BASIC ELECTRICAL AND ELECTRONIC CIRCUITS

Syllabus

Course Code: 25EC1101 **L-T-P-S : 3-0-2-0**

CO-3: Semiconductor devices: PN Junction diode (Operation, VI Characteristics), Applications: Diode as a switch, Rectifiers (HWR, FWR), Clippers and Clampers, Zener Diode (Breakdown) and voltage regulator, LED **Bipolar Junction Transistor:** Operation of Transistor, CB, CE, CC Configurations-input and output characteristics and applications, Transistor as switch.
CO-4: Integrated Circuits: Operational Amplifiers IC 741 and applications, 555 Timer and applications, Voltage regulators: 78XX, 79XX and LM723

KONERU LAKSHMAIAH EDUCATION FOUNDATION
(Deemed to be University, Estd, u/s. 3 of UGC Act 1956)

B.Tech - Odd Sem : Semester In Exam-II
Academic Year:2025-2026

25EC1101 – BASIC ELECTRICAL AND ELCTRONIC CIRCUITS

Set No:

Model Question Paper

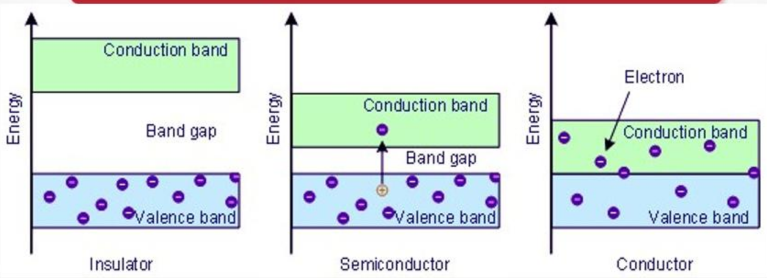
Time: 90 Mins		Max. Marks: 50					
S.NO	Answer All Questions	Choice	Options	Marks	CO	CO BTL	COI BTL
1.	**ANSWER ALL QUESTIONS (6 X 2 = 12 M)**			**12Marks**			
1.A.				2Marks	CO3		
1.B.				2Marks	CO3		
1.C.				2Marks	CO3		
1.D.				2Marks	CO4		
1.E.				2Marks	CO4		
1.F.				2Marks	CO4		
2.	**ANSWER ALL QUESTIONS (4 X 4 = 16 M)**			**16Marks**			
2.A.				4Marks	CO3		
2.B.				4Marks	CO3		
2.C.				4Marks	CO4		
2.D.				4Marks	CO4		
3.	**ANSWER ALL QUESTIONS (5 + 6 = 11 M)**	**choice Q-4**		**11Marks**	**CO3**		
3.A.				5Marks	CO3		
3.B.				6Marks	CO3		
4.	**ANSWER ALL QUESTIONS (5 + 6 = 11 M)**			**11Marks**	**CO3**		
4.A.				5Marks	CO3		
4.B.				6Marks	CO3		
5.	**ANSWER ALL QUESTIONS (5 + 6 = 11 M)**	**choice Q-6**		**11Marks**	**CO4**		
5.A.				5Marks	CO4		
5.B.				6Marks	CO4		
6.	**ANSWER ALL QUESTIONS (5 + 6 = 11 M)**			**11Marks**	**CO4**		
6.A.				5Marks	CO4		
6.B.				6Marks	CO4		

CO3 Terminal Important Questions (2 Marks/4 Marks/5 Marks/6 Marks)

1. **List out the differences between intrinsic and extrinsic semiconductors.**
2. **List out the differences between n-type and p-type semiconductors.**
3. **Describe the formation and characteristics of a PN junction in a diode (or) Discuss about forward and reverse biasing of a PN diode with neat diagrams.**
4. **Sketch VI characteristics of diode.**
5. **Write the diode current equation and the effect of temperature on diode Characteristics.**
6. **Describe the working of LED.**
7. **List out the applications of LEDs.**
8. **Describe the working of Zener Voltage Regulator**
9. **Describe the Break down Mechanisms in diodes (or) Explain about Avalanche and Zener breakdown mechanisms in diodes (or) List out the differences between Zener break down and Avalanche break down**
10. **What is the purpose of using a rectifier in electronic circuits?**
11. **Describe the working of Half Wave Rectifier (HWR) with neat sketches.**
12. **Prove that in the case of practical Half Wave Rectifier (HWR), the efficiency is always less than 40.6%.**
13. **Derive the percentage voltage regulation for a Half Wave Rectifier (HWR) assuming a resistive load.**
14. **With neat sketches explain the operation of a Centre Tapped Full Wave Rectifier (CT-FWR) (or) Explain the working of center tapped full wave rectifier with neat circuit and input-output waveforms.**
15. **Prove that in the case of practical Centre Tapped Full Wave Rectifier (CT-FWR), the efficiency is always less than 81.2%.**
16. **Derive the percentage voltage regulation for a Full Wave Rectifier (FWR), assuming a resistive load.**
17. **With neat sketches explain the operation of a Bridge Full Wave Rectifier (B-FWR).**
18. **Summarize the advantages and disadvantages of Half Wave Rectifier (HWR), Centre Tapped Full Wave Rectifier (CT-FWR), and Bridge Full Wave Rectifier (B-FWR).**
19. **Compare Half Wave Rectifier (HWR), Centre Tapped Full Wave Rectifier (CT-FWR), and Bridge Full Wave Rectifier (B-FWR).**

20. Define Clippers and Clampers.
21. Discuss the operations with circuit diagram of Series positive/negative clippers, Shunt positive/negative clippers, and Series and Shunt Clampers with waveforms.
22. With the help of neat circuit diagram and input-output waveforms, discuss the working of a series positive clipper with positive bias voltage.
23. Draw the circuit of the common base (CB) configuration and explain its input and output characteristics.
24. Draw the circuit of the common emitter (CE) configuration and explain its input and output characteristics.
25. Draw the circuit of the common collector (CC) configuration and explain its input and output characteristics.
26. Discuss about a transistor with the help of the input characteristics of common base (CB) configuration.
27. Discuss about cut-off, saturation and active regions in a transistor with the help of the output characteristics of common base (CB) configuration.
28. Discuss about a transistor with the help of the input characteristics of common emitter (CE) configuration.
29. Discuss about cut-off, saturation and active regions in a transistor with the help of the output characteristics of common emitter (CE) configuration.
30. Discuss about a transistor with the help of the input characteristics of common collector (CC) configuration.
31. Discuss about cut-off, saturation and active regions in a transistor with the help of the output characteristics of common collector (CC) configuration.
32. Explain the working of a transistor as a switch (Cutoff and Saturation).
33. Mention the applications of a transistor.

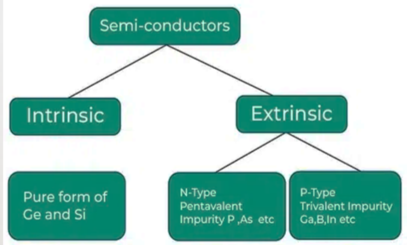
Insulator, Semiconductor & Conductor



Property	Insulator	Semiconductor	Conductor
Electrical Conductivity	Very low (almost zero)	Moderate	Very high
Band (Forbidden) Gap	Large	Small	Overlapping bands
Electron Flow	No free electrons	Few free electrons	Large number of free electrons
Examples	Rubber, Glass, Wood	Silicon (Si), Germanium (Ge)	Copper, Silver, Gold

Semiconductors & Types

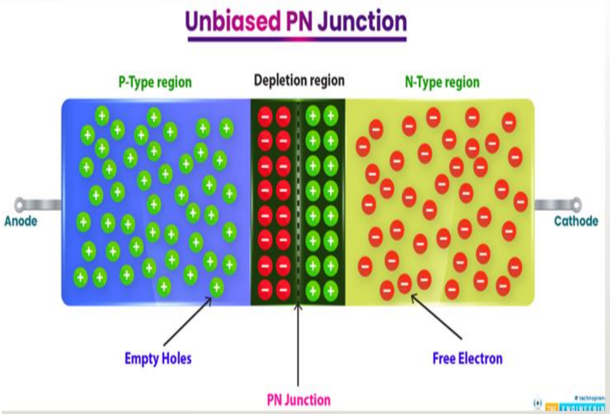
- Form the core of diodes, transistors, and integrated circuits (ICs).
- Used for switching, amplification, and signal processing.
- Basis of modern electronics (transistors, ICs, etc.).



Intrinsic	Extrinsic
Pure semiconductor material without any impurities	Semiconductor material doped with impurities to modify electrical properties
Made of pure elements like Silicon (Si) and Germanium (Ge)	Contains added impurities (dopants) like Phosphorus (P), Arsenic (As), Gallium (Ga), Boron (B) etc.
Low conductivity	Higher conductivity

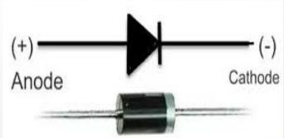
n-type Semiconductor	p-type Semiconductor
Formed by adding **pentavalent (Group V)** impurities.	Formed by adding **trivalent (Group III)** impurities.
Ex: Phosphorus (P), Arsenic (As), Antimony (Sb) etc.	Ex: Gallium (Ga), Boron (B), Indium (In) etc.
Electrons = majority carriers, holes = minority carriers.	**Holes = majority carriers, electrons = minority carriers.**
Conductivity increases due to more electrons	Conductivity increases due to more holes

PN Junction Diode



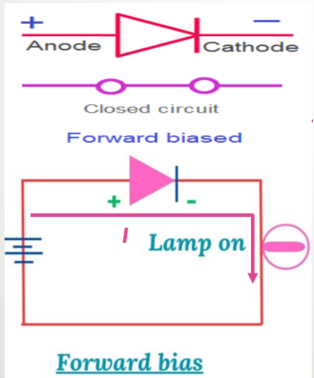
P-Type: Silicon doped with trivalent impurities

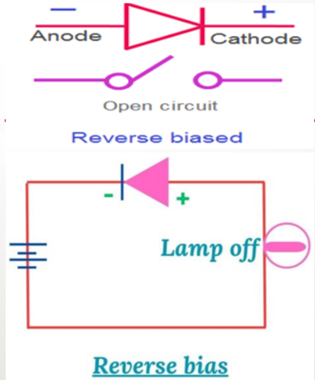
N-Type: Silicon doped with pentavalent impurities



- A **semiconductor diode** that allows current flow in only one direction.
- Types of diodes: PN Junction, Zener, LED, Schottky, etc.
- Barrier potential: Typically, 0.7V for Silicon (Si), 0.3V for Germanium (Ge).

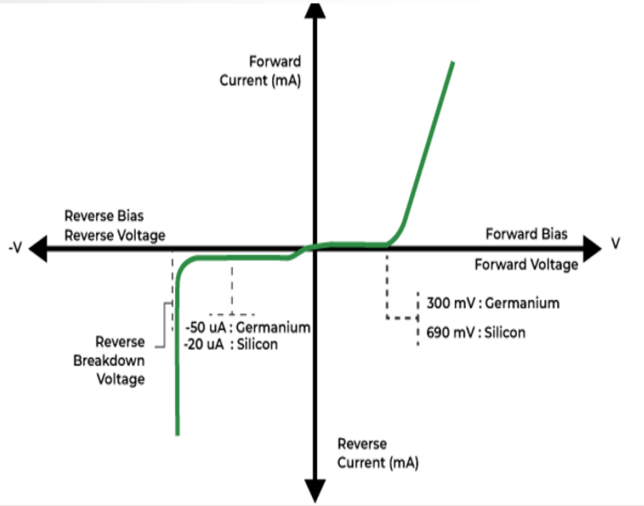
Operation: Diode Forward and Reverse Bias





- In Forward bias, the diode acts as a low-resistance (closed circuit) path. The diode allows current to flow through the circu turning the lamp ON.
- In Reverse bias, the diode acts as a high-resistance (open circuit) path. The diode blocks current flow, preventing the lar from turning ON.

VI Characteristics of Diode



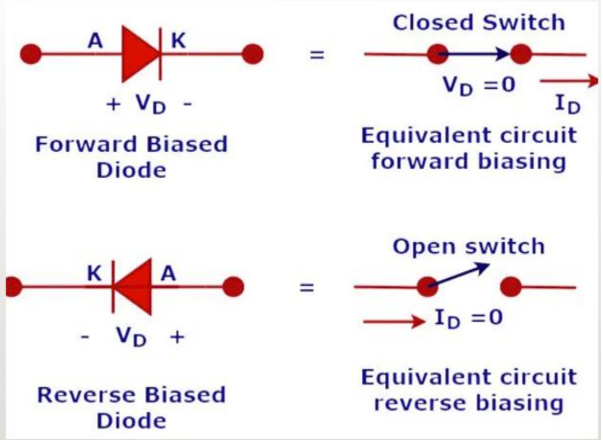
Graph of Current (I) vs. Voltage (V):

Forward Bias: Rapid increase in current after threshold voltage. Threshold Voltage: 0.7V (Si) and 0.3V (Ge).

Reverse Bias: Minimal leakage current until breakdown voltage (Avalanche or Zener breakdown)is reached.

Diode Applications & Diode acts as switch

- **Basic application:** Diode acts as a Switch
- **Rectification:** Converts AC to DC (e.g., Full-Wave and Half-Wave Rectifiers).
- **Clipping/Clamping:** Modifies waveform shapes.
- **Voltage Regulation:** Zener diodes maintain a constant voltage.
- **Signal Mixing/Demodulation:** Used in communication circuits.



Diode Current Equation

- It describes how the current through a diode responds to the voltage applied across it.

$$I = I_0\left(e^{\frac{qV}{\eta KT}} - 1\right)$$

(Or)

$$I_D = I_s\left(e^{\frac{qV_D}{\eta KT}} - 1\right)$$

(Or)

$$I_D = I_s\left(e^{\frac{V_D}{\eta V_T}} - 1\right)$$

- I or I_D is the current flowing through the diode
- I_0 or I_s is the dark saturation current (diode leakage current density in the absence of light)
- q is the charge on the electron (1.602×10^{-19} C)
- V or V_D is the voltage applied across the diode
- η is the (exponential) ideality factor, 1 for Ge & 2 for Si.
- K is the Boltzmann constant ($K=1.38\times 10^{-23} JK^{-1}$)
- T is the absolute temperature in kelvin

At room temperature (T=27°C=300K), $\boxed{\text{Thermal Voltage } V_T = \frac{q}{KT} \approx 26mV}$

Effect of Temperature on Diode Characteristics

- The Barrier potential (V_B) or Contact potential (V_γ) or threshold voltage(V_{Th}) or Knee voltage(V_K) also depends on temperature. For every 1°C raise of temperature of V_B decreases by 2mV.

$$\boxed{V_B(T_2) = V_B(T_1) - 0.002\ (T_2 - T_1)}$$

- The reverse saturation current I_0 or I_s depends on temperature.
  For every 1°C increase → I_0 or I_s increases by 7%
  For every 10°C increase → I_0 or I_s doubles

$$I_0(T_2) = I_0(T_1)\text{x } 2^{\left(\frac{T_2 - T_1}{10}\right)}$$

(Or)

$$I_s(T_2) = I_s(T_1)\text{x } 2^{\left(\frac{T_2 - T_1}{10}\right)}$$

1. Given a diode current of 6mA, $V_T = 26mV$, $\eta=1$, and $I_s = 1nA$, find the applied voltage V_D.

Sol

Diode current $I_D = 6mA = 6\times10^{-3}A$

$V_T = 26mV = 26\times10^{-3}V$

$\eta = 1$

$I_S = 1nA = 1\times10^{-9}A$

Current through a diode (Diode current Equation)

$$\boxed{I_D = I_S\left(e^{\frac{V_D}{\eta V_T}} - 1\right)}$$

$$\frac{I_D}{I_S} = e^{\frac{V_D}{\eta V_T}} - 1$$

$$\frac{I_D}{I_S} + 1 = e^{\frac{V_D}{\eta V_T}}$$

Take logarithm on both sides,

$$\ln\left(\frac{I_D}{I_S} + 1\right) = \frac{V_D}{\eta V_T}$$

$$V_D = \eta V_T \ln\left(\frac{I_D}{I_S} + 1\right)$$

$$= 1\times26\times10^{-3}\ln\left[\left(\frac{6\times10^{-3}}{1\times10^{-9}}\right)+1\right]$$

$$= 0.026\ln(6\times10^{6}+1)$$

$$= 0.026\ln(6000001)$$

$$= 0.026\times15.607$$

$$\boxed{V_D = 0.406\,V}$$

2. Given a diode current of 8mA and $\eta=2$, find I_s if the applied voltage is 0.5 V and the temperature is room temperature (27°C).

