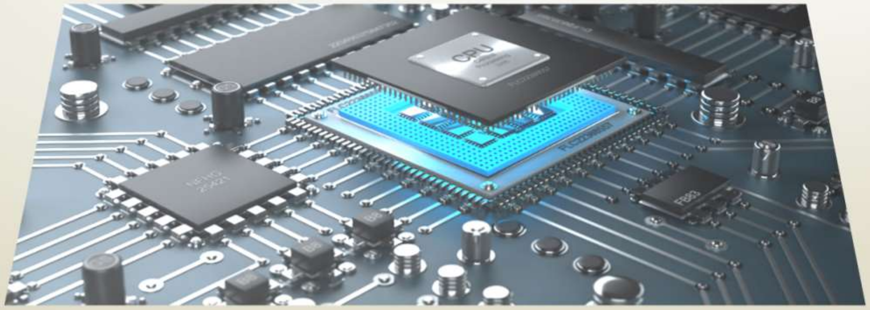
Electronic I

Electrical engineering department

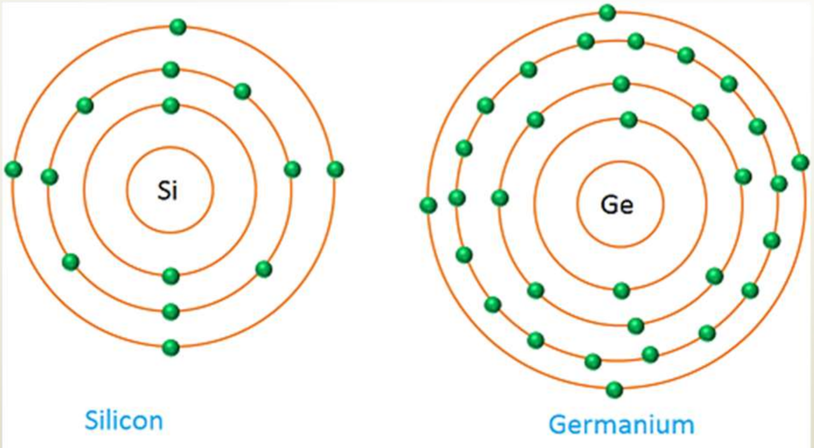
ENG. BILAL ALTAMIMI

SEMICONDUCTORS



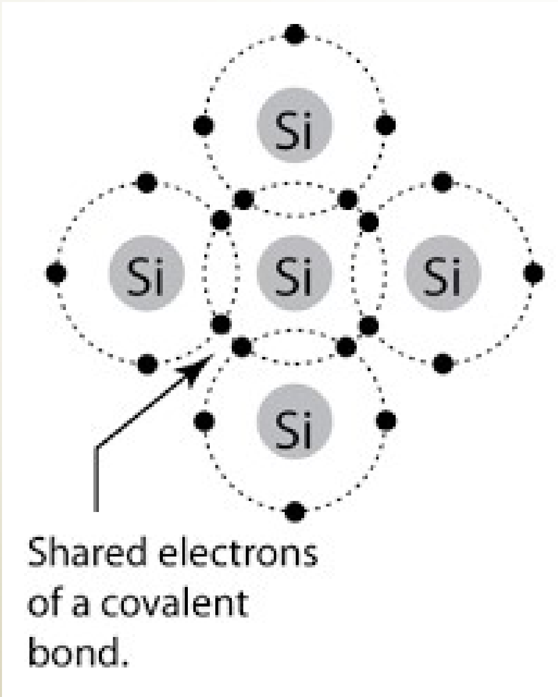
Atom Structure of Semiconductors

- Semiconductors typically have a crystalline structure, meaning that their atoms are arranged in a regular, repeating pattern. Such as silicon, germanium, and carbon (in the form of diamond)



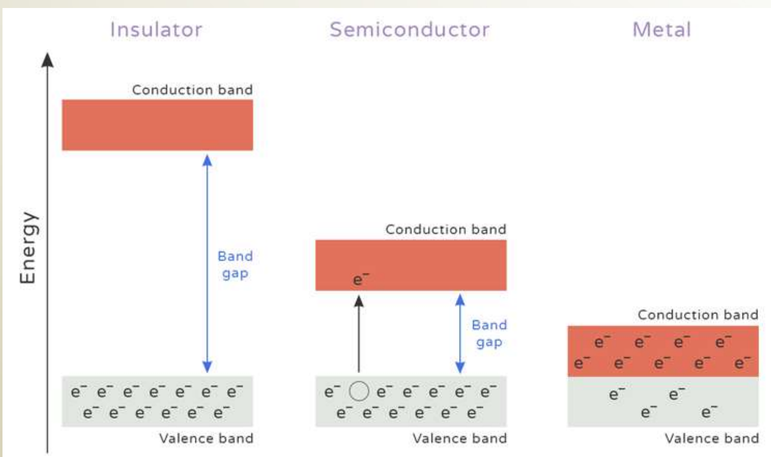
Atom Structure of Semiconductors'

- When these atoms bond together to form a crystal, they share their valence electrons with neighboring atoms. This creates a strong covalent bond between the atoms.

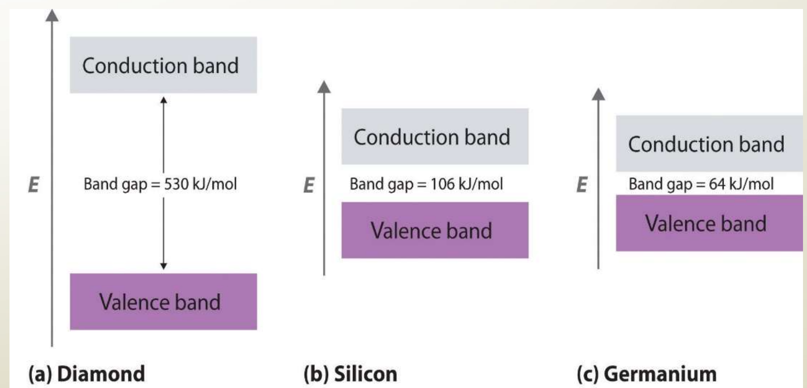


Band Theory of Semiconductors

- Semiconductors are materials where the valence band (filled with electrons) and conduction band (empty) are close in energy. At low temperatures, electrons are tightly bound in the valence band. As temperature rises, some electrons gain enough energy to jump into the conduction band, becoming free to move and conduct electricity.



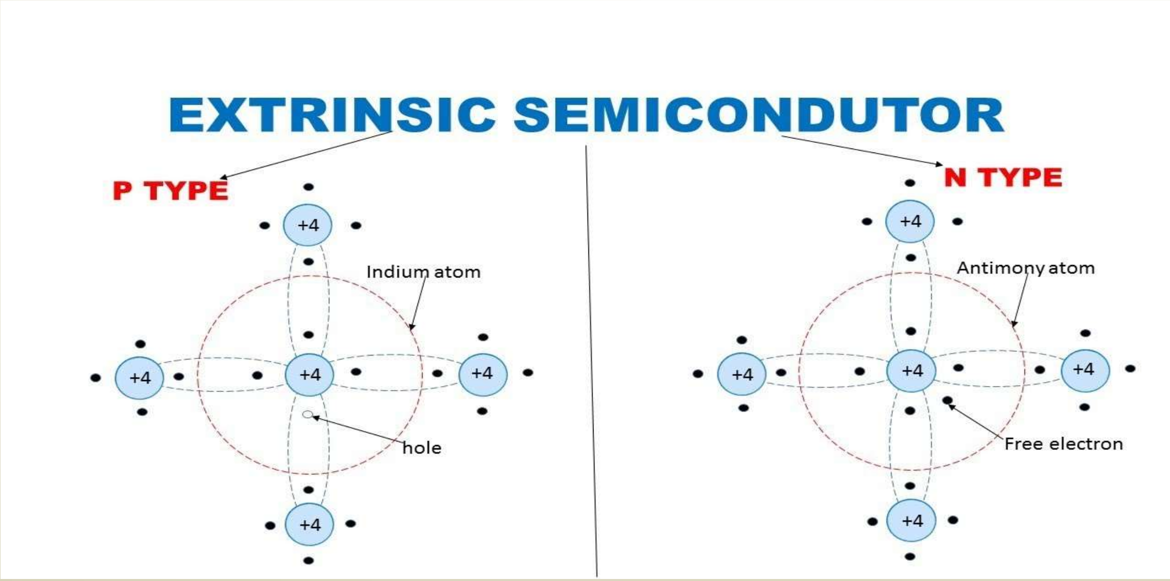
Conduction Band



Energy-Band Diagrams for Diamond, Silicon, and Germanium

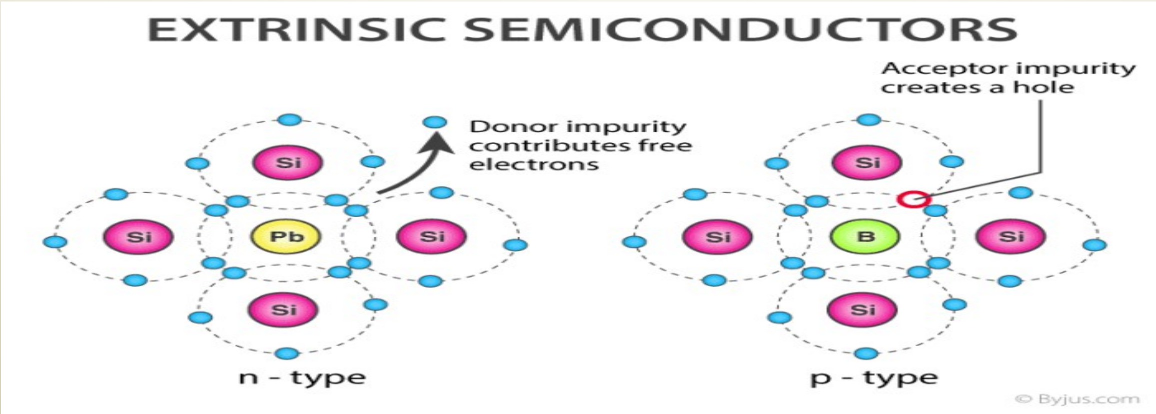
Extrinsic semiconductors

- These are semiconductors that have been doped with impurities. Doping involves adding small amounts of other elements to the semiconductor material. This can change the electrical conductivity of the semiconductor.



types of doping:

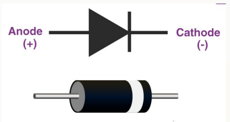
- **n-type doping:** This involves adding impurities with more valence electrons than the semiconductor atoms, such as phosphorus or arsenic. This creates an excess of free electrons in the semiconductor.
- **p-type doping:** This involves adding impurities with fewer valence electrons than the semiconductor atoms, such as boron or aluminum. This creates an excess of "holes" in the semiconductor, which can be thought of as positively charged particles.



