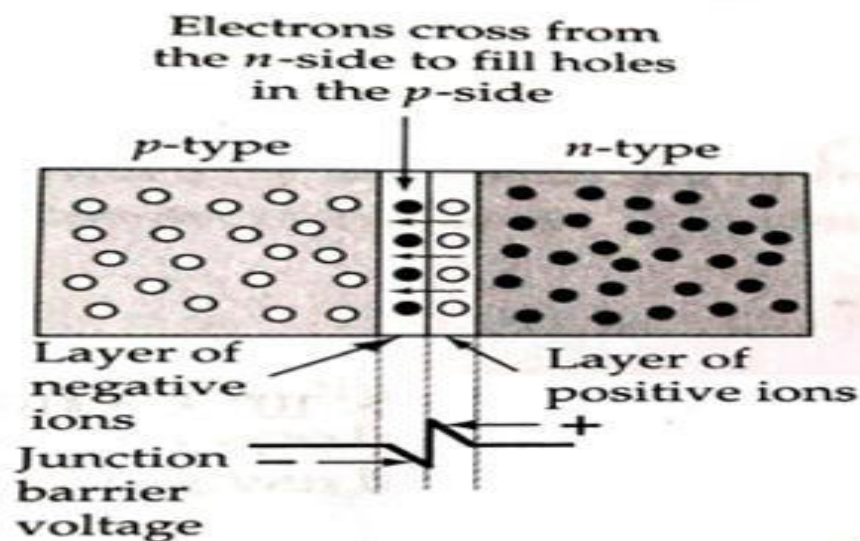
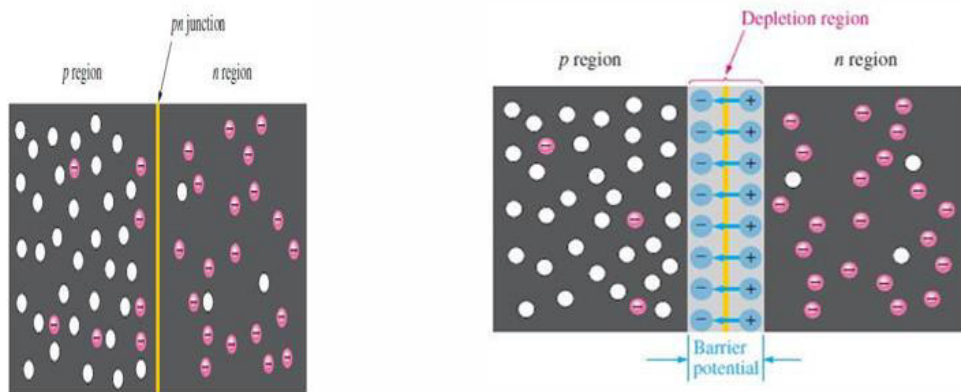


Typical diode packages

Diode Operation and Characteristics

Unbiased PN Junction

- Since holes and electrons are close together at the junction, some free electrons from the n-side are attracted across the junction to fill adjacent holes on the p-side.
- They are said to diffuse across the junction from a region of high carrier concentration to one of low concentration.
- The free electrons crossing the junction create negative ions on the p side by giving some atoms one more electron than their total number of protons.
- The electrons also leave positive ions (atoms with one lesser electron than the number of protons) behind them on the n-side.



Depletion Region

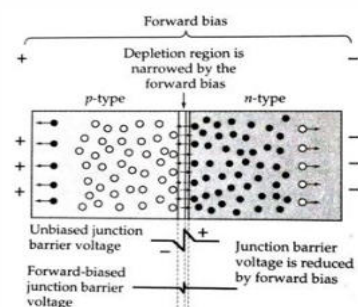
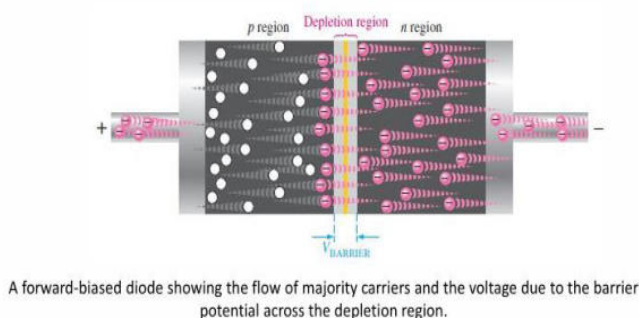
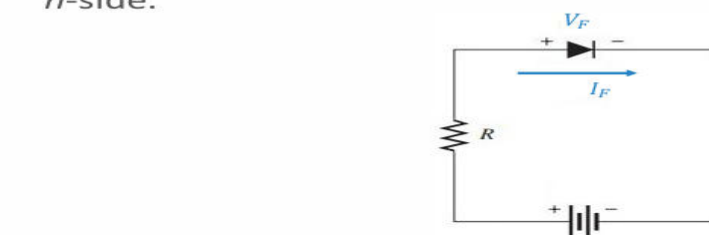
- The movement of charge carriers across the junction leaves a layer on each side that is depleted of charge carriers.
- This region is called the depletion region.
- On the n-side, the depletion region is made up of donor impurity atoms that have become positively charged by losing the free electron associated with them.

Barrier Voltage

- On the p-side, the depletion region is made up of acceptor impurity atoms that have become negatively charged by losing the hole associated with them.
 - The n-type and p-type materials are both electrically neutral before the diffusion of charge carriers across the junction.
 - The diffusion of charge carriers creates positive and negative ions on n side and p-side, which results in an electric field near the junction.
 - This creates a potential difference across the depletion region which acts as a barrier.
 - This region is called the barrier voltage or barrier potential or junction potential, which is negative on the p-side and positive on the n-side.
 - Typical barrier voltages at 25°C are 0.3 V for germanium and 0.7 V for silicon junctions.
- Forward Biasing of Diode** • A diode is said to be forward biased when the positive terminal of the battery is connected to the p-side and negative terminal to the n-side.

Forward Biasing of Diode

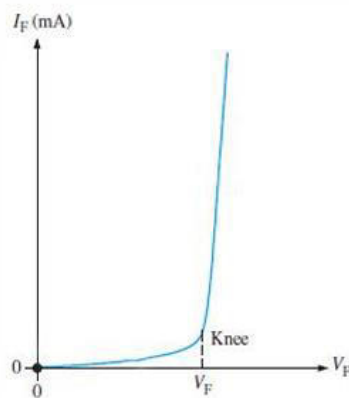
- A diode is said to be forward biased when the positive terminal of the battery is connected to the *p*-side and negative terminal to the *n*-side.



The holes on the p-side, being positively charged particles, are repelled from the positive terminal and driven toward the junction.

- Similarly, the electrons on the n-side are repelled from the negative terminal toward the junction.
- As a result, the width of the depletion region and the barrier voltage are both reduced.
- When the applied bias voltage is progressively increased from zero, the barrier voltage gets smaller until it effectively disappears and charge carriers easily flow across the junction.
- Electrons from the n-side are now attracted to the positive bias terminal on the p-side, and holes from the p-side are attracted to the negative terminal on the n-side.
- The majority charge carrier current flows, and the junction is said to be forward biased

Forward Characteristic

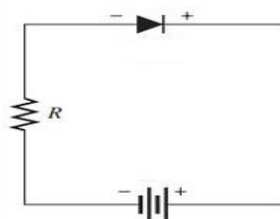


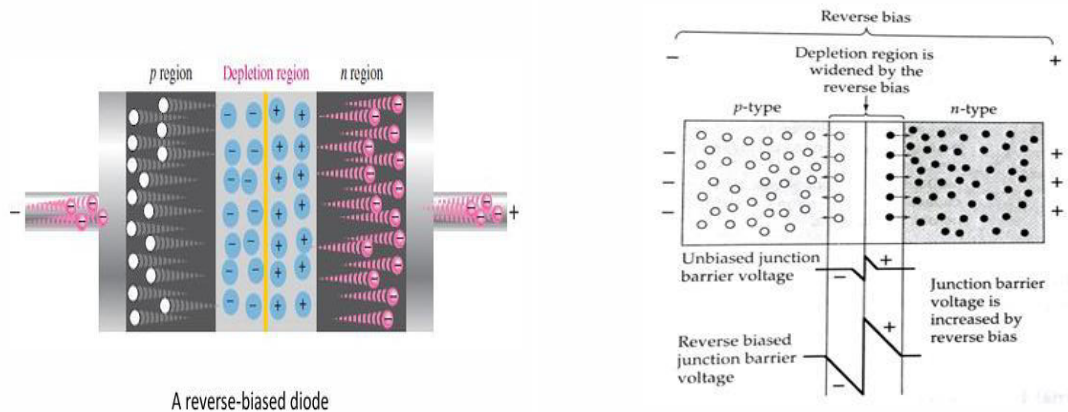
Forward Characteristic (V-I characteristic of a forward biased diode)

- From the forward characteristic, it can be seen that there is a very little forward current until V_F exceeds the junction barrier voltage (0.3 V for germanium and 0.7 V for silicon).
- When V_F is increased from zero toward the knee of the characteristic, the barrier voltage is progressively overcome, allowing more majority charge carriers to flow across the junction.
- Above the knee of the characteristic, I_F increases almost linearly with increase in V_F .