Sol

Diode current $I_D = 8mA = 8\times10^{-3}A$

$\eta = 2$

applied voltage $V_D = 0.5V$

Current through a diode (Diode current Equation)

$$\boxed{I_D = I_S\left(e^{\frac{V_D}{\eta V_T}} - 1\right)}$$

$$I_S = \frac{I_D}{e^{\frac{V_D}{\eta V_T}} - 1}$$

$$= \frac{8\times10^{-3}}{e^{\frac{0.5}{2\times26\times10^{-3}}} - 1}$$

$$\boxed{\because V_T = 26mV}$$

$$= \frac{8\times10^{-3}}{e^{9.615} - 1}$$

$$= \frac{8\times10^{-3}}{14987.9 - 1}$$

$$= \frac{8\times10^{-3}}{14986.9}$$

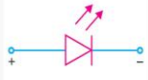
$$= 5.337\times10^{-7}$$

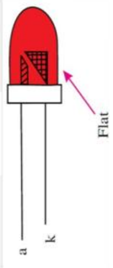
$$\boxed{I_S = 0.5337\times10^{-6} = 0.509\,\mu A}$$

3. Determine the barrier potiential of a Si diode at boiling and freezing points of water. Sol Boiling points of water $T_2 = 100^\circ C$ Freezing points of water $T_2 = 0^\circ C$ Room Temperature $T_1 = 27^\circ C$ Barrier potential of a Si diode $= 0.7V$ Barrier Potential (V_b) at boiling points of water $V_b = 0.7 - 0.002(T_2 - T_1)$ $= 0.7 - 0.002(100 - 27)$ $= 0.55V$ Barrier potential (V_b) at Freezing points of water $V_b = 0.7 - 0.002(T_2 - T_1)$ $= 0.7 - 0.002(0 - 27)$ $= 0.75V$	4. The reverse saturation current of a Si diode at room temperature is 100nA. Determine the reverse saturation current at a temperature of 37° C and 50° C. Sol Reverse saturation Current of a si diode at room temperature $I_S(T_1) = 100nA = 100 \times 10^{-9} A$ Room temperature $T_1 = 27^\circ C$ At a temperature $T_2 = 37^\circ C$, reverse saturation Current $\boxed{I_S(T_2) = I_S(T_1) \times 2^{\left(\frac{T_2 - T_1}{10}\right)}}$ $= 100 \times 10^{-9} \times 2^{\left(\frac{37-27}{10}\right)}$ $= 100 \times 10^{-9} \times 2^{\cancel{10}/\cancel{10}}$ $\boxed{I_S(T_2) = 200nA}$ At a temperature $T_2 = 50^\circ C$, reverse saturation Current $\boxed{I_S(T_2) = I_S(T_1) \times 2^{\left(\frac{T_2 - T_1}{10}\right)}}$ $= 100 \times 10^{-9} \times 2^{\left(\frac{50-27}{10}\right)}$ $= 100 \times 10^{-9} \times 2^{\frac{23}{10}}$ $= 100 \times 10^{-9} \times 2^{2.3}$ $= 100 \times 10^{-9} \times 4.924$ $\boxed{I_S(T_2) = 492.4nA}$

Light Emitting Diode (LED)

An LED is a **forward-biased P–N junction** that emits visible light. LEDs **do not emit light in reverse bias**. Reverse bias can **damage or destroy** an LED.





Blue LEDs are also available, but **red LEDs are most common**.

When electrons from the N-side recombine with holes on the P-side, **energy is released as photons**.

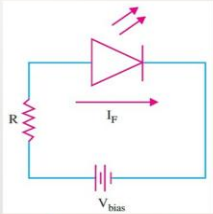
In Si and Ge, most energy becomes heat, not **visible light** → therefore light is **negligible**.

Materials like **GaAs, GaP, and GaAsP** efficiently convert recombination energy into visible light.

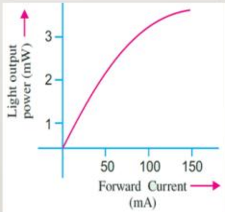
The **colour of light** depends on the **material used**:

- **GaAs** → Infrared (invisible), **GaP** → Red or green light, **GaAsP** → Red or yellow (amber) light

Working of LED



- A simple LED circuit uses a **series resistor** to limit current and protect the LED during forward bias.
- The **forward voltage** required by an LED is **higher** than that of a normal silicon diode.
- An LED typically needs **1.2 V to 3.2 V** (depending on colour and material).
- Most LEDs fail permanently if the reverse voltage exceeds about 5 V.
- An LED produces light only when a **sufficient forward current** flows through it.
- The **light output (power)** increases as the **forward current increases**.
- This relationship is shown in the graph:
  - At low current → low light output
  - At higher current → higher light output
- Therefore, **greater forward current gives greater brightness**, up to a safe limit.



Applications of LED

- Used in **alphanumeric displays** (7-segment, dot-matrix).
- Used in **hand-held calculators** for numeric displays.
- Used in **burglar-alarm systems** for indication.
- Used in **data links** and **remote controllers** (IR LEDs).
- Used in **solid-state video displays** (replacing CRTs).
- Used in **image sensing circuits** (e.g., picturephone).
- Used in **optical fiber communication** systems using GaAs LEDs.
- Used for **writing data** into optical computer memories.
- Used as **polarity indicators** and **continuity testers**.

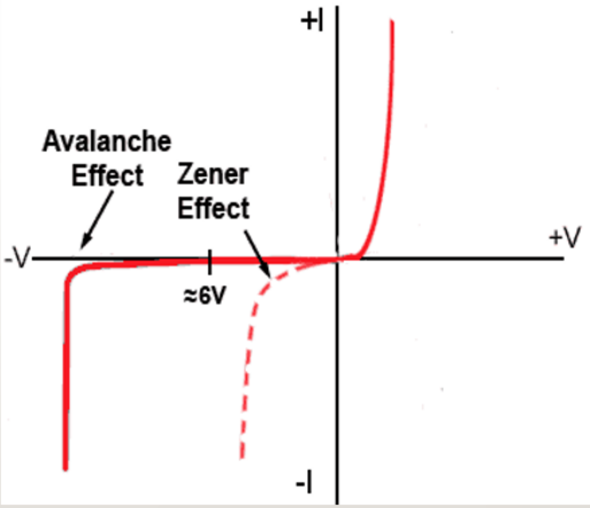
Additional Common Applications

- **Digital clocks**
- **Clock radios**
- **Calculators**
- **Wristwatches**
- **Speedometers**
- **Vehicle odometers**
- **Radio-frequency (RF) indicators**

Zener and Avalanche Breakdown

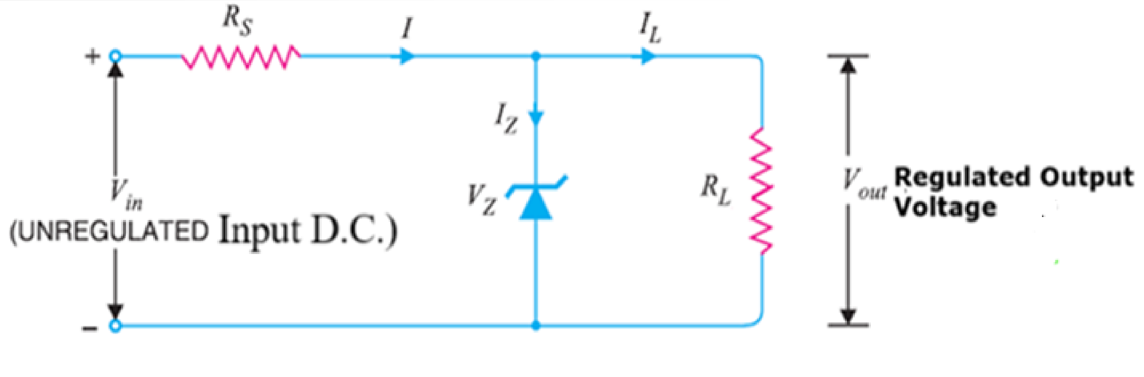
Feature	Zener Breakdown	Avalanche Breakdown
Definition	Zener breakdown occurs in a heavily doped p-n junction under low reverse bias, where the narrow depletion region causes a strong electric field that enables electrons to tunnel through, leading to a sudden rise in reverse current.	Avalanche breakdown occurs in a lightly doped p-n junction under high reverse bias, where the wide depletion region allows electrons to acquire enough energy to ionize atoms by collision, leading to a sudden rise in reverse current.
Occurrence Voltage	Typically below 6V	Typically above 6V
Mechanism	Quantum tunneling of electrons	Impact ionization due to collisions
Doping Level	Heavily doped p-n junction	Lightly doped p-n junction
Depletion Region	Narrow	Wide
Temperature Coefficient	Negative	Positive
Breakdown Sharpness	Very sharp	Less sharp
Application	Used in Zener diodes for voltage regulation below 6V	Used for voltage regulation above 6V
Effect in Graph	Occurs around ≤6V, sudden drop in voltage with increased current	Occurs around ≥6V, more gradual breakdown

V-I characteristic curves or breakdown characteristic graphs for Zener Diode



Zener Diode as a Voltage Regulator

A Zener voltage regulator is an electronic circuit that maintains a stable (constant) DC voltage regardless of variations in load current, temperature, and AC line voltage.



Example:

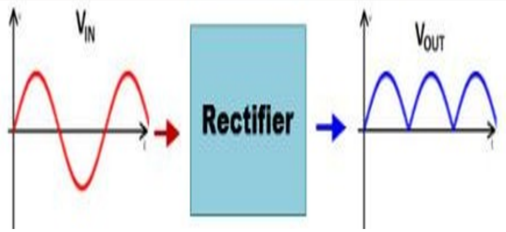
- $\mathbf{V_{in}}$ = 7-12V (can vary)
- $\mathbf{V_z}$ = 6V (Zener diode)
- $\mathbf{R_L}$ = 100Ω (chosen to limit current safely)

- The circuit is supplied with an unregulated input voltage.
- A series resistor Rs is used to limit the current flowing through the Zener diode and to drop the excess voltage.
- The Zener diode is connected in reverse bias across the load. When the input voltage exceeds the Zener breakdown voltage (V_z), the diode starts conducting in reverse. Once conducting, the Zener diode maintains a constant voltage (equal to V_z) across the load, effectively regulating the output voltage.

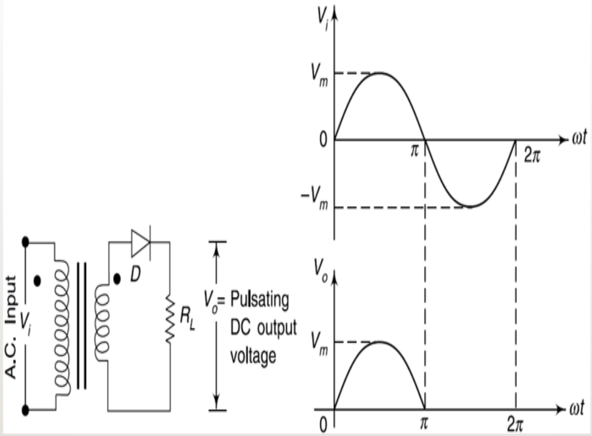
RECTIFIER

Rectifier is an electronic device that converts Alternating Current (AC) into pulsating Direct Current (DC) (every half cycle of the input). They play a crucial role in various electronic devices and power supplies where a DC power source is required.

Types of Rectifiers:
1. **Half Wave Rectifier (HWR)**
2. **Centre Tapped Full Wave Rectifier (CT-FWR)**
3. **Bridge Full Wave Rectifier (B-FWR)**



HALF WAVE RECTIFIER (HWR)



Rectifier converts an AC voltage into a pulsating DC voltage using only one half of the applied AC voltage.

The diode D is **forward-biased** (conducts current), allowing voltage to pass through to the load resistor (R_L). Only the **positive half-cycles** appear at the output.

The diode D is **reverse-biased** (blocks current), no current flows through R_L, and the output voltage is **zero.**

Parameters: HWR

- I_{dc}, V_{dc}
- I_{rms}, V_{rms}
- γ = Ripple Factor
- P_{dc}, P_{ac}
- η = Efficiency (Ratio of rectification)
- Peak Inverse Voltage (PIV)
- % Regulation

HWR: DC and RMS Voltage and Currents

Idc, Vdc : I_{dc} or I_{avg} = DC or Average value of current
V_{dc} or V_{avg} = DC or Average value of voltage

$V=V_s=V_m$ Sinωt,

$I= I_s = I_L = I_m$ Sinωt

ω = 2πf

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} I_m Sin\omega t d(\omega t) = \frac{I_m}{\pi} \quad \text{Similarly, } V_{dc} = \frac{V_m}{\pi}$$

Irms, Vrms : I_{rms} = AC or RMS Value of Current
V_{rms} = AC or RMS Value of the voltage

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(I_m \sin\omega t)^2 d(\omega t)} = \frac{I_m}{2} \quad \text{Similarly, } V_{rms} = \frac{V_m}{2}$$

HWR: Ripple factor

Ripple Factor (γ): The pulsating components present in the rectifier output are ripples and measure of such ripples present in the output is known as ripple factor.

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

Now for a half wave circuit,

$$I_{rms} = \frac{I_m}{2} \quad I_{dc} = \frac{I_m}{\pi}$$

This indicates that the ripple content in the output are 1.211 times the dc component. i.e., 121.1% of the dc component.

$$\boxed{\gamma = 1.211}$$

HWR: Rectifier Efficiency

Rectifier Efficiency (η):

It is the Percentage of total ac power that is converted into useful DC output power.

$$\eta = \frac{D.C.\ output\ power}{A.C.\ input\ power} = \frac{P_{dc}}{P_{ac}} = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{I_m^2}{4}(R_s + R_f + R_L)}$$

$$\boxed{\%\eta = 40.6\%}$$

Ideal case

It has **zero secondary winding series resistance** (Rs=0) and **zero forward resistance** (R_f=0).

$$\boxed{\eta_{ideal} = \frac{4R_L}{\pi^2(0+0+R_L)} = \frac{4}{\pi^2} = 40.6\%}$$

Practical case

Since $R_s + R_f$ is positive, the denominator increases, reducing efficiency.

$$\boxed{\eta_{practical} < 40.6\%}$$

Thus, due to diode forward voltage drop, leakage currents, and transformer losses, the efficiency of a practical half-wave rectifier is always less than 40.6%.

HWR: PIV, % Regulation

Peak Inverse Voltage (PIV):

The maximum reverse voltage that appears across the diode during reverse bias condition.

PIV for HWR: V_m

% Regulation: The variation of dc output voltage as a function of dc load current is called regulation. The percentage regulation is defined as

$$\boxed{\%\text{Regulation} = \frac{V_{no\,load} - V_{full\,load}}{V_{full\,load}} \times 100\%}$$

$$I_{dc} = \frac{I_m}{\pi} = \frac{1}{\pi}\frac{V_m}{(R_s + R_f + R_L)}$$

$$I_{dc}(R_s + R_f + R_L) = \frac{V_m}{\pi}$$

$$\boxed{\therefore I_{dc}R_L = \frac{V_m}{\pi} - I_{dc}(R_s + R_f)}$$

$$V_{full\,load} = I_{dc}R_L = \frac{V_m}{\pi} - I_{dc}(R_s + R_f); \quad V_{no\,load} = \frac{V_m}{\pi}$$

$$\%\text{Regulation} = \frac{\frac{V_m}{\pi} - \left(\frac{V_m}{\pi} - I_{dc}(R_s + R_f)\right)}{I_{dc}R_L} \times 100\%$$

$$= \frac{I_{dc}(R_s + R_f)}{I_{dc}R_L} \times 100\%$$

$$\boxed{\%\text{Regulation} = \frac{R_s + R_f}{R_L} \times 100\%}$$

1. A HWR has a load of 3.5kΩ. If the diode resistance and secondary coil resistance together have a resistance of 800Ω and the input voltage has a signal voltage of peak value 240V. Calculate (a) Peak, average and rms value of current flowing (b) dc power output (c) ac power input (d) efficiency of the rectifier

Solution:

Load resistance in a HWR, $R_L = 3.5\text{k}\Omega$

Secondary coil and Diode resistance $R_s + R_f = 800\Omega$

Peak value of input voltage = 240V

a) Peak value of current $I_m = \frac{V_m}{(R_s+R_f+R_L)} = \frac{240}{4300} = 55.81\text{mA}$

Average value of current $I_{dc} = \frac{I_m}{\pi} = \frac{240}{4300} = \frac{55.81\times10^{-3}}{\pi} = 17.77\text{mA}$

RMS value of current $I_{RMS} = \frac{I_m}{2} = \frac{55.81\times10^{-3}}{2} = 27.905\text{mA}$

b) DC power output $P_{dc} = (I_{dc})^2 \times = (17.77 \times 10^{-3})^2 \times 3500 = 1.105\text{W}$

c) AC power input $P_{ac} = (I_{RMS})^2 \times (R_f + R_L) = (27.905 \times 10^{-3})^2 \times 4300 = 3.348\text{W}$

d) Efficiency of the rectifier $\eta = \frac{P_{dc}}{P_{ac}} = \frac{1.105}{3.348} \times 100 = 33\%$

2. An ac supply of 230V is applied to a half-wave rectifier circuit through transformer of turns ratio 5:1. Assume the diode is an ideal one. The load resistance is 300V. Find (a) dc output voltage (b) PIV (c) maximum, and (d) average values of power delivered to the load.