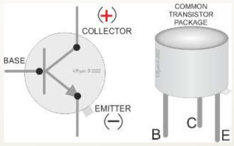
Applications of Semiconductors

➢ Semiconductors are used in a wide variety of electronic devices, including:

- Diodes



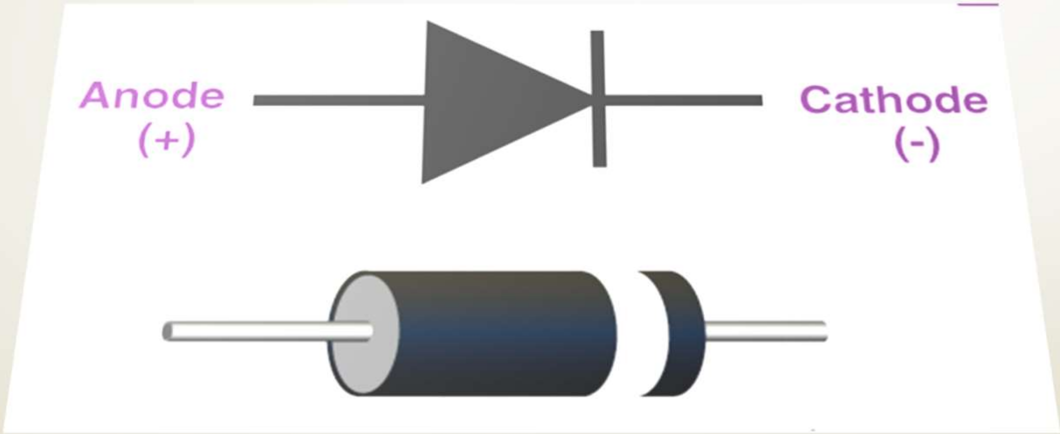
- Transistors



- Integrated circuits

❖ Semiconductors have revolutionized the electronics industry and are essential to modern technology.

Diodes

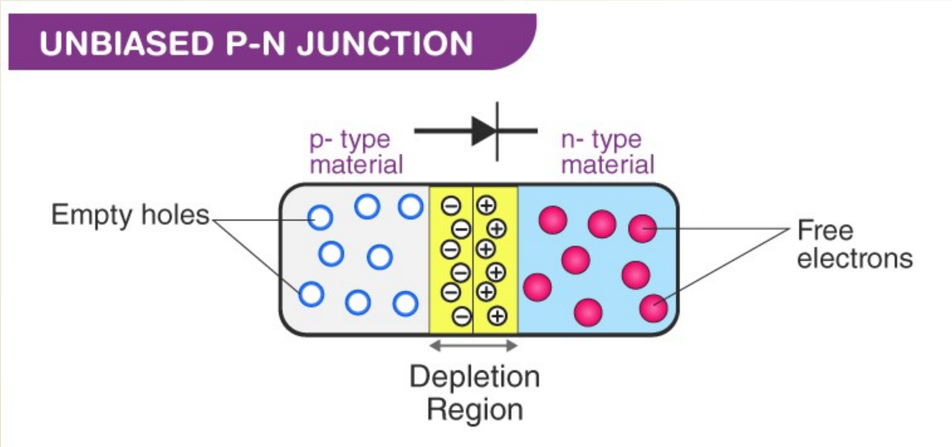


- The One-Way Gates of Electronics

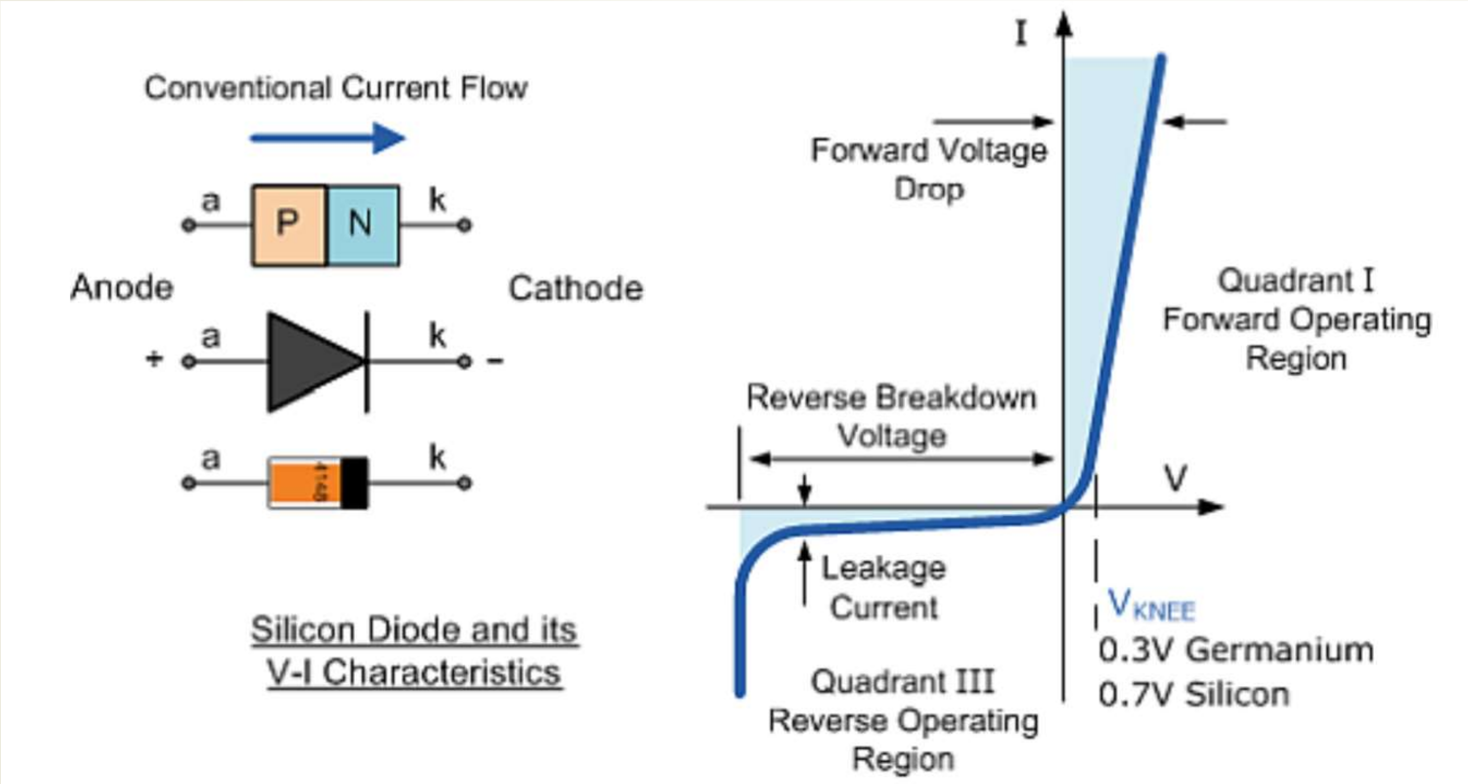
Diodes

- **A (P-N) junction** is a fundamental component in semiconductor devices. It's formed by joining a p-type semiconductor (doped with acceptor atoms) and an n-type semiconductor (doped with donor atoms).

➢ ***Diodes are semiconductor devices that allow current to flow in one direction but block it in the opposite direction.***



Diode Characteristics



Forward Bias Diodes

➢ Understanding Forward Bias

- **Built-in potential barrier:** A P-N junction has a built-in potential barrier due to the difference in doping levels between the P and N regions. This barrier prevents the flow of current under equilibrium conditions.