Reverse Biasing of Diode

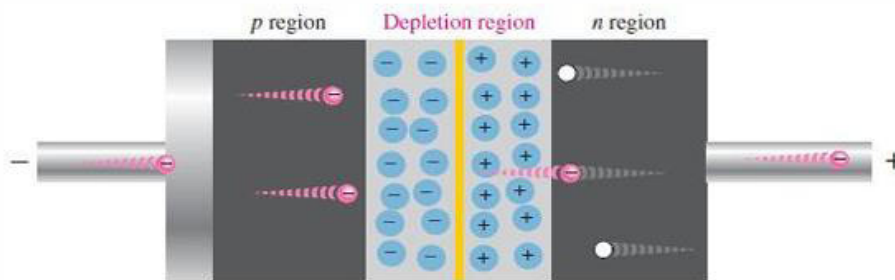
- A diode is said to be reverse biased when the positive terminal of the battery is connected to the *n*-side and negative terminal to the *p*-side.





A reverse-biased diode

- Electrons from the n-side are attracted to the positive terminal away from the junction, and holes on the p-side are attracted to the negative terminal away from the junction.
- This causes the depletion region to be widened and the barrier voltage to be increased.
- With the barrier voltage increase, there is no possibility of a majority charge carrier current flow across the junction, and the junction is said to be reverse biased.
- Although, there is very small reverse current and hence the reverse biased PN junction can be said to have a high resistance.

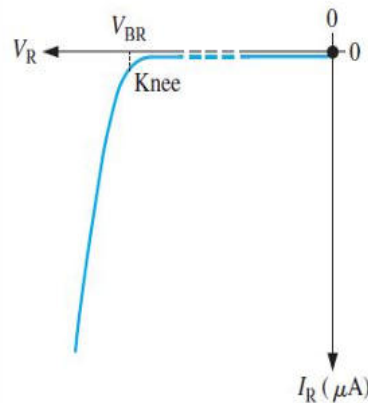


The extremely small reverse current in a reverse-biased diode is due to the minority carriers from thermally generated electron-hole pairs.

- Although there is no possibility that a majority charge carrier current can flow across a reverse biased junction, minority carriers generated on each side can still cross the junction.
- Electrons in the p-side are attracted across the junction to the positive voltage on the n-side, and holes on the n-side may flow across to the negative voltage on the p-side.
- Since only a very small reverse bias voltage is necessary to direct all available minority carriers across the junction, further increase in bias voltage does not increase the current level.
- This current is known as reverse saturation current.
- The reverse saturation current is normally a very small quantity, ranging from nanoamperes (nA) to microamperes (μA).

- If the reverse bias voltage is increased to a value called the breakdown voltage, the diode breaks down and the reverse current will increase drastically.

Reverse Characteristic



Reverse Characteristic (V-I characteristic of a reverse biased diode)

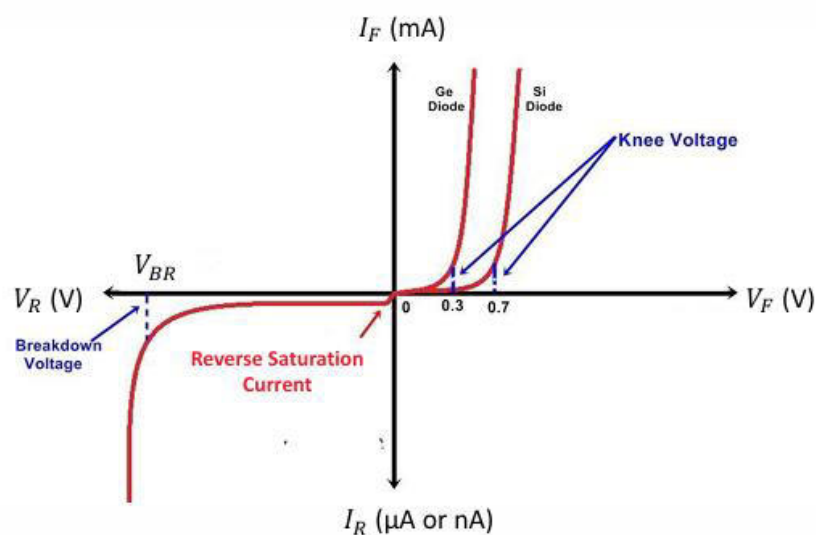
From the reverse characteristic, it can be seen that I_R is largely a minority charge carrier reverse saturation current.

- A small increase in I_R can occur with increasing reverse bias voltage, as a result of minority charge carriers leaking along the junction surface. •

Normally, the reverse current is very small and it can be neglected.

- However, if the reverse bias voltage is increased to a value called the breakdown voltage, the reverse current will drastically increase.

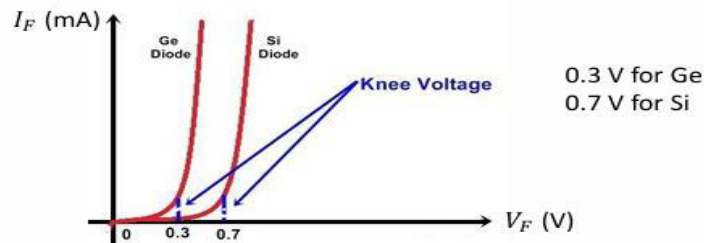
Forward and Reverse Characteristic



Diode Parameters

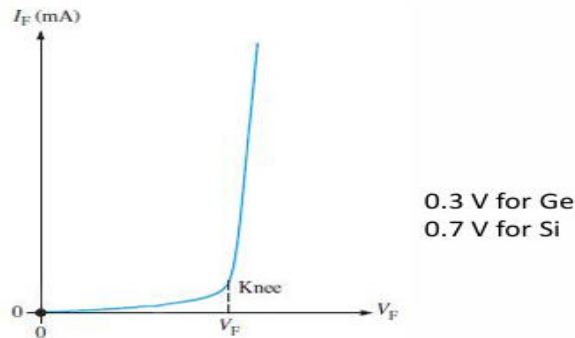
Knee Voltage

- It is the small forward voltage applied to a forward biased diode at which current starts increasing exponentially.
- Also called *threshold voltage* (V_T) or *cut-in voltage*.



Forward Voltage Drop (V_F)

- It is the voltage drop across a forward biased diode.

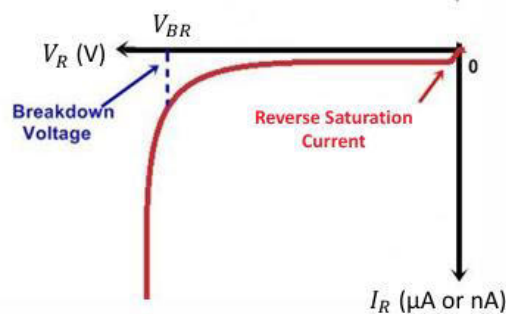


Maximum Forward Current ($I_{F(max)}$)

- It is the maximum current that a forward biased diode can conduct without burning out.