Solution:

a) The transformer secondary RMS voltage $V_{s(RMS)} = \frac{\text{Primary Voltage }(V_p)}{\text{Turns ratio }(n)} = \frac{230}{5} = 46\text{V}$

Maximum value of secondary voltage $V_m = V_{s(RMS)}\sqrt{2} = 46 \times \sqrt{2} = 65\text{V}$

dc output voltage $V_{dc} = \frac{V_m}{\pi} = \frac{65}{\pi} = 20.7\text{V}$

b) PIV of a diode = $V_m = 65\text{V}$

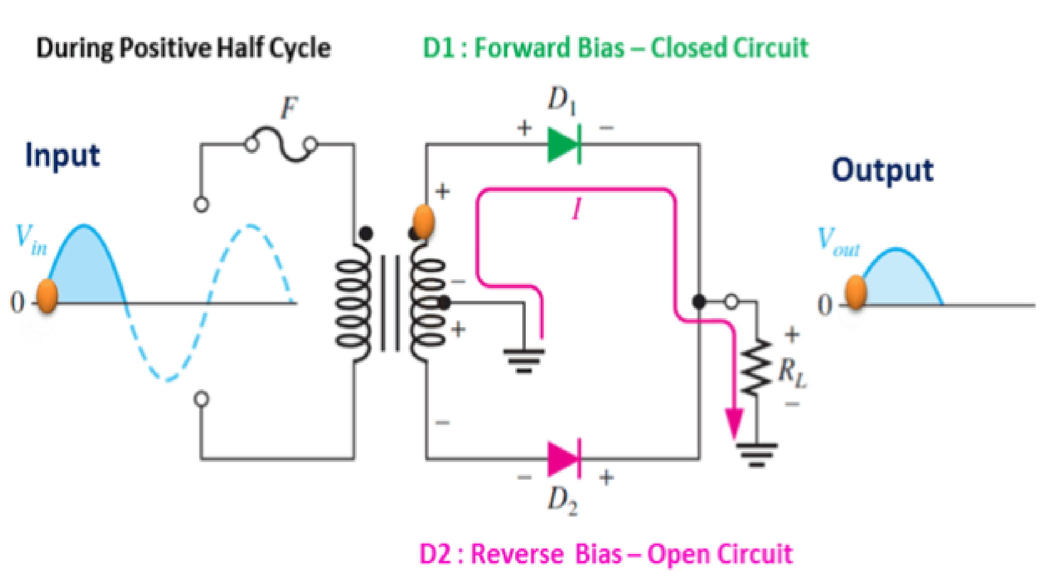
c) Maximum value of load current $I_m = \frac{V_m}{R_L} = \frac{65}{300} = 0.217\text{A}$

Maximum value of power delivered to the load $P_m = I_m^2 \times R_L = (0.217)^2 \times 300 = 14.1\text{W}$

d) Average value of current $I_{dc} = \frac{V_{dc}}{R_L} = \frac{20.7}{300} = 0.069\text{A}$

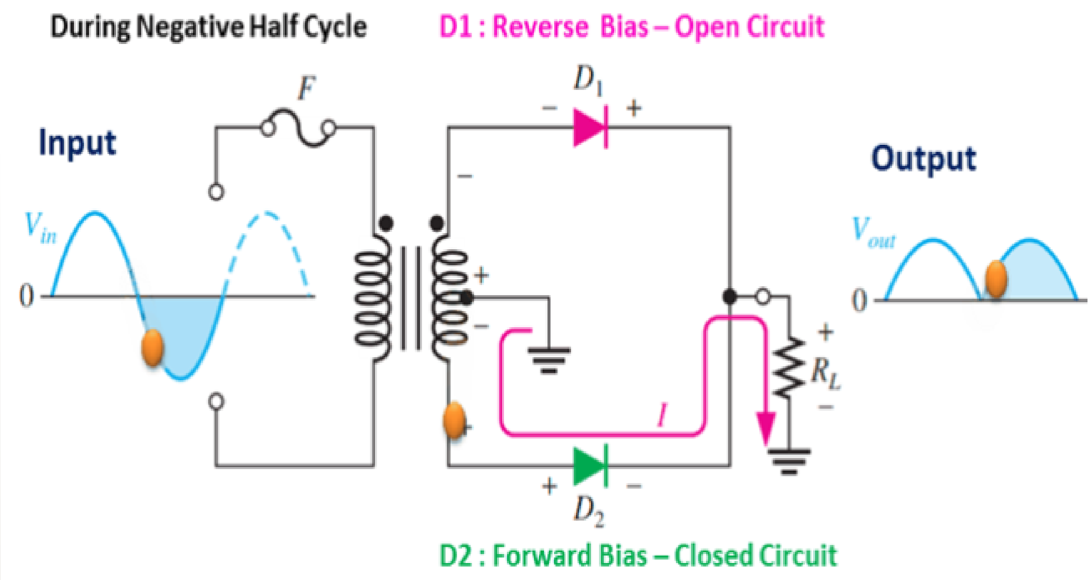
Average value of power delivered to the load $P_{dc} = I_{dc}^2 \times R_L = (0.069)^2 \times 300 = 1.43\text{W}$

Center Tapped Full Wave Rectifier (CT-FWR) – Positive half cycle



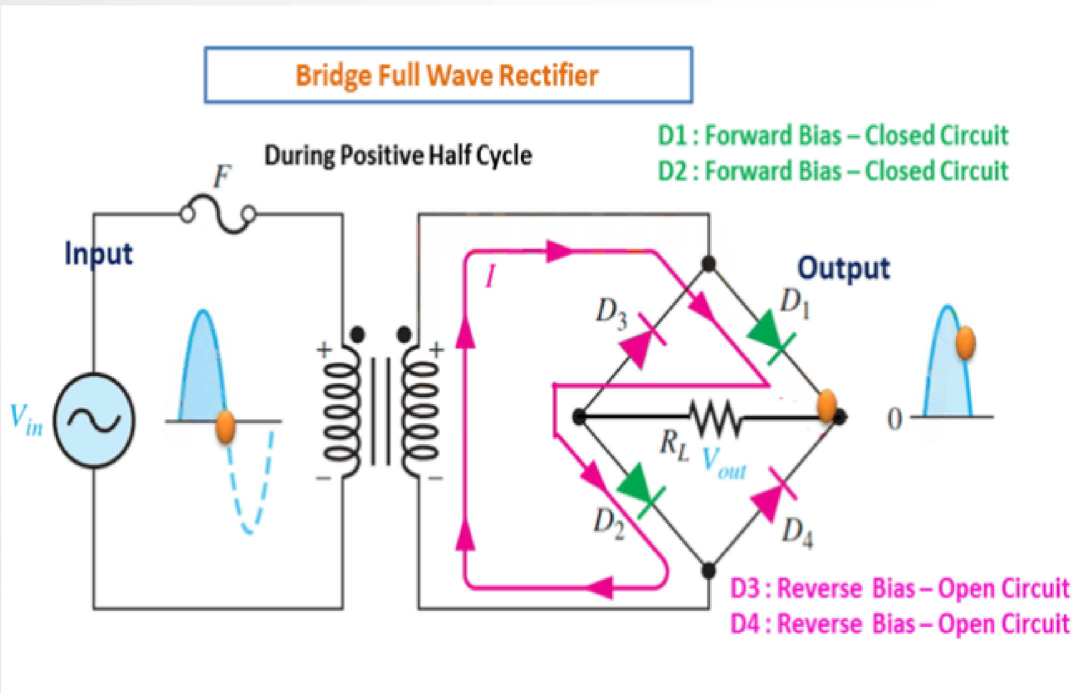
Center tap acts as a reference (ground).
D_1 is forward biased → Conducts current. The **current (I)** flows through the load resistor **(R_L)**, generating a **positive output voltage (V_{out}).**
D_2 is reverse biased → Does not conduct.

Center Tapped Full Wave Rectifier (CT-FWR) – Negative half cycle



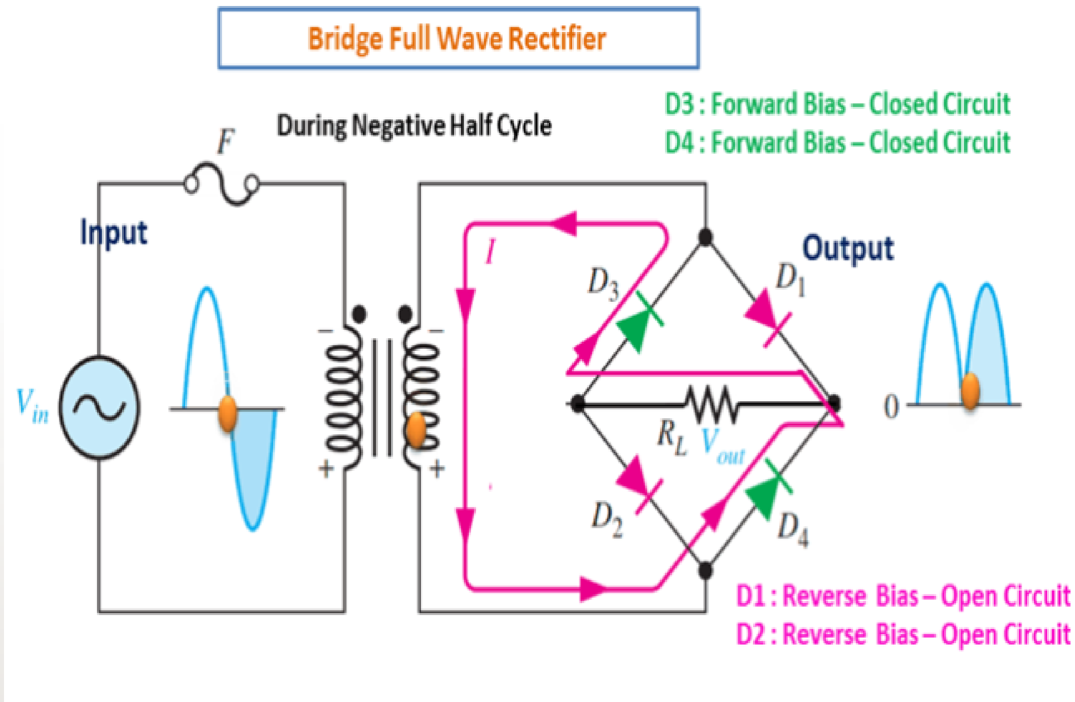
Center tap acts as a reference (ground).
D_1 is reverse biased → Does not conduct.
D_2 is forward biased → Conducts current. The **current (I)** flows through the load resistor **(R_L)**, generating a **positive output voltage (V_{out}).**

Bridge Full Wave Rectifier(B-FWR) – Positive half cycle



Diodes D_1 **and** D_2 **are forward biased** → They **conduct** current. Current **flows through the load resistor** (R_L), generating a **positive output voltage.**
Diodes D_3 **and** D_4 **are reverse biased** → They **do not conduct.**

Bridge Full Wave Rectifier(B-FWR) – Negative half cycle



Diodes D_3 **and** D_4 **are forward biased** → They **conduct** current. Current **flows through the load resistor** (R_L), generating a **positive output voltage.**
Diodes D_1 **and** D_2 **are reverse biased** → They **do not conduct.**

FWR: DC and RMS Voltage and Currents

Idc, Vdc : I_{dc} or I_{avg} = DC or Average value of current
V_{dc} or V_{avg} = DC or Average value of voltage

$V=V_s=V_m \sin\omega t$,

$I=I_s=I_L=I_m \sin\omega t$

$\omega = 2\pi f$

$$I_{dc}=\frac{1}{\pi}\int_0^{\pi} I_m \sin\omega t\, d(\omega t)=\frac{2I_m}{\pi} \quad \text{Similarly, } V_{dc}=\frac{2V_m}{\pi}$$

Irms, Vrms : I_{rms} = AC or RMS Value of Current
V_{rms} = AC or RMS Value of the voltage

$$I_{rms}=\sqrt{\frac{1}{\pi}\int_0^{\pi}(I_m \sin\omega t)^2\, d(\omega t)}=\frac{I_m}{\sqrt{2}} \quad \text{Similarly, } V_{rms}=\frac{V_m}{\sqrt{2}}$$

FWR: Ripple factor

Ripple Factor (γ): The pulsating components present in the rectifier output are ripples and measure of such ripples present in the output is known as ripple factor.

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

Now for a full wave circuit,

$$I_{rms}=\frac{I_m}{\sqrt{2}} \quad I_{dc}=\frac{2I_m}{\pi}$$

This indicates that the ripple content in the output are 0.48 times the dc component. i.e., 48% of the dc component.

$$\boxed{\gamma = 0.48}$$

FWR: Rectifier Efficiency

Rectifier Efficiency (η):

It is the Percentage of total ac power that is converted into useful DC output power.

$$\eta=\frac{D.C.\,output\ power}{A.C.\,input\ power}=\frac{P_{dc}}{P_{ac}}=\frac{I_{dc}^2 R_L}{I_{rms}^2(R_s+R_f+R_L)}=\frac{\frac{4I_m^2}{\pi^2}R_L}{\frac{I_m^2}{2}(R_s+R_f+R_L)}$$

Ideal case (Centre Tapped Full Wave Rectifier (CT-FWR)

It has **zero secondary winding series resistance** (Rs=0) and **zero forward resistance** (R_f=0).

$$\boxed{\%\eta_{ideal}=\frac{8R_L}{\pi^2(0+0+R_L)}=\frac{8}{\pi^2}=81.2\% \ \textbf{(Double of an HWR)}}$$

Practical case (Centre Tapped Full Wave Rectifier (CT-FWR)

Since R_s + R_f is positive, the denominator increases, reducing efficiency.

$$\boxed{\%\eta_{practical}<81.2\% \ \textbf{(Double of an HWR)}}$$

Thus due to diode forward voltage drop, leakage currents and transformer losses the efficiency of a practical full wave rectifier is always less than 81.2%.

CT-FWR Peak Inverse Voltage (PIV):

The maximum reverse voltage that appears across the diode during reverse bias condition.
PIV for FWR: $2V_m$

B-FWR Peak Inverse Voltage (PIV):

The maximum reverse voltage that appears across the diode during reverse bias condition.
PIV for FWR: V_m

FWR: % Regulation

% Regulation: The variation of dc output voltage as a function of dc load current is called regulation. The percentage regulation is defined as

$$\%\text{Regulation}=\frac{V_{no\,load}-V_{full\,load}}{V_{full\,load}}\times 100\%$$

Centre Tapped Full Wave Rectifier (CT-FWR)

$$V_{full\,load}=I_{dc}R_L=\frac{2V_m}{\pi}-I_{dc}(R_s+R_f);\quad V_{no\,load}=\frac{2V_m}{\pi}$$

$$\%\text{Regulation}=\frac{\frac{2V_m}{\pi}-\left(\frac{2V_m}{\pi}-I_{dc}(R_s+R_f)\right)}{I_{dc}R_L}\times 100\%$$

$$=\frac{I_{dc}(R_s+R_f)}{I_{dc}R_L}\times 100\%$$

$$\boxed{\%\text{Regulation}=\frac{R_s+R_f}{R_L}\times 100\%}$$

$$I_{dc}=\frac{2I_m}{\pi}=\frac{2}{\pi}\frac{V_m}{(R_s+R_f+R_L)}$$

$$I_{dc}(R_s+R_f+R_L)=\frac{2V_m}{\pi}$$

$$\boxed{\therefore I_{dc}R_L=\frac{2V_m}{\pi}-I_{dc}(R_s+R_f)}$$

NUMERICAL PROBLEMS

1. A 230V (rms), 60Hz voltage is applied to the primary of a 5:1 step-down, center-tap transformer used in a full wave rectifier having a load of 900V. If the diode resistance and secondary coil resistance together has a resistance of 100Ω, determine (a) dc voltage across the load, (b) dc current flowing through the load, (c) dc power delivered to the load, (d) PIV across each diode, (e) rectification efficiency.