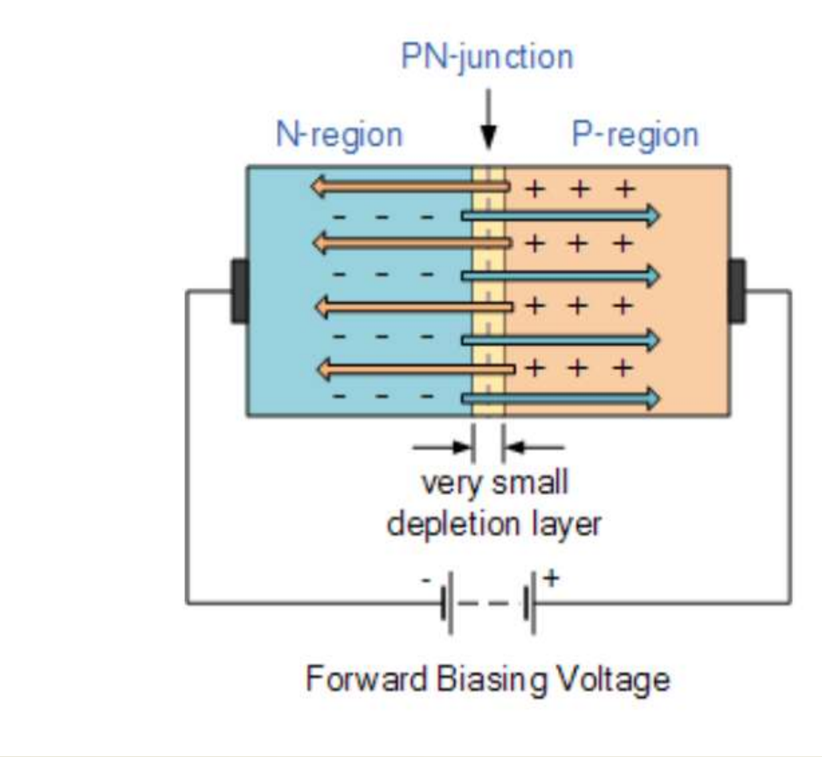
- **Forward bias:** When an external voltage is applied in a direction that reduces this barrier, the diode becomes conductive. This is known as forward bias.

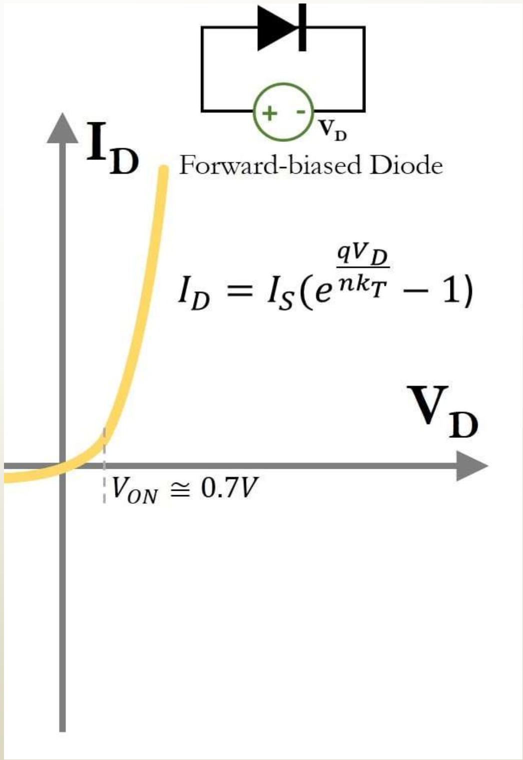
- **Current flow:** In forward bias, majority charge carriers (holes in the P region and electrons in the N region) can easily cross the junction, resulting in a significant current flow.

➢ Characteristics of a Forward-Biased Diode

- **Low resistance:** The diode exhibits a very low resistance in forward bias, allowing for large currents to flow.
- **Voltage drop:** There is a small voltage drop across the diode, typically around 0.7V for silicon diodes and 0.3V for germanium diodes.
- **Exponential relationship:** The current through a forward-biased diode is exponentially related to the applied voltage. This relationship is described by the diode equation.

➢ Characteristics of a Forward-Biased Diode'





Applications of Forward-Biased Diodes

- **Rectification:** Diodes are commonly used to convert alternating current (AC) to direct current (DC). In this application, the diode is forward-biased during one half of the AC cycle and reverse-biased during the other half, allowing only the positive half-cycle to pass.
- **Switching:** Diodes can be used as switches to control the flow of current in circuits. By applying a forward bias voltage, the diode can be turned on, allowing current to flow.
- **Logic gates:** Diodes are used as components in various logic gates, such as AND, OR, and NOT gates.
- **LEDs (Light-Emitting Diodes):** When a diode is forward-biased, it emits light. This property is used in LEDs for various applications, including lighting, displays, and indicators.

Reverse Bias Diodes

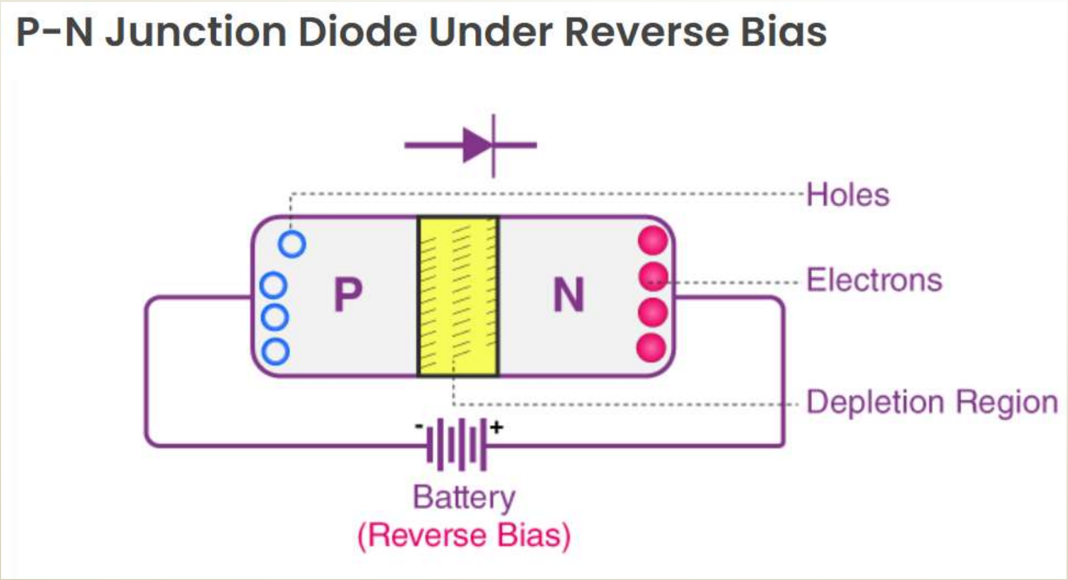
Understanding Reverse Bias

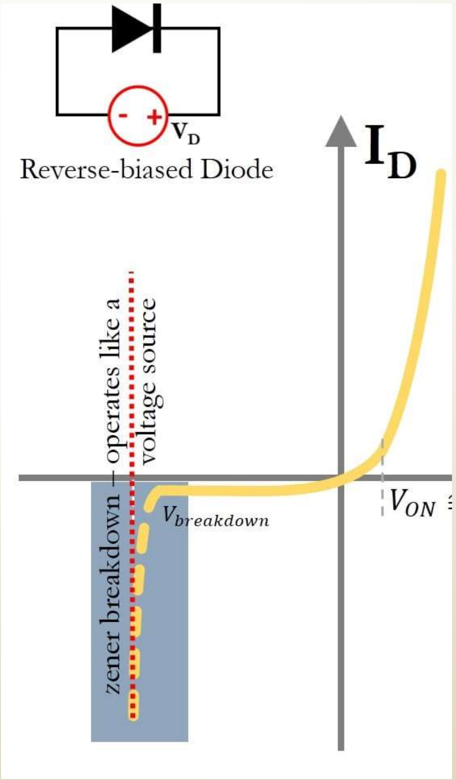
- **Reverse bias:** When an external voltage is applied in a direction that reinforces this barrier, the diode becomes non-conductive. This is known as reverse bias.
- **Built-in potential barrier:** As discussed earlier, a P-N junction has a built-in potential barrier that opposes the flow of current.
- **Current flow:** In reverse bias, the majority charge carriers are repelled away from the junction, and only a small leakage current flows.

Applications of Reverse-Biased Diodes

- **Voltage clamping:** Diodes can be used to clamp a voltage to a specific level. In this application, the diode is reverse-biased, and when the voltage exceeds the breakdown voltage, the diode conducts, limiting the voltage to the breakdown value.
- **Voltage protection:** Diodes can be used to protect sensitive electronic components from excessive voltages. By connecting a diode in reverse bias across the component, it can shunt away any excessive voltage.
- **Zener diodes:** Zener diodes are specially designed diodes that operate in the breakdown region. They are used as voltage regulators to maintain a constant voltage across their terminals, even when the current varies.

