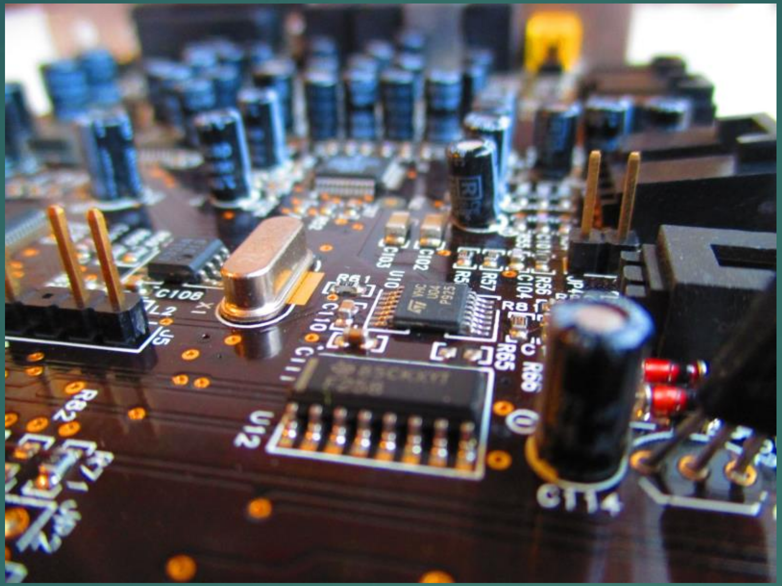
EE3301 Analog Electronics



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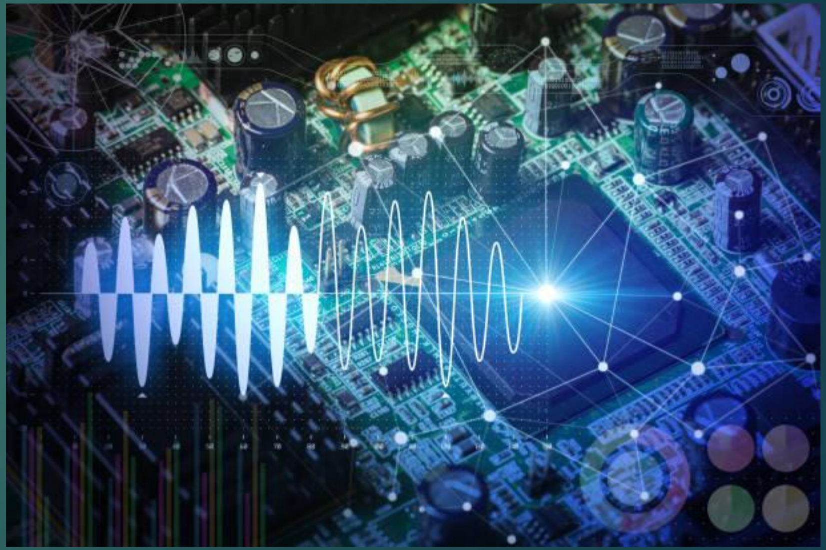


DC POWER SUPPLIES AND REGULATION CIRCUITS

1. Diodes
2. Half Wave Rectification and Full wave Rectification
3. Clamping and Clipping
4. Filtering and Regulation

Diodes

Types of materials

1. Conductor

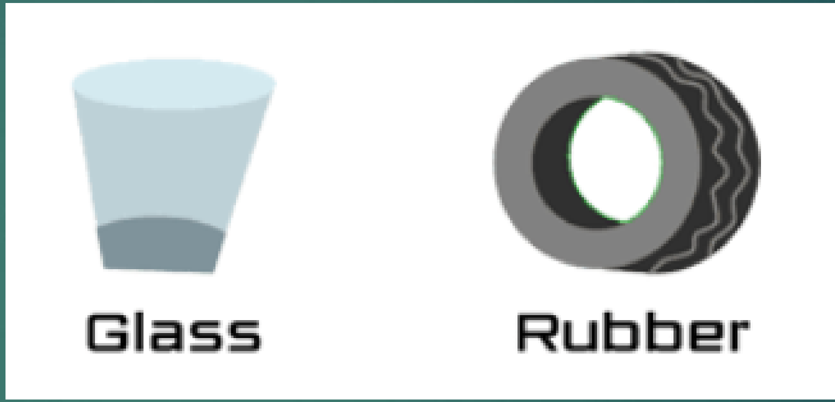
   is defined as materials that allow electricity to flow through them easily.

   Eg:- Copper, Gold, Iron, Aluminum

2. Insulator

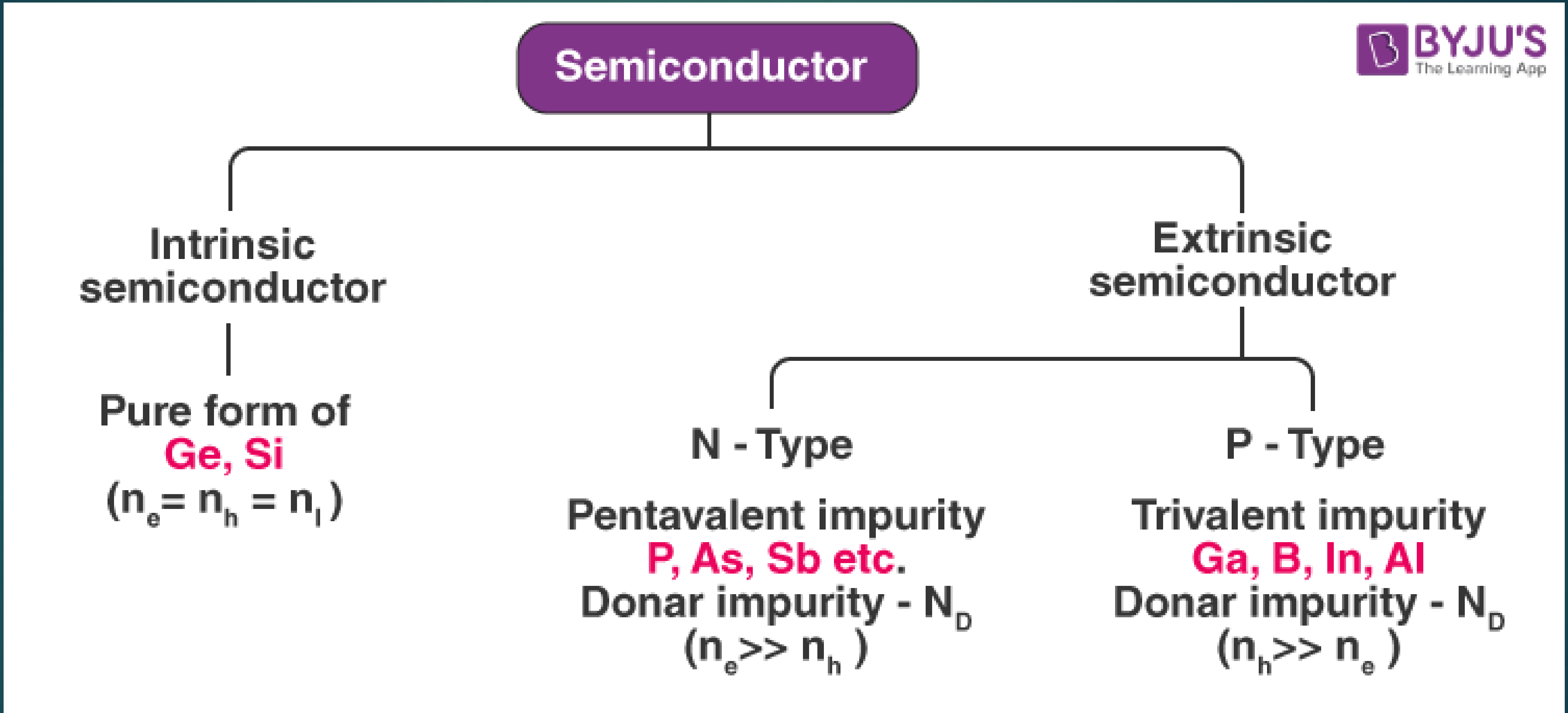
is a material that does not conduct electrical current

Eg:- Plastic, Wood, Glass

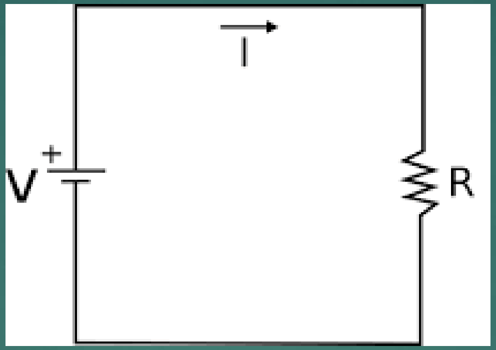


3. Semiconductor

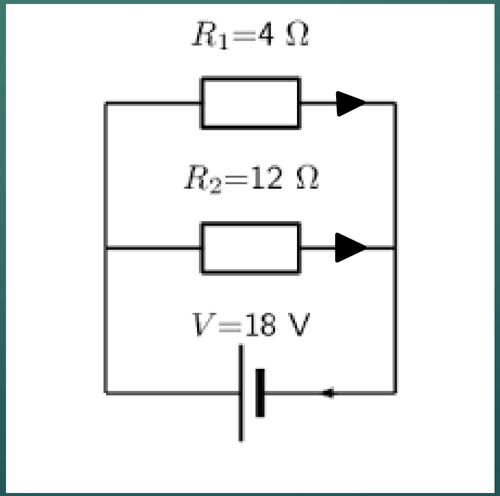
is a material that has a conductivity between conductors and insulators


BYJU'S
The Learning App
Semiconductor
Intrinsic semiconductor
Pure form of
Ge, Si
$(n_e = n_h = n_i)$
Extrinsic semiconductor
N - Type
Pentavalent impurity
P, As, Sb etc.
Donar impurity - N_D
$(n_e >> n_h)$
P - Type
Trivalent impurity
Ga, B, In, Al
Donar impurity - N_D
$(n_h >> n_e)$

Q1) When V= 8.8 V and R= 2.2 KΩ, Calculate the current through the resistor.



Q2) Calculate the total current drawn from the battery.



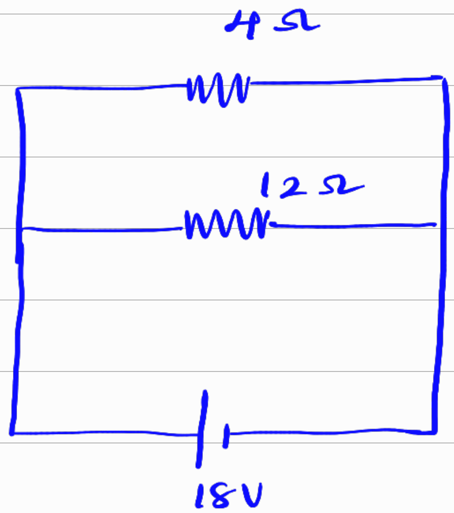
Q1. $V = IR$

$8.8 = I \times 2.2 \times 10^{3}$

$I = 4 \times 10^{-3}$

$I = 4\ mA$

Q2



$R_{eq} = \frac{4 \times 12}{16}$

$R_{eq} = 3\ \Omega$

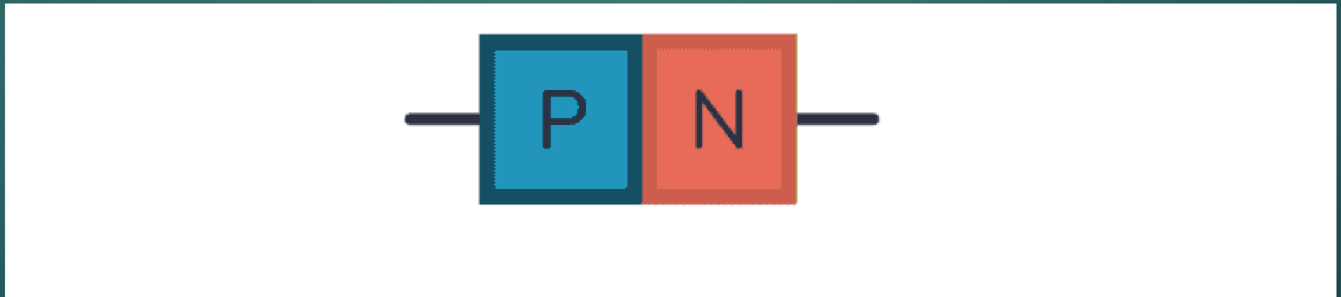
$V = IR$

$18 = I \times 3$

$I = 6\ A$

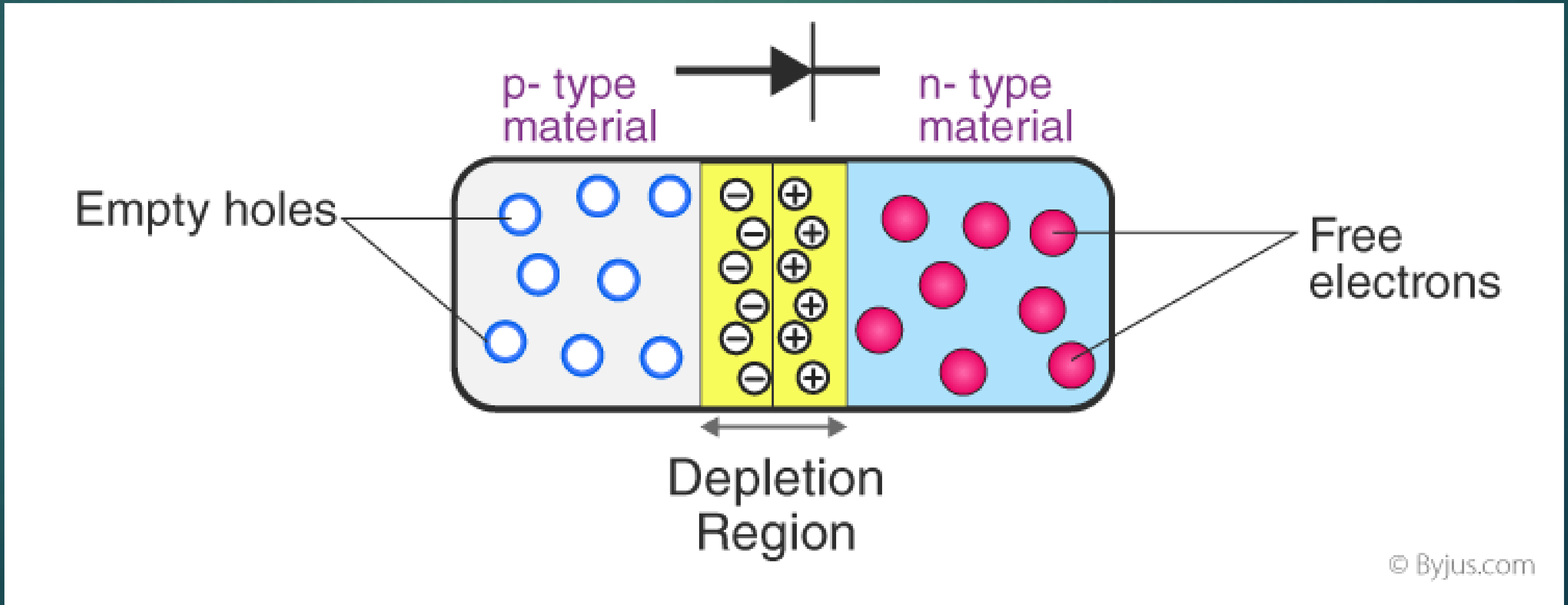
What is a Diode?