Solution:

The voltage across the two ends of secondary $V_s=\frac{\text{Primary Voltage }(V_P)}{\text{Turns ratio }(n)}=\frac{230}{5}=46\text{V}$

Since it's center-tapped, the voltage across each half of the secondary winding $V_{RMS}=\frac{V_s}{2}=\frac{46}{2}=23\text{V}$

a) dc voltage across the load $V_{dc}=\frac{2V_m}{\pi}=\frac{2V_{RMS}\sqrt{2}}{\pi}=\frac{2\times 23\times\sqrt{2}}{\pi}=20.7\text{V}$

b) dc current flowing through the load $I_{dc}=\frac{V_{dc}}{(R_s+R_f+R_L)}=\frac{20.7}{1000}=20.7\text{mA}$

c) dc power delivered to the load $P_{dc}=(I_{dc})^2\times R_L=(20.7\times 10^{-3})^2\times 900=0.386\text{W}$

d) PIV of a diode $=2V_m=2V_{RMS}\sqrt{2}=65\text{V}$

e) Rectification efficiency $\eta=\frac{P_{dc}}{P_{ac}}=\frac{\frac{(V_{dc})^2}{R_L}}{\frac{(V_{RMS})^2}{R_L}}=\frac{(20.7)^2}{(23)^2}=0.81\times 100=81\%$

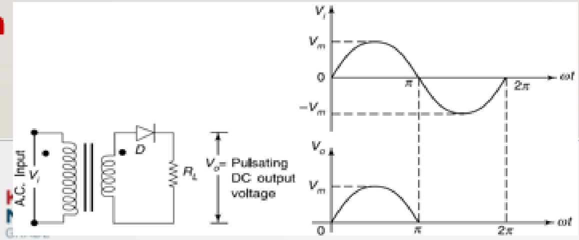
Advantages and Disadvantages of HWR, CT-FWR and B-FWR

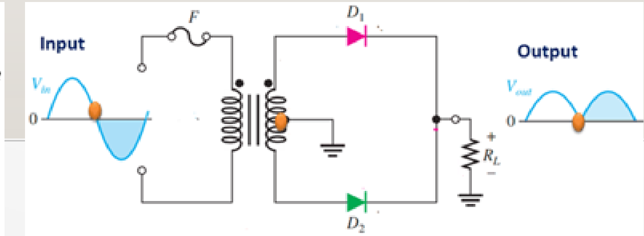
	Half-Wave Rectifier (HWR)	Center Tapped Full Wave Rectifier (CT-FWR)	Bridge Full Wave Rectifier (B-FWR)
Advantages	• Simple design and low cost • No center-tap required • Uses only one diode • PIV=Vm (Low)	• Utilizes full AC cycle input • High efficiency (81.2%) • Lower ripple (0.48) • Higher average DC output	• Utilizes full AC cycle input • No center-tap required • High efficiency (81.2%) • Lower ripple (0.48) • Higher average DC output • PIV=Vm (Low)
Disadvantages	• Utilizes only one half-cycle of the AC input. • High ripple (1.21) • Low average DC output	• Requires center-tapped transformer • PIV=2Vm (High)	• Requires four diodes

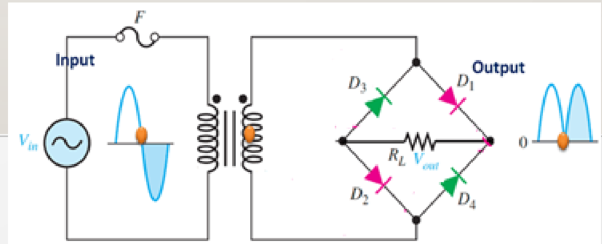
Comparison of Rectifiers

Parameter	HWR	CT-FWR	B-FWR
DC current (I_{dc})	I_m/π	$2I_m/\pi$	$2I_m/\pi$
DC voltage (V_{dc})	V_m/π	$2V_m/\pi$	$2V_m/\pi$
RMS current (I_{rms})	$I_m/2$	$I_m/\sqrt{2}$	$I_m/\sqrt{2}$
RMS voltage (V_{rms})	$V_m/2$	$V_m/\sqrt{2}$	$V_m/\sqrt{2}$
Form Factor	1.57	1.11	1.11
Ripple factor (γ)	1.21	0.48	0.48
DC Power (P_{dc})	$(I_m / \pi)^2\ R_L$	$(2I_m / \pi)^2\ R_L$	$(2I_m / \pi)^2\ R_L$
AC Power (P_{ac})	$I_m^2\ (R_s+R_f+R_L)/4$	$I_m^2\ (R_s+R_f+R_L)/2$	$I_m^2(R_s+R_f+R_L)/2$
Efficiency(%η)	40.6%	81.2% (Double of an HWR)	81.2% (Double of an HWR)
PIV	V_m	$2V_m$	V_m
% Regulation	$\frac{R_s + R_f}{R_L} \times 100\%$	$\frac{R_s + R_f}{R_L} \times 100\%$	$\frac{R_s + 2R_f}{R_L} \times 100\%$
TUF	0.287	0.693	0.812
Ripple frequency	f_s	$2f_s$	$2f_s$
No. of Diodes	1	2	4

Circuit Diagram





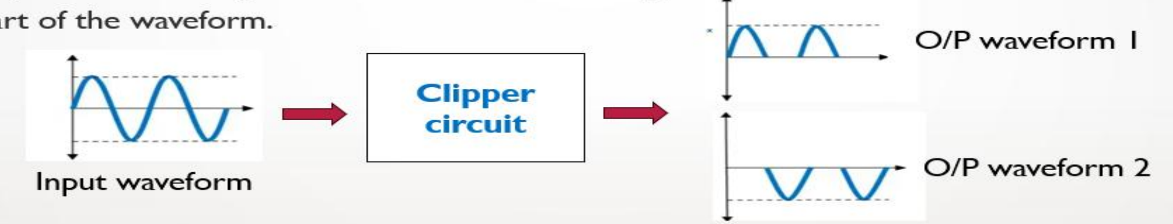


APPLICATIONS

- Power supplies
- Battery charging
- Welding
- Signal processing
- RF communication
- HVDC transmission
- Electrolysis
- UPS
- Renewable energy systems
- Automotive applications

Clippers

- A Nonlinear wave shaping circuit which can cut or trim the unwanted portion of the waveform.
- A clipper circuit prevents the output waveform from exceeding a certain level and at the same time it does not distort the remaining part of the waveform.



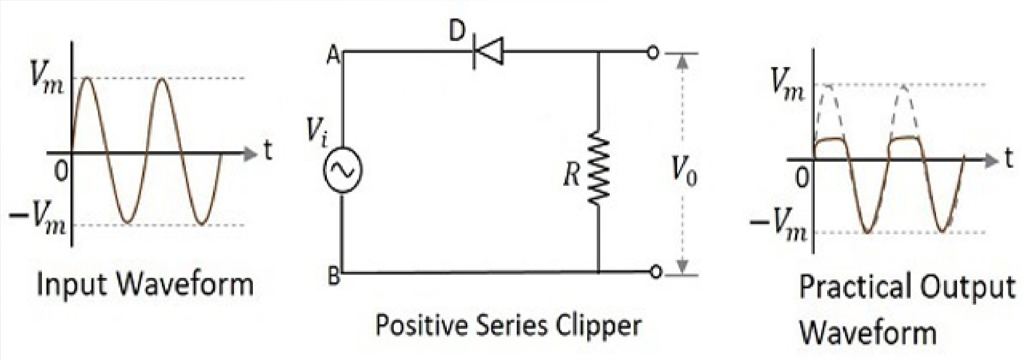
Types of Clipper Circuits

Clipper Circuits

- Series Clipper Circuits
  - Positive
  - Negative
  - Positive biased
  - Negative biased
- Shunt Clipper Circuits
  - Positive
  - Negative
  - Positive biased
  - Negative biased

Positive Series Clipper

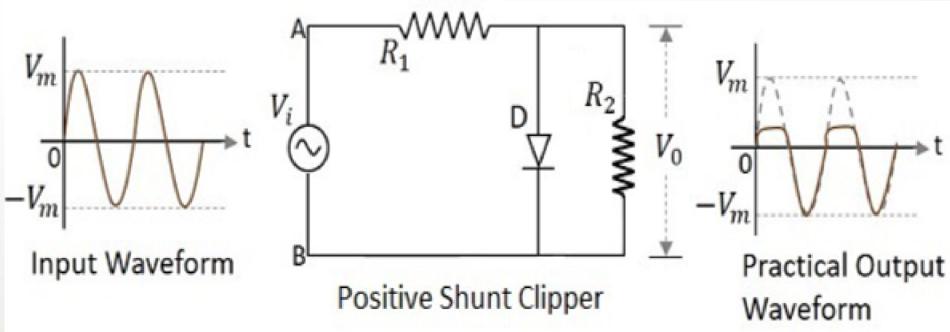
Circuit Hint: $\overleftarrow{D}$, R, +ve portions of O/P waveform clips



In a clipper circuit, the diode (D) is connected in series with the load resistor (R) and input signal (V_i).
It clips (removes) the positive portions of the input waveform, and the negative cycles remain unchanged.

Positive Shunt Clipper

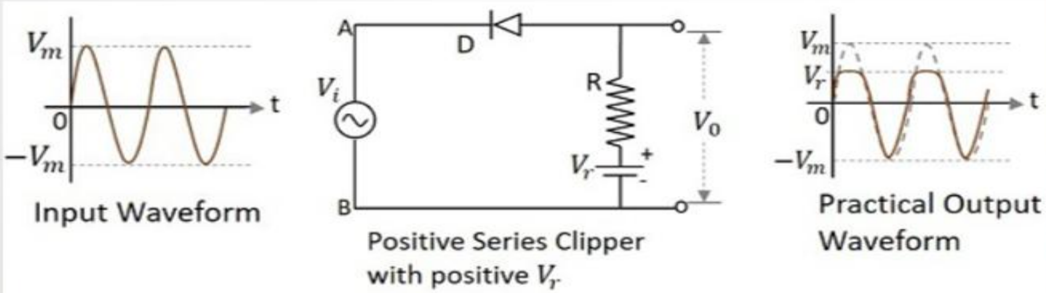
Circuit Hint: R1,D↓,R2, +ve portions of O/P waveform clips



A resistor (R_1) in series with the input voltage (V_i). The diode (D) is connected in parallel (shunt) with the load resistor (R_2).
It clips (removes) the positive portions of the input waveform, and the negative cycles remain unchanged.

Positive Series Clipper with Positive Biased (Vr)

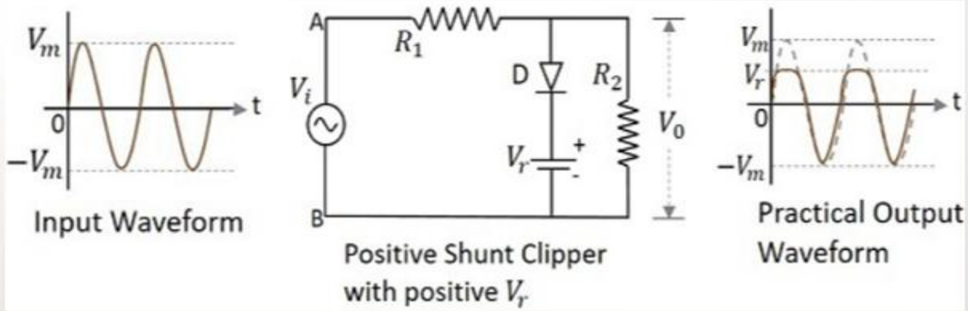
Circuit Hint: $\overleftarrow{D}$, R, +Vr (+ve ☒ +ve = +ve →Large O/P Waveform)



- The circuit consists of an input voltage (V_i), a diode (D) in series with a resistor, and a positive bias voltage (Vr).
- The positive portions of the waveform are clipped at +Vr, and the negative cycles remain unchanged.

Positive Shunt Clipper with Positive Biased (Vr)

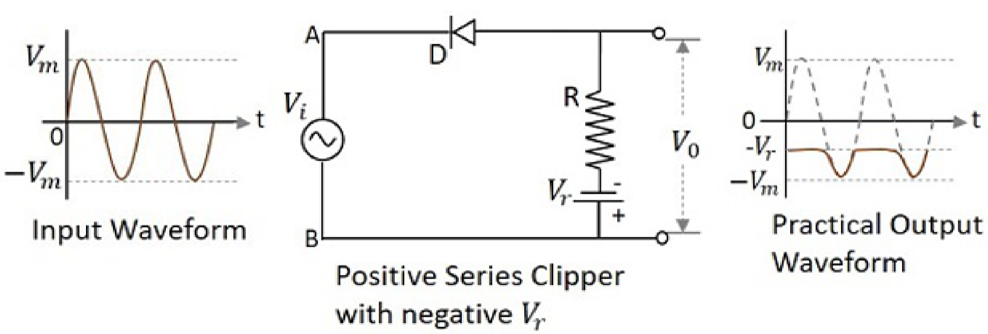
Circuit Hint: R1, D↓,+Vr, R2 (+ve ☒ +ve = +ve →Large O/P Waveform)



- A resistor (R_1) in series with the input voltage (V_i). The diode (D) is connected in parallel (shunt) with the load resistor (R_2). A positive bias voltage (Vr) is applied in series with the diode.
- The positive portions of the waveform are clipped at +Vr, and the negative cycles remain unchanged.

Positive Series Clipper with Negative Biased (Vr)

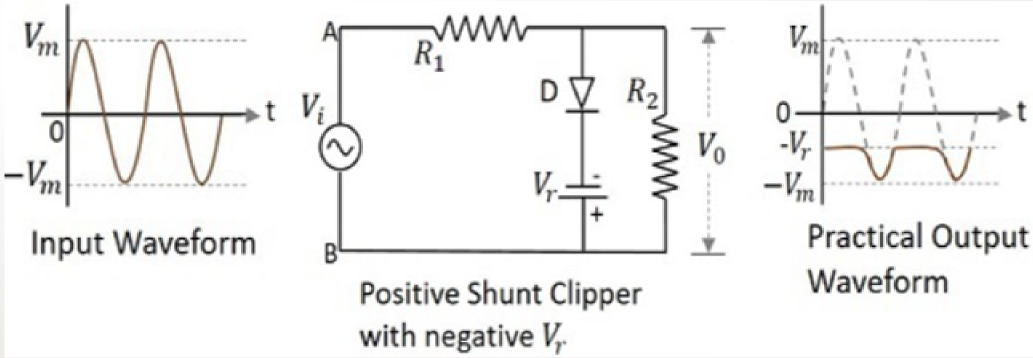
Circuit Hint: D⃖, R, -Vr (+ve ☒ -ve = -ve →Small O/P waveform)



- The circuit consists of an input voltage (V_i), a diode (D) in series with a resistor, and a negative reference voltage (Vr).
- The waveform is clipped at −Vr removing (blocking) the upper portions while keeping the negative cycles.

Positive Shunt Clipper with Negative Biased (Vr)

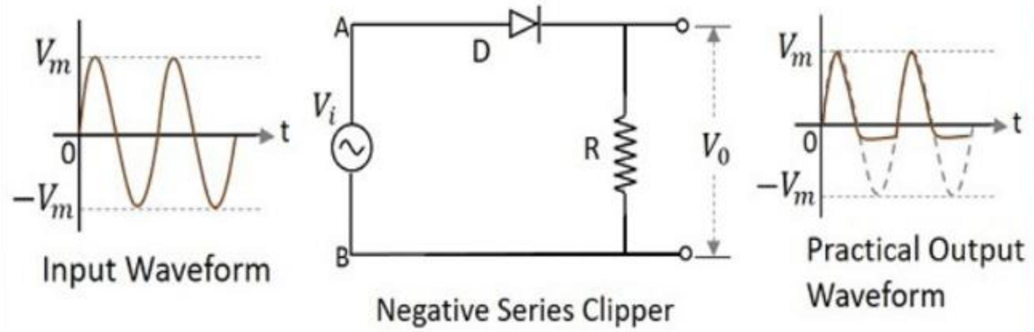
Circuit Hint: R1,D↓,-Vr, R2 (+ve ☒ -ve = -ve →Small O/P waveform)



- A resistor (R_1) in series with the input voltage (V_i). The diode (D) is connected in parallel (shunt) with the load resistor (R_2). A negative bias voltage (Vr) is applied in series with the diode.
- The waveform is clipped at −Vr removing (blocking) the upper portions while keeping the negative cycles.

Negative Series Clipper

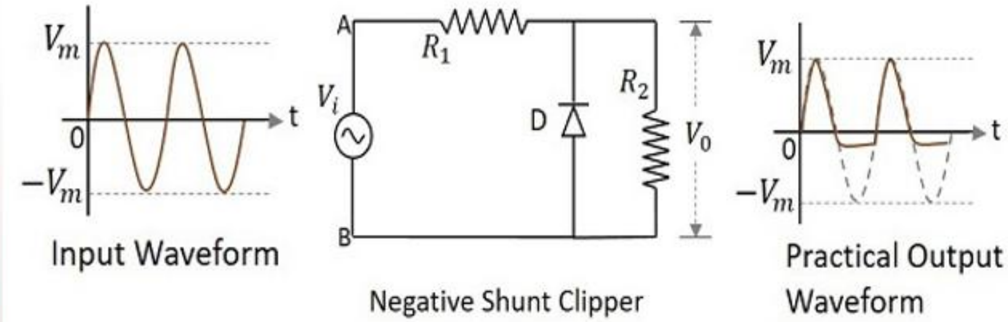
Circuit Hint: D⃗, R, -ve portions of O/P waveform clips



In a clipper circuit, the diode (D) is connected in series with the load resistor (R) and input signal (V_i).
It clips (removes) the negative portions of the input waveform, and the positive cycles remain unchanged.