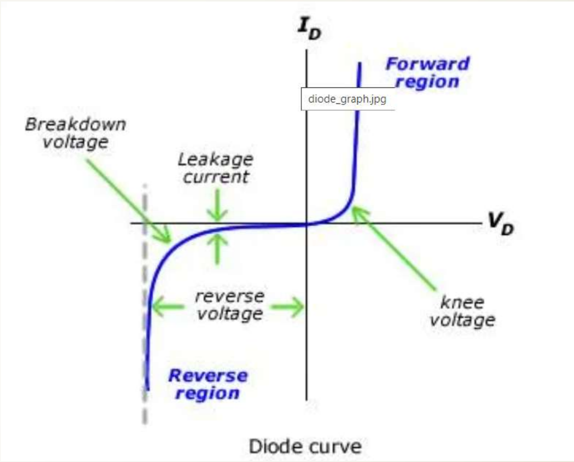
Characteristics of a reverse-Biased Diode





Diode Equation

$$I = I_o\left(e^{\frac{qv}{nkT}} - 1\right)$$



where:-

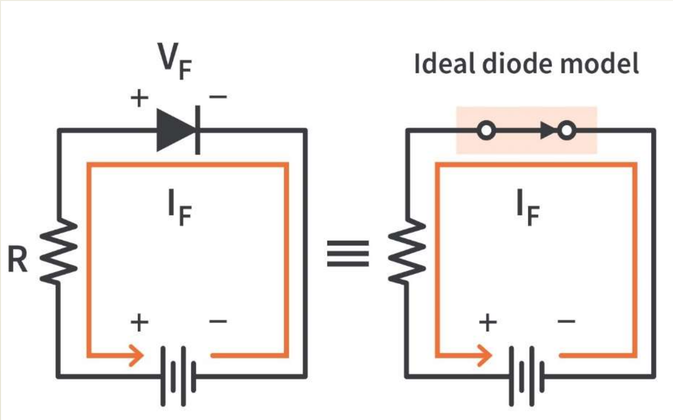
- I = the net current flowing through the diode;
- I0 = "dark saturation current", the diode leakage current density in the absence of light;
- V = applied voltage across the terminals of the diode;
- q = absolute value of electron charge;
- k = Boltzmann's constant;
- T = absolute temperature (K).
- n = ideality factor, a number between 1 and 2 which typically increases as the current decreases.

Diode models

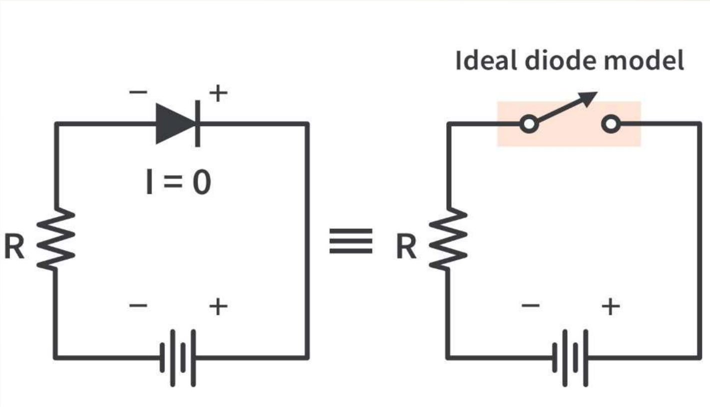
The Ideal Diode Mode

- When the diode is forward-biased, it ideally acts like a closed (on) switch .
- When the diode is reverse-biased, it ideally acts like an open (off) switch.
- The barrier potential, the forward dynamic resistance, and the reverse current are all neglected.
- the ideal V-I characteristic curve graphically depicts the ideal diode operation.

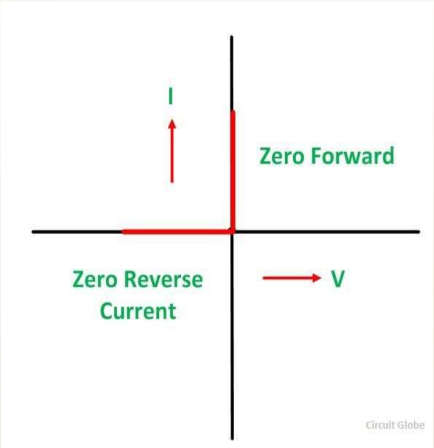
The Ideal Diode Mode



a) Forward-biased



b) reverse-biased

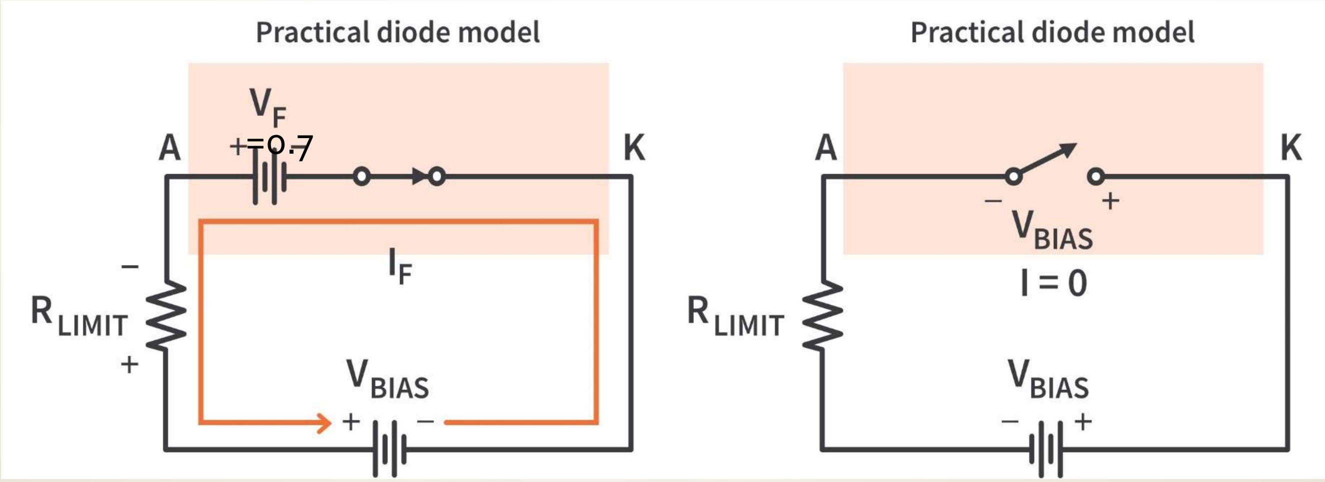


ideal V-I characteristic curve

The Practical Diode Model

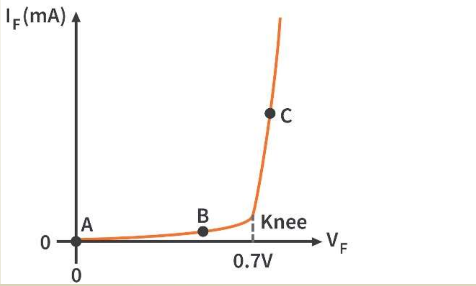
- Constant Voltage Drop Model.
- includes the barrier potential.
- Forward-biased: diode is equivalent to a closed switch in series with a small equivalent voltage source (VF) equal to the barrier potential(0.7 V) with the positive side toward the anode.
- The barrier potential, the forward dynamic resistance, and the reverse current are all neglected.
- Reverse-biased: diode is equivalent to an open switch just as in the ideal model. The barrier potential does not affect reverse bias.

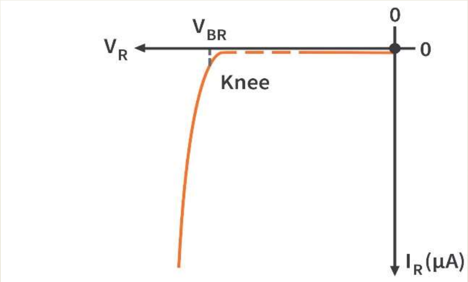
The Practical Diode Model



a) Forward-biased

b) reverse-biased





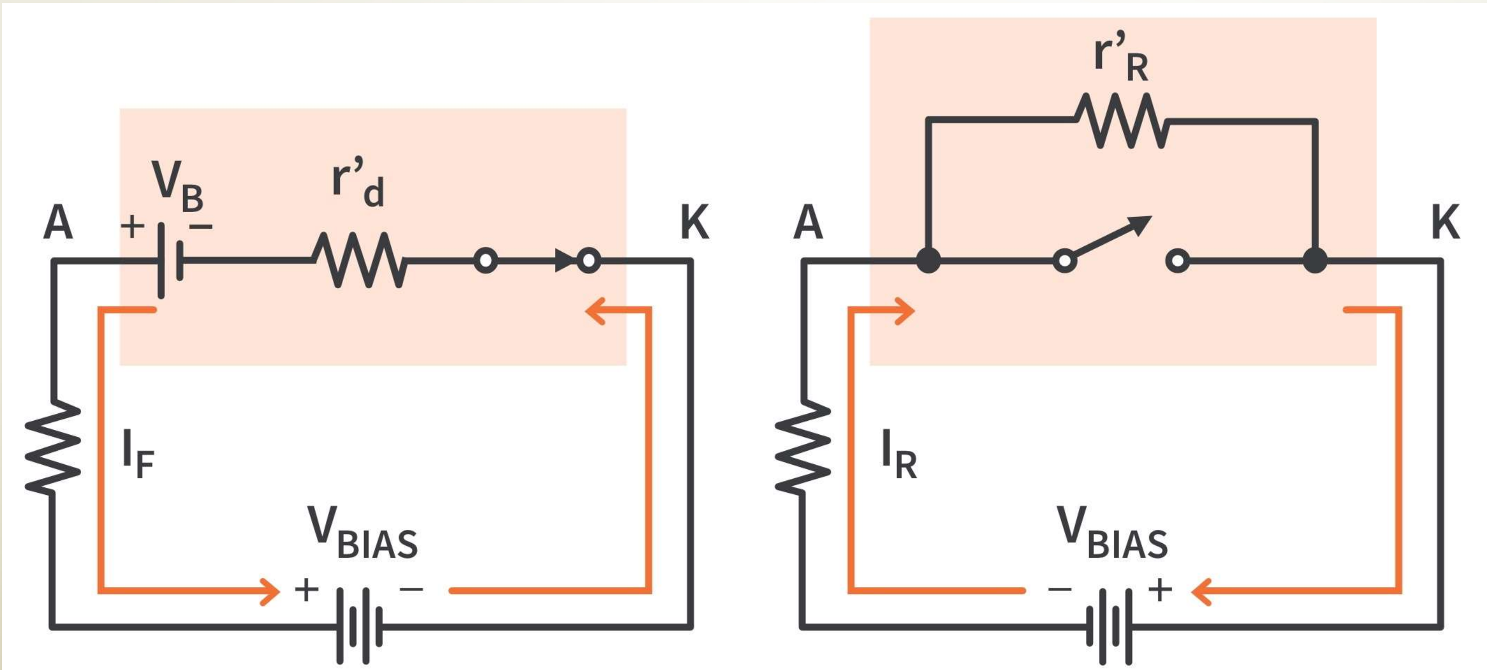
The Complete Diode Model

- small forward dynamic resistance (r'd) and large internal reverse resistance (r'R).
- Forward-biased: diode acts as a closed switch in series with the equivalent barrier potential voltage (VB) and r'd.
- Reverse-biased: diode acts as an open switch in parallel with r'_R. The barrier potential does not affect reverse bias.