- A diode is a component that lets current flow in one direction and blocks it from flowing in the other direction.
- The diode is created from a PN junction. Can get a PN junction by taking a negatively doped and positively doped semiconductor material and putting it together.

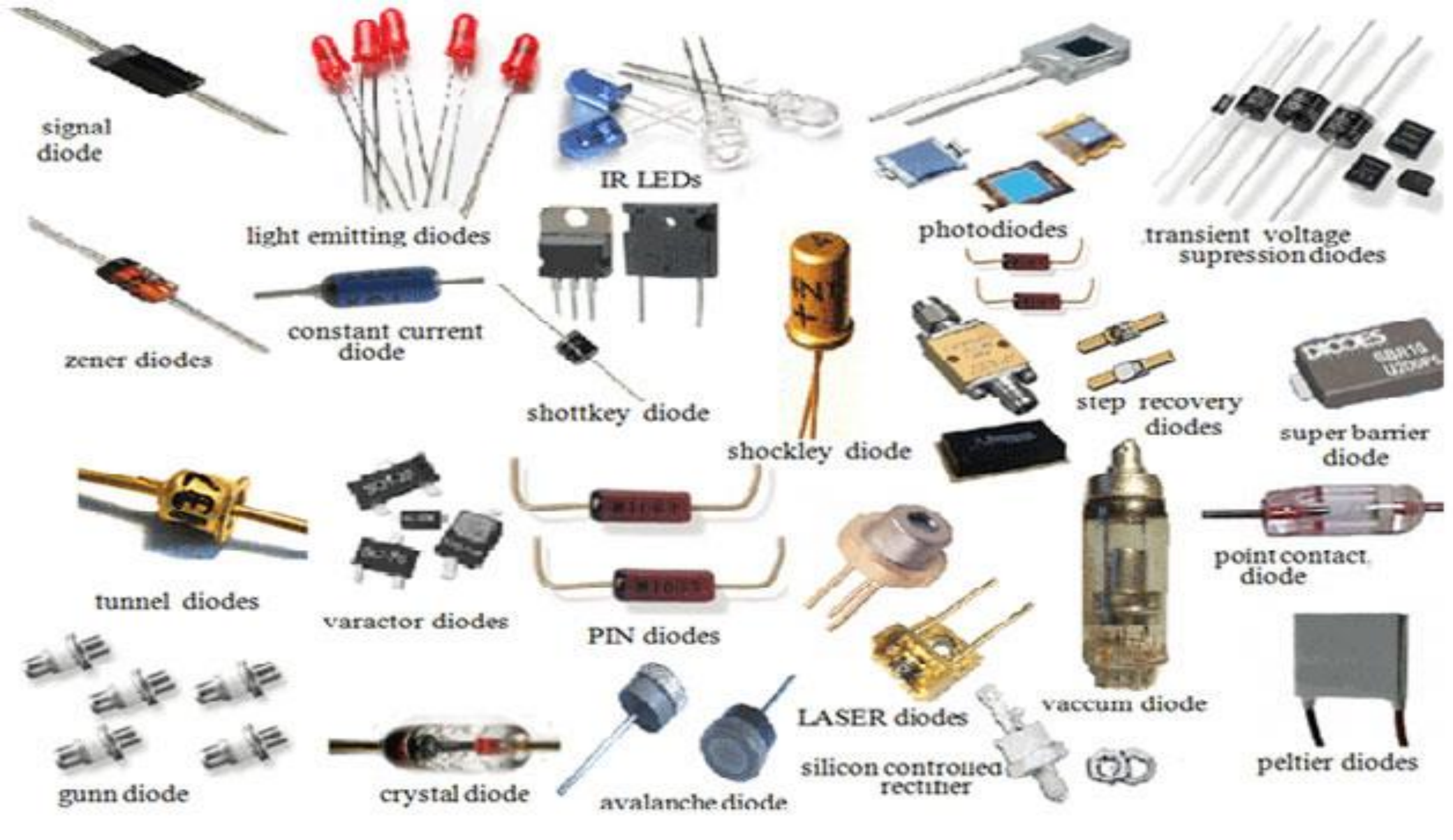


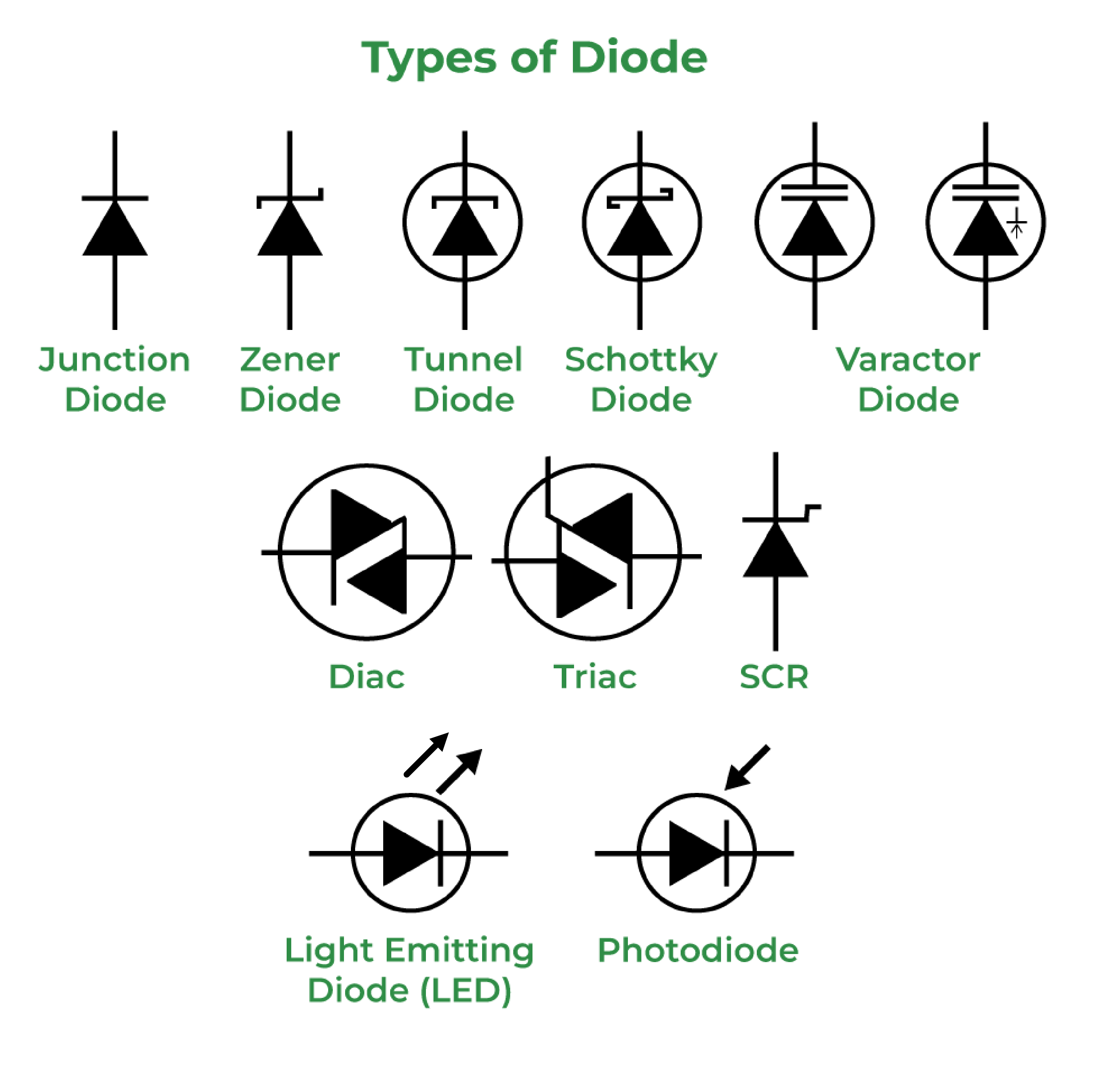
What is P-N Junction?

A P-N junction is an interface or a boundary between two semiconductor material types, namely the p-type and the n-type, inside a semiconductor.

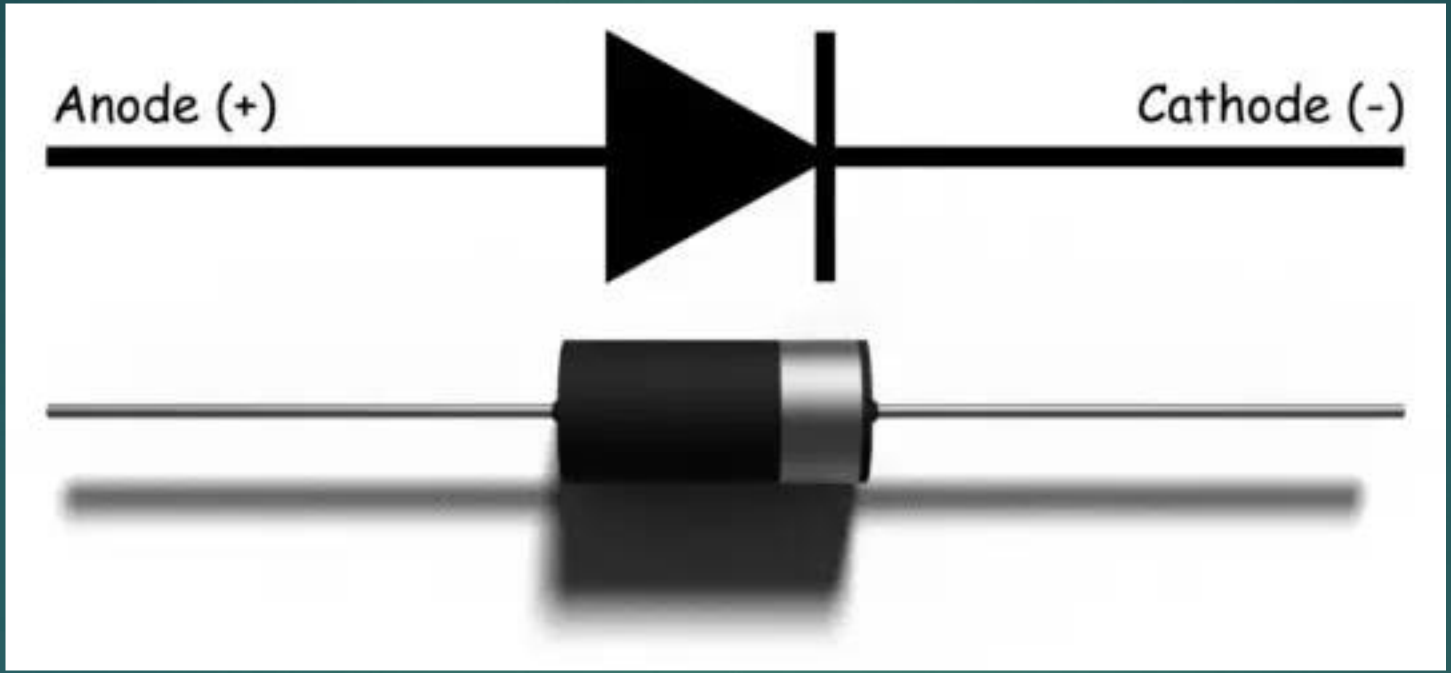


Types of Diodes



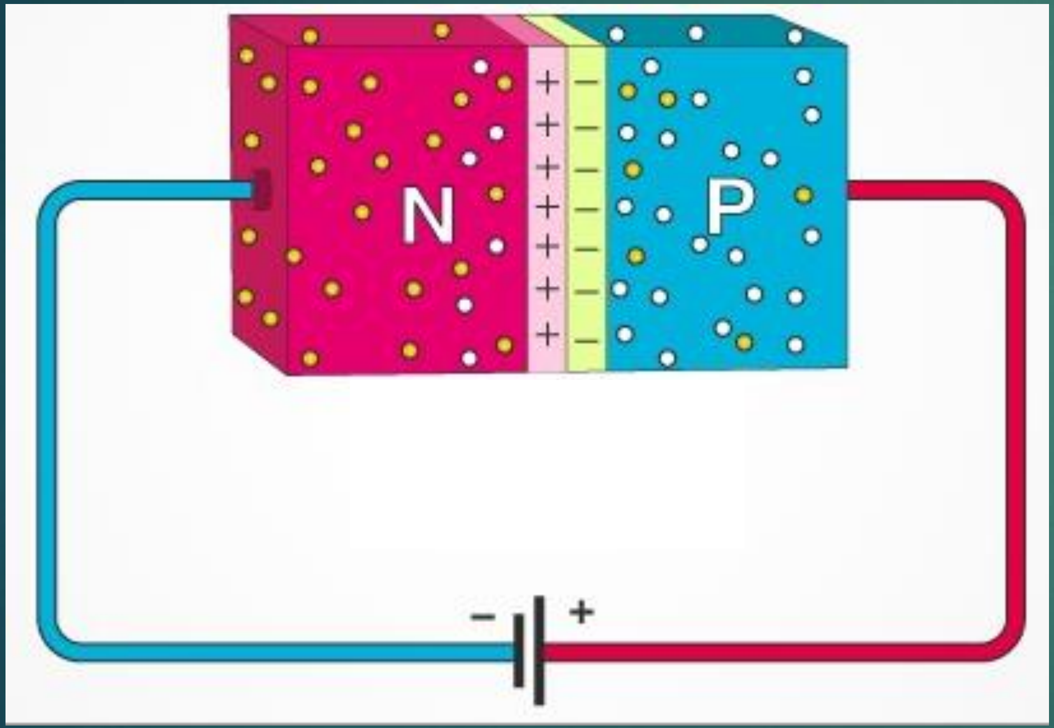

Types of Diode
Junction Diode
Zener Diode
Tunnel Diode
Schottky Diode
Varactor Diode
Diac
Triac
SCR
Light Emitting Diode (LED)
Photodiode

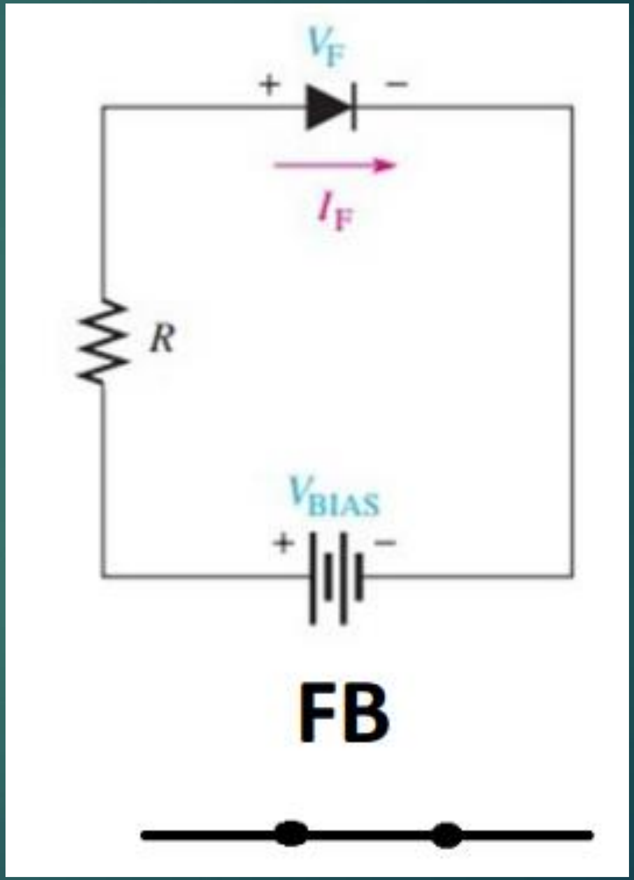
Rectifier Diode



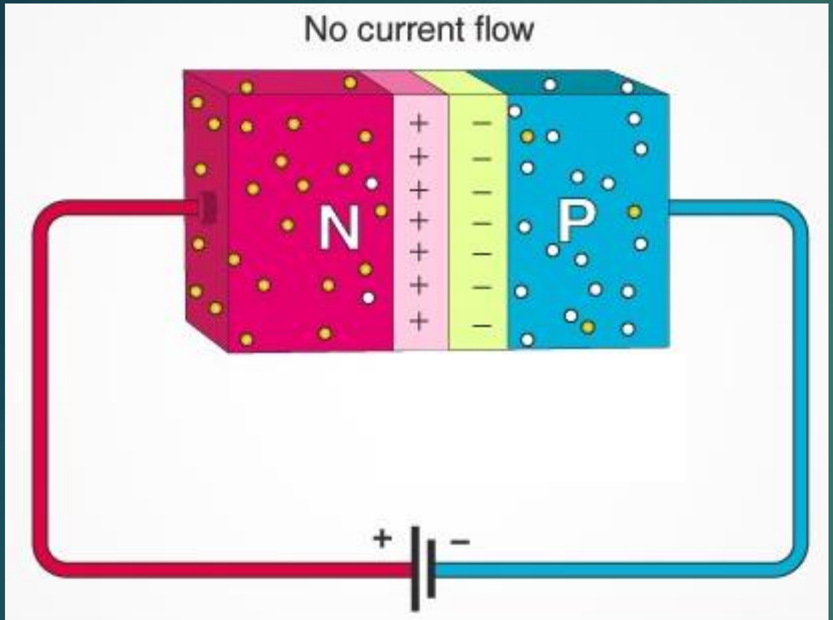
Diode modes

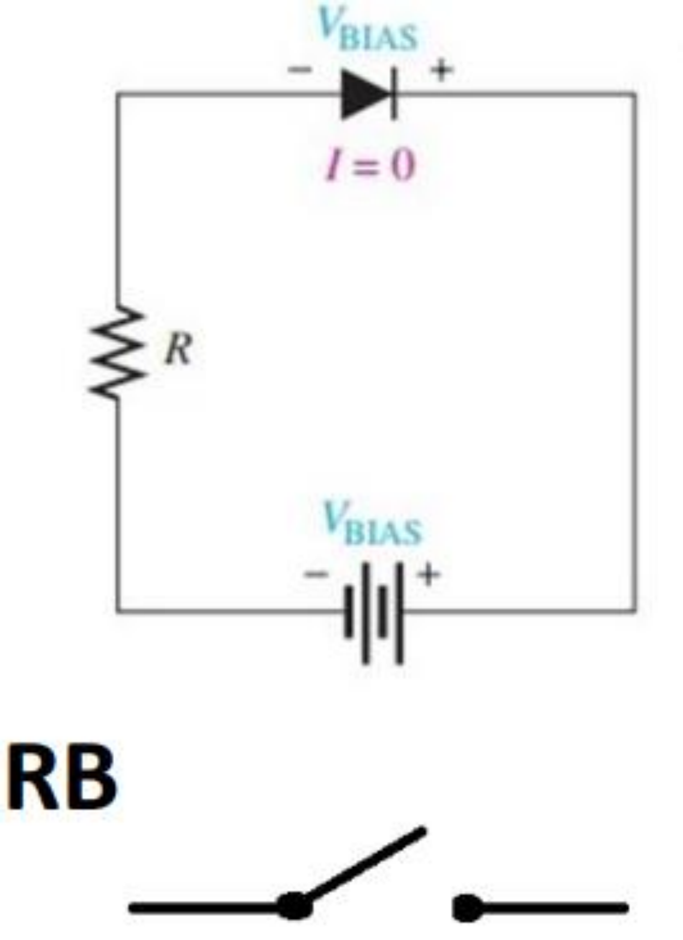
1. **Forward Bias**



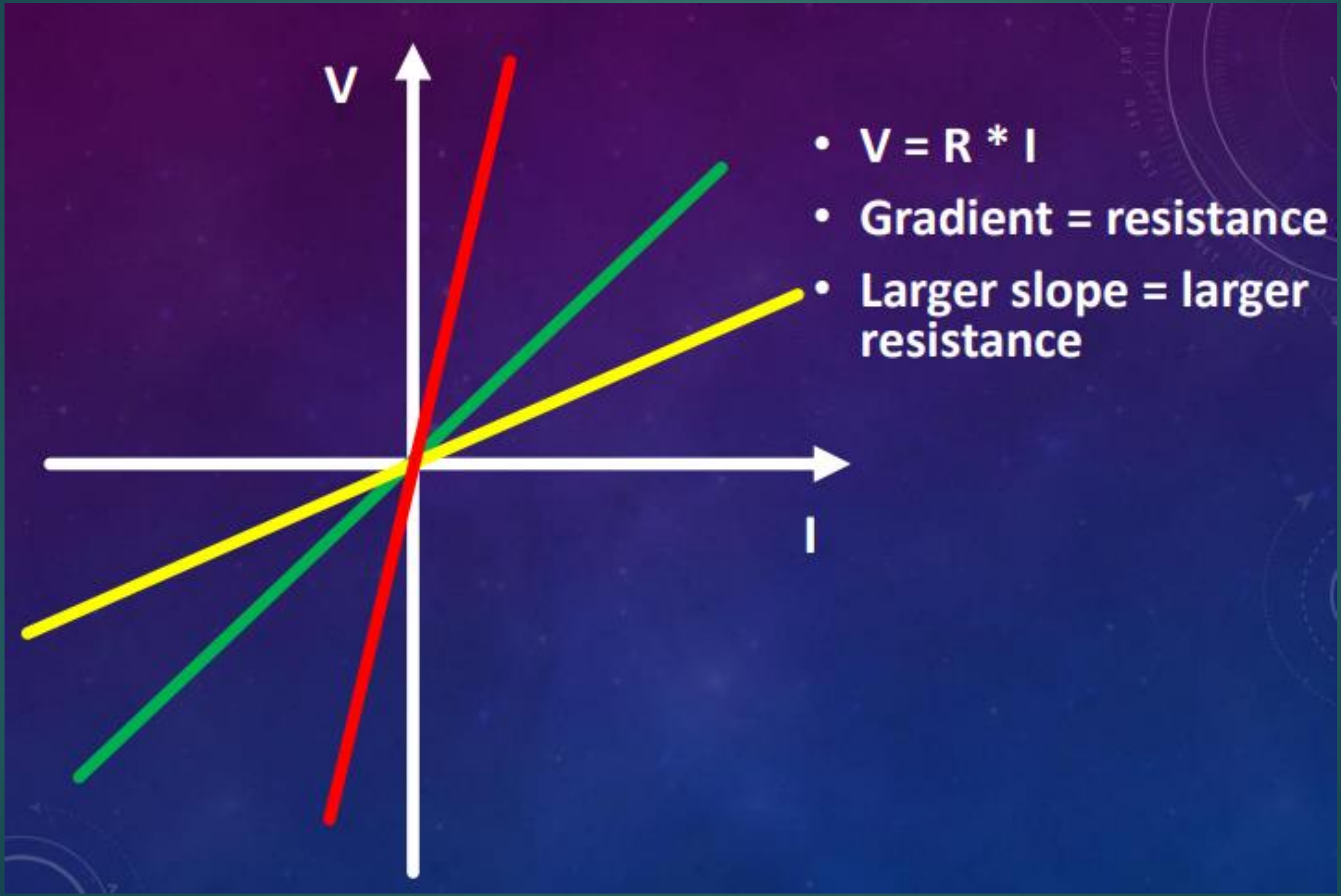


2. Reverse Bias

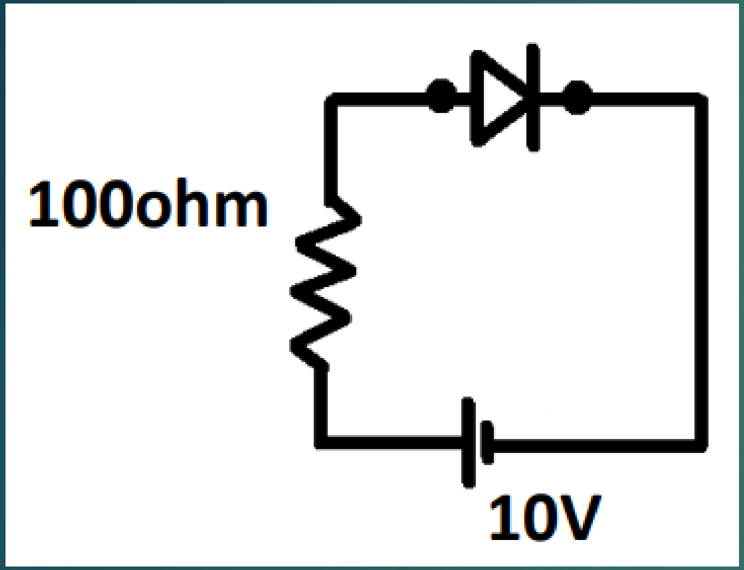


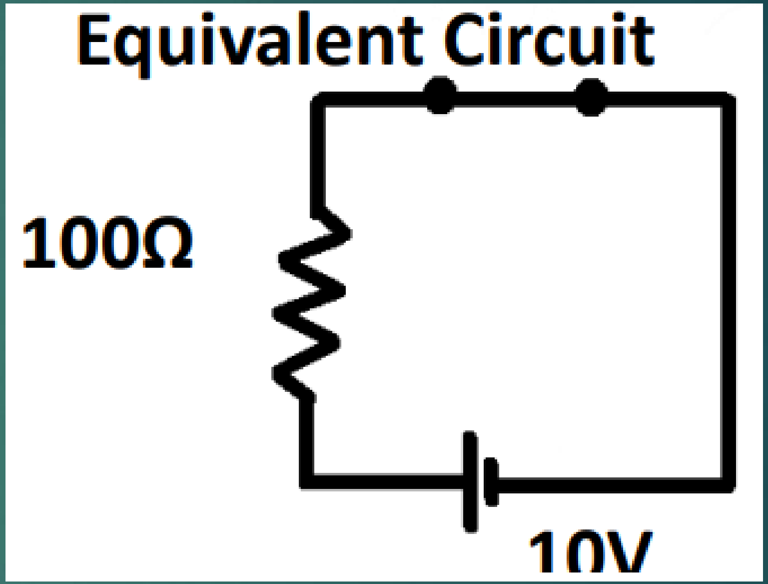


Resistor I-V Characteristics



Q3) Considering the diode is a ideal one, calculate the current through the diode. Then draw an equivalent circuit and graph.



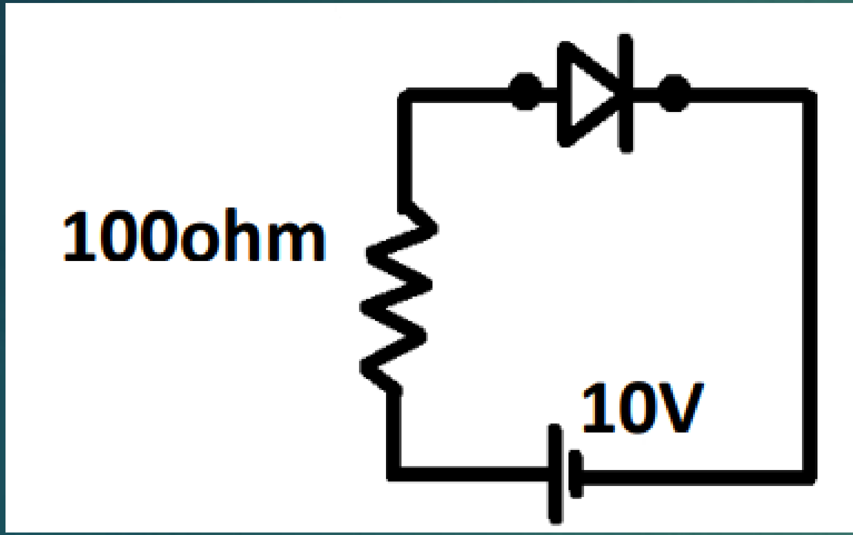


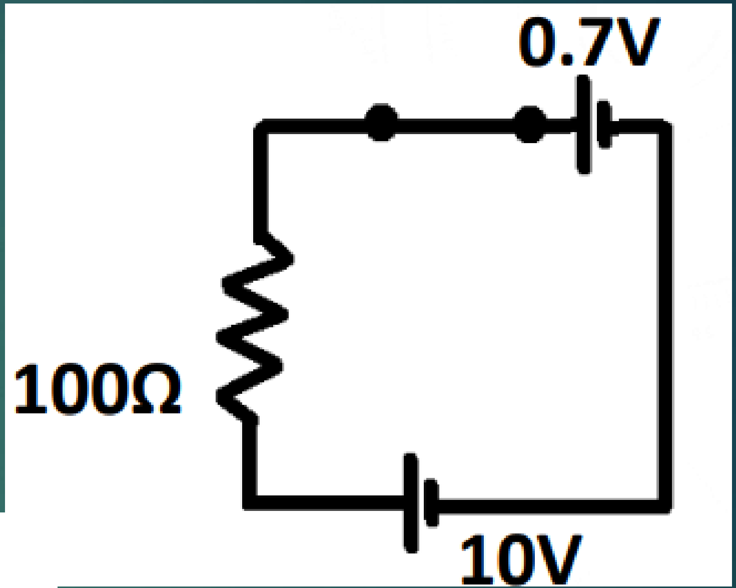
$I = V/R$

$= 10/100$

$= 0.1A$

Q4) Calculate the current through the Si diode. Then draw an equivalent circuit and graph. (0.7 V Silicon)

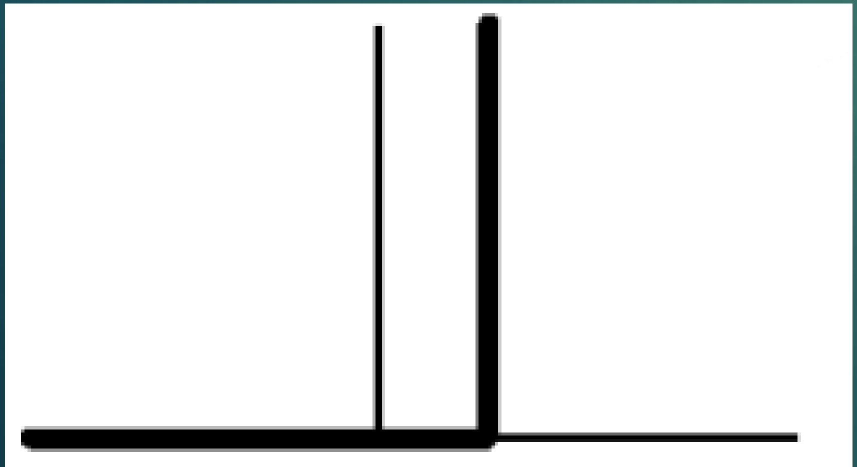




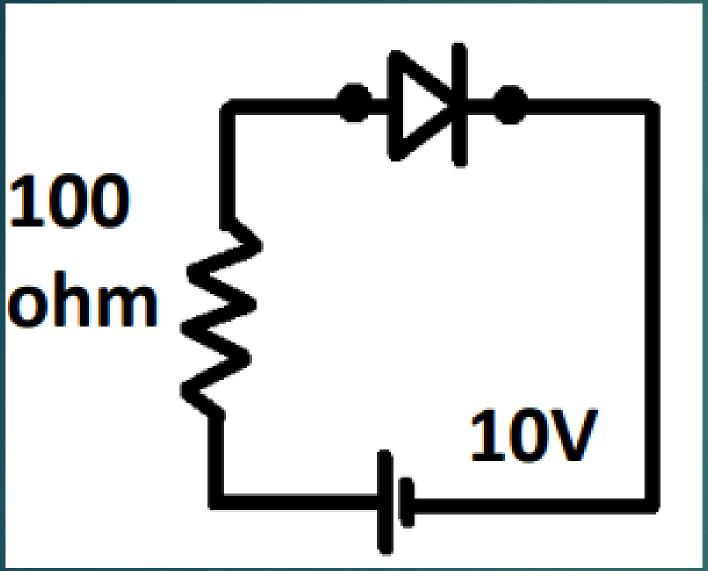
$I = V/R$

$= (10-0.7)/100$

$= 0.093A$



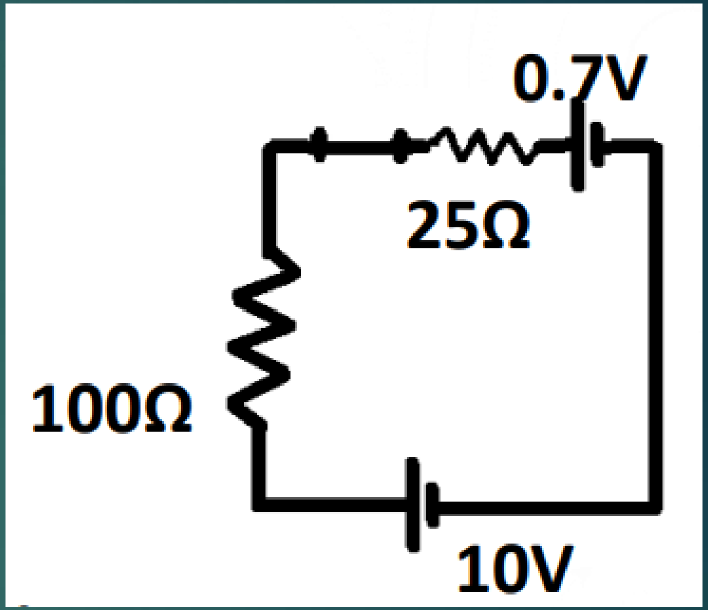
Q5) Calculate the current through the Si diode when the diode has a resistance of 25 ohm. Then draw an equivalent circuit and graph.

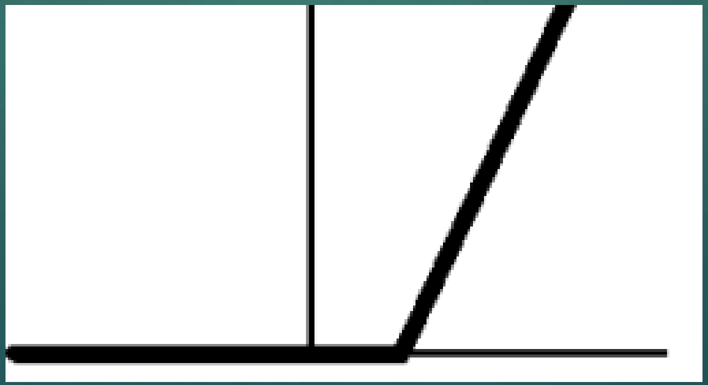


$I = V/R$

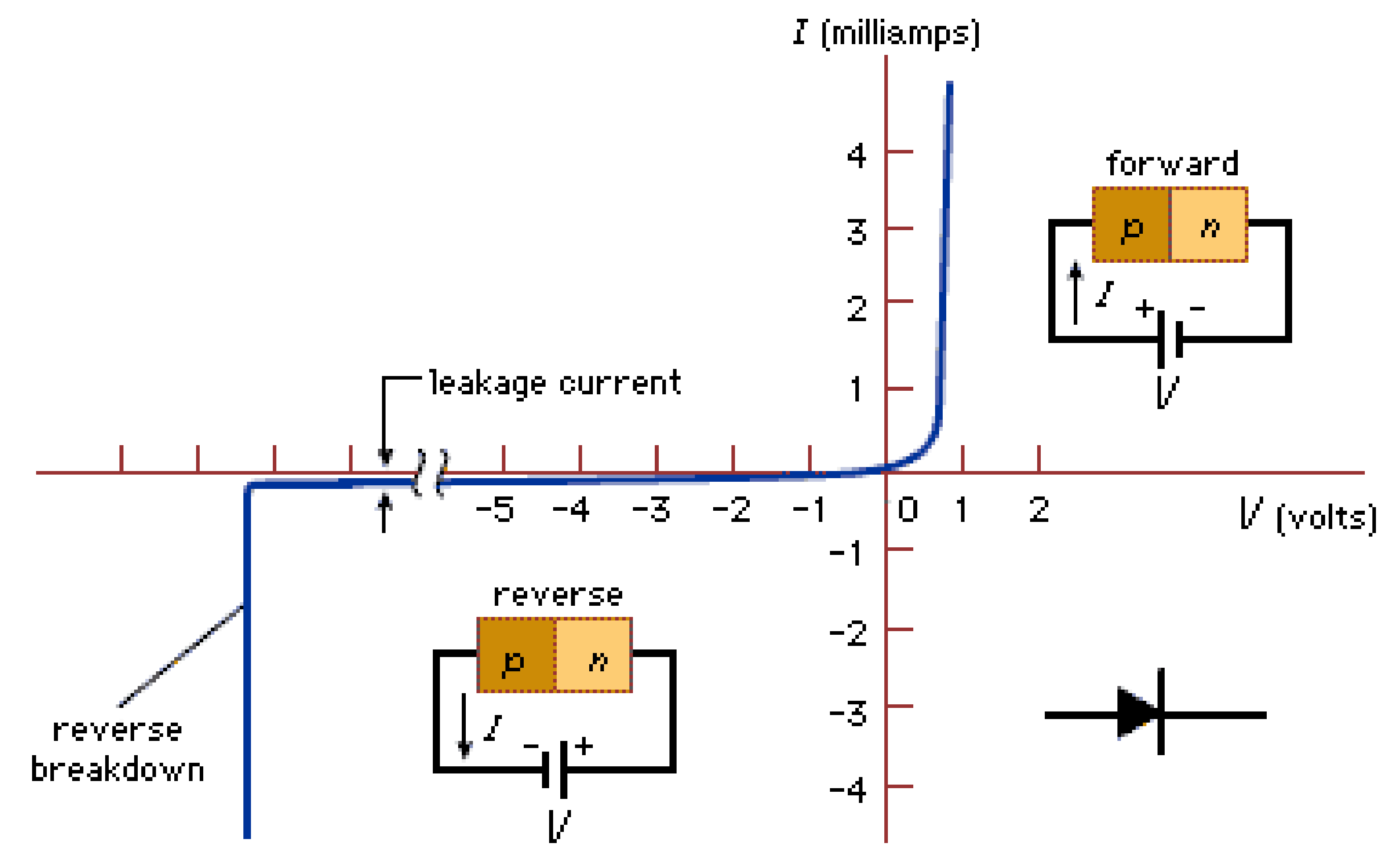
$= (10-0.7)/(100+25)$

$= 0.074A$





Diode I-V Characteristics



Applications

1. **Rectifier Diode:** A rectifier diode is a kind of diode that is used for the rectification of current (A.C).
2. **LED:** LEDs are diodes used for providing light.
3. **Zener Diode:** Zener diode is used for the stabilization of current and voltage in electronic systems.
4. **Photodiode:** Photodiodes are used to detect light.
5. **Switching Diode:** Switching diodes are used for providing fast switching in circuits.
6. **Tunnel Diode:** A tunnel diode is a special type used in the negative resistance region.

Common Diodes
1N4001–7 silicon power diode

Characteristic	Symbol	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	V
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	V
Average Rectified Output Current (Note 1) @ T_A =+75°C	I_O	1.0							A
Non-Repetitive Peak Forward Surge Current 8.3ms Single Half Sine-Wave Superimposed on Rated Load	I_{FSM}	30							A
Forward Voltage @ I_F = 1.0A	V_{FM}	1.0							V
Peak Reverse Current @T_A = +25°C at Rated DC Blocking Voltage @ T_A = +100°C	I_{RM}	5.0 50							µA
Typical Junction Capacitance (Note 2)	C_j	15				8			pF
Typical Thermal Resistance Junction to Ambient	$R_{\theta JA}$	100							K/W
Maximum DC Blocking Voltage Temperature	T_A	+150							°C
Operating and Storage Temperature Range	T_J, T_{STG}	-65 to +150							°C

Notes:
1. Leads maintained at ambient temperature at a distance of 9.5mm from the case.
2. Measured at 1.0 MHz and applied reverse voltage of 4.0V DC.
3. EU Directive 2002/95/EC (RoHS). All applicable RoHS exemptions applied, see EU Directive 2002/95/EC Annex Notes.

Common Diodes

- 1N4001-7 silicon power diode
- 1N34, 1N34A Detector Diodes
- 1N4448 silicon signal diode
- MPN3404 (or BA479) PIN diode
- KV1360NT variable capacitance diode (varicap)

Replacement and Equivalent

You can replace the 1N4004 with the

RL207, RL206, RL205, RL204, HER208, HER207, HER206, HER205, HER158, HER157, HER156, HER155, HER108, HER107, HER106, HER105, FR207, FR206, FR205, FR204, FR157, FR156, FR155, FR154, FR107, FR106, FR105, FR104, EM520, EM516, EM513, BY133, 1U8, 1U7, 1U6, 1U5, 1N5399, 1N5398, 1N5397, 1N5395, 1N4937, 1N4936, 1N4007, 1N4006, 1N4005, 1A7, 1A6, 1A5, 1A4, SF16, SF18, SF26, SF28, UF4004, UF4005, UF4006, UF4007, 1N4004G, 1N4005G, 1N4006G, 1N4007G, 1N4936G, 1N4937G

EE3301 Analog Electronics

DC power Supplies and Regulation Circuits

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2.0 Rectifiers

- "Rectify"
  - To set right, make one directional
- "Rectifier"
  - It rectifies
  - Permits current to flow through it in one direction only
- Peak Inverse Voltage (PIV)
  - Maximum permissible reverse biased voltage that the diode can withstand without a breakdown
  - $\boldsymbol{PIV} \geq \boldsymbol{V}\mathrm{p}$

Frequency

- $f = 1 / T$

- Angular velocity

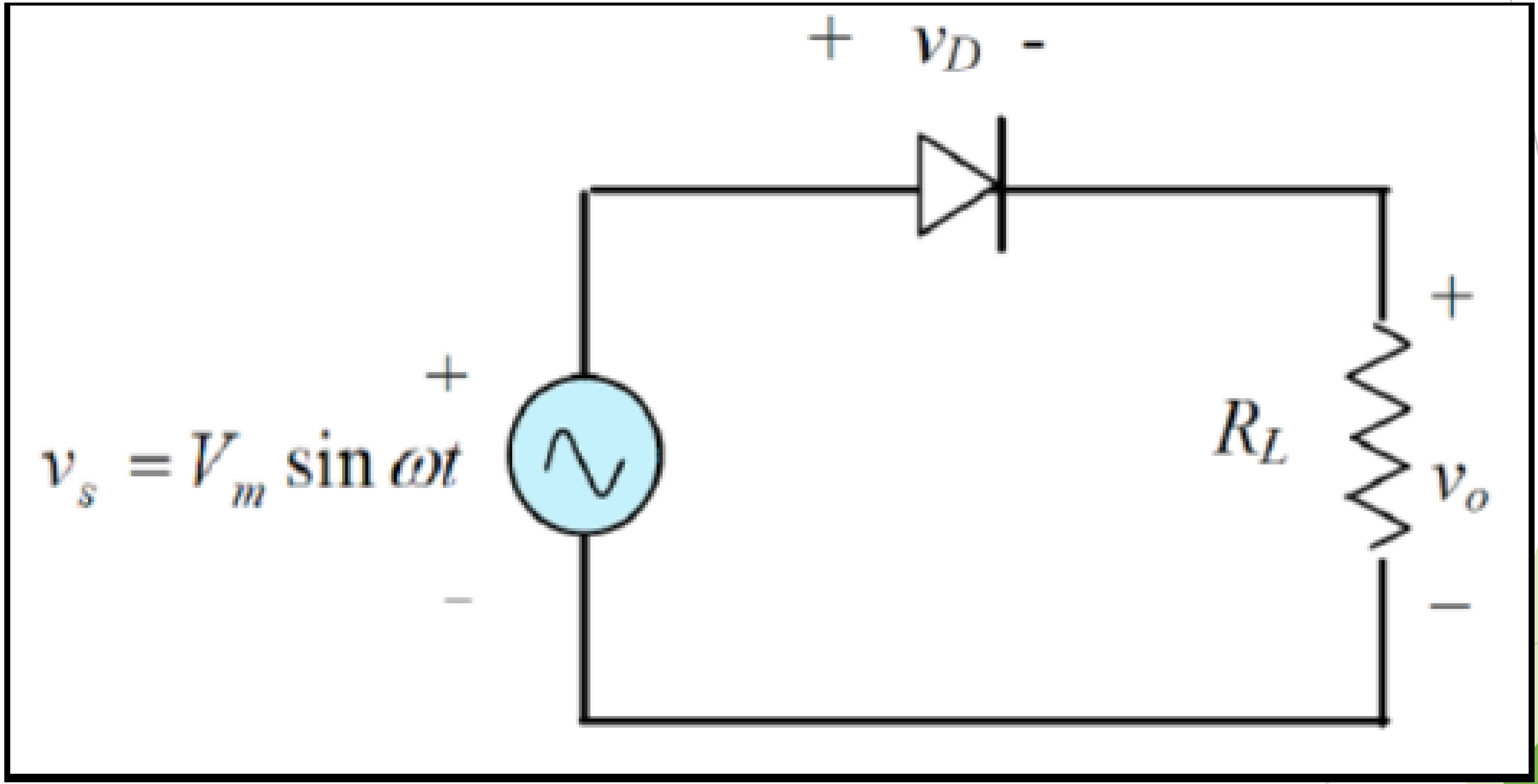
$$\omega = 2\pi f$$

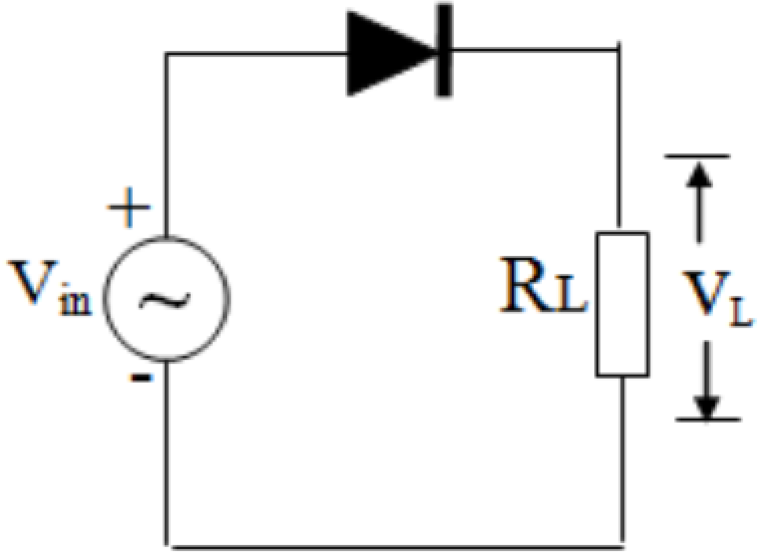
Rectifiers

Half- Wave Rectifiers

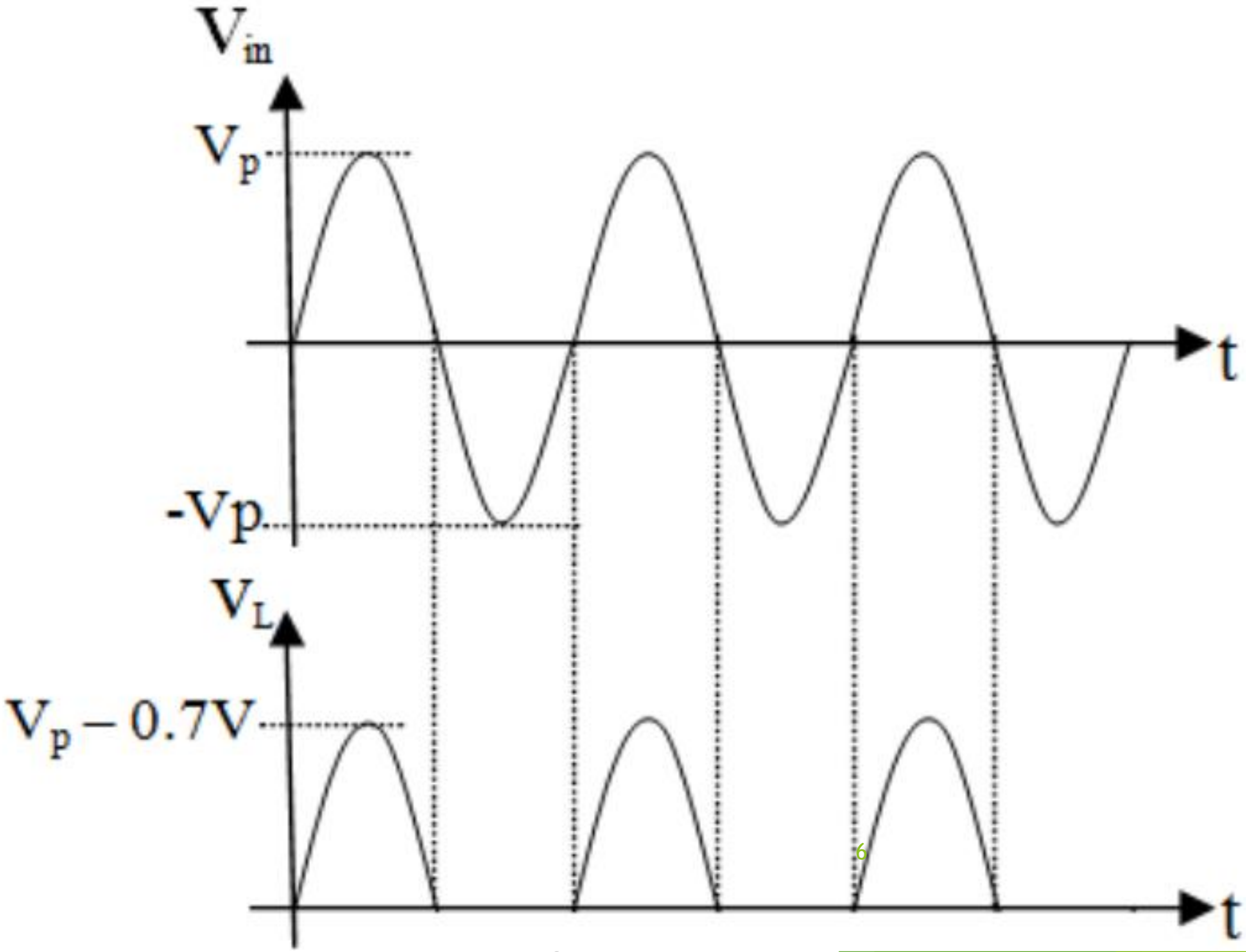
Full - Wave Rectifiers

2.1 Half- Wave Rectifiers





+
V_{in}
-
R_L
V_L

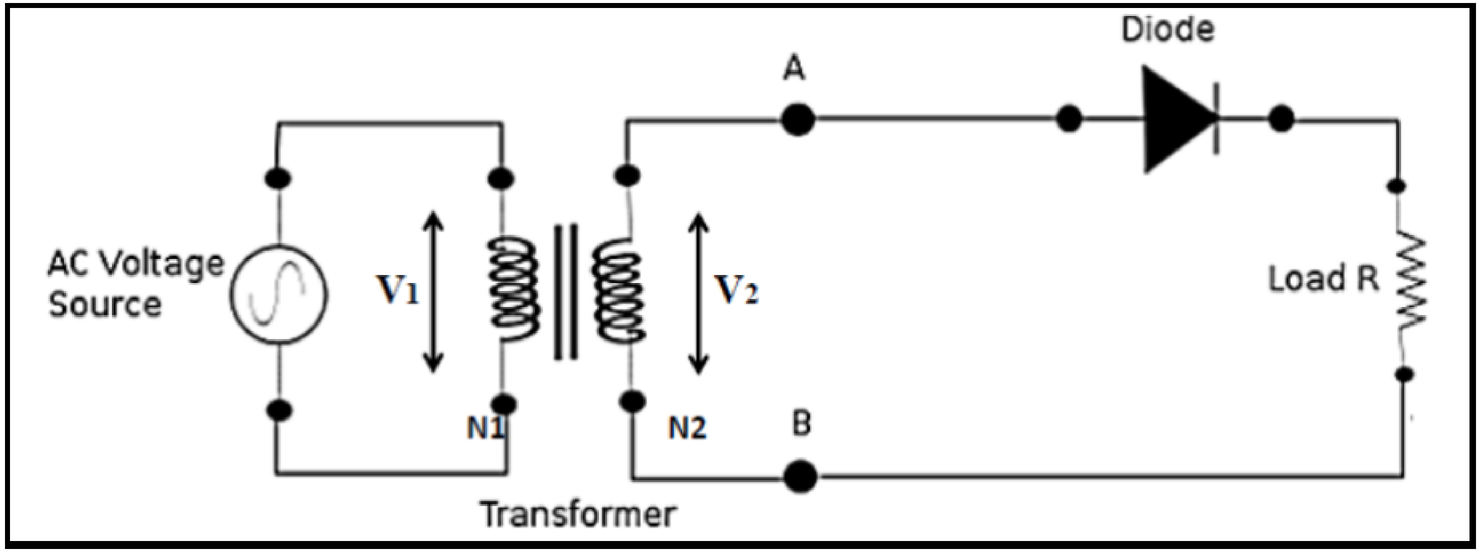


V_{in}
V_p
-Vp
t
V_L
$V_p - 0.7V$
t

- AC waveform, One diode
- During the positive half cycle
  - Diode is forward biased
- Conduct all instantaneous voltages greater than the cutting voltage
- $V_{PR} = V_P - 0.7$

  Where; V_{PR} = peak value of rectified voltage
- During the negative half cycle
  - Diode is reverse biased
  - No voltage output

2.2 HWR with Transformer coupled input

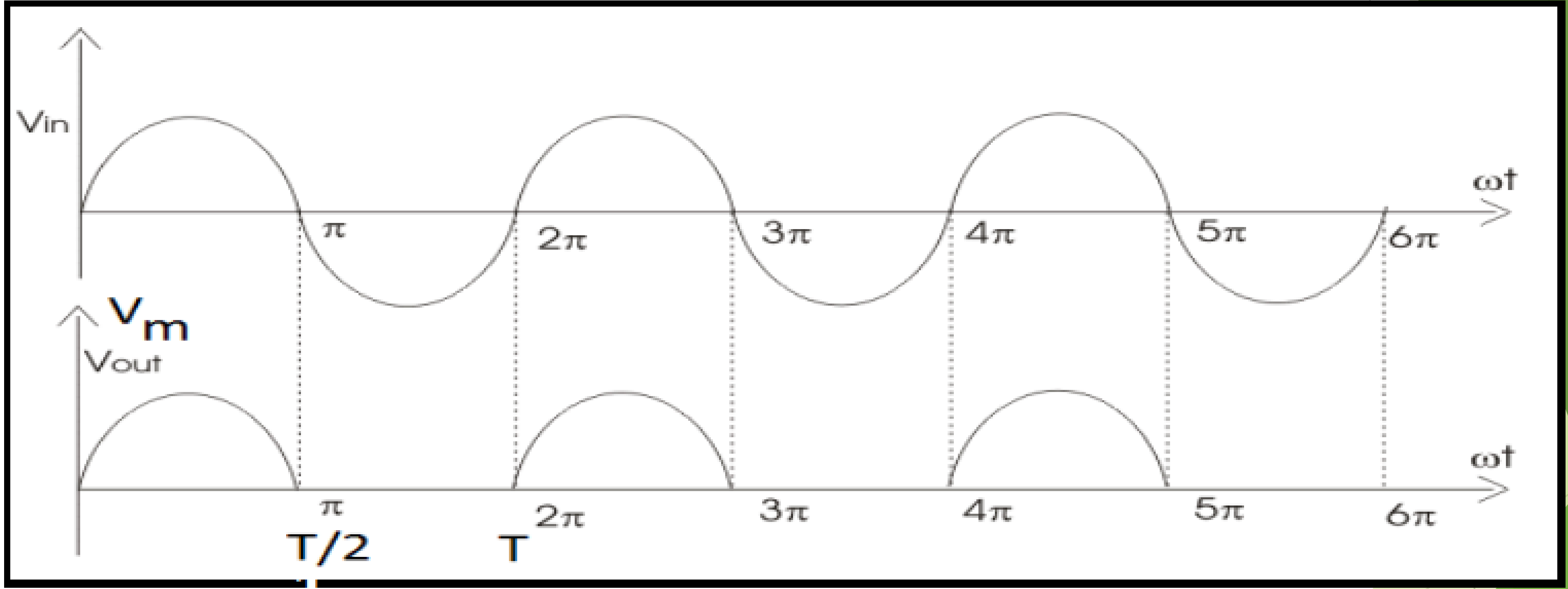


- V2 / V1 = ?
- V1 - rms value of primary voltage
- V2 - rms value of secondary voltage
- N1 – No. of turns in the primary winding
- N2 – No. of turns in the secondary winding
- Advantages….
  - AC source is electrically isolated from the load
  - Allows source voltage step up or step down

Average and RMS values

- RMS – Root mean square
- RMS gives you the equivalent DC voltage for the same power

2.3 Calculate the Average and RMS of HWR



- Period $\boldsymbol{T = 2\pi}$, $\boldsymbol{f = 1/2\pi}$
- $\boldsymbol{f_{out} = f_{in}}$
- $V_{avg} = \frac{1}{T}\int_0^T v(t)dt \longrightarrow V_{avg} = \frac{V_m}{\pi}$
- $V_{rms} = \sqrt{\frac{1}{T}\int_0^T V(t)^2 dt} \longrightarrow V_{rms} = \frac{V_m}{2}$

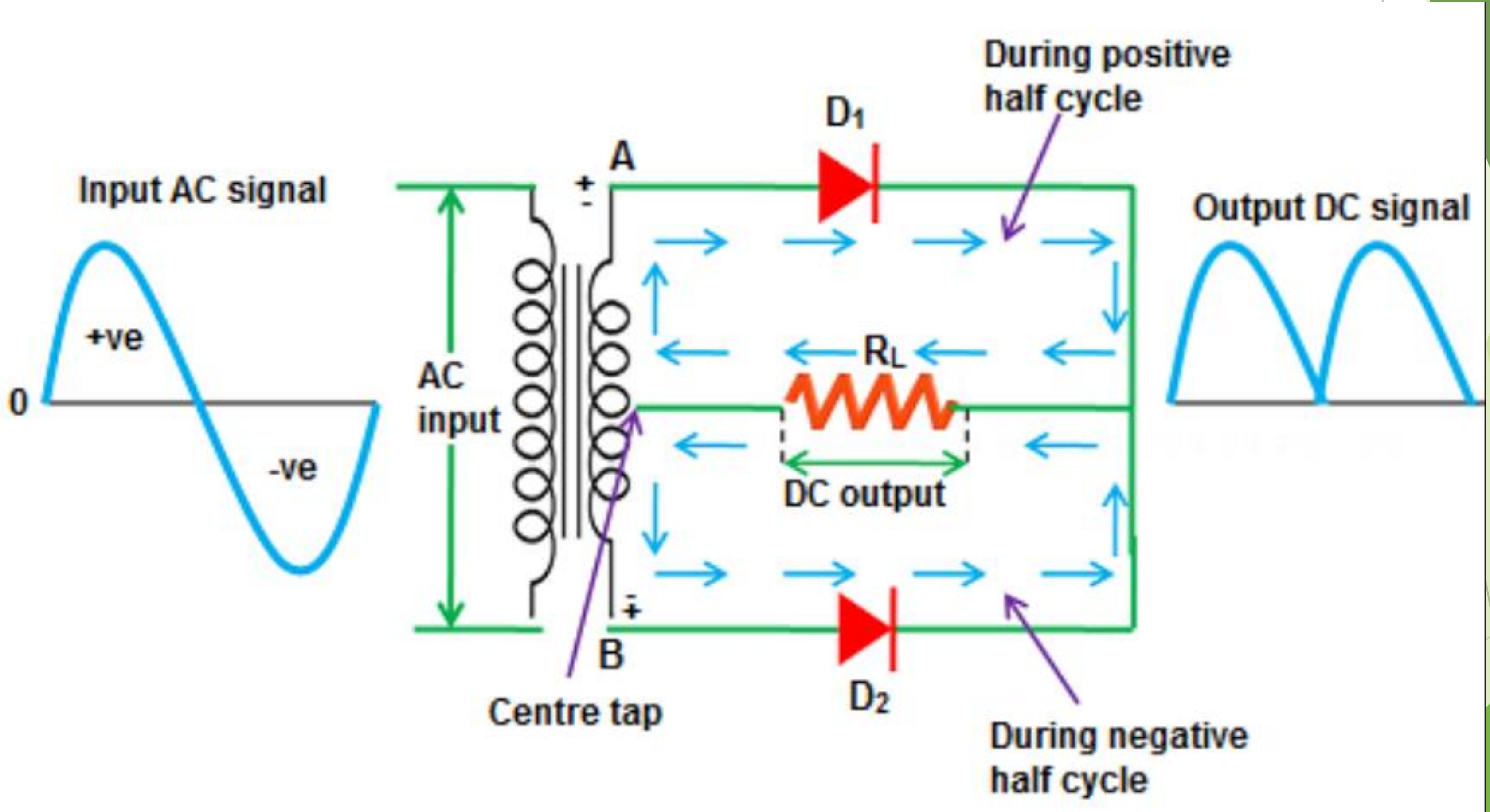
2.4 Full Wave Rectifiers

- A full-wave rectifier is a circuit that allows a unidirectional current to flow through the load during the ENTIRE input cycle.

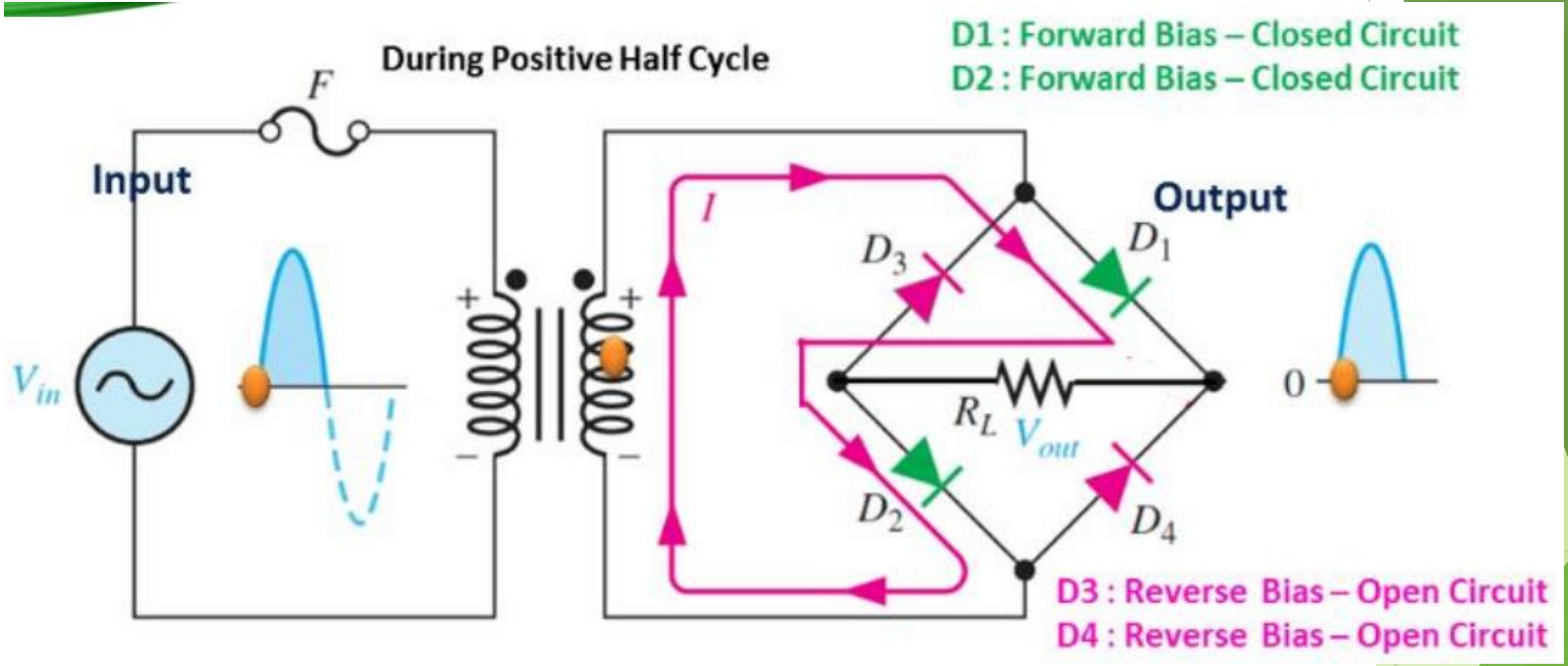
Center Tapped Full-Wave Rectifier

Full-Wave Bridge Rectifier

2.4.1 Center Tapped Full-Wave Rectifier



2.4.2 Full-Wave Bridge Rectifier



$$V_{PR} = V_P - 1.4$$

2.5 Calculate the Average and RMS of FWR

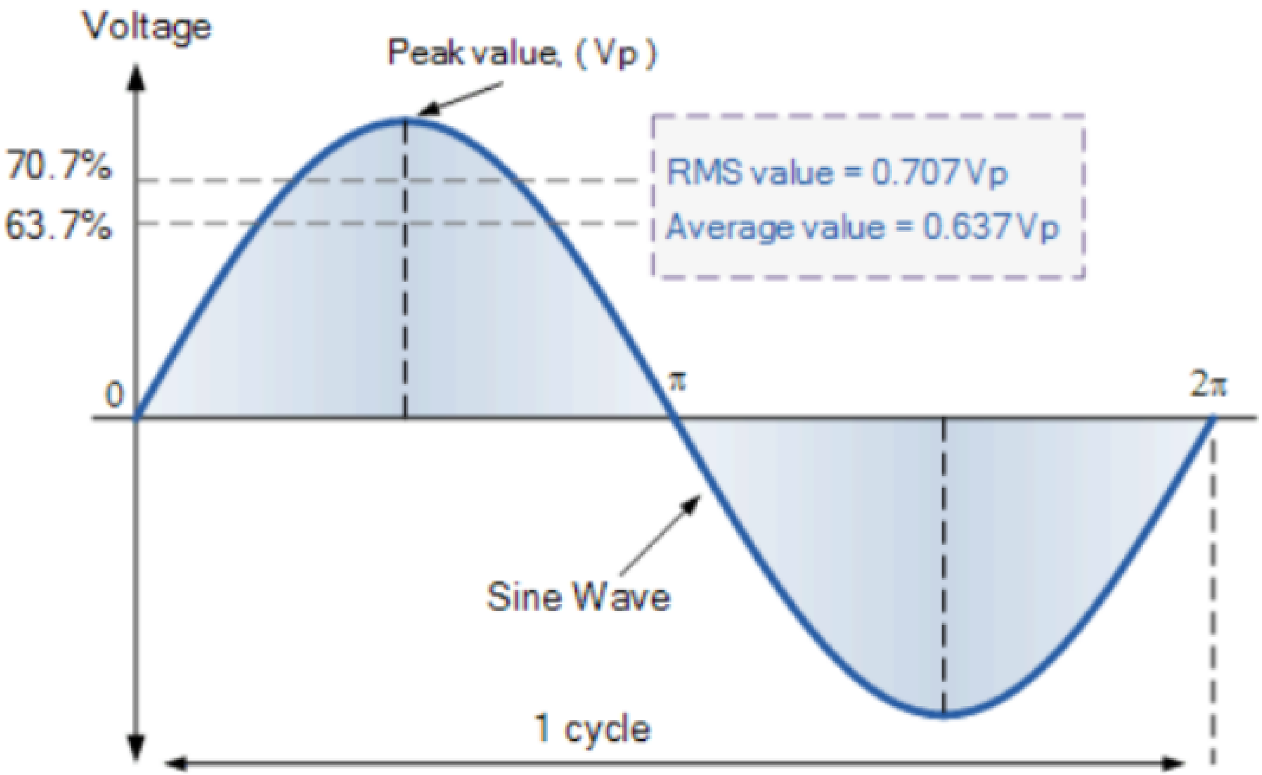
- $V_{avg} = \frac{1}{T}\int_0^T v(t)dt \longrightarrow V_{avg} = \frac{2V_m}{\pi}$

- $V_{rms} = \sqrt{\frac{1}{T}\int_0^T V(t)^2 dt} \longrightarrow V_{rms} = \frac{V_m}{\sqrt{2}}$

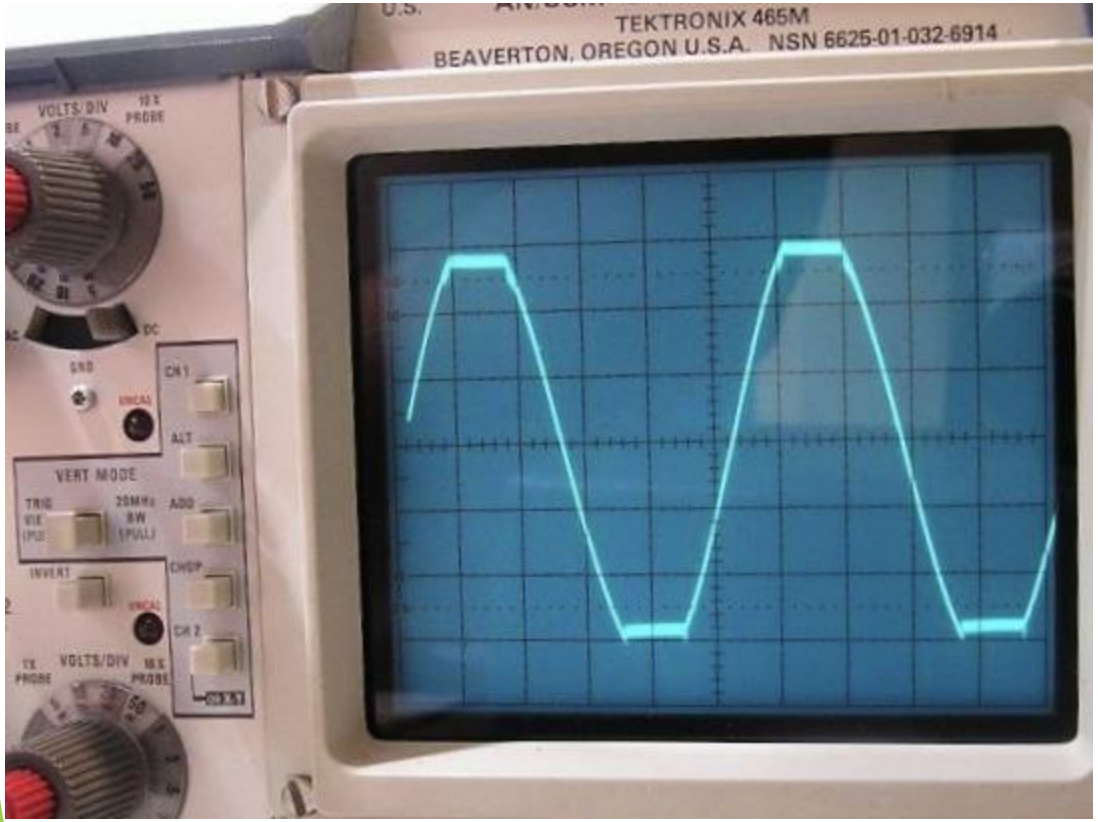
For a pure sinusoidal waveform ONLY, both the average voltage and the RMS voltage (or currents) can be easily calculated as:

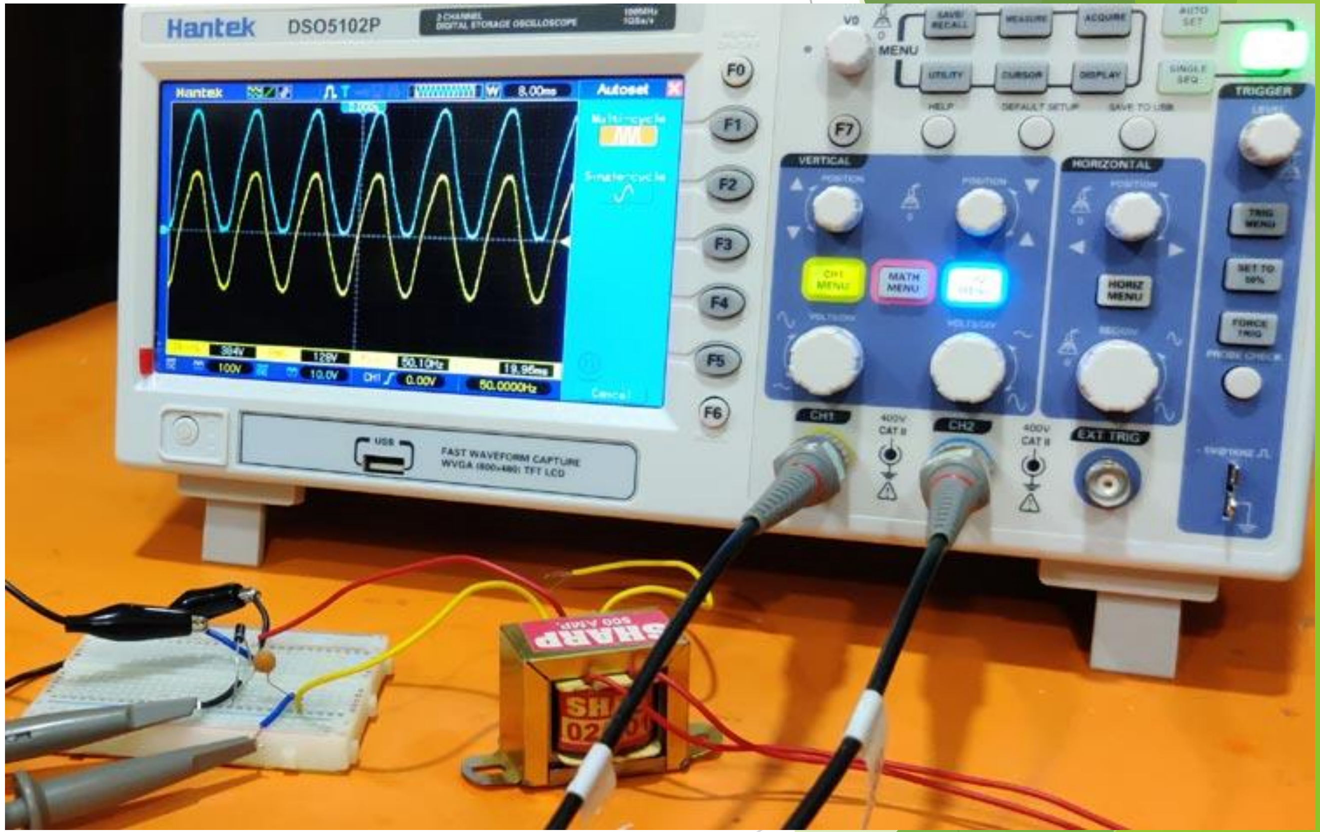
Average value = 0.637 × maximum or peak value, Vpk

RMS value = 0.707 × maximum or peak value, Vpk

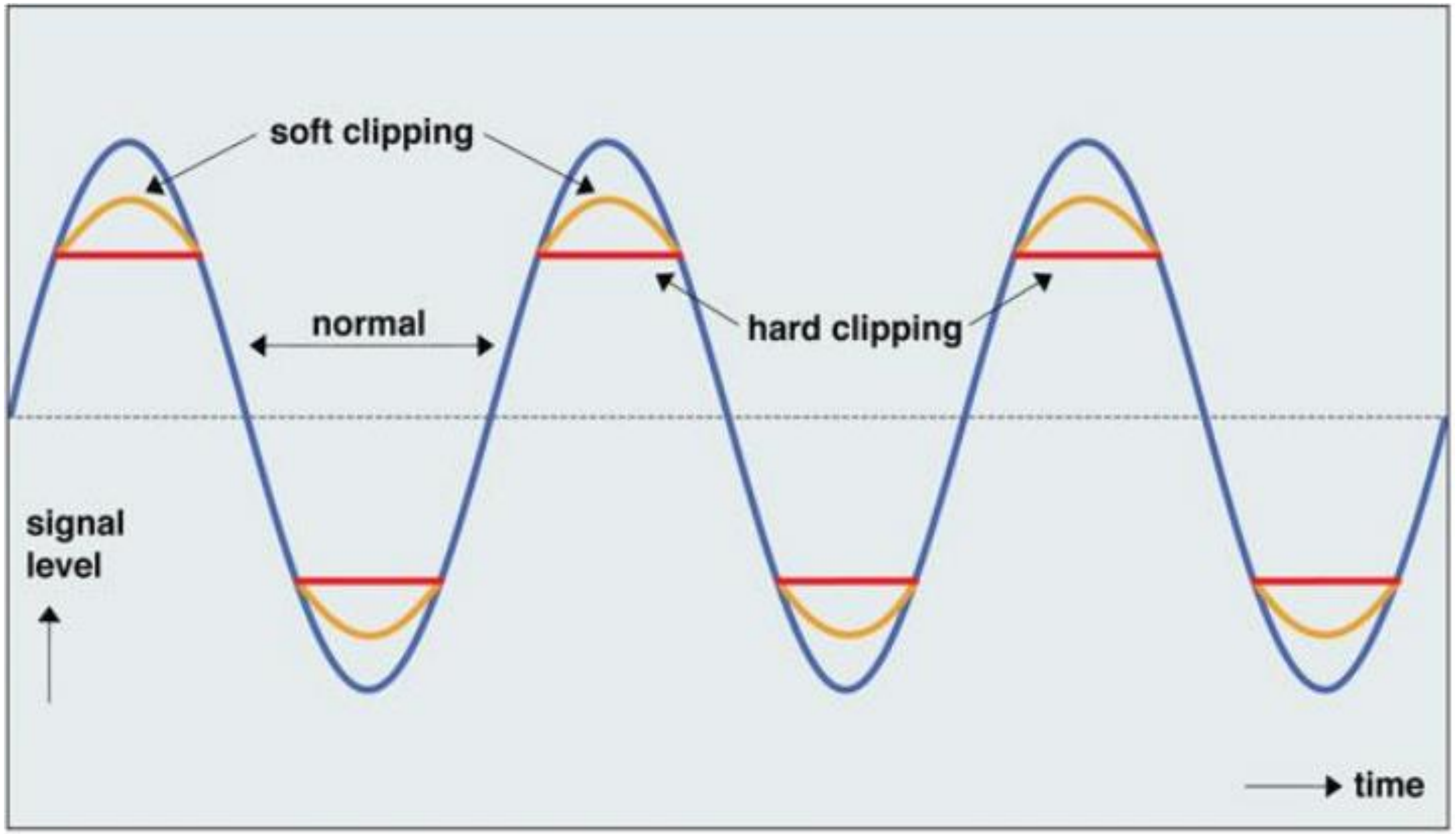


3. Clipping and Clamping

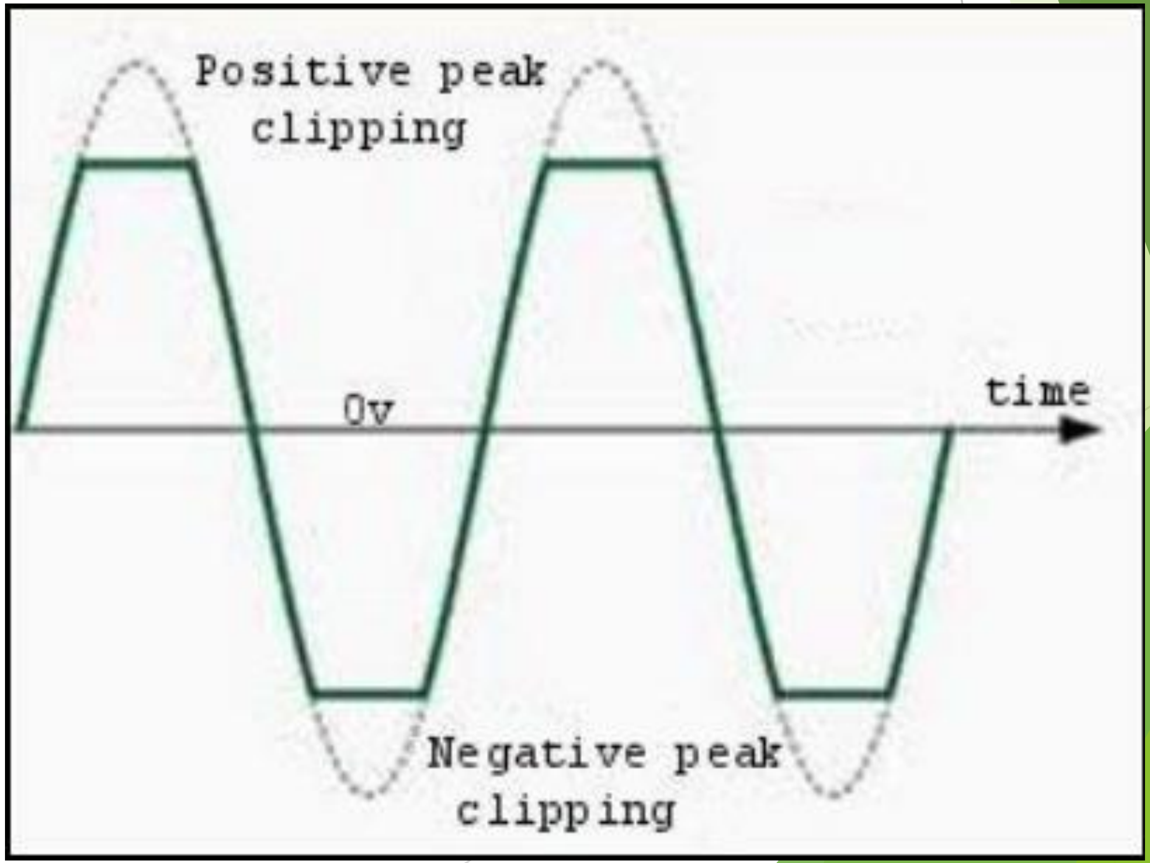




3.1 Clipping



- If the output voltage exceeds a certain level, it limits the tops/ bottoms of a waveform.
- But does not distort the remaining part of the waveform.
- Limit the voltage in circuits

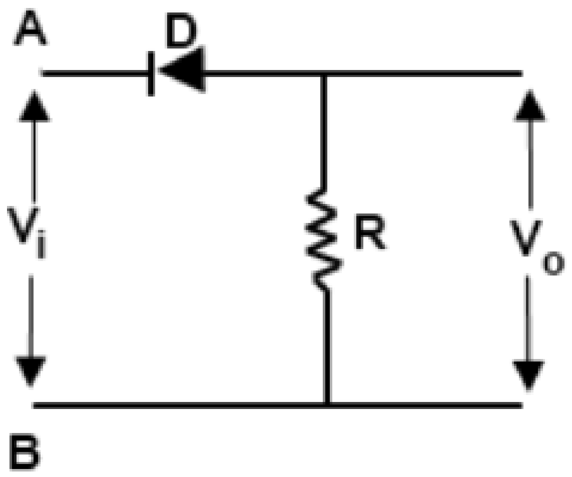


3.1.2 Clipping Circuits

- Series positive
- Series negative
- Shunt or parallel positive
- Shunt or parallel negative
- Clipper Dual (combination) Diode

Series positive Clipper

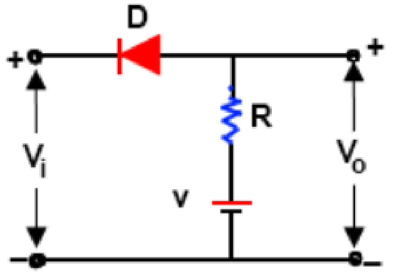
- In a series positive clipper, a diode is connected in series with the output

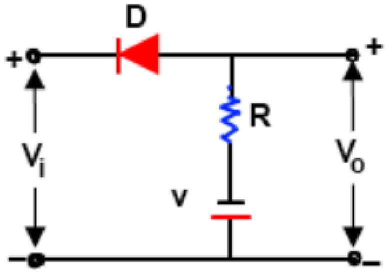


(a) Positive Clipper

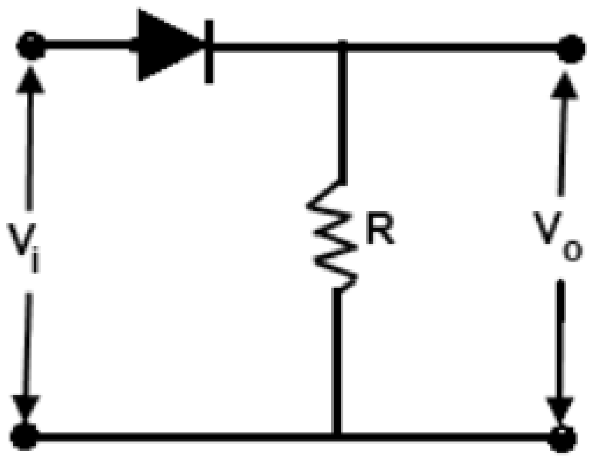
Series-positive Clipper With Bias

- The clipping takes place during the positive cycle only when the input voltage is greater than the battery voltage (i.e. $V_i > V$). The chipping level can be shifted up or down by varying the bias voltage (V)

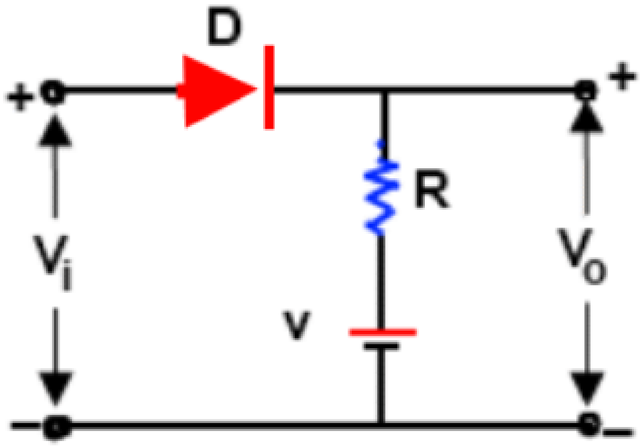


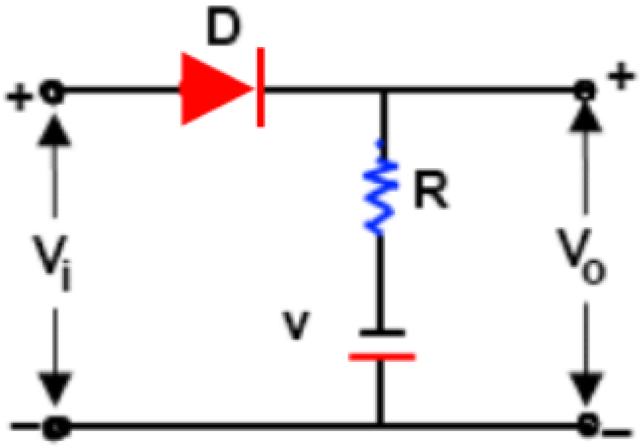


Series Negative Clipper



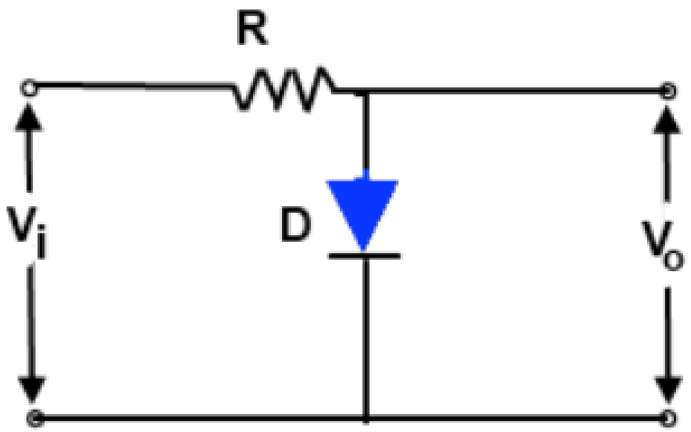
Series-negative Clipper With Bias



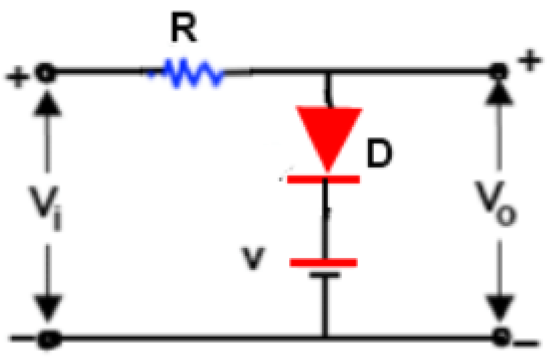


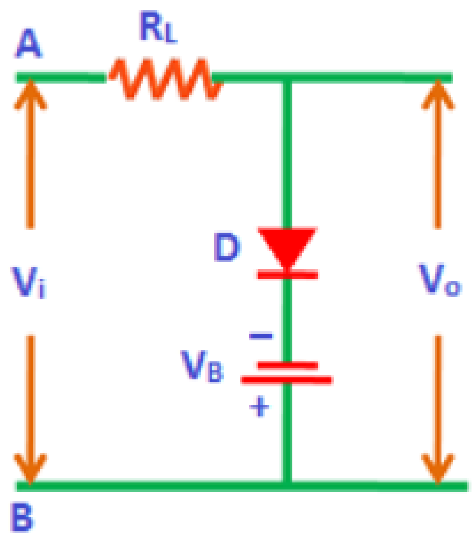
Shunt Or Parallel Positive Clipper

In shunt clipper, the diode is connected in parallel with the output load.

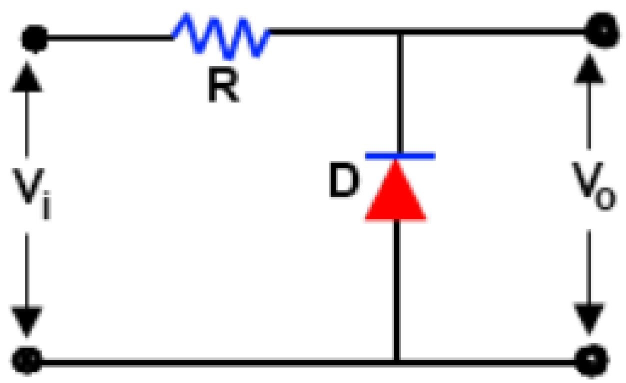


Shunt Or Parallel Positive Clipper With Bias

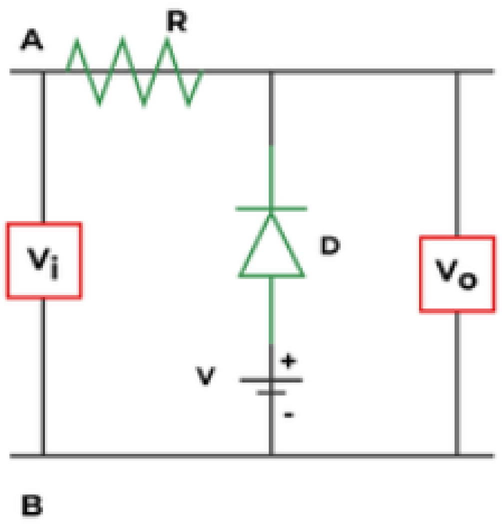


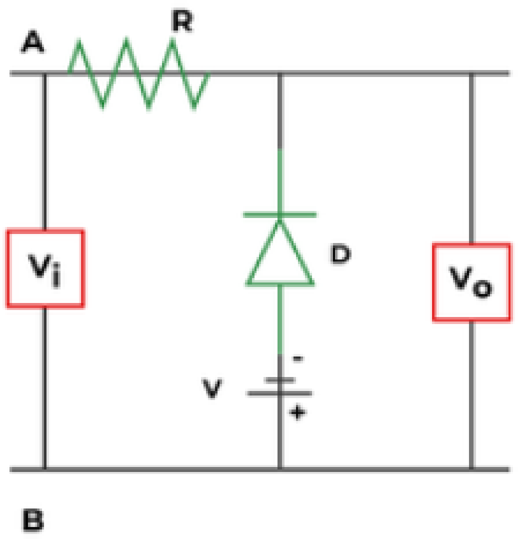


Shunt Or Parallel Negative Clipper

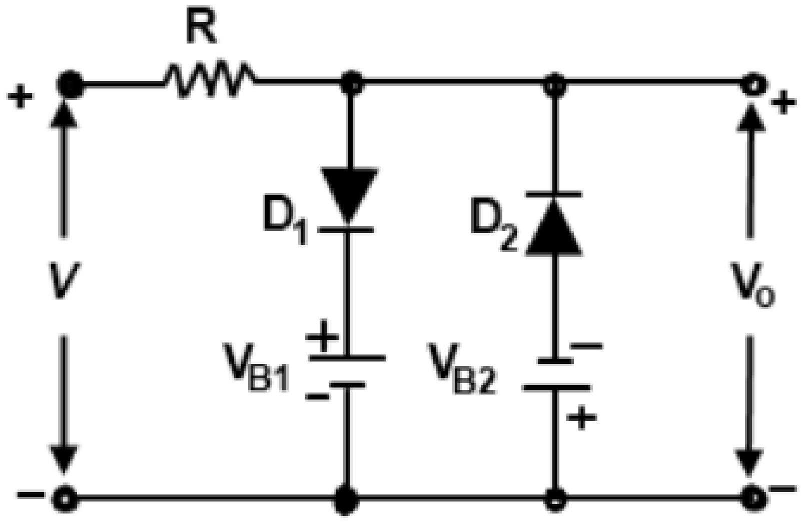


Shunt Or Parallel Negative Clipper With Bias





Dual (Combination) Diode Clipper



EE3301 Analog Electronics

DC power Supplies and Regulation Circuits

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4. Filtering and Regulation

- Device/process to remove unwanted components/features from a signal.
- Removes the ripples from the rectified output
- Most common: c-filter (capacitor) – allows AC and blocks DC
  - Charge: when input voltage is higher than Vc
  - Discharge: when input voltage is lower than Vc

Ripple Factor

- A measure of the purity of the DC output
- Want it to be as small as possible

$$r = \frac{\textit{rms of AC component of output}}{\textit{Avg value of output}}$$

$$r = \frac{V_{ACrms}}{V_{DC}}$$

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

Can also be given as $r = \frac{I_{AC}}{I_{DC}}$

Ripple Factor of Half Wave Rectifier

- **HWR**

$$r = \sqrt{\left(\frac{V_m/2}{V_m/\pi}\right)^2 - 1}$$

$$r = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1}$$

$$r = 1.211$$

Percentage Ripple = 121.1%

Ripple Factor of Full Wave Rectifier

- FWR

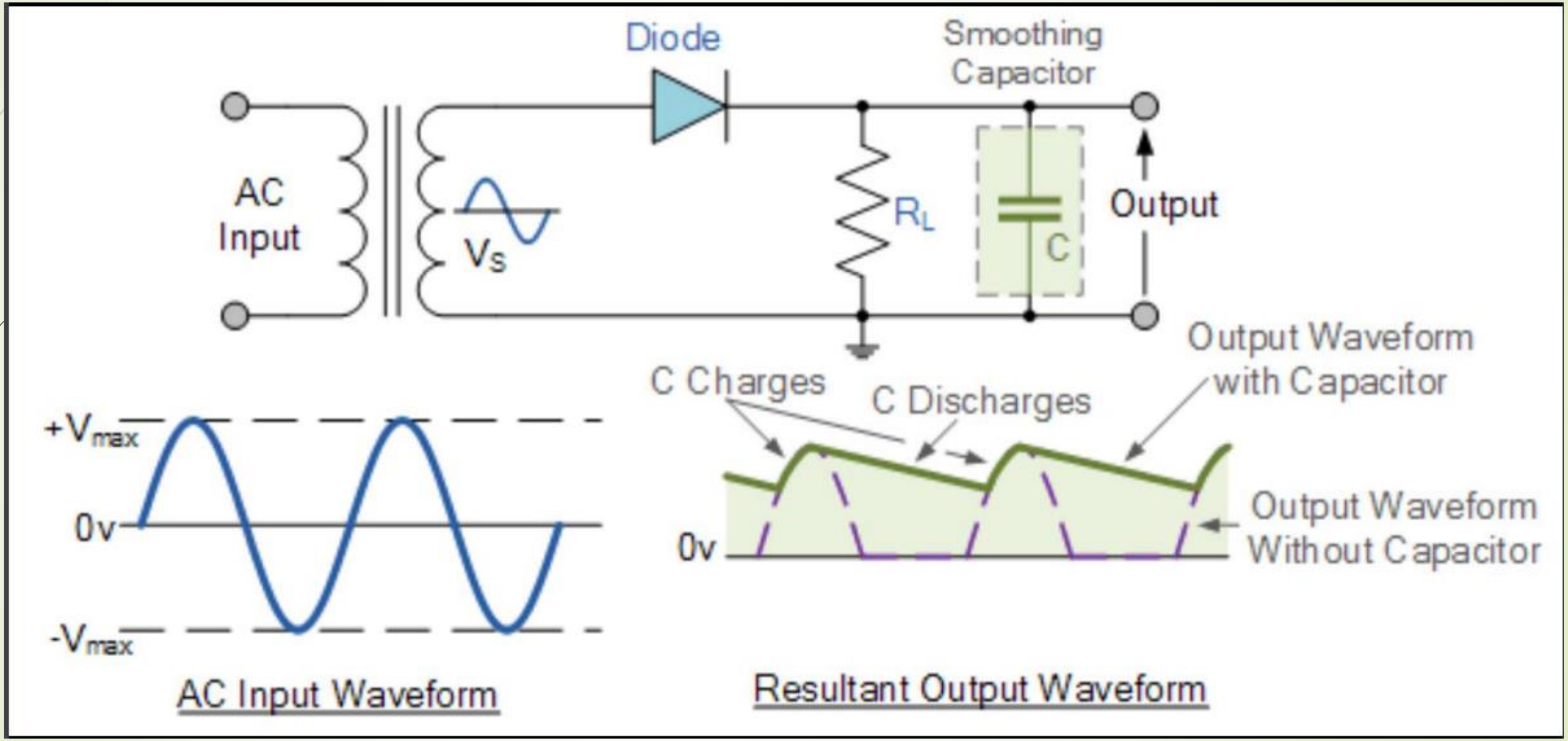
$$r = \sqrt{\left(\frac{V_m/\sqrt{2}}{2V_m/\pi}\right)^2 - 1}$$

$$r = \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1}$$

$$r = 0.483$$

- Percentage Ripple = 48.3%

HWR with Smoothing Capacitor



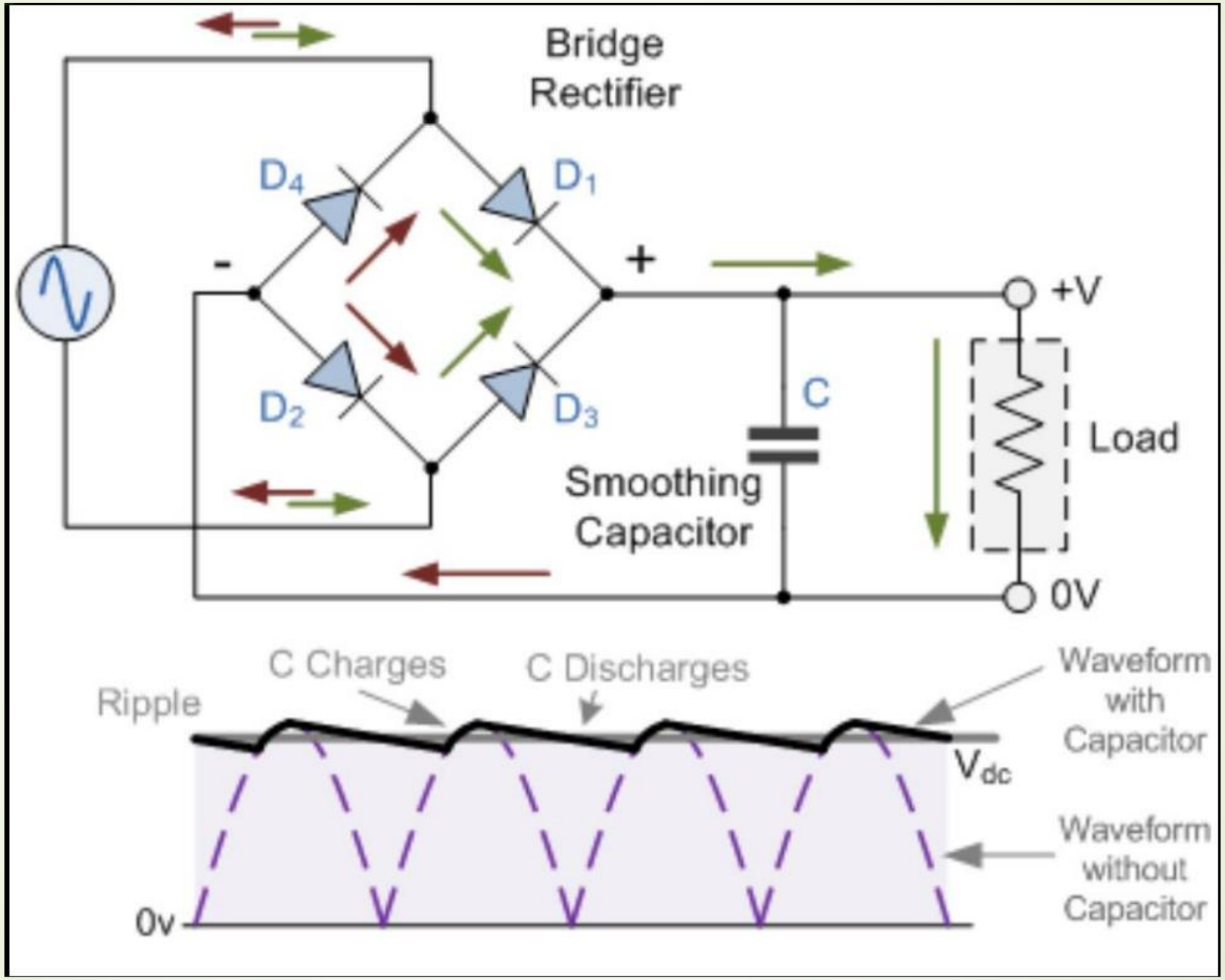
Rectifiers with RC filters

Assumptions

- Ripple voltage is small as compared to the dc component
- Capacitor voltage does not decay significantly from its peak value between the rectified pulses that recharge the capacitor
- Saw tooth waveform (Vpp)
  - Capacitor charges instantly
  - Voltage decays linearly

Note:
Circuit Design: f and R fixed. Select C such that ripple is minimized

FWR with Smoothing Capacitor



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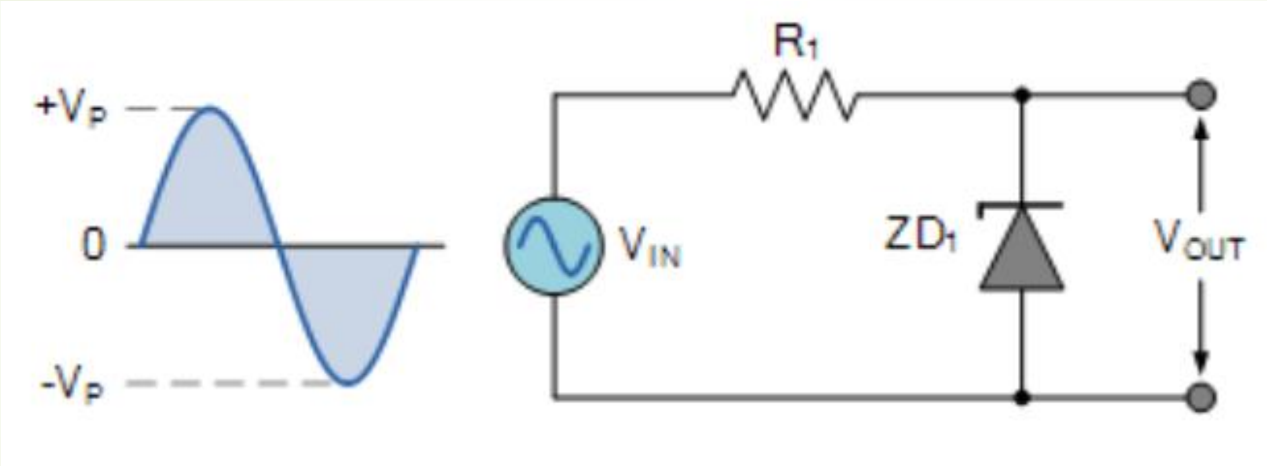
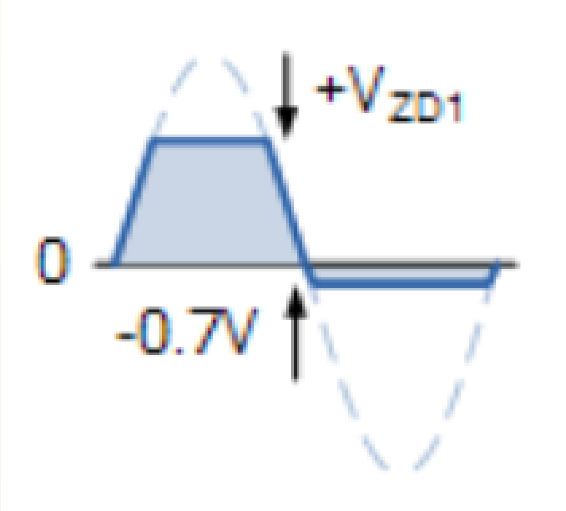
Zener Diode Clipping

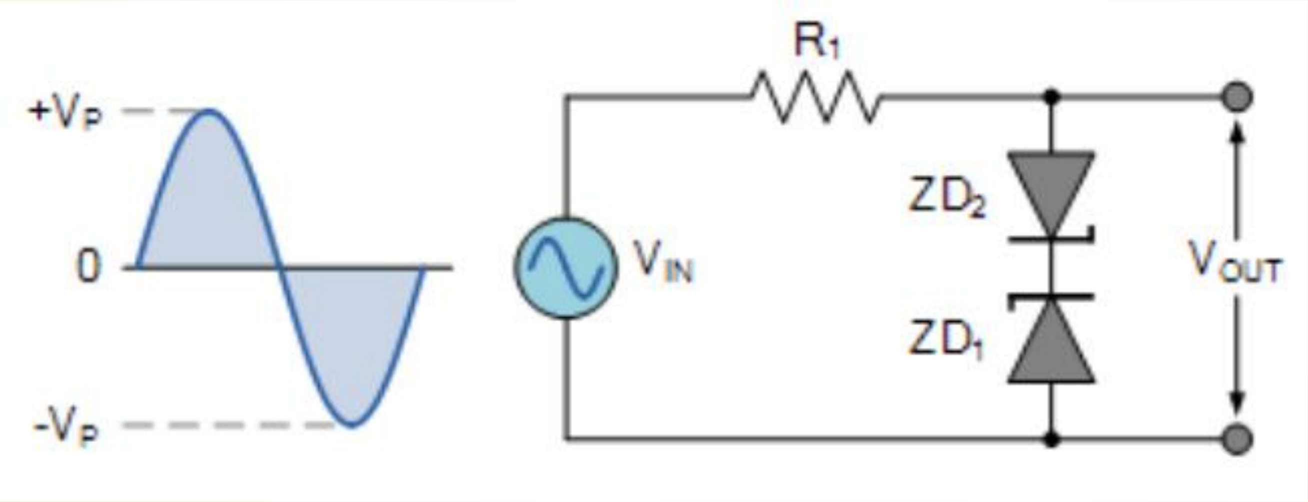
The Zener diode acts like a biased diode clipping circuit with the bias voltage being equal to the Zener breakdown voltage.

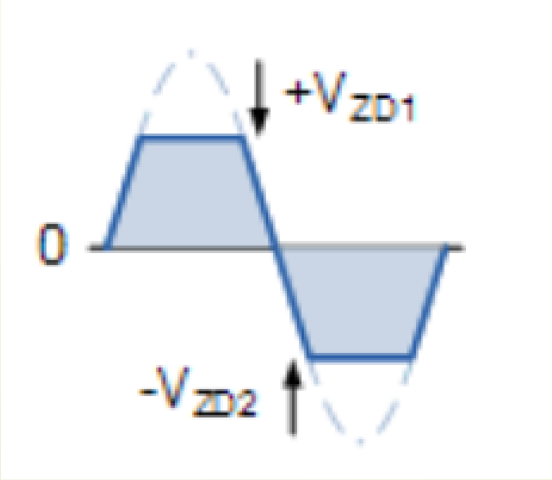




Full-wave Zener Diode Clipping

The output waveform will be clipped at the Zener voltage plus the 0.7V forward volt drop of the other diode.





Clamping