Negative Shunt Clipper

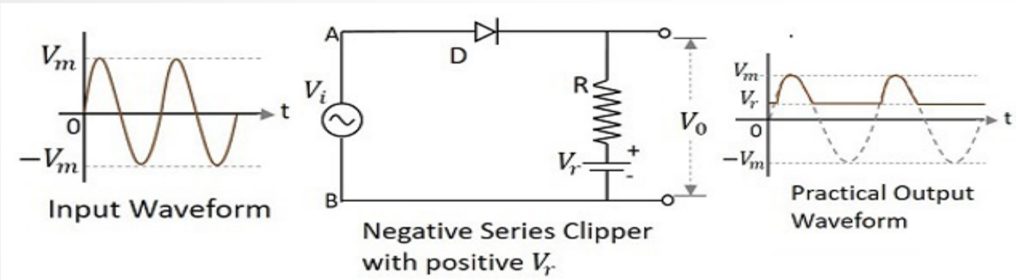
Circuit Hint: R1,D↑,R2, -ve portions of O/P waveform clips



A resistor (R_1) in series with the input voltage (V_i). The diode (D) is connected in parallel (shunt) with the load resistor (R_2).
It clips (removes) the negative portions of the input waveform, and the positive cycles remain unchanged.

Negative Series Clipper with Positive Biased (Vr)

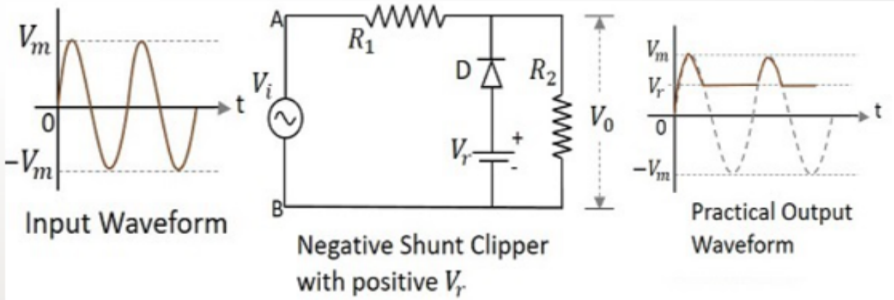
Circuit Hint: $\vec{D}$, R, +Vr (-ve ⊠ +ve = -ve →Small O/P waveform)



- The circuit consists of an input voltage (V_i), a diode (D) in series with a resistor, and a positive bias voltage (Vr).
- The waveform is clipped at +Vr removing (blocking) the lower portions while keeping the positive cycles.

Negative Shunt Clipper with Positive Biased (Vr)

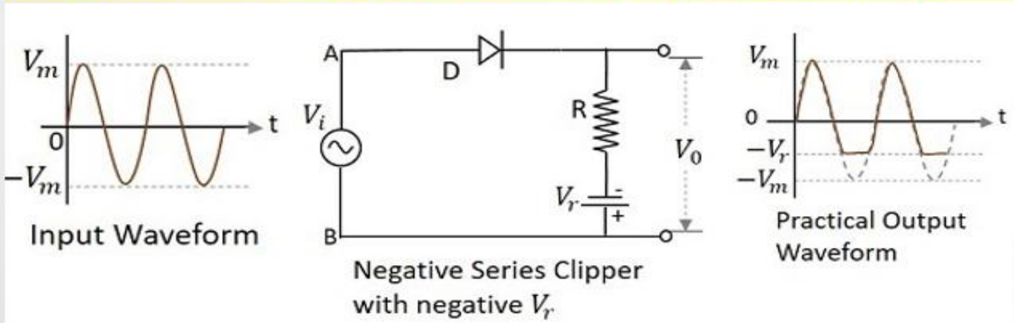
Circuit Hint: R1, D↑, +Vr, R2 (-ve ⊠ +ve = -ve →Small O/P waveform)



- A resistor (R_1) in series with the input voltage (V_i). The diode (D) is connected in parallel (shunt) with the load resistor (R_2). A positive bias voltage (Vr) is applied in series with the diode.
- The waveform is clipped at +Vr removing (blocking) the lower portions while keeping the positive cycles.

Negative Series Clipper with Negative Biased (Vr)

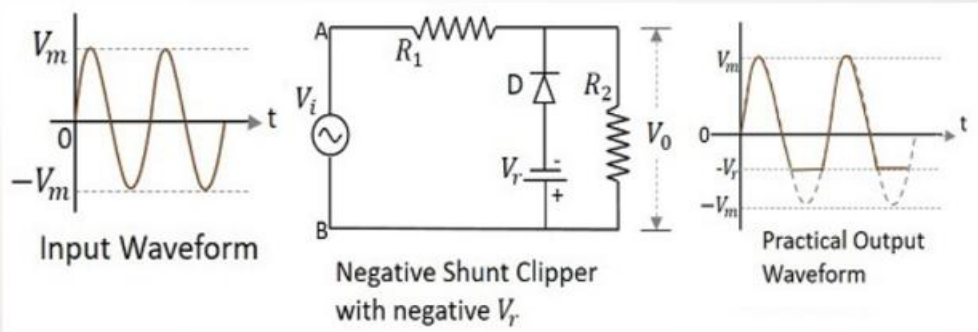
Circuit Hint: $\vec{D}$, R -Vr, (-ve ⊠ -ve = +ve →Large O/P waveform)



- The circuit consists of an input voltage (V_i), a diode (D) in series with a resistor, and a negative reference voltage (Vr).
- The **negative portions of the waveform are clipped** at -**Vr** instead of 0V.

Negative Shunt Clipper with Negative Biased (Vr)

Circuit Hint: R1, D↑, -Vr, R2 (-ve ⊠ -ve = +ve →Large O/P waveform)



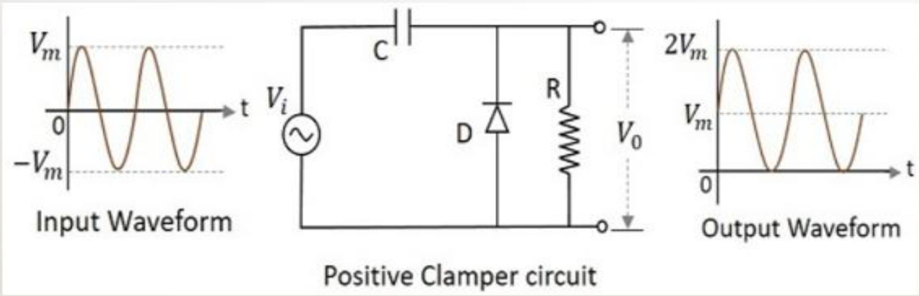
- A resistor (R_1) in series with the input voltage (V_i). The diode (D) is connected in parallel (shunt) with the load resistor (R_2). A negative bias voltage (Vr) is applied in series with the diode.
- The **negative portions of the waveform are clipped** at **-Vr** instead of 0V.

Clampers

- Clampers are used to shift the DC level of a signal without altering its shape (clamper circuit "shifts" the waveform up or down without altering its shape).
- The clamper circuit consists of a capacitor (C), a diode (D), a resistor (R) and a dc battery if required. The capacitor (C) stores and releases charge to shift the waveform.

Positive Clamper

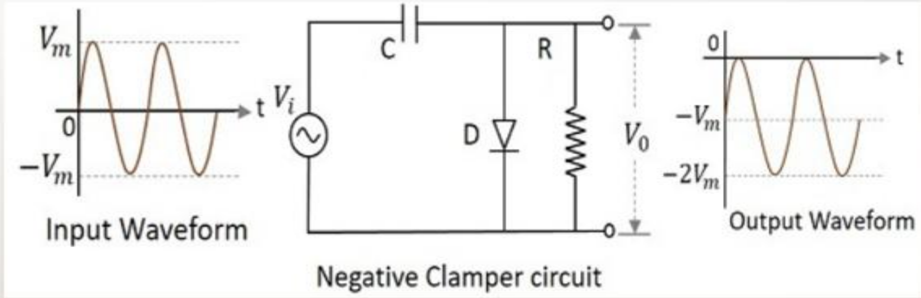
Circuit Hint: C, D↑, R, O/P waveform Shift Upward



The output waveform is shifted (clamped) positively.
The output waveform is shifted **upward** by Vm, with the lowest point at **0V** and the highest at **2Vm**.

Negative Clamper

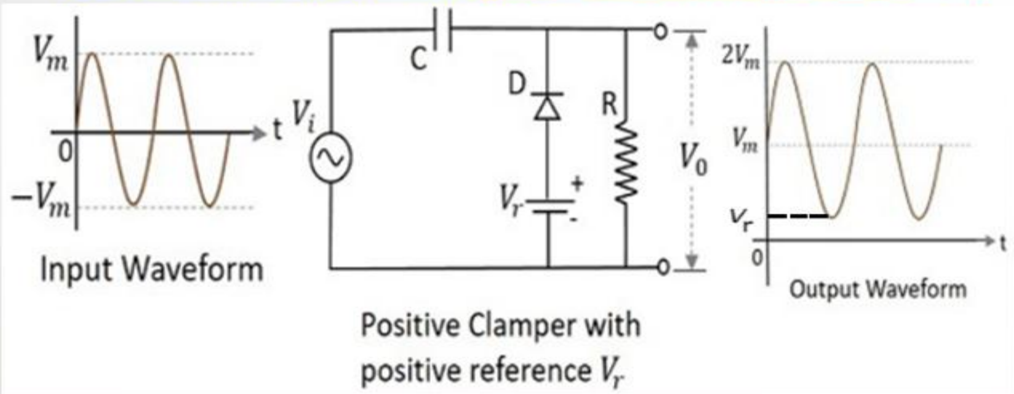
Circuit Hint: C, D↓, R, O/P waveform Shift Downward



The output waveform is shifted (clamped) negatively.
The output waveform is shifted **downward** by Vm, with the highest point at **0V** and the lowest at **-2Vm**.

Positive Clamper with Positive Biased (Vr)

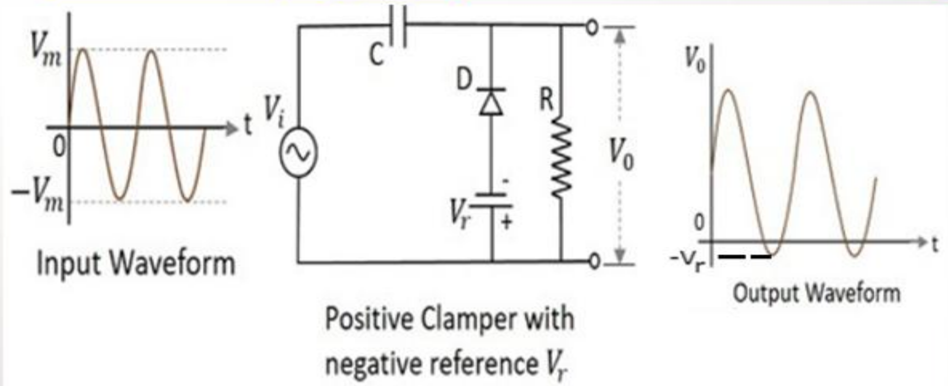
Circuit Hint: C, D↑, +Vr, R, O/P waveform Shift above +Vr



A reference voltage +Vr is in series with the diode. This causes the waveform to shift **above +Vr**. The output oscillates between **+Vm and +2Vm**.

Positive Clamper with Negative Biased (Vr)

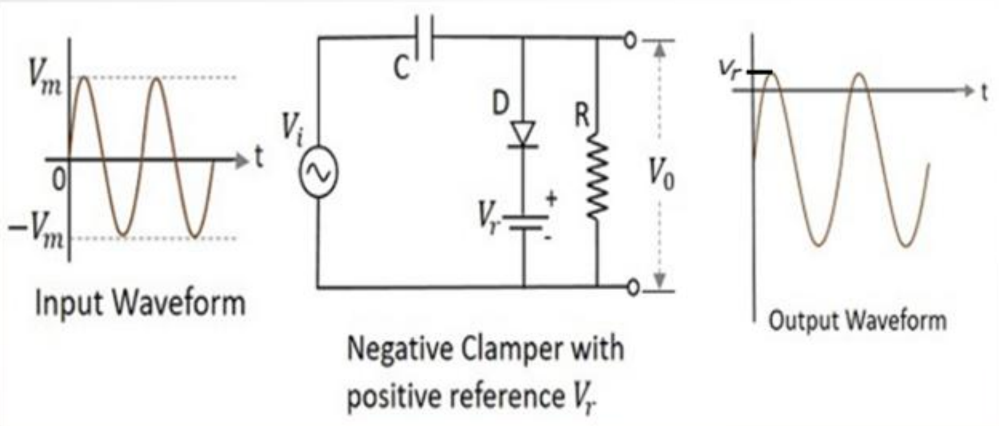
Circuit Hint: C, D↑, -Vr, R, O/P waveform Shift above -Vr



A reference voltage -Vr is in series with the diode. This causes the waveform to shift **above -Vr** and change the clamping level.

Negative Clamper with Positive Biased (Vr)

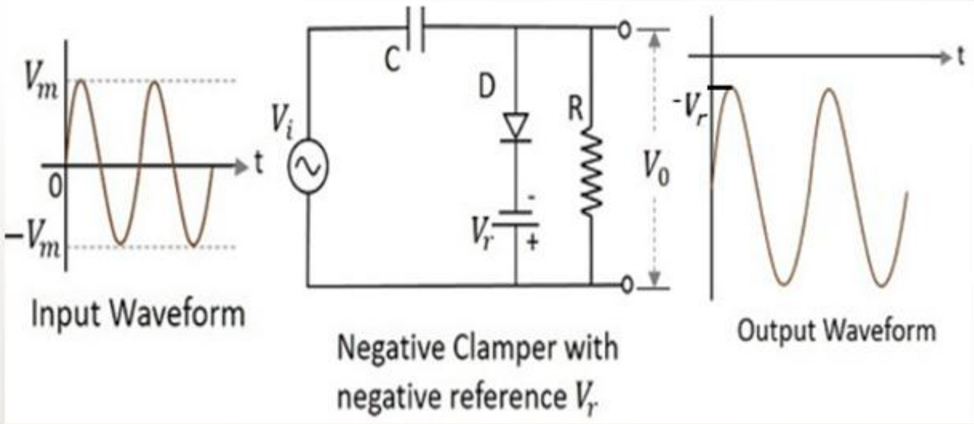
Circuit Hint: C, D↓, +Vr, R, O/P Waveform Shift below +Vr



A reference voltage +Vr is in series with the diode. The output waveform is shifted so the minimum value is shifted **to +Vr**.

Negative Clamper with Negative Biased (Vr)

Circuit Hint: C, D↓, -Vr, R, O/P Waveform Shift below -Vr



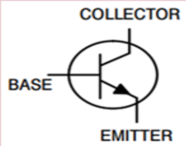
A reference voltage -Vr is in series with the diode. The output waveform is shifted downward, so the **maximum value of the waveform is shifted at -Vr**.

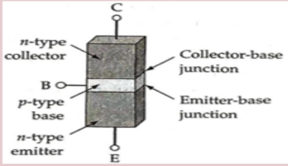
Types of Bipolar Junction Transistor

NPN bipolar junction transistor	PNP bipolar junction transistor

BJT consists of three terminals
Collector : C
Base : B
Emitter : E

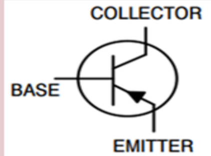
NPN bipolar junction transistor

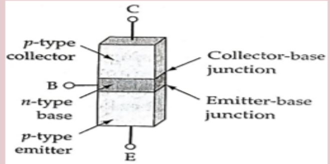




One P-type semiconductor is sandwiched between the two N-type semiconductors. The current flows from collector to emitter terminal.