$$V_F = 0.7V + I_F r'_d$$

$$I_F = \frac{(V_{BIAS} - 0.7V)}{(R_{LIMIT} + r'_d)}$$

The Complete Diode Model

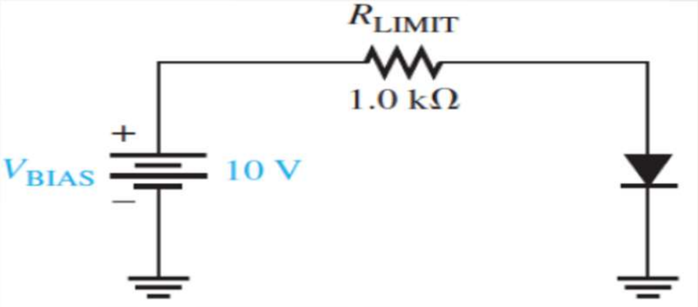


a) Forward-biased

b) reverse-biased

Examples

Ex: Determine the forward voltage and forward current for the diode in Figure 10(a) for each of ideal and practical diode models. Also, find the voltage across the limiting resistor in each case. Take (rd'=10 Ω)



- **Ideal mode**

Vf=0

$$If = \frac{Vbias}{Rlimit} = \frac{10}{1000}$$

=0.01=10mA

- **practical mode**

Vf=0.7

- $$If = \frac{Vbias - Vf}{Rlimit}$$

$$= \frac{10-0.7}{1000}$$

=0.0093=9.3mA

VRlimit= Vbias –Vf

= 10-0.7= 9.3 V

- **Complete mode**

Vf=0.7 rd= 10 Ω

$$If = \frac{Vbias - Vf}{Rlimit + rd}$$

$$= \frac{10-0.7}{10}$$

=0.00921=9.21mA

VRlimit= Vbias –Vf – (If * rd)

= 10-0.7- (0.00921*10)

= 9.207 V

Diode’s Load line analysis

Load line analysis for a diode circuit

- The load line is a straight line on the I-V (current-voltage) characteristic curve of the diode. It represents the possible combinations of voltage and current that the external circuit can provide to the diode.

Key points to remember:

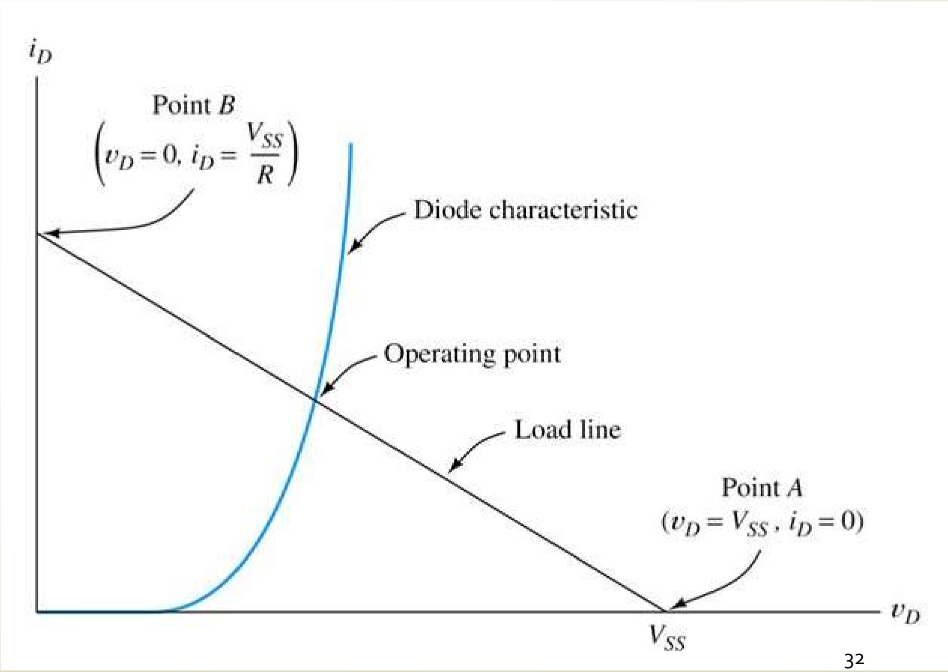
- **Slope:** The slope of the load line is determined by the resistance in the circuit. A steeper slope indicates a higher resistance.
- **Voltage intercept:** This point represents the maximum voltage that can be applied across the diode when the current is zero (open-circuit condition).
- **Current intercept:** This point represents the maximum current that can flow through the diode when the voltage across it is zero (short-circuit condition).

Steps to Perform Load Line Analysis:-

Draw the I-V Characteristic Curve: the relationship between the diode current (ID) and the voltage across it (VD).

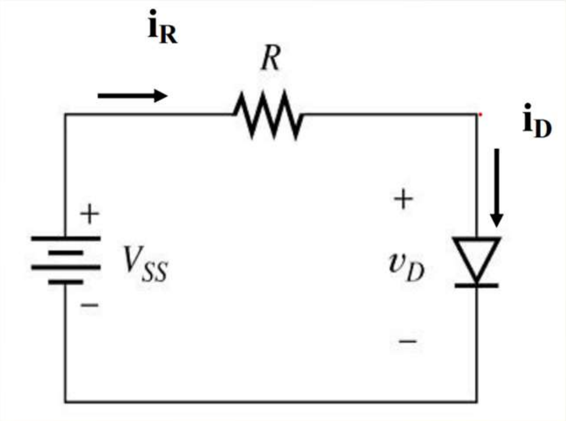
Use Kirchhoff's Voltage Law (KVL) to find the equation of the load line.
Plot the load line on the same graph as the I-V curve.

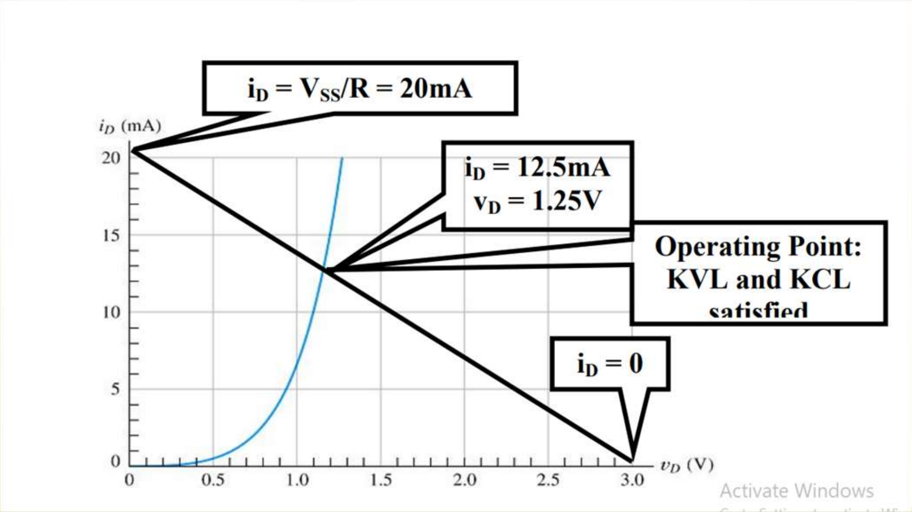
The Q-point is the intersection of the load line and the diode's I-V curve.
The coordinates of the Q-point give the operating values of the diode current (I_DQ) and voltage (V_DQ).



Example on load line analysis

- V_{SS}= 3 v , R=150 Ω
- When V_D= 0 ➔ $i_R=I_D=\frac{Vss}{R}=\frac{3}{150}$=0.02 Amp
- When $V_D=V_{ss}$ ➔ $i_R=I_D$=0





Diode Applications

Diodes Rectification

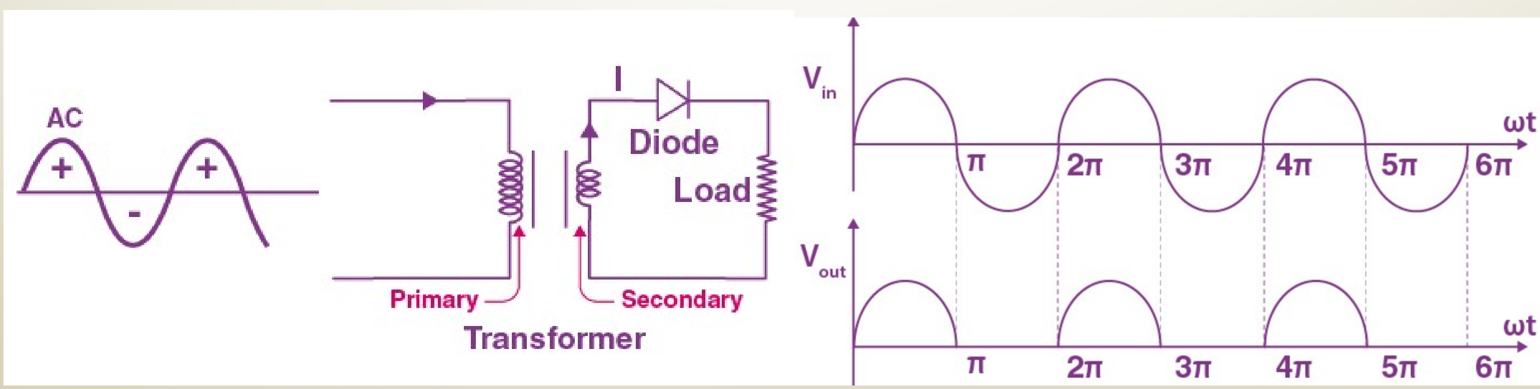
- ✓ diodes, semiconductor devices that allow current to flow in only one direction, are the key components in rectification circuits.
- ✓ rectification is a fundamental process in electronics that converts alternating current (AC) into direct current (DC).
- ✓ This conversion is essential for powering various electronic devices, from simple battery chargers to complex power supplies.