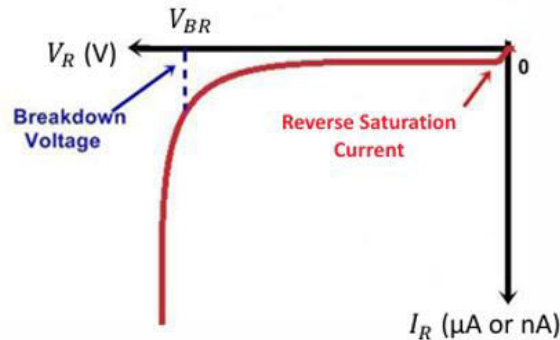
Reverse Saturation Current ($I_{R(sat)}$ or I_s)

- It is the small amount of constant reverse current flowing through the diode when it is reverse biased.



Reverse Breakdown Voltage (V_{BR})

- It is the value of reverse voltage at which the diode breaks down and the reverse current increases drastically.
 - The diode gets damaged due to breakdown.



Peak Inverse Voltage (PIV)

- It is the maximum value of reverse voltage that can be applied to the diode without causing breakdown.
 - It is also called PIV rating of the diode.

Maximum Power Rating (MPR)

- It is the maximum power that the diode can dissipate safely, without increasing the junction temperature above its limiting value.

Static Resistance

- Static resistance is also called dc resistance.

Static Forward Resistance (R_F)

- It is the resistance offered by the forward biased PN junction diode and calculated at a particular point on the forward characteristics.

The diagram shows a diode symbol with the anode (+) at the top and the cathode (-) at the bottom. A forward current I_F is shown flowing from the anode to the cathode. The forward voltage V_F is indicated across the diode. To the right, a resistor symbol is shown with the equation $R_F = \frac{V_F}{I_F}$.

(a) Forward resistance

Static Reverse Resistance (R_R)

- It is the resistance offered by the reverse biased PN junction diode and calculated at a particular point on the reverse characteristics.

The diagram shows a diode symbol with the anode (+) at the top and the cathode (-) at the bottom. A reverse current I_R is shown flowing from the cathode to the anode. The reverse voltage V_R is indicated across the diode. To the right, a resistor symbol is shown with the equation $R_R = \frac{V_R}{I_R}$.

(b) Reverse resistance

Static Resistance – Numerical Example

From the characteristics, at $V_R = 50\text{ V}$, $I_R \approx 100\text{ nA}$

The reverse resistance,

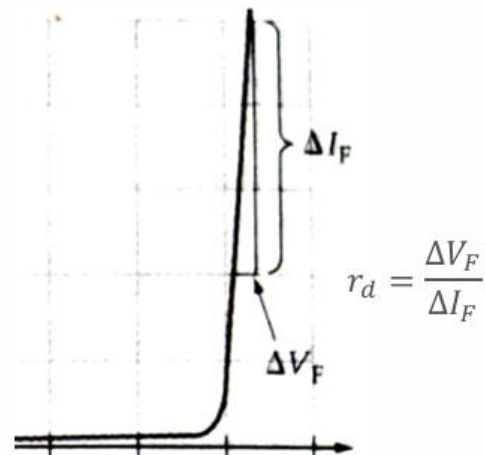
$$R_R = \frac{V_R}{I_R}$$

$$R_R = \frac{50\text{ V}}{100\text{ nA}}$$

$$R_R = 500\text{ M}\Omega$$

Dynamic Resistance

- The dynamic resistance of the diode is the resistance offered to the changing levels of forward voltage.
 - It is indicated by r_d .
- It is the reciprocal of the slope of the forward characteristics beyond the knee.
- Dynamic resistance is also called *incremental resistance* or *ac resistance*.



Dynamic Resistance

- The dynamic resistance can also be calculated from the rule-of-thumb equation

$$r'_d = \frac{26\text{ mV}}{I_F}$$

- For example, the dynamic resistance for a diode passing a 1 mA forward current is

$$r'_d = \frac{26\text{ mV}}{I_F} = \frac{26\text{ mV}}{1\text{ mA}} = 26\text{ }\Omega$$

Diode Approximations

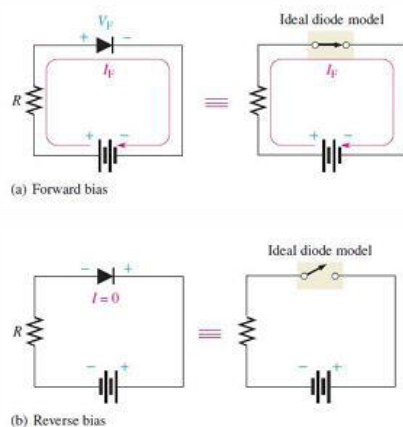
Equivalent Circuits of Diode

- An equivalent circuit for a device is a circuit that represents the device behaviour.
- A diode equivalent circuit may be substituted for the device when investigating a circuit containing the diode.

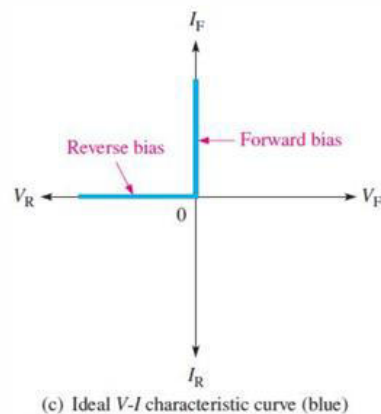
Ideal Model

- An ideal diode (or perfect diode) would have zero forward resistance and zero forward voltage drop.
- It would also have an infinitely high reverse resistance, which would result in zero reverse current.
- The ideal model of a diode is the least accurate approximation and can be represented by a simple switch.
- When the diode is forward biased, it ideally acts like a closed switch (ON).
- When the diode is reverse biased, it ideally acts like an open switch (OFF).
- The barrier voltage, the forward dynamic resistance and the reverse current are all neglected.

Ideal Model



Ideal Model of a Diode



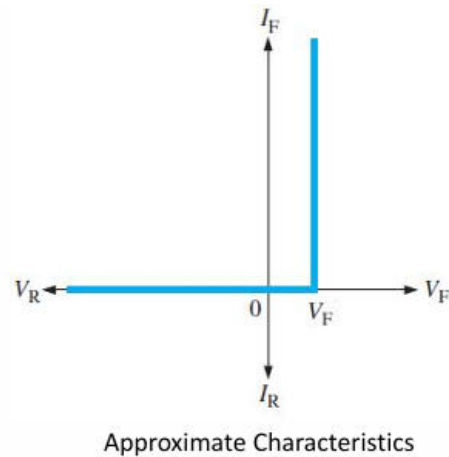
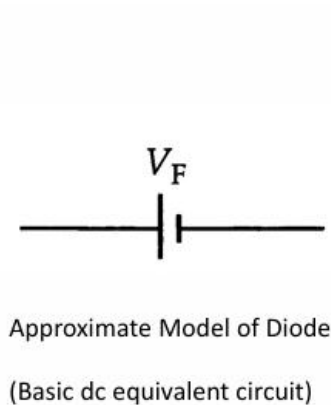
(c) Ideal V-I characteristic curve (blue)

An ideal diode has $V_F = 0$, $I_R = 0$ and $r_d = 0$

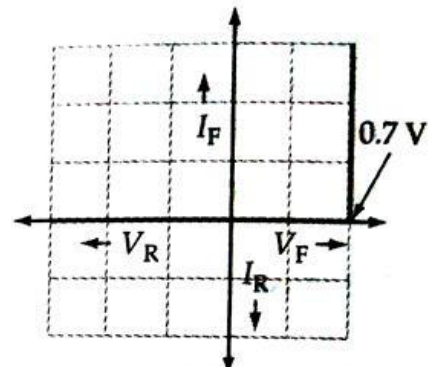
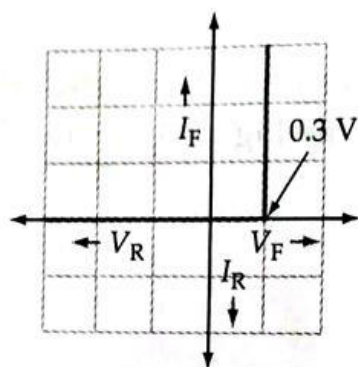
Approximate Model (Practical Model)

- The approximate model or practical model of diode includes the barrier voltage.
- A forward biased diode is assumed to have a constant forward voltage drop (V_F) and negligible resistance.
- In this case, the diode equivalent circuit is assumed to be a voltage cell with a voltage V_F .