PNP bipolar junction transistor





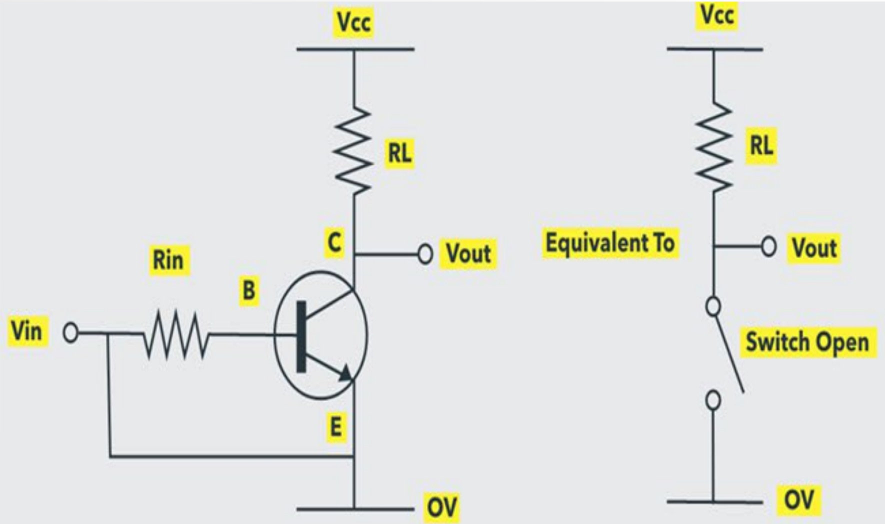
One N-type semiconductor is sandwiched between the two P-type semiconductors. The current flows from emitter to collector terminal.

Operating Regions of Transistor

There are two junctions in a transistor: base-emitter and collector-base junction. These junctions could be forward-biased or reverse-biased.

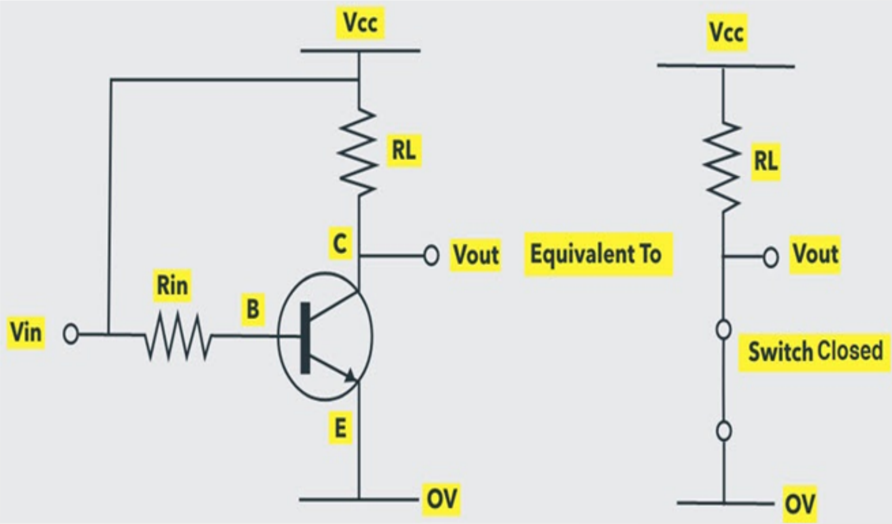
Region of operation	**Condition**	**Emitter-Base junction**	**Collector-Base junction**
Active region (transistor operate as an amplifier)	FR	Forward-biased	Reverse-biased
Saturation region (transistor is fully on and operates as a closed switch)	FF	Forward-biased	Forward-biased
Cut-off region (transistor is fully off and operates as an open switch)	RR	Reverse-biased	Reverse-biased

Transistor as a Switch – Cutoff



- The input, Base and Emitter are grounded **(0V)**
- Base-Emitter voltage **VBE < 0.7V**
- Emitter-Base junction is reverse biased
- Collector-Base junction is reverse biased
- Transistor is **"fully-OFF" (Cut-off region)**
- No Collector current flows (IC = 0)
- VOUT = VCE = **VCC = "Logic 1"**
- Transistor operates as an **"open switch"**

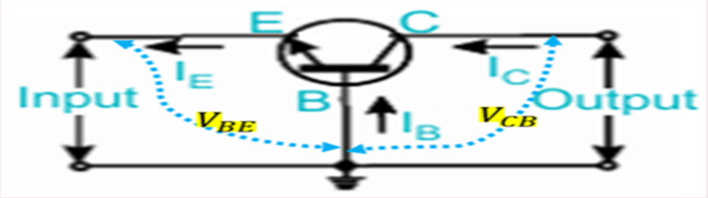
Transistor as a Switch – Saturation



- The input and Base are connected to **VCC**
- Base-Emitter voltage **VBE > 0.7V**
- Emitter-Base junction is forward biased
- Collector-Base junction is forward biased
- Transistor is **"fully-ON" (Saturation region)**
- Max Collector current flows (IC = Vcc/RL)
- VOUT = VCE = **0V="Logic 0"**
- Transistor operates as a **"closed switch"**

Operations/Types of Transistor Configurations

Common Base (CB)



In CB Configuration, the base terminal of the transistor will be connected common between the output and the input terminals.

Input current = I_E, Output current = I_C

Current amplification factor $\alpha = \frac{I_C}{I_E}$

Relation between Alpha α, Beta β, and Gamma γ

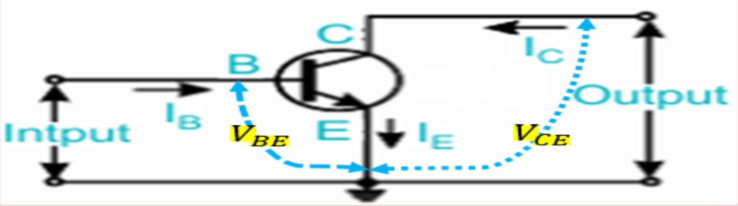
α in terms of β

$$\alpha = \frac{\beta}{1+\beta}$$

α in terms of γ

$$\alpha = \frac{\gamma - 1}{\gamma}$$

Common Emitter (CE)



In CE Configuration, the Emitter terminal of the transistor will be connected common between the output and the input terminals.

Input current = I_B, Output current = I_C

Current amplification factor $\beta = \frac{I_C}{I_B}$

Relation between Alpha α, Beta β, and Gamma γ

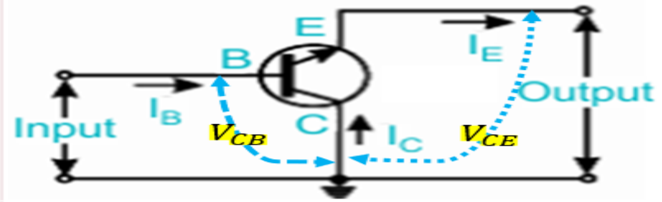
β in terms of α

$$\beta = \frac{\alpha}{1-\alpha}$$

β in terms of γ

$$\beta = \gamma - 1$$

Common Collector (CC)



In CC Configuration, the Collector terminal of the transistor will be connected common between the output and the input terminals.

Input current = I_B, Output current = I_E

Current amplification factor $\gamma = \frac{I_E}{I_B}$

Relation between Alpha α, Beta β, and Gamma γ

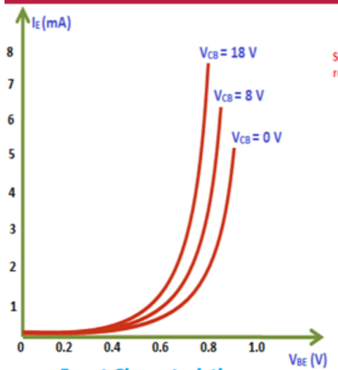
γ in terms of α

$$\gamma = \frac{1}{1-\alpha}$$

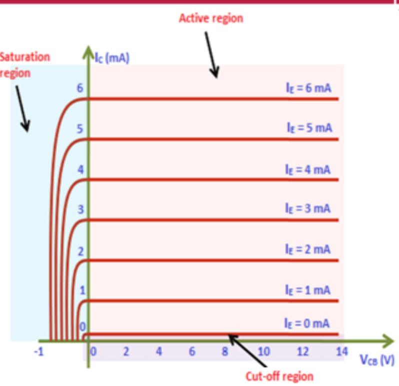
γ in terms of β

$$\gamma = 1 + \beta$$

Common Base (CB)



Input Characteristics



Output Characteristics

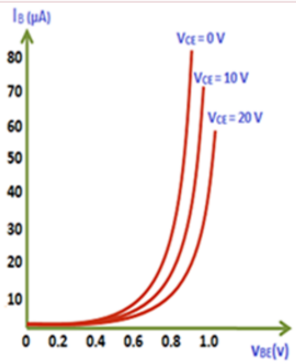
Input Characteristics

The variation of emitter current(I_E) with Base-Emitter voltage(V_{BE}), keeping Collector-Base voltage(V_{CB}) constant.

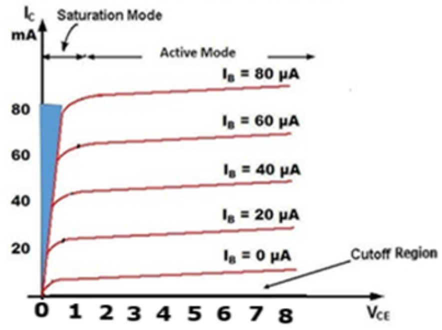
Output Characteristics

The variation of collector current(I_C) with Collector-Base voltage(V_{CB}), keeping the Emitter Current(I_E) constant.

Common Emitter (CE)



Input Characteristics



Output Characteristics

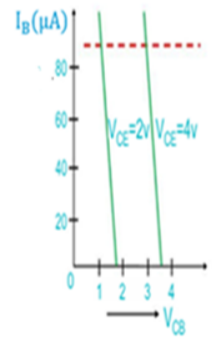
Input Characteristics

The variation of base current(I_B) with Base-Emitter voltage(V_{BE}), keeping Collector-Emitter voltage(V_{CE}) constant.

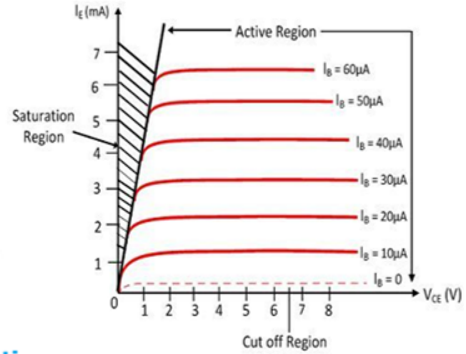
Output Characteristics

The variation of collector current(I_C) with Collector-Emitter voltage(V_{CE}), keeping the Base Current(I_B) constant.

Common Collector (CC)



Input Characteristics



Output Characteristics

Input Characteristics

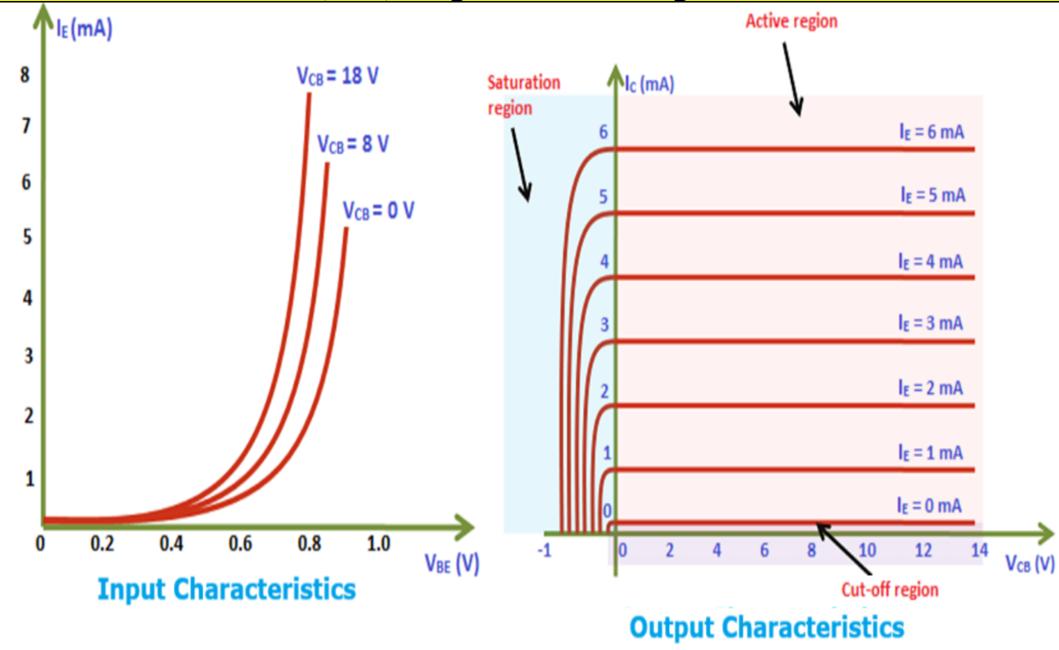
The variation of base current(I_B) with Collector-Base voltage(V_{CB}), keeping Collector-Emitter voltage(V_{CE}) constant.

Output Characteristics

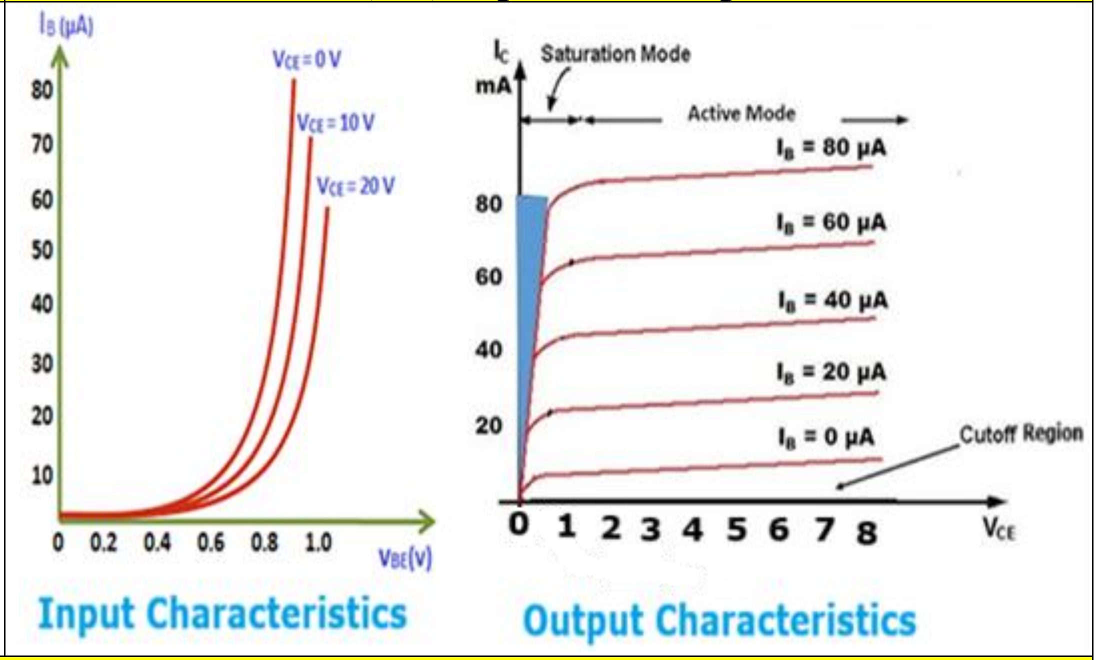
The variation of emitter current(I_E) with Collector-Emitter voltage(V_{CE}), keeping the Base Current(I_B) constant.