<u>Half-Wave Rectifier:</u>

Principle: Only one half-cycle of the AC input waveform is allowed to pass through the diode.

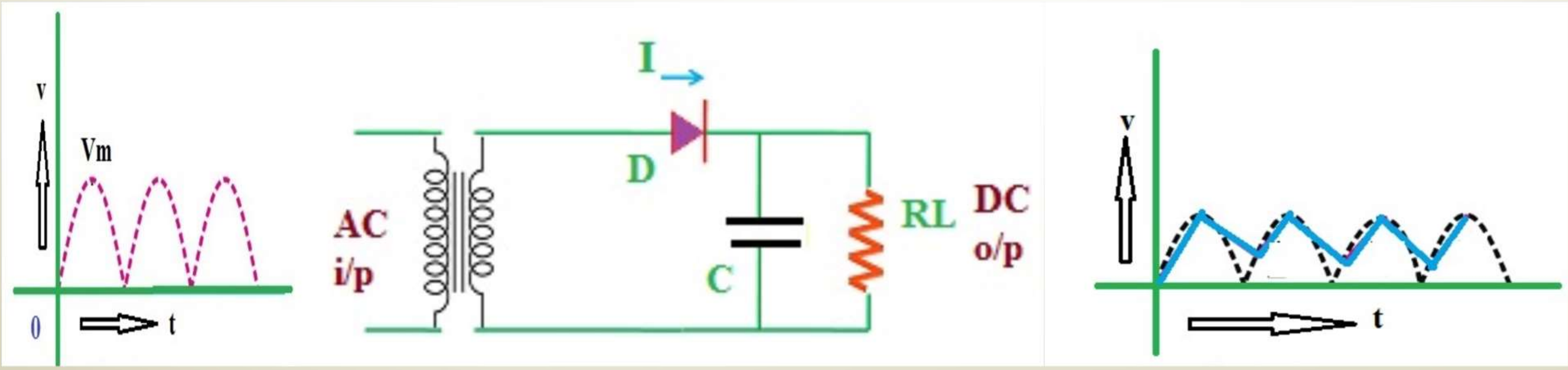
Circuit: A single diode is connected in series with the load resistor.

Output: A pulsating DC waveform with a significant amount of ripple



Half-Wave Rectifier with Capacitor Filter

- a capacitor filter, it can provide a relatively smooth DC output, though not as smooth as a full-wave rectifier.



Half Wave Rectifier Formula

➢ Ripple Factor of Half Wave Rectifier: -

- Ripple factor determines how well a halfwave rectifier can convert AC voltage to DC voltage.
- Ripple factor can be quantified using the following formula

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1}$$

$$V_{rms} = \frac{V_M}{2} \quad , \quad V_{dc} = \frac{V_M}{\pi}$$

Half Wave Rectifier Formula

Form factor of a Halfwave Rectifier the form factor is the ratio between RMS value and average value and is given by the formula:

form factor $= \frac{rms\ value}{avrage\ value}$

- **Efficiency of Halfwave Rectifier** the efficiency of a halfwave rectifier is the ratio of output DC power to the input AC power.

$$\eta = \frac{P_{DC}}{P_{AC}}$$

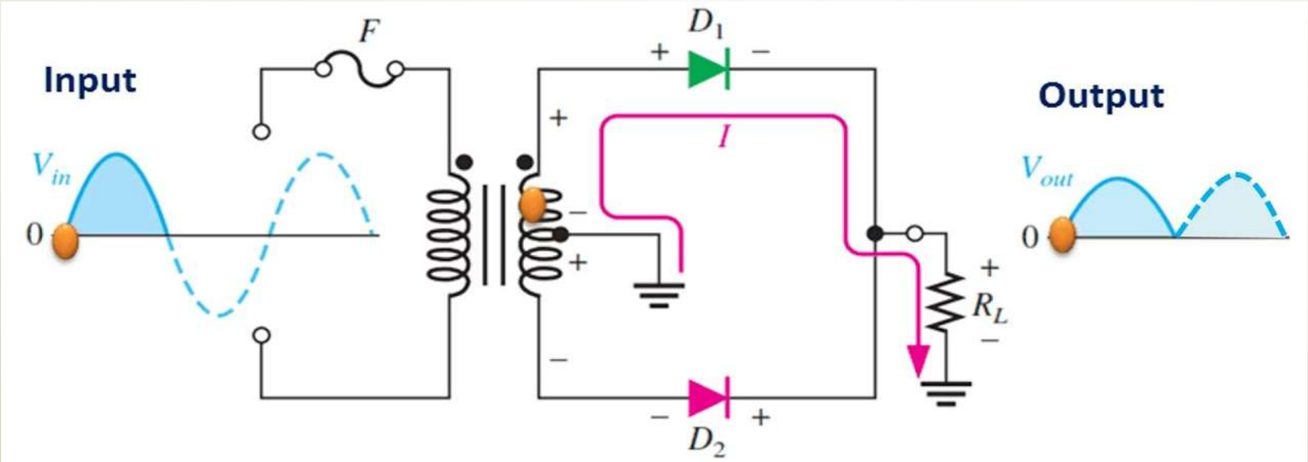
❖ ***The filter in a half-wave rectifier is used to smoothen the pulsating fluctuating DC component***

➢ **Disadvantages of Half Wave Rectifier**

- Power loss
- Low output voltage
- The output contains a lot of ripples

Full-Wave Rectifier

- A full-wave rectifier is an electronic circuit that converts alternating current (AC) into direct current (DC) by utilizing both halves of the AC input waveform.
- a more efficient and smoother DC output compared to a half-wave rectifier



Characteristics of Full Wave Rectifier

➢ Ripple factor

- The ripple factor can be defined as the ratio of ripple voltage and the pure DC voltage.
- based on the ripple factor, the DC signal can be indicated
- When the ripple factor is high then it indicates a high pulsating DC signal
- when the ripple factor is low then it indicates a low pulsating DC signal.

ripple factor is given by

$$\gamma = \sqrt{(V_{rms} V_{DC})^2 - 1}$$

$\gamma = 0.48$ **for pure sinwave**

➢ DC Output Current

- The flow of current in both the diodes like D1 & D2 at the o/p load resistor like RL is in the same direction. So, the o/p current is the amount of the current in both the diodes
- The current generated through the D1 diode is $\frac{\text{Imax}}{\pi}$
- The current generated through the D2 diode is $\frac{\text{Imax}}{\pi}$.
- **DC Output Current=** $2\,\frac{\text{Imax}}{\pi}$ 'Imax' is the max DC load current

➢ <u>Peak Inverse Voltage (PIV)</u>

- Peak inverse voltage or PIV is also known as peak reverse voltage.
- It can be defined as when a diode can withstand maximum voltage within the reverse bias state.
- If the applied voltage is higher as compared with the PIV, then the diode will destroy permanently.
- **PIV = 2Vs max**

➢ DC Output Voltage

- The DC o/p voltage can appear at the load resistor (RL) and that can be given like $\mathbf{V_{DC} = 2V_{max}/\pi}$ **where** 'V_{max}' is the max secondary voltage.
- I_{RMS} The root mean square value of the load current of a full-wave rectifier is $I_{RMS} = \frac{\mathbf{Im}}{\sqrt{\mathbf{2}}}$.
- $\mathbf{V_{RMS}}$ Root mean square value of the o/p load voltage of a full-wave rectifier is $\mathbf{V_{RMS} = I_{RMS} \times R_L = * \ RL}$