- In circuits with supply voltages much larger than the forward voltage drop, V_F can be assumed to be constant without introducing any serious errors.
- In approximate or practical model, the forward dynamic resistance and the reverse current are neglected.

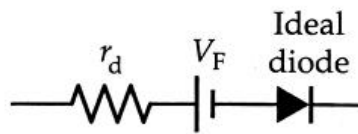


In practical diode, V_F is considered, $I_R = 0$ and $r_d = 0$



Piecewise Linear Model (Complete Model)

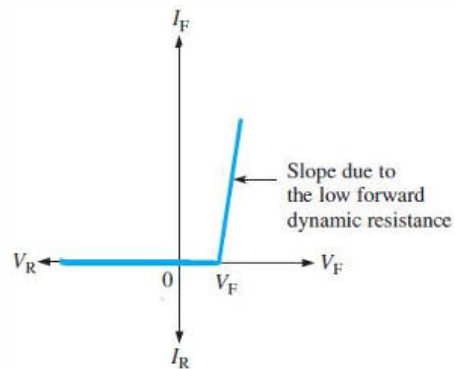
- The complete model of a diode is the most accurate approximation and includes the barrier voltage (forward voltage drop dynamic resistance (r_d)). V_F and the small forward
- The complete dc equivalent circuit includes the diode dynamic resistance (r_d) in series with the voltage cell with a voltage V_F .
- This takes account of the small variations in V_F that occur with change in forward current.
- The piecewise linear characteristic is the straight-line approximation of the forward characteristic and can be employed when the forward characteristic of a diode is not available.



Complete Model of Diode

(Complete dc equivalent circuit)

Note: An ideal diode is also included to show that current flows only in one direction.



Piecewise Linear Characteristics

In piecewise linear model, V_F and r_d are considered

Diode Circuits – Numerical Example 1

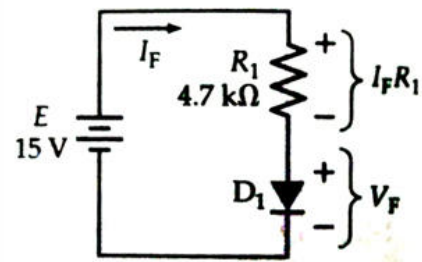
A silicon diode is used in the circuit shown in the figure. Calculate the diode current.

Solution:

Given that it is a silicon diode. Hence $V_F = 0.7\text{ V}$

Using KVL, $E = I_F R_1 + V_F$

$$\begin{aligned} \text{Or } I_F &= \frac{E - V_F}{R_1} \\ &= \frac{15\text{ V} - 0.7\text{ V}}{4.7\text{ k}\Omega} \\ &= 3.04\text{ mA} \end{aligned}$$



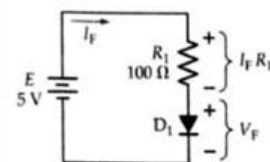
DC Load Line Analysis

DC Load Line

- A *dc load line* is a straight line that illustrates all dc conditions that could exist within the circuit.
- It is drawn on the diode forward characteristics.
- Consider a circuit shown in the figure.
- Using KVL, we can write

$$E = I_F R_1 + V_F \longrightarrow (1)$$

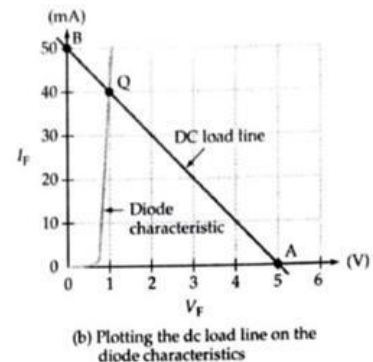
- DC load line can be drawn by obtaining points A and B.



(a) Diode-resistor series circuit

DC Load Line

- At point A, $I_F = 0$. Using this in Eqn. (1), we get $V_F = E$
- At point B, $V_F = 0$. Using this in Eqn. (1), we get $I_F = \frac{E}{R_1}$
- After obtaining points A and B, mark them and join using a straight line.



Q-Point

- The quiescent point or Q-Point is the only point on the dc load line where the diode voltage and current are compatible with the circuit conditions.
- It is also called dc bias point.
- It is the point where the dc load line intersects the diode forward characteristic.

Rectification

Rectification

- *Rectification* is the process of converting alternating current (ac) to direct current (dc).
- Since semiconductor diodes conduct current in the forward direction and block current in the other direction, they can be used for rectification.
- A *rectifier* is a circuit which converts alternating current (ac) into direct current (dc).
- Rectifiers are found in all dc power supplies that operate from an ac voltage source.
 - A power supply is an essential part of each electronic system from the simplest to the most complex.



Why do we need Rectification?

- The source available to us is 230 V, 50 Hz *ac* power supply.
- However, most of the electronic circuits such as amplifiers, oscillators, etc. require a dc voltage in the range of 5 V to 25 V for their proper operation.
- Hence, it is essential to convert *ac* to *dc*.

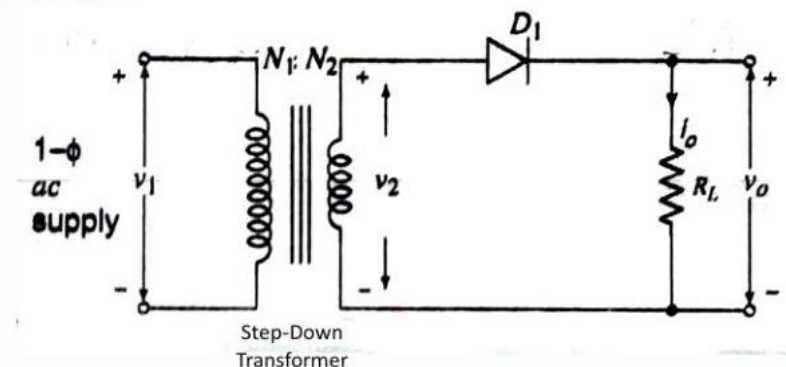
Types of Rectifiers

- Half-Wave Rectifier
- Full-Wave Rectifier
 - Full-Wave Rectifier using two diodes and a centre-tapped transformer
 - Full-Wave Bridge Rectifier using four diodes

Half-Wave Rectifier

A Half-Wave Rectifier (HWR) is a circuit which converts only one half-cycle of the input ac to pulsating dc.

Circuit Diagram



Half-Wave Rectifier

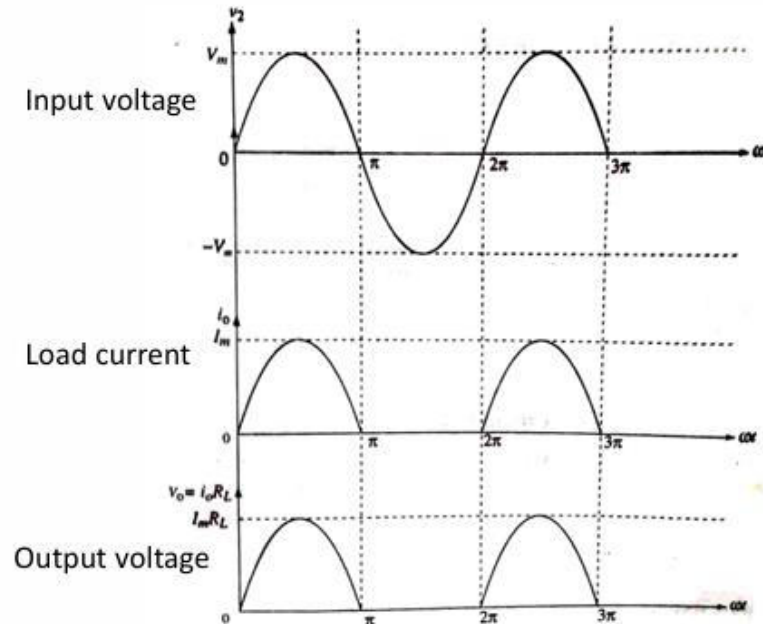
- The half-wave rectifier consists of a single diode as shown.
- A step-down transformer is used to reduce the available ac voltage to the required level.
- Resistor R_L is the load resistance which consumes power from the rectifier.

Working of Half Wave Rectifier

In this section, let us understand how a half-wave rectifier transforms AC into DC.

1. A high AC voltage is applied to the primary side of the step-down transformer. The obtained secondary low voltage is applied to the diode.
2. The diode is forward biased during the positive half cycle of the AC voltage and reverse biased during the negative half cycle.

Waveforms

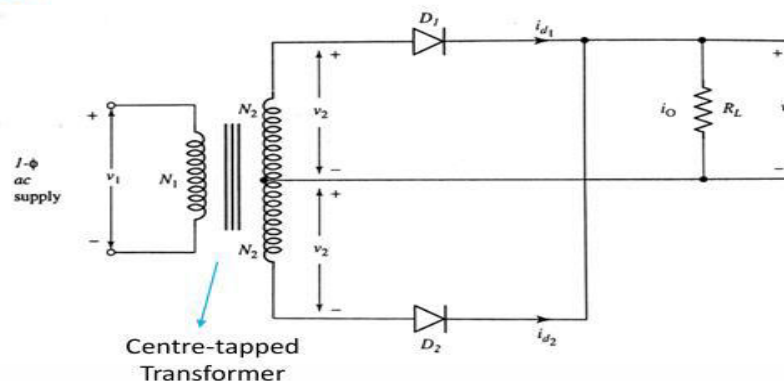


Full-Wave Rectifier

- A Full-Wave Rectifier (FWR) is a circuit which converts both the half cycles of the input ac to pulsating dc.
- A full-wave rectifier can be constructed using two ways:
 - Using two diodes and a centre-tapped Rectifier
 - Using four diodes (Bridge Rectifier)

Full wave Centre-tapped Rectifier

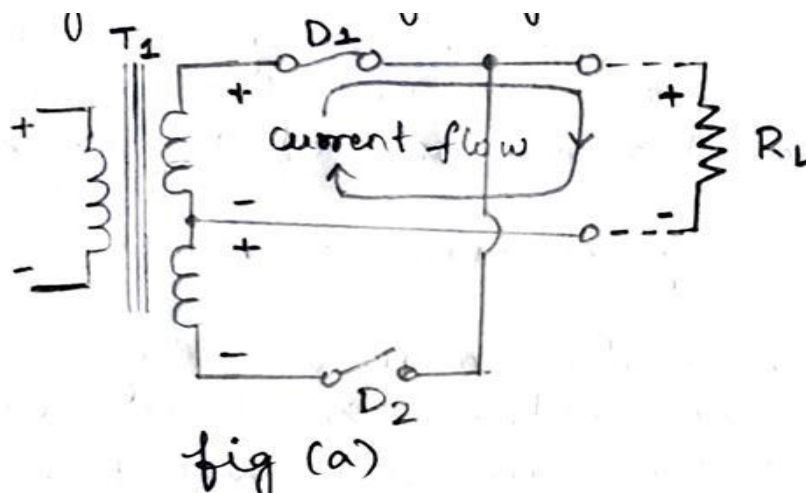
Circuit Diagram



- The full-wave rectifier consists of two diodes D_1 and D_2 as shown.
- A step-down transformer is used to reduce the available ac voltage to the required level.
- The transformer is centre-tapped so that two equal voltages are induced at both halves of the transformer secondary.
- Resistor R_L is the load resistance which consumes power from the rectifier.

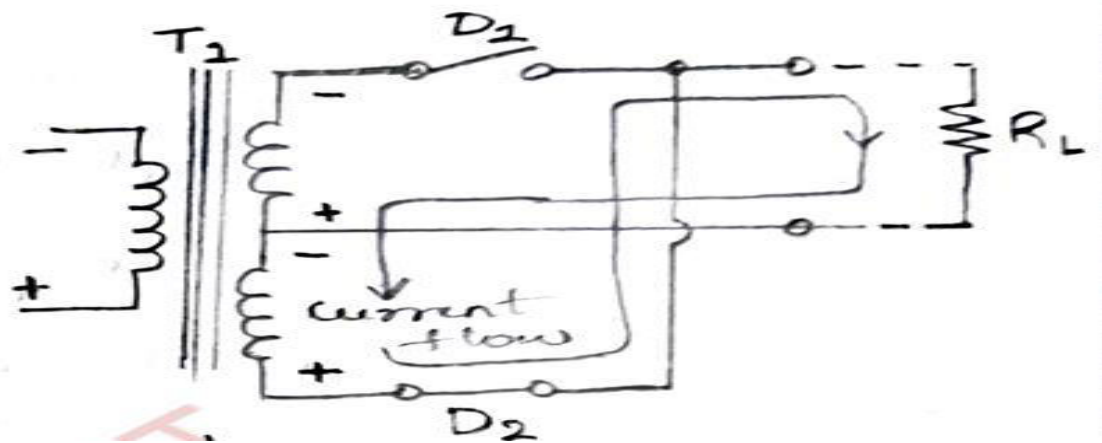
(i) **During positive half-cycle of ac supply**

- The top end of the transformer secondary becomes positive, and the bottom end becomes negative relative to the center tap.
- Diode D_1 is forward-biased and conducts, while diode D_2 is reverse-biased and remains off.
- Current flows from the top end of the secondary, through D_1 , through the load resistor R_L , and back to the center tap.

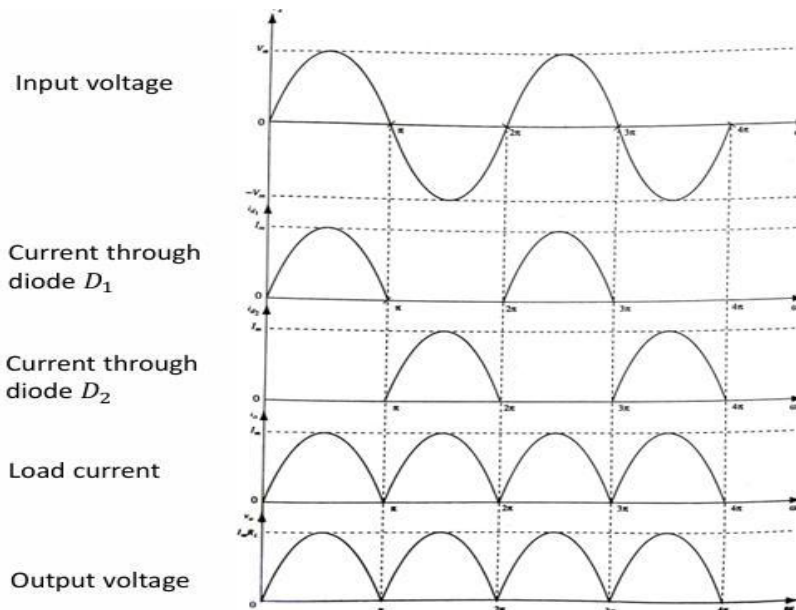


(ii) **During negative half-cycle of ac supply**

- The top end of the transformer secondary becomes negative, and the bottom end becomes positive relative to the center tap.
- Diode D_2 is now forward-biased and conducts, while diode D_1 is reverse-biased and remains off.
- Current flows from the bottom end of the secondary, through D_2 , through the load resistor R_L , and back to the center tap.



Waveforms



Peak Inverse Voltage (PIV)

- Peak Inverse Voltage (PIV) is the maximum reverse voltage to which the diode can be subjected.
- If the applied reverse voltage across the diode is greater than its PIV rating, the reverse breakdown of the diode which causes a permanent damage to the diode.

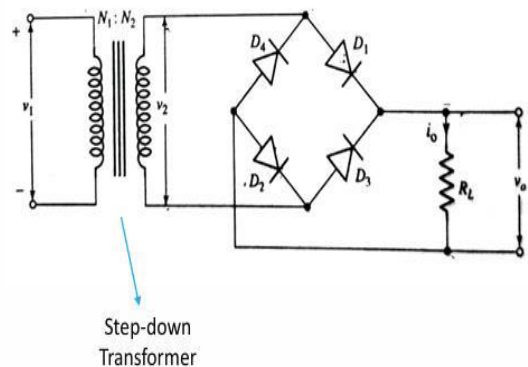
Bridge Rectifier

Construction

The construction of a bridge rectifier is shown in the figure below.

- The bridge rectifier circuit is made of four diodes D_1 , D_2 , D_3 , D_4 , and a load resistor R_L .
- The four diodes are connected in a closed-loop configuration to efficiently convert the alternating current (AC) into Direct Current (DC).
- The main advantage of this configuration is the absence of the expensive centre-tapped transformer. Therefore, the size and cost are reduced.

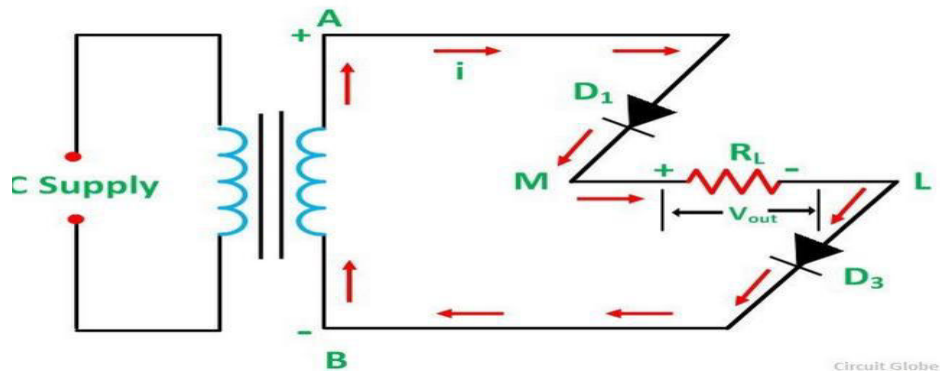
Circuit Diagram



- The bridge rectifier consists of four diodes D_1 , D_2 , D_3 and D_4 which are arranged in the form of a bridge as shown.
- A step-down transformer is used to reduce the available ac voltage to the required level.
- Resistor R_L is the load resistance which consumes power from the rectifier.

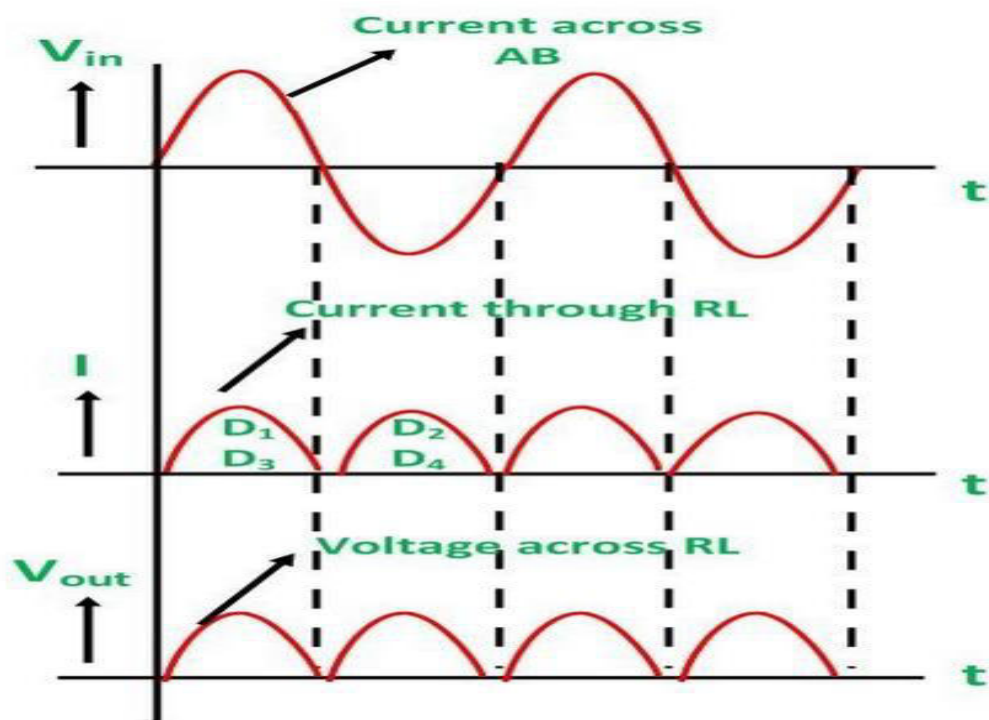
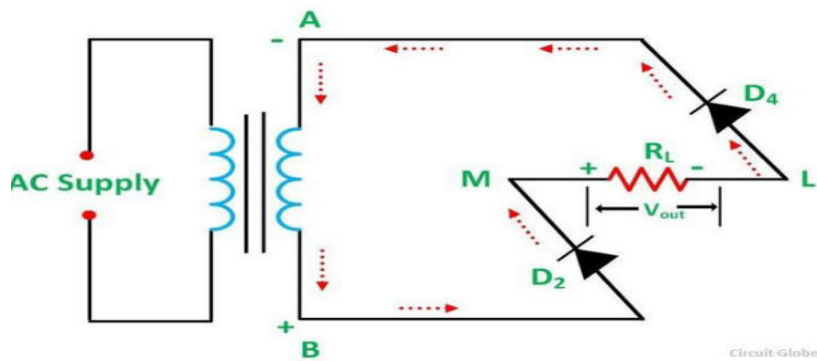
(i) During positive half-cycle of ac supply

- The diodes D_1 and D_3 are forward biased and hence they conduct, whereas the diodes D_2 and D_4 are reverse biased and hence they remain off.
- The conducting diodes can be replaced by forward resistance R_f and the non conducting diodes can be replaced by open circuit and the equivalent circuit can be drawn as shown.



(ii) During negative half-cycle of ac supply

- The diodes D_2 and D_4 are forward biased and hence they conduct, whereas the diodes D_1 and D_3 are reverse biased and hence they remain off.
- The conducting diodes can be replaced by forward resistance R_f and the non conducting diodes can be replaced by open circuit.



Capacitor Filter Circuit

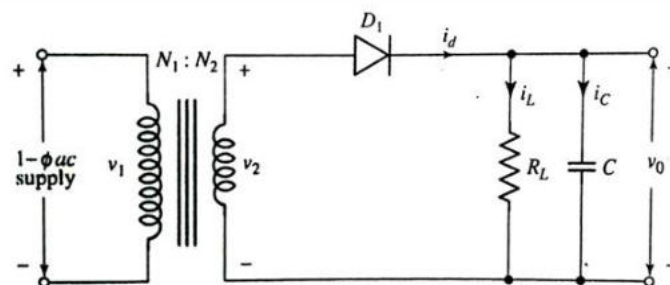
- Filter is a circuit used to reduce the ripple content present in the rectified output.
- A capacitor connected in parallel with the load resistor acts as a filter by reducing the ripple content present in the rectified output.
- The output from half-wave and full-wave rectifiers is not a smooth dc due to the ripple content.
- The ripple content of half-wave rectified output is 121% of dc component whereas it is 48.3% of dc component in full-wave rectified output.
- In order to obtain smooth dc, it is necessary to filter out the ripple content.

Half-Wave Rectifier with a 'C' Filter

- During the positive half-cycle of the ac supply, the diode conducts and charges the capacitor to the peak value V_m of the input voltage.
- When the input voltage falls below V_m , the diode stops conducting.
- Now, the capacitor starts discharging into the load RL and the voltage on capacitor decreases.
- The discharging of the capacitor continues till the diode starts conducting again and charges the capacitor in the next positive half-cycle of the ac supply.

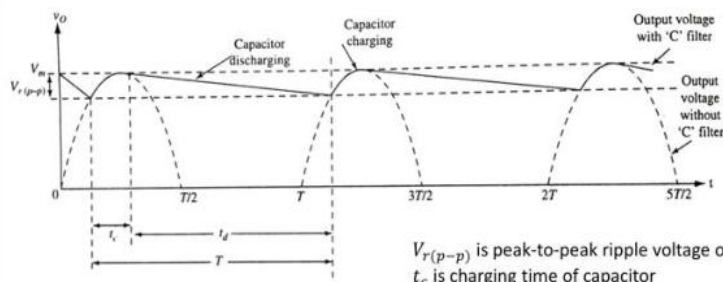
Half-Wave Rectifier with a 'C' Filter

Circuit Diagram



Half-wave rectifier with capacitor filter

Output Voltage Waveform



Output voltage waveforms with and without 'C' filter

$V_{r(p-p)}$ is peak-to-peak ripple voltage on capacitor
 t_c is charging time of capacitor
 t_d is discharging time of capacitor
 T is the time period of output waveform ($T = t_c + t_d$)

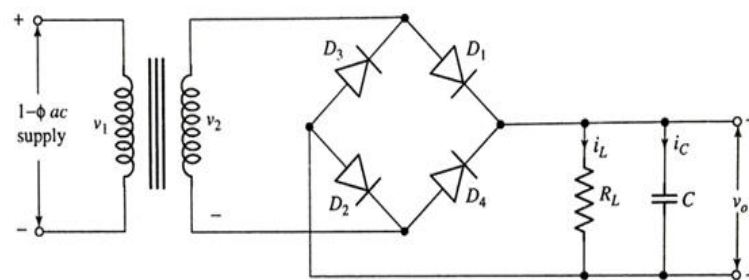
- From the waveforms, we find that without capacitor filter, the output voltage v_o varies between 0 and V_m and with capacitor filter, the variation is between $[V_m - V_r(p-p)]$ and V_m .]
- It can be observed that, with filter, the variation in v_o is smaller than that without filter.
- Thus, by using a capacitor filter, the ripple content of the output voltage is considerably reduced.

Full-Wave Rectifier with a 'C' Filter

For Two-Diode Full-Wave Rectifier with 'C' Filter

- During the positive half-cycle of the ac supply, the diode D_1 conducts and charges the capacitor to the peak value V_m of the input voltage.
- When the input voltage falls below V_m , the diode stops conducting.
- Now, the capacitor starts discharging into the load R_L and the voltage on capacitor decreases.

Circuit Diagram

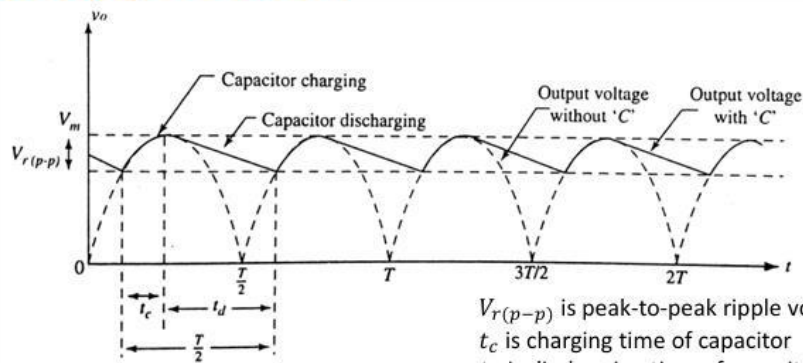


Bridge rectifier with capacitor filter

- The discharging of the capacitor continues until the diode D_2 starts conducting
- During the positive half-cycle of the ac supply, the diodes D_1 and D_2 conduct and charge the capacitor to the peak value V_m of the input voltage.
- When the input voltage falls below V_m , the diodes D_1 and D_2 stop conducting.
- Now, the capacitor starts discharging into the load R_L and the voltage on capacitor decreases.
- The discharging of the capacitor continues until the diodes D_3 and diodes D_1 and D_4 start conducting in the next half-cycle and charge the capacitor again.
- From the waveforms, we find that without capacitor filter, the output voltage v_o varies between 0 and V_m and with capacitor filter, the variation is between $[V_m - V_r(p-p)]$ and V_m .]
- It can be observed that, with filter, the variation in v_o is smaller than that without filter.

- Thus, by using a capacitor filter, the ripple content of the output voltage is considerably reduced.

Output Voltage Waveform



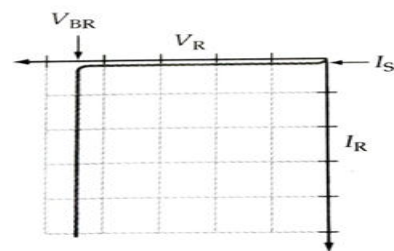
Output voltage waveforms with and without 'C' filter

$V_{r(p-p)}$ is peak-to-peak ripple voltage on capacitor
 t_c is charging time of capacitor
 t_d is discharging time of capacitor
 $\frac{T}{2}$ is the time period of output waveform ($\frac{T}{2} = t_c + t_d$)

Zener Diode

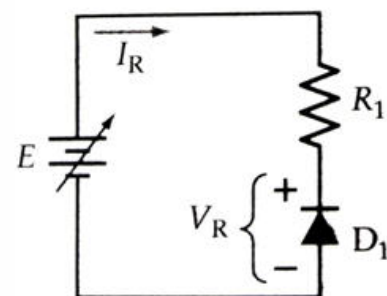
Junction Breakdown

- When a PN junction diode is reverse biased, there is normally only a very small reverse saturation current I_S .
- When the reverse voltage is sufficiently increased, the junction breaks down and a large reverse current flows.



Diode reverse characteristic

- If the reverse current is limited by means of a suitable series-connected resistor R_1 , the power dissipation in the diode can be kept to a level that will not destroy the device.
- In this case, the diode may be operated continuously in reverse breakdown.
- The reverse current returns to its normal level when the voltage is reduced below the reverse breakdown level.



Diode-resistor circuit

- There are two mechanisms that cause breakdown in a reverse biased PN junction:
 - Zener breakdown
 - Avalanche breakdown

Zener Breakdown

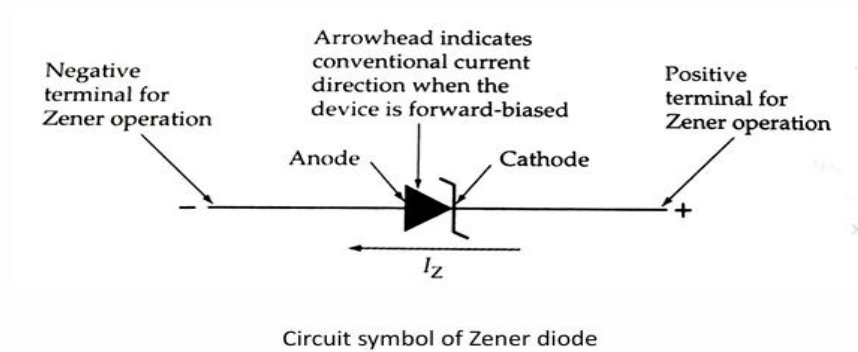
- When the depletion region is very narrow, the electric field strength produced by a reverse bias voltage can be very high.
- The high-intensity electric field causes electrons to break away from their atoms, thus converting the depletion region from an insulating material into a conductor.
- This is called *ionization by electric field*, also called *Zener breakdown*.
- This usually occurs with reverse bias voltage less than 5 V.

Avalanche Breakdown

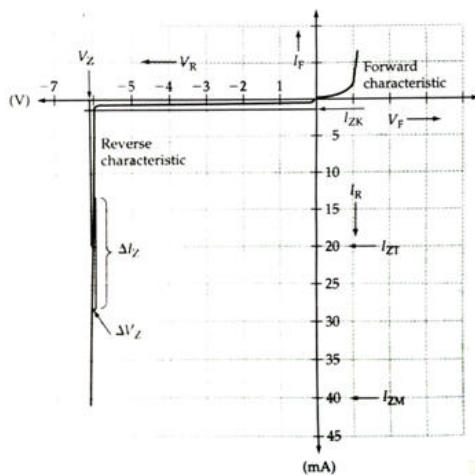
- When the depletion region is too wide, the electrons in the reverse saturation current can be given sufficient energy to strike atoms within the depletion region and cause other electrons to break free.
- The electrons released in this way collide with other atoms to produce more free electrons in an avalanche effect.
- This is called *ionization by collision*, also called *avalanche breakdown*.
- This usually occurs with reverse bias voltage above 5 V.

Zener Diode

- Zener diode is a diode designed specially for operation in reverse breakdown.
 - Also called *breakdown diode*.
- Zener diodes have a breakdown voltage that remains extremely stable over a wide range of current levels.
- This property makes Zener diodes suitable for many useful applications as a voltage reference source.