The same above image for Good Quality Visualization

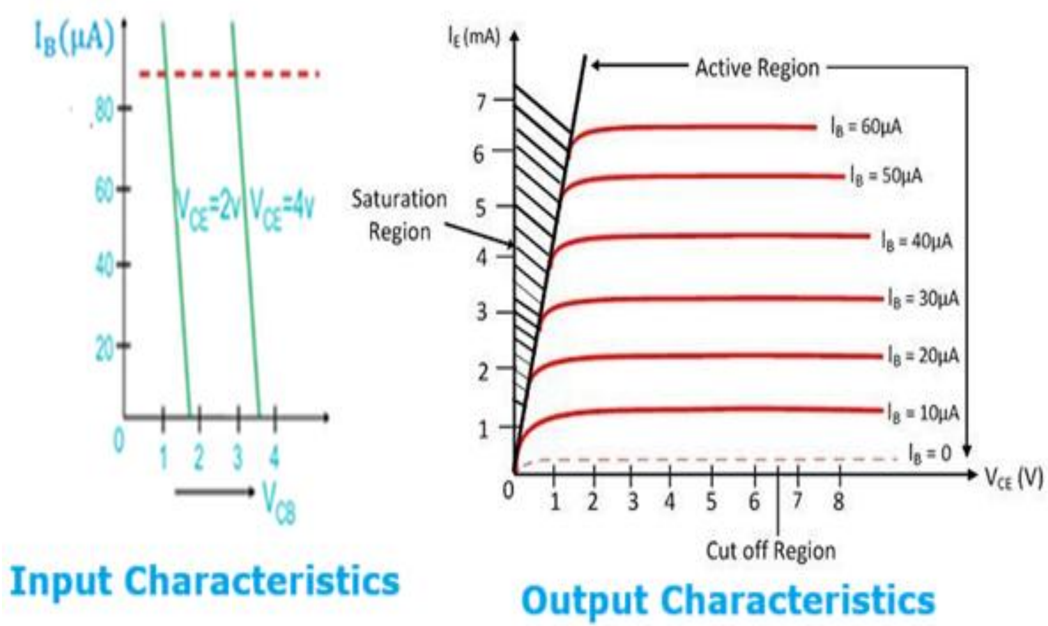
Common Base (CB) Input and Output Characteristics



Common Emitter (CE) Input and Output Characteristics



Common Collector (CC) Input and Output Characteristics



CO4 Terminal Important Questions (2 Marks/4 Marks/5 Marks/6 Marks)

1. **Describe the functionality of analog and digital ICs.**
2. **List out the differences between analog and digital ICs.**
3. **Discuss the advantages and disadvantages of analog and digital ICs.**
4. **Mention the pin configuration of IC741.**
5. **Sketch the transfer characteristics of an Op-Amp.**
6. **Compare ideal and practical Op-Amp characteristics.**
7. **List out the applications of Op-Amp.**
8. **Discuss about inverting amplifier using Opamp and derive its closed loop voltage gain.**
9. **Discuss about non-inverting amplifier using Opamp and derive its closed loop voltage gain.**
10. **Discuss about applications of Opamp.**
11. **Describe the pin configuration of IC 555.**
12. **List out the applications of IC 555.**
13. **Explain the operating modes of IC 555.**
14. **With a neat circuit diagram, explain about astable mode of operation of 555 timer.**
15. **With a neat circuit diagram, explain about monostable mode of operation of 555 timer.**
16. **Write about the necessity (importance) of voltage regulators. List out the types and applications of IC voltage regulators.**
17. **Compare LM7805 and LM7905.**
18. **Mention the pin configuration of LM7905 and LM7812.**
19. **Draw the pin diagram of LM723 voltage regulator and discuss its specifications.**

INTEGRATED CIRCUIT(IC)

Multiple electronic components are interconnected on a single semiconductor chip, that chip is called an Integrated Circuit (IC). An integrated Circuit is a semiconductor wafer on which thousands or millions of tiny resistors, capacitors, and transistors are fabricated, both **active** components (such as transistors and diodes) and **passive** components (such as resistors and capacitors).

Integrated Circuits (ICs) offer many advantages.

- Compact size, Lesser weight
- Low power consumption
- Reduced cost
- Increased reliability, Improved operating speeds

Types of Integrated Circuits (ICs)

Analog Integrated Circuits are ICs that operate over an entire range of continuous values of the signal amplitudes. Examples of analog ICs include operational amplifiers (op-amps), voltage regulators, and audio amplifiers.

Digital Integrated Circuits are electronic circuits that process discrete signals and work with binary data represented as 0s and 1s. Examples of digital ICs include memory chips (like RAM and ROM), logic gates (such as AND, OR, and NOT gates), and microprocessors.

Characteristics/Differences between Analog(Linear) and Digital ICs

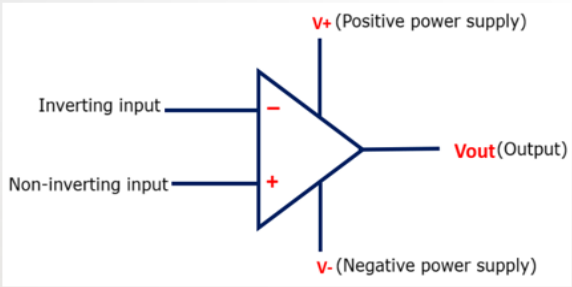
Feature	Analog(Linear) ICs	Digital ICs
Signal Type	Continuous signals (like voltage and current)	Discrete binary signals, 0s and 1s (ON/OFF states)
Number of Transistors	Few transistors (usually tens to hundreds)	Millions to Billions of transistors
Physical Size	Larger	Smaller
Precision & Accuracy	Higher precision but can suffer from lower accuracy due to noise and temperature effects	Limited precision and high accuracy
Data Storage	Cannot store data	Can store and process data (e.g., RAM, ROM, Flash Memory)
Noise Immunity and Sensitivity	Low Noise Immunity and High Sensitivity	High Noise Immunity and Low Sensitivity
Power Consumption	Generally Higher	Typically Lower
Design Complexity	High	Low
Functionality	Amplification, filtering, modulation, etc.	Logic operations, computation, data storage, etc.
Examples	Operational Amplifiers (Op-Amps), Voltage Regulators, Analog Filters, Audio Amplifiers	Logic Gates, Flip-flops, Memory Chips, FPGAs
Applications	Television Circuits, Analog Cameras	Digital TVs, Digital cameras, Smartphones

Advantages and Disadvantages of Analog ICs and Digital ICs

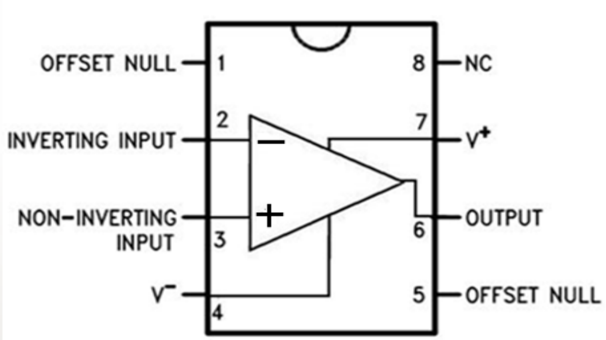
Analog (Linear) ICs.	Digital ICs
Advantages: •**Higher precision**. •Capable of **amplification, filtering, and modulation**. •**Works with real-world signals** (voltage, current, temperature, etc.). **Disadvantages:** •**Larger physical size**. •**High design complexity**. •**Harder to test and debug**. •**Cannot store data**. •**Generally higher power consumption**. •**Low noise immunity** and **high sensitivity** to external disturbances. •**Lower accuracy** under noise and temperature variations.	**Advantages:** •**Smaller physical size**. •**Lower design complexity**. •**Easier to test and debug** due to binary logic and built-in testing. •**Can store and process data** (e.g., RAM, ROM, Flash Memory). •**Lower power consumption**. •**High noise immunity** and **less sensitivity**. •**High accuracy.** **Disadvantages:** •**Limited precision**. •**Not suitable for directly handling analog signals** without ADC/DAC. •**Cannot naturally process continuously varying signals**.

IC 741 Op-Amp

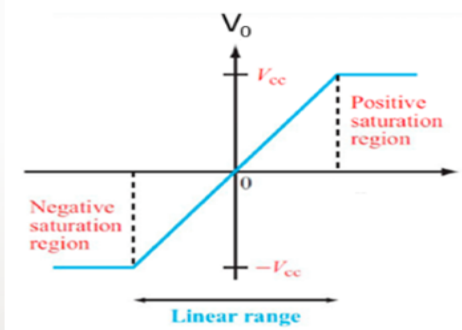
Block diagram of a general Op-Amp



IC 741 Pinout Diagram



Transfer voltage characteristics of Op-Amp



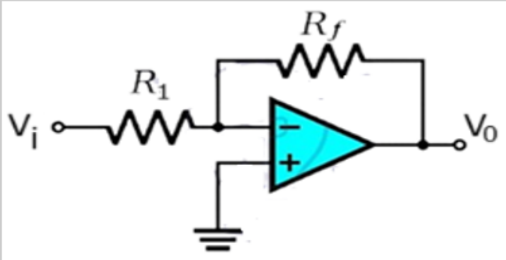
- An op-amp is a DC-coupled high-gain voltage amplifier. An IC 741 op-amp is defined as a monolithic integrated circuit that contains a single operational amplifier.
- It is packaged in an 8-pin dual-in-line (DIP) plastic or metal case.
- The IC 741 op amp has three main terminals: an inverting input (pin 2), a non-inverting input (pin 3), and an output (pin 6).
- It also has two power supply terminals: a positive supply (pin 7) and a negative supply (pin 4).
- Additionally, it has two offset null terminals (pin 1 and pin 5) that can be used to adjust the input offset voltage to zero by adding an external potentiometer and No Connection (NC) (pin 8).

Ideal and Practical Characteristics of Op-Amp

Ideal characteristics	Practical characteristics
Open loop voltage gain = ∞	Open loop voltage gain is very high
Input impedance = ∞	Input impedance is high (greater than 1MΩ)
Output impedance = 0	Output impedance is small (few hundred ohms)
Bandwidth = ∞	Bandwidth is Finite
Zero Offset Voltage Vo = 0 when $V_1=V_2=0$	Offset voltage has a small nonzero value.
Slew rate = ∞	Slew rate is Finite (0.5V/μs).
CMRR = ∞	CMRR is high but finite (typically 70–120 dB).

Inverting Amplifier

The input signal (V_i) is applied to the inverting terminal (-) with input resistor (R_1) while the non-inverting terminal (+) is grounded. A feedback resistor (Rf) connects the output to the inverting terminal (-).



Virtual Ground Concept (V_+=V_-):

Let us assume the op-amp is ideal. i.e., its gain (A) and input resistance (R_1) are equal to ∞. Hence, there is no current (I) entering into either inverting (-) as well as non-inverting (+) input terminals. So, the potential is equal to inverting (-) and non-inverting (+) input terminals.

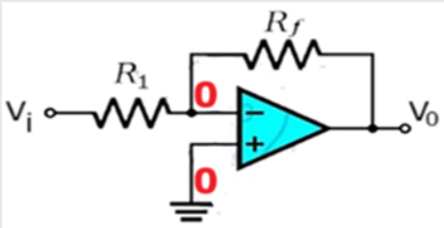
Apply KCL at inverting terminal

$$\frac{0 - V_i}{R_1} + \frac{0 - V_o}{R_f} = 0$$

$$\frac{V_i}{R_1} = -\frac{V_o}{R_f}$$

It has a negative voltage gain

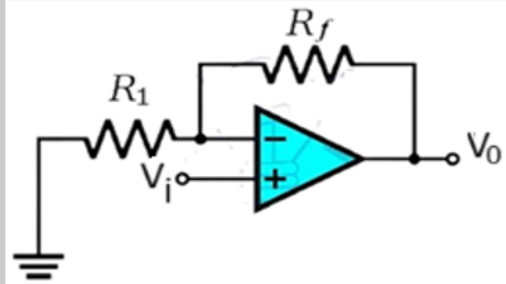
$$\boxed{A_v = \frac{V_o}{V_i} = -\frac{R_f}{R_1}}$$



This diagram is not required here. Just added understanding of the expression

Non-Inverting Amplifier

The input signal (V_i) is applied to the non-inverting terminal (+). An input resistor (R_1) connects the inverting terminal (-) to ground. A feedback resistor (Rf) connects the output to the inverting terminal (-).



Virtual Short Concept (V_+=V_-):

Let us assume the op-amp is ideal. i.e., its gain (A) and input resistance (R_1) are equal to ∞. Hence, there is no current (I) entering into either inverting (-) as well as non-inverting (+) input terminals. So, the potential is equal to inverting (-) and non-inverting (+) input terminals.

Apply KCL at inverting terminal

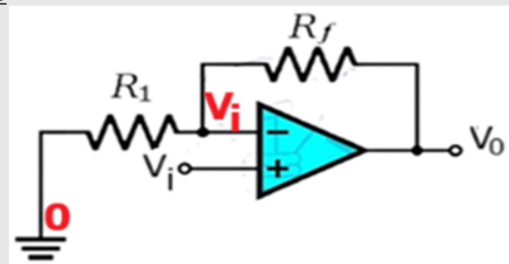
$$\frac{V_i - 0}{R_1} + \frac{V_i - V_o}{R_f} = 0$$

$$V_i\left(\frac{1}{R_1} + \frac{1}{R_f}\right) = \frac{V_o}{R_f}$$

$$\frac{V_o}{V_i} = R_f\left(\frac{1}{R_1} + \frac{1}{R_f}\right)$$

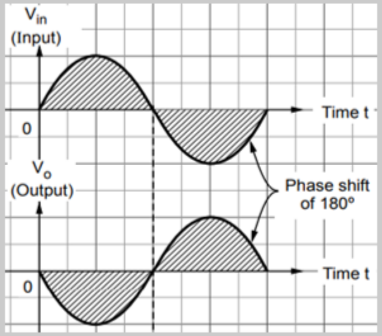
It has a positive voltage gain

$$\boxed{A_v = \frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}}$$

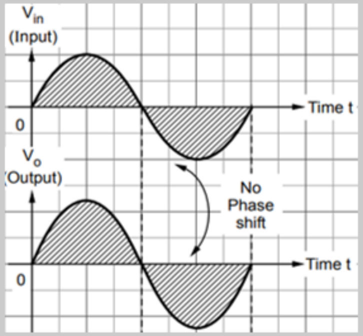


This diagram is not required here. Just added understanding of the expression

It generates an amplified output signal that is 180° out of phase with the input signal.



It generates an amplified output signal that is in phase with the applied input signal.



Applications of Op-Amp

- **Voltage follower:** It produces an output voltage (V_o) equal to the input voltage (V_i).

$$\boxed{V_o = V_i}$$

- **Inverting amplifier:** It generates an amplified output signal that is 180° out of phase with the input signal.
- **Non-inverting amplifier**: It generates an amplified output signal that is in phase with the applied input signal.
- **Summing amplifier:** This is a circuit that produces an output voltage that is proportional to the sum of two or more input voltages.
- **Differential amplifier:** It produces an output voltage proportional to the voltage difference of two input signals applied to the inputs of the inverting and non-inverting terminals of an operational amplifier.
- **Integrator:** This is a circuit that produces an output voltage that is proportional to the integral of the input voltage with respect to time.
- **Differentiator:** This is a circuit that produces an output voltage that is proportional to the derivative of the input voltage with respect to time.
- It can be used as a building block for many analog circuits, such as filters, oscillators, comparators, amplifiers, and so on.

1. For an **inverting amplifier**, $R_f = 90\ k\Omega$, $R_1 = 10\ k\Omega$ and the input signal is 0.5 V. Find the output voltage and voltage gain in dB. Repeat the problem if it is a **non-inverting amplifier.**

Sol

$R_f = 90k\Omega$
$R_1 = 10k\Omega$

inverting amplifier

$$\boxed{A_V = \frac{V_o}{V_i} = \frac{-R_f}{R_1}}$$

To find Output voltage (V_o)

if $V_{in} = 0.5V$

$$V_o = \frac{-R_f}{R_1} \times V_i$$

$$= -\frac{90k\Omega}{10k\Omega} \times 0.5 \quad \text{(or)} \quad = \frac{-90\times10^3}{10\times10^3}\times 0.5$$

$$\boxed{V_o = -4.5V}$$

To find Voltage gain in dB

$$A_V = \frac{-R_f}{R_1}$$

$$= \frac{-90k\Omega}{10k\Omega} \quad \text{(or)} \quad -\frac{90\times10^3}{10\times10^3}$$

$$= -9$$

Voltage gain in dB

$$A_V(dB) = 20\log|-9|$$
$$= 20\log 9 \qquad \boxed{|-9| = 9}$$

$$\boxed{A_V(dB) = 19.08\,dB}$$

$R_f = 90k\Omega$
$R_1 = 10k\Omega$

non-inverting amplifier

$$\boxed{A_V = \frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}}$$

To find output voltage (V_o)

if $V_{in} = 0.5V$

$$V_o = \left(1 + \frac{R_f}{R_1}\right)V_i$$

$$= \left(1 + \frac{90k\Omega}{10k\Omega}\right)\times 0.5 \quad \text{(or)} \quad \left(1+\frac{90\times10^3}{10\times10^3}\right)\times 0.5$$

$$= 10 \times 0.5$$

$$\boxed{V_o = 5V}$$

To find voltage gain in dB

$$A_V = 1 + \frac{R_f}{R_1}$$

$$= 1 + \frac{90k\Omega}{10k\Omega} \quad \text{(or)} \quad 1 + \frac{90\times10^3}{10\times10^3}$$

$$= 10$$

Voltage gain in dB

$$A_V(dB) = 20\log 10$$

$$\boxed{A_V(dB) = 20dB}$$

2. An **inverting amplifier** has $R_1 = 10\ k\Omega$ and $R_f = 100\ k\Omega$. If $V_{in} = 0.5$ V (DC), find A_v and V_{out}. Repeat the problem if it is a **non-inverting amplifier.**

Sol

$R_1 = 10k\Omega$
$R_f = 100k\Omega$

inverting amplifier

$$\boxed{A_V = \frac{V_o}{V_i} = -\frac{R_f}{R_1}}$$

To find A_V

$$A_V = -\frac{R_f}{R_1}$$

$$= \frac{-100k\Omega}{10k\Omega}$$

$$\boxed{A_V = -10}$$

To find Vout

if $V_{in} = 0.5V$

$$V_o = \frac{-R_f}{R_1} \times V_i$$

$$= \frac{-100k\Omega}{10k\Omega} \times 0.5$$

(or)

$$= -\frac{100\times10^3}{10\times10^3} \times 0.5$$

$$\boxed{V_o = -5V}$$

$R_1 = 10k\Omega$
$R_f = 100k\Omega$

non-inverting amplifier

$$\boxed{A_V = \frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}}$$

To find A_V

$$A_V = 1 + \frac{R_f}{R_1}$$

$$= 1 + \frac{100k\Omega}{10k\Omega}$$

(or)

$$= 1 + \frac{100\times10^3}{10\times10^3}$$

$$\boxed{A_V = 11}$$

To find Vout

if $V_{in} = 0.5V$

$$V_o = \left(1 + \frac{R_f}{R_1}\right)V_i$$

$$= \left(1 + \frac{100k\Omega}{10k\Omega}\right)\times 0.5$$

(or)

$$= \left(1 + \frac{100\times10^3}{10\times10^3}\right)\times 0.5$$

$$= 11 \times 0.5$$

$$\boxed{V_o = 5.5V}$$

3. An **inverting amplifier** has a gain of -30. The resistor $R_1 = 1\ k\Omega$. Find the value of feedback resistor R_f. If an input voltage of 50mV is applied, find the output voltage.