➢ Form Factor

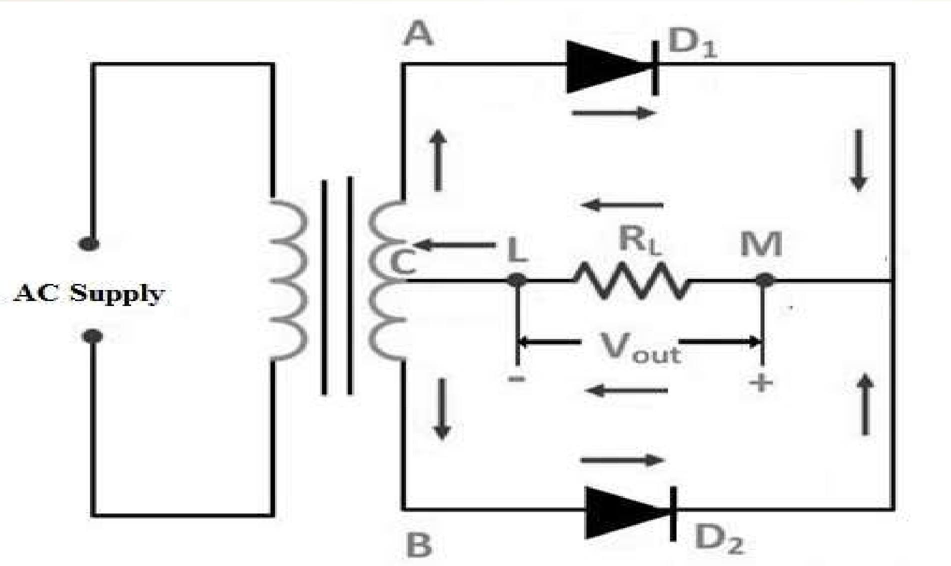
- The form factor of the full-wave rectifier can be defined as the ratio of RMS value of current and DC output current.
- **Form Factor = RMS Value of Current /DC Output Current.**
- For a full-wave rectifier, the form factor is 1.11

➢ Rectifier Efficiency

- When the rectifier efficiency is high then it is called a good rectifier,
- whereas the efficiency is low then it is called an inefficient rectifier.
- $$H = \frac{Output(PDC)}{Input(PAC)}$$

Types of Full-Wave Rectifiers

❖ **Center-Tapped Full-Wave Rectifier:**



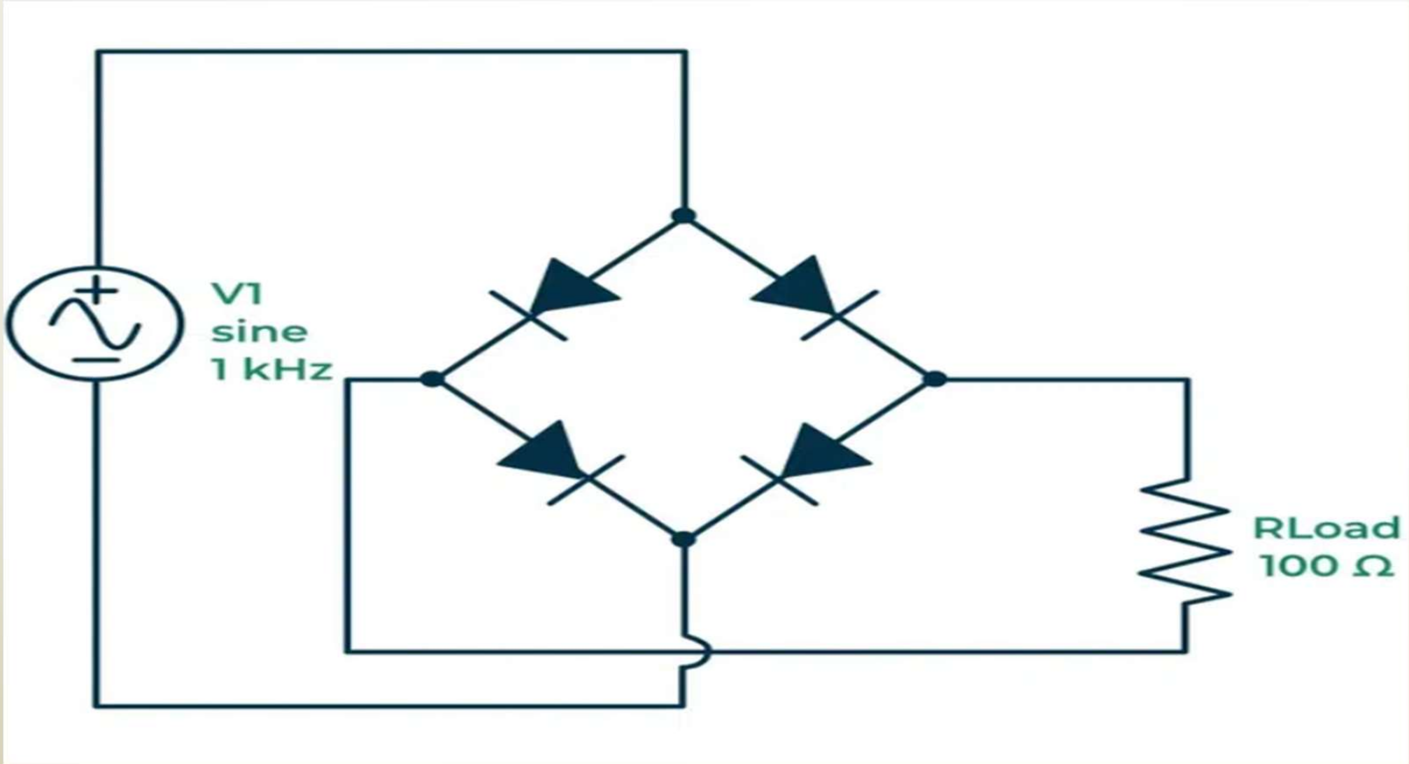
❖ Center-Tapped Full-Wave Rectifier:

- Uses a center-tapped transformer and two diodes.
- During the positive half-cycle, one diode conducts, and during the negative half-cycle, the other diode conducts.
- The center tap of the transformer provides a reference point for the diodes.

Working Principle of

- During the positive half-cycle, the top terminal of the transformer is positive, forward-biasing diode D1.
- Current flows through D1 and the load resistor.
- During the negative half-cycle, the bottom terminal of the transformer is positive, forward-biasing diode D2.
- Current flows through D2 and the load resistor.

Bridge Rectifier:



Bridge Rectifier:

- four diodes arranged in a bridge configuration.
- During each half-cycle, two diodes conduct, allowing current to flow through the load in the same direction.
- More efficient than the center-tapped rectifier as it doesn't require a center-tapped transformer.

Working Principle for Bridge Rectifier:

- During the positive half-cycle, diodes D1 and D2 conduct, allowing current to flow from the positive terminal of the AC source, through D1, the load resistor, D2, and back to the negative terminal of the AC source.
- During the negative half-cycle, diodes D3 and D4 conduct, allowing current to flow from the negative terminal of the AC source, through D3, the load resistor, D4, and back to the positive terminal of the AC source.

Advantages of Full-Wave Rectifiers

- **Higher Efficiency:** Utilizes both halves of the AC cycle, resulting in higher power output.
- **Smoother Output:** Produces a smoother DC output with less ripple compared to half-wave rectifiers.
- **Wider Range of Applications:** Used in various applications, including power supplies, battery chargers, and audio amplifiers.

Disadvantages of Full-Wave Rectifiers

- More Complex Circuit: Requires more components compared to half-wave rectifiers.
- Higher Voltage Drop: Due to the series connection of diodes, there is a higher voltage drop across the rectifier, reducing the output voltage.

Applications of full wave rectifier

- Power supplies for electronic devices
- Battery chargers
- Audio amplifiers
- DC motor control circuits

C = I / (2 * f * Vr)

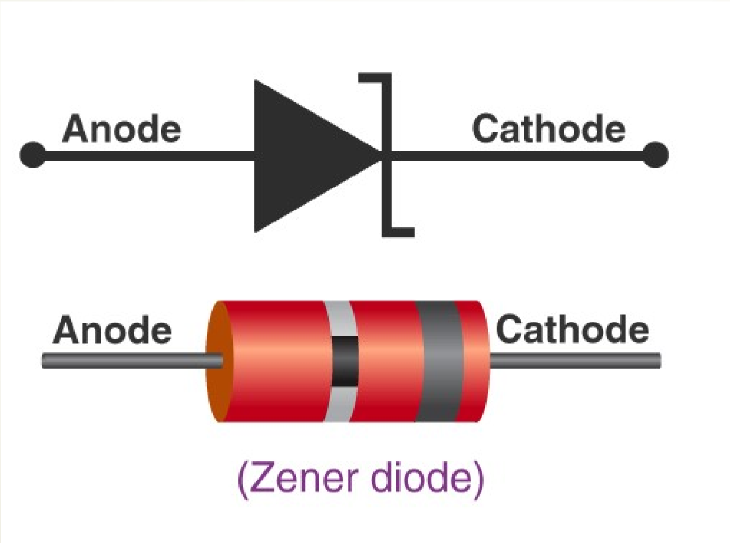
Smoothing Capacitor

- Charging: During the positive half-cycle of the rectified waveform, the capacitor charges up to the peak voltage.
- Discharging: When the input voltage drops, the capacitor discharges through the load, maintaining the voltage across the load.
- Repeat: This process repeats for each half-cycle, resulting in a smoother output voltage.
- $C = \frac{I}{(2 * f * Vripple)}$

Factors Affecting Capacitor Selection

- **Capacitance Value:** A larger capacitance value allows the capacitor to store more charge, resulting in a smoother output.
- **Ripple Voltage:** The desired ripple voltage determines the required capacitance. A lower ripple voltage requires a larger capacitor.
- **Load Current:** The load current affects the capacitor's discharge rate. A higher load current requires a larger capacitor to maintain the output voltage.
- **Input Frequency:** The input frequency determines the rate at which the capacitor charges and discharges.
- **Voltage Rating:** The capacitor's voltage rating must be greater than the peak voltage of the rectified waveform to prevent damage.

Zener Diode



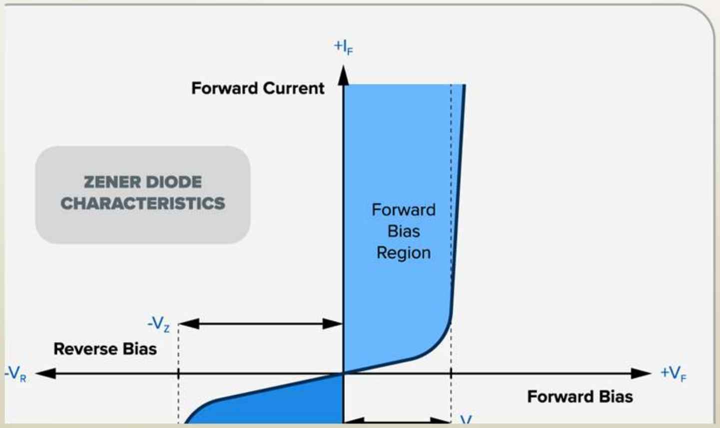
What is a Zener Diode?

- is a type of semiconductor device that allows current to flow in both the forward direction (like a regular diode)**.**
- also in the reverse direction when the voltage across it exceeds a specific value known as the **Zener breakdown voltage**.
- It is primarily used to regulate voltage in electronic circuits.

How Does a Zener Diode Work?

Forward Bias:

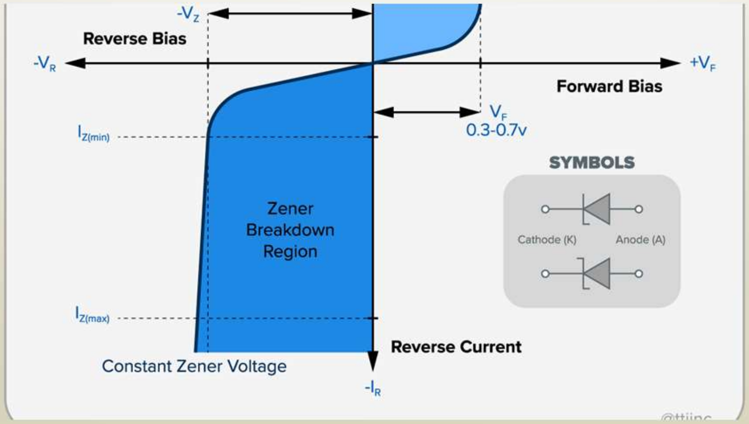
- When the Zener diode is forward-biased (positive voltage applied to the anode), it behaves like a regular diode, allowing current to flow once the forward voltage is reached (typically 0.7V for silicon diodes).



How Does a Zener Diode Work?

Reverse Bias:

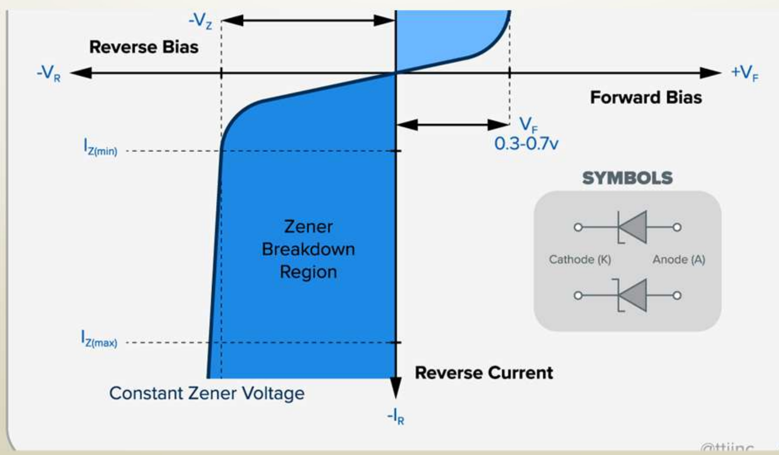
- When the Zener diode is reverse-biased (positive voltage applied to the cathode), it blocks current like a standard diode—until the reverse voltage reaches the **Zener breakdown voltage**.
- At this point, the diode begins to conduct in the reverse direction, maintaining a constant voltage across its terminals.



Zener Breakdown

The "Zener breakdown" occurs due to:

- **Quantum Tunneling:** When the reverse voltage is high enough, electrons tunnel through the depletion region, allowing current to flow without damaging the diode.
- The diode is designed to handle this condition without failure, ensuring stable voltage regulation.



Applications of Zener Diodes

- **Voltage Regulation:** Used in power supplies to provide a stable output voltage.
- **Overvoltage Protection:** Protects sensitive electronics from voltage spikes.
- **Voltage Reference:** Acts as a precise voltage reference in circuits like ADCs or DACs.
- **Clipping Circuits:** Limits voltage to a specific range in signal processing

❖ A typical circuit connects the Zener diode in reverse bias across a load, with a resistor to limit current.

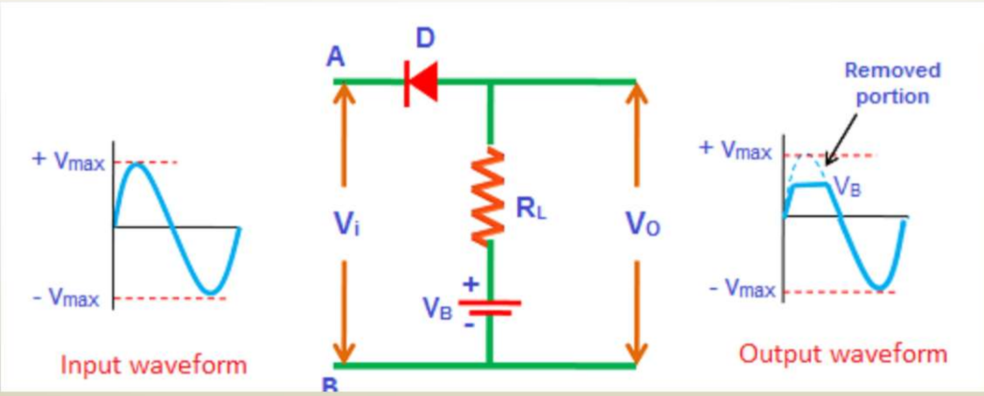
Clipping

Clipping circuit

- electronic circuit designed to remove or "clip" portions of a signal's amplitude without distorting the remaining part of the waveform.
- It is commonly used in signal processing to shape or limit voltage levels to a desired range.

Operation

- A clipping circuit alters the input signal by "cutting off" the parts of the waveform that exceed a certain threshold.
- The clipped waveform is usually bounded by a fixed voltage level.



Calculation Steps:

- input Voltage Range:

$V_{in}(t)=V_m \sin(\omega t)$

Vm : Peak amplitude of the sine wave.

ω: Angular frequency

Clipping Threshold:

When $V_{in}>V_{ref}+V_f$, the diode conducts,

output voltage is $V_{out}=V_{ref}+V_f$

When $V_{in}\leq V_{ref}+V_f$ the diode is off ⇒ $Vout=Vin$

Types of Clipping Circuits:

- **Positive Clipper**: Clips the positive part of the input signal above a threshold voltage.
- **Negative Clipper:** Clips the negative part of the input signal below a threshold voltage.
- **Dual Clipper (Positive and Negative):** Clips both positive and negative parts of the waveform, often creating a waveform bounded within a specific range.

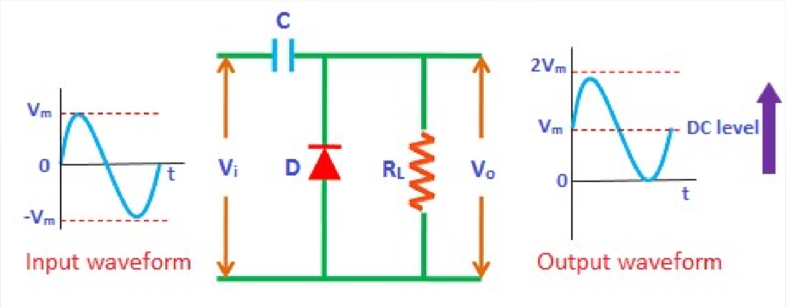
Applications:

- **Signal Conditioning**: To protect circuits from excessive voltage levels.
- **Waveform Shaping**: To limit distortion in audio or communication signals.
- **Voltage Regulation**: Zener diodes in clippers can regulate voltage levels.
- **Pulse Shaping**: To generate sharp edges for digital circuits.

Clamping

Clamping circuit

- an electronic circuit that shifts the voltage level of a waveform without altering its shape.
- Unlike a clipping circuit, a clamping circuit moves the entire signal vertically, either up or down, so that it is "clamped" to a new DC reference level.
- also known as a **DC restorer**:



Clamping calculation

- Clamped Output Voltage (V_{out}):

$$V_{out}=V_{in}+V_{shift}$$

V_{shift} : Voltage shift caused by the clamping circuit.

Positive Clamper: $_{Vshift}=-V_{ref}-V_f$

Negative Clamper: $V_{shift}=V_{ref}+V_f$

Purpose:

- To shift the baseline voltage of an AC signal to a desired DC level.
- The peak-to-peak amplitude of the waveform remains unchanged.

Types of Clamping Circuits:

- Positive Clamper: Shifts the waveform so that the most negative point of the signal touches the zero or a positive reference level.
- Negative Clamper: Shifts the waveform so that the most positive point of the signal touches the zero or a negative reference level..

Applications of Clamping Circuits

- Signal Processing: Restoring the DC component of a signal in television receivers or communication systems.
- Voltage Level Adjustment : Shifting signal levels for compatibility with other circuits or devices.
- Waveform Modifications: Used in test equipment or oscilloscopes to alter signal reference levels for easier measurement.