Zener Characteristics and Parameters



- V_Z → Zener breakdown voltage
- I_{ZT} → Test current for measuring V_Z
- I_{ZK} → Reverse current near the knee of the characteristic, the minimum reverse current to sustain breakdown
- I_{ZM} → Maximum Zener current, limited by the maximum power dissipation

Typical characteristics of a Zener diode

Zener Characteristics and Parameters

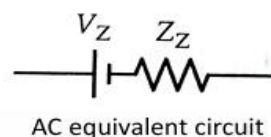
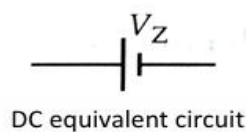
- Dynamic Impedance

$$Z_Z = \frac{\Delta V_Z}{\Delta I_Z}$$

- Power Dissipation

$$P_D = V_Z I_{ZM}$$

- Equivalent Circuit

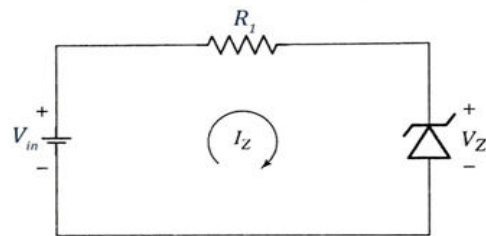


Zener Diode as a Voltage Regulator

- Since Zener diodes have a breakdown voltage that remains extremely stable over a wide range of current levels, they can be used as voltage regulators.
- The regulators can be with a load or without a load.

Regulator with No Load

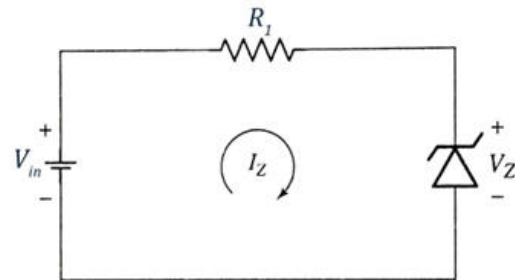
- Zener diode can be used as a voltage regulator as shown in the figure.
- This circuit does not have a load resistance and is normally used as a voltage reference source that supplies only a very low current (much lower than I_Z) to the output.



- Resistor R_1 limits the Zener diode current to the desired level.

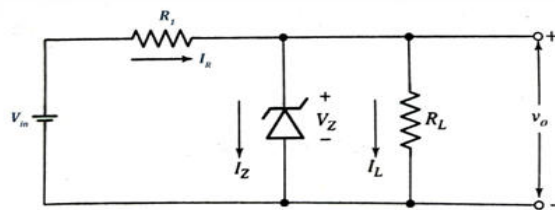
- From the circuit,

$$I_Z = \frac{V_{in} - V_Z}{R_1}$$



Regulator with a Load (Loaded Regulator)

- In this circuit, a load resistor is connected in parallel with the Zener diode.
- The total supply current (flowing through R_1) is the sum of Zener current I_Z and load current I_L .



- Care must be taken to ensure that the minimum Zener current is large enough to keep the diode in reverse breakdown.
- Typically, $I_{Z(min)} = 5 \text{ mA}$ for a Zener diode with an I_{ZT} of 20 mA .
- Since load resistor R_L and Zener diode are in parallel, the voltage across R_L is equal to the voltage across Zener diode.
i.e., $V_o = V_Z$ (1)
- So V_o remains constant even if V_{in} happens to change due to the fluctuations in ac line voltage.

From the circuit,

$$I_R = I_Z + I_L \quad (2)$$

$$I_Z = I_R - I_L \quad (3)$$

Also,

$$I_R = \frac{V_{in} - V_o}{R_1} \quad (4)$$

Using Eqn. (4) in (3),

$$I_Z = \left[\frac{V_{in} - V_o}{R_1} \right] - I_L \quad (5)$$

Diode Logic Circuit

AND Gate

- A logic circuit produces an output voltage which is either *high* or *low*, depending upon the levels of several input voltages. The two basic logic circuits are the *AND gate* and the *OR gate*.
- The Fig 1a is the circuit diagram of a diode AND gate. The circuit has a single output terminal at the diode common anodes and three inputs at the device cathode

terminals. (An AND gate could have almost any number of input terminals from 2 up to perhaps 50.) The diode anodes are connected via resistor R_1 to a supply of $V_{CC} = 5\text{ V}$.

- If one or more of the input terminals is grounded, current flows from the supply through R_1 and through the forward-biased diodes to ground.
- In this case, the output voltage is just V_F above ground (0.7 V for silicon). The output is said to be *low*. When input levels of 5 V are applied to all three input terminals, none of the diodes is forward biased, and no significant voltage drop occurs across R_1 .
- Thus, the output voltage is equal to V_{CC} , and it is referred to as a *high output level*.
- The AND gate gives a low output voltage when one or more of its inputs are low and a high output when input A is high and input B is high and input C is high. Hence the name AND gate.

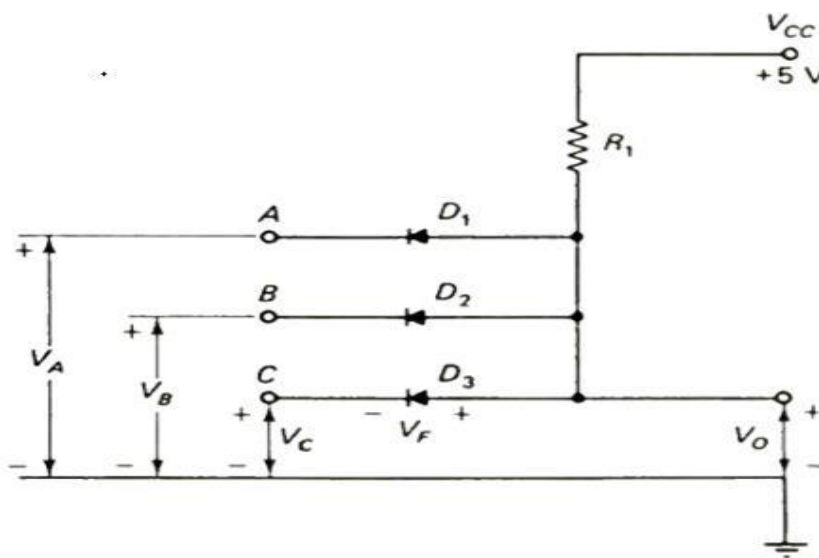
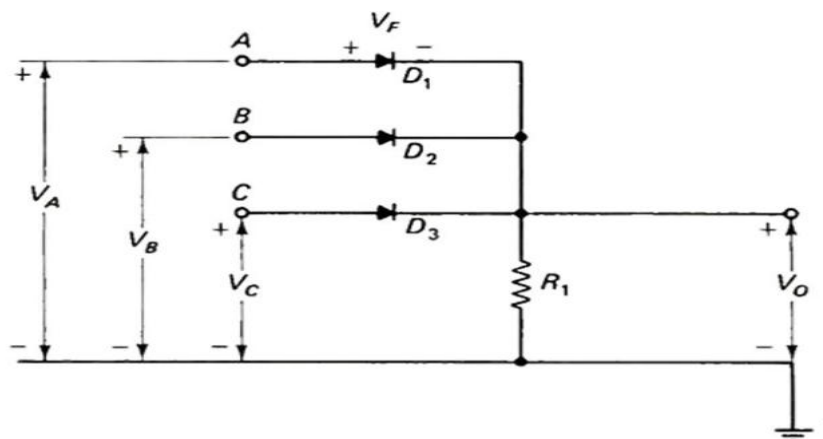


Fig 1a: Circuit of a 3 input diode AND gate

OR gate

- The circuit diagram of a three-input terminal *OR gate* is shown in Fig. 1b. Again, the gate could have two or more inputs. It is fairly obvious that the output voltage of the OR gate is *low* when all three inputs are low.



- Now suppose that a +5-V input is applied to terminal A, while terminals B and C remain grounded. Diode D_1 becomes forward biased, and its cathode voltage (i.e., the output voltage) is $+(5\text{ V} - V_F)$. The output is *high*.
- Diodes D_2 and D_3 are reverse biased with $+V_o$ on the anodes and ground at the cathodes.
- As its name implies, the OR gate produces a *high* output when a high input level is applied to terminal A *or* terminal B *or* terminal C.
- Both AND and OR gates can be designed and constructed using discrete components. Alternatively, small integrated-circuit (IC) packages are available, each of which contain many diodes already fabricated in the form of the desired gate.

NOTE: ALL THE DERIVATIONS AND PROBLEMS DONE IN CLASS ARE INCLUDED IN THE SYLLUBUS