Sol

Gain $A_v = -30$

$R_1 = 1K\Omega$

inverting amplifier negative voltage gain

$$\boxed{A_v = \frac{V_o}{V_i} = -\frac{R_f}{R_1}}$$

To find feedback resistor (R_f)

$$A_v = -\frac{R_f}{R_1}$$

Feedback resistor $R_f = -A_v R_1$

$= -(-30) \times 1 \times 10^3$ $\quad \therefore 1K\Omega = 1\times10^3\Omega$

$$\boxed{R_f = 30K\Omega}$$

To find output voltage (V_o)

if $V_i = 50\times10^{-3}V$

$$V_o = -\frac{R_f}{R_1} \times V_i \quad \therefore 1mV = 10^{-3}V$$

$$= -\frac{30K\Omega}{1K\Omega} \times 50\times10^{-3}$$

(or)

$$= -\frac{30\times10^3}{1\times10^3} \times 50\times10^{-3}$$

$$\boxed{V_o = -1500\times10^{-3} = -1.5\ V}$$

4. A **non-inverting amplifier** has a gain of 51. The resistor $R_1 = 1\ k\Omega$. Find the value of feedback resistor R_f. If an input voltage of 20mV is applied, find the output voltage.

Sol

Gain $Av = 51$

$R_1 = 1K\Omega$

non-inverting amplifier positive voltage gain

$$\boxed{Av = \frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}}$$

To find feedback resistor (R_f)

$$Av = 1 + \frac{R_f}{R_1}$$

$$Av - 1 = \frac{R_f}{R_1}$$

$R_f = R_1(Av - 1)$

$= 1\times10^3(51-1)$ $\quad \therefore 1K\Omega = 1\times10^3\Omega$

$$\boxed{R_f = 50K\Omega}$$

To find Output Voltage (V_o)

if $V_i = 20\times10^{-3}V$ $\quad \therefore 1mV = 10^{-3}V$

$$V_o = \left(1 + \frac{R_f}{R_1}\right)V_i$$

$$= \left(1 + \frac{50K\Omega}{1K\Omega}\right) \times 20\times10^{-3}$$

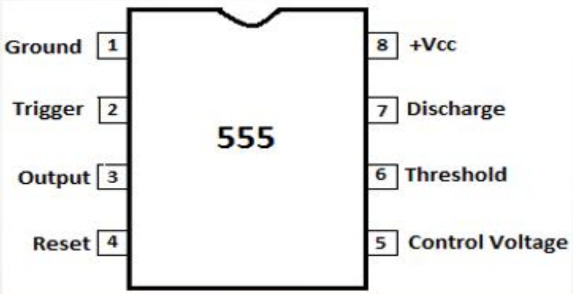
(or)

$$= \left(1 + \frac{50\times10^3}{1\times10^3}\right) \times 20\times10^{-3}$$

$= 51\times20\times10^{-3}$

$$\boxed{V_o = 1020\times10^{-3} = 1.02\,mV}$$

555 Timer IC Pin Diagram



Pin no	Pin description	Purpose
1	Ground	Ground reference voltage (0V).
2	Trigger	Activates the output when voltage drops below **1/3 VCC**.
3	Output	Provides the output signal (either **high** or **low**).
4	Reset	Resets the timer when driven **low**; overrides other inputs.
5	Control voltage	Adjusts internal voltage divider (default **2/3 VCC**).
6	Threshold	Ends the timing interval when voltage exceeds **2/3 VCC**.
7	Discharge	Discharges the timing capacitor to **GND** during intervals.
8	VCC	Positive supply voltage (**+5V to +15V**).

FEATURES OF IC555 TIMERS

- 555 timer is used in almost every electronic circuit.
- A 555 timer works as a flip-flop or as a multi-vibrator, it has a particular set of configurations.
- It operates from a wide range of supply voltage from +5 Volts to +18 Volts.
- Sinking or sourcing 200 mA of load current.
- Maximum power dissipation per package is 600 mW,
- The duty cycle of the timer is adjustable.
- Trigger pulse and reset inputs have logic compatibility.

MODES OF OPERATION OF IC555

The NE555 timer IC generally operates in 3 modes:

1) Astable Mode 2) Monostable Mode 3) Bi-stable modes

1. Astable Mode

No stable state; output continuously switches between high and low, acting like a clock or square wave generator.

2. Monostable Mode

- This configuration has one stable state and one unstable state. The stable state can be set as either high (1) or low (0). If the stable state is high, the timer output starts high.
- When an interrupt occurs, the timer output turns low (unstable) but automatically returns to high once the interrupt ends. Similar is the case for a low stable monostable mode.

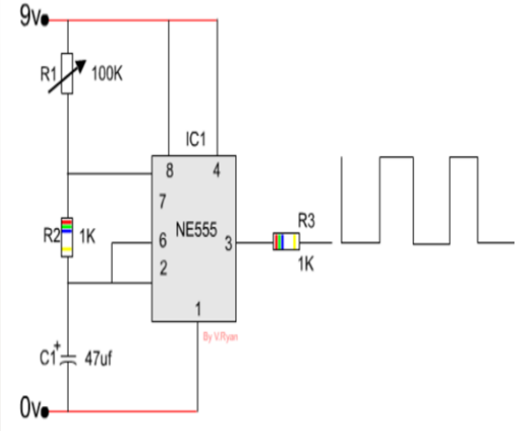
3. Bi-stable Mode

- In bistable mode, both output states (0 and 1) are stable. Each interrupt switches the output between these states.
- For example, if the output is high (1), an interrupt will change it to low (0) and it will remain low until the next interrupt switches it back to high (1).

ASTABLE MODE OF OPERATION

Saved to this PC

- In this mode, 555 acts as an electronic oscillator. The output continuously switches from high to low as per the configured period. This mode is used for pulse generation, clock signal generation and LED/Lamp flashers.

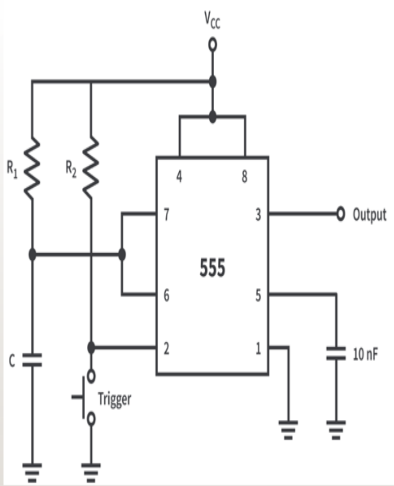


- The time-period of astable operation is
  $T = 0.69(R_1+2R_2)C_1$

- Applications:
  a) Square wave generator b) Pulse generation

MONOSTABLE MODE OF OPERATION

- This mode is also known as the "one-shot". When triggered, the timer generates only a single output pulse and returns to its stable state.



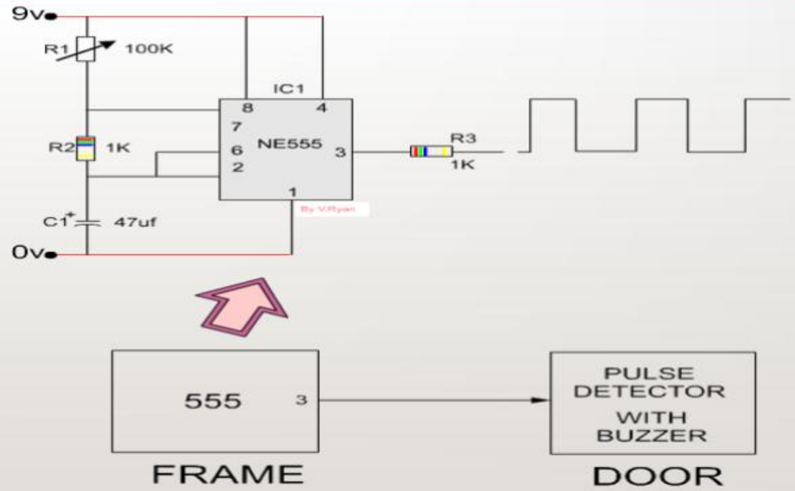
- Time period of the monostable operation is
  $T = 1.1R_1C$

- Applications include time delay generation, touch switches, pulse width modulation

IC 555 TIMER APPLICATIONS

List of some applications of **555** timer:

- Traffic Light Systems
- Dimmer Circuits
- Pulse Generator Circuits
- Alarming Circuits
- Duty Cycle Adjuster
- Square Wave Generators



Necessity of Voltage Regulation

A voltage regulator is an electronic circuit that maintains a stable (constant) DC voltage regardless of variations in load current, temperature, and AC line voltage.

1. Maintains a Constant Voltage
2. Protects Electronic Components
3. Improves Efficiency and Performance
4. Prevents Data Loss and System Malfunctions
5. Supports Battery-Powered Devices
6. Required for High-Power Applications

Advantages
Stable Voltage Output
Protection for Components
Improved Efficiency
Reduced Heat Dissipation

Disadvantages
Power Loss
More Complex Design
Higher Output Noise

Applications
Microcontroller, logic circuits, op-amps, or general electronics, dual power supplies

Types of Voltage Regulators

1. Linear Voltage Regulators
   - It uses a series pass transistor to adjust the output voltage.
   - Simple, easy to design, and suitable for low to moderate-power applications.
   - Limited efficiency and often generates heat.
2. Switching Voltage Regulators
   - It rapidly switches the input voltage ON and OFF and uses inductors and capacitors to filter the output.
   - More complex and suitable for high-power applications.
   - Offer higher efficiency.

Types of Voltage Regulators Based on Output Voltage

1. Positive Voltage Regulators

Provide a regulated positive voltage.

Example: **LM78XX series** (e.g., **LM7805** for +5V, **LM7809** for +9V, **LM7812** for +12V).

2. Negative Voltage Regulators

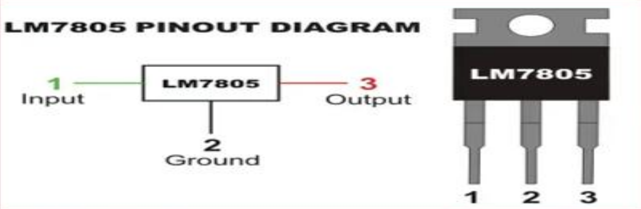
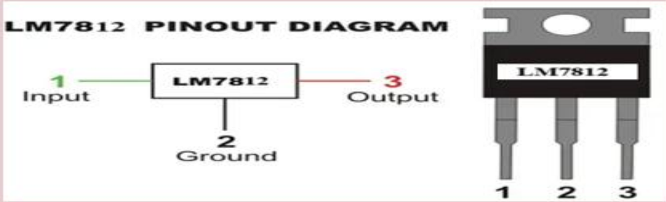
Provide a regulated negative voltage.

Example: **LM79XX series** (e.g., **LM7905** for -5V, **LM7909** for -9V, **LM7912** for -12V).

DIFFERENCE/CHARACTERISTIC FEATURES/ADVANTAGES

Feature	LM7805 (Positive Regulator)	LM7905 (Negative Regulator)
Type	Positive Voltage Regulator	Negative Voltage Regulator
Input Voltage Range	7V to 35V	-7V to -35V
Output Voltage Range	+5V	-5V
Maximum Output Current	1A (with heatsink up to 1.5A)	1A (with heatsink up to 1.5A)
Dropout Voltage	~2V (Needs at least **7V input** for **5V output**)	~2V (Needs at least **-7V input** for **-5V output**)
Line and Load Regulation	3mV/V and 50mV	3mV/V and 50mV
Short Circuit Protection and Internal current limiting	Yes	Yes
Common Use Case/Applications with Examples	Provides **+5V** for a microcontroller, logic circuits, op-amps, or general electronics	Provides **-5V** for dual power supplies, op-amps, or analog applications

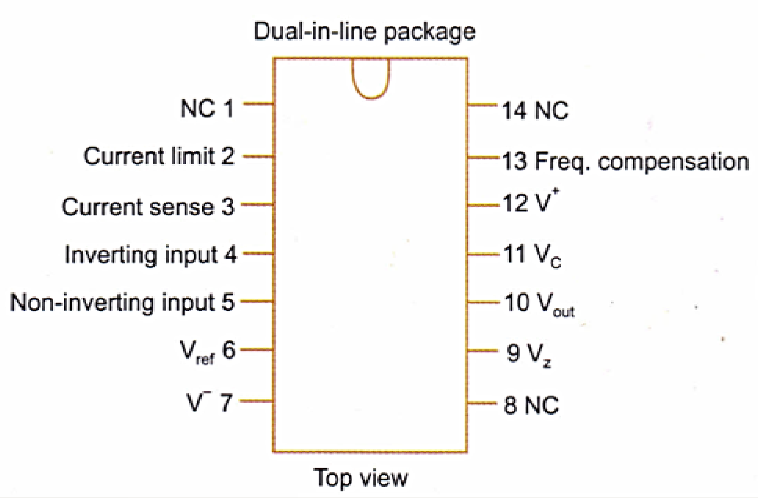
Pin Description for LM78XX and LM79XX

LM7805 (Positive Regulator)	LM7905 (Negative Regulator)
	
Pin 1: Input (Vin) – Accepts unregulated DC voltage Pin 2: Ground (GND) – Common ground Pin 3: Output (Vout) – Regulated +5V output	Pin 1: Ground (GND) – Common ground Pin 2: Input (Vin) – Accepts unregulated negative voltage Pin 3: Output (Vout) – Regulated -5V output
LM7812 (Positive Regulator)	**LM7912 (Negative Regulator)**
	
Pin 1: Input (Vin) – Accepts unregulated DC voltage Pin 2: Ground (GND) – Common ground Pin 3: Output (Vout) – Regulated +12V output	Pin 1: Ground (GND) – Common ground Pin 2: Input (Vin) – Accepts unregulated negative voltage Pin 3: Output (Vout) – Regulated -12V output

Voltage Regulator LM723

- There are various types of voltage regulators for getting a regulated power supply like 7812, 7805, etc. However, all these regulators provide a fixed value output. For inconsistent voltage regulation, an LM317 IC voltage regulator.
- Three terminal regulators limitations are the no short circuit protection and output voltage (positive or negative) is fixed.
- To overcome this problem, 723 general purpose regulators can be adjusted over a wide range of either positive or negative regulated voltage.
- This IC is low current device and it can be boosted to provide 5 amps or more current by connecting external components.

Pin diagram for 14 pin DIP



Pin Number	Function
1	NC (No Connection)
2	Current Limit
3	Current Sense
4	Inverting Input
5	Non-Inverting Input
6	Vref (Reference Voltage)
7	V^- (Negative Supply)
8	NC (No Connection)
9	Vz (Zener Voltage)
10	Vout (Output Voltage)
11	V_C (Control Voltage)
12	V^+ (Positive Supply)
13	Frequency Compensation
14	NC (No Connection)

ADVANTAGES OF LM723

- The maximum input voltage will be 40V.
- Adjustable output voltage from 2V to 37V.
- It can drive external pass transistors to support higher currents (up to 10A or more).
- Low noise operation and wide operating temperature range.
- It is used to design both switching and linear regulators.
- Built-in short circuit Protection.
- It can be used as a series, shunt, switching, or floating regulator, making it a multi-purpose IC.

DISADVANTAGES/LIMITATIONS OF LM723

- Difficulty in design and complexity.
- Current limiting is not very precise and sensitive to overload.
- Requires a high dropout voltage (not LDO).
- Moderate error amplifier gain and bias current issues.

FEATURES/SPECIFICATIONS OF LM723

Parameter	Value
Input Voltage Range	9V to 40V
Output Voltage Range	2V to 37V
Maximum Output Current (With External Pass Transistor)	up to 10A or more
Reference Voltage (VREF)	7.15V
Dropout Voltage	3V to 5V
Operating Temperature Range	-55°C to +125°C
Line and Load Regulation	0.01%/V and 0.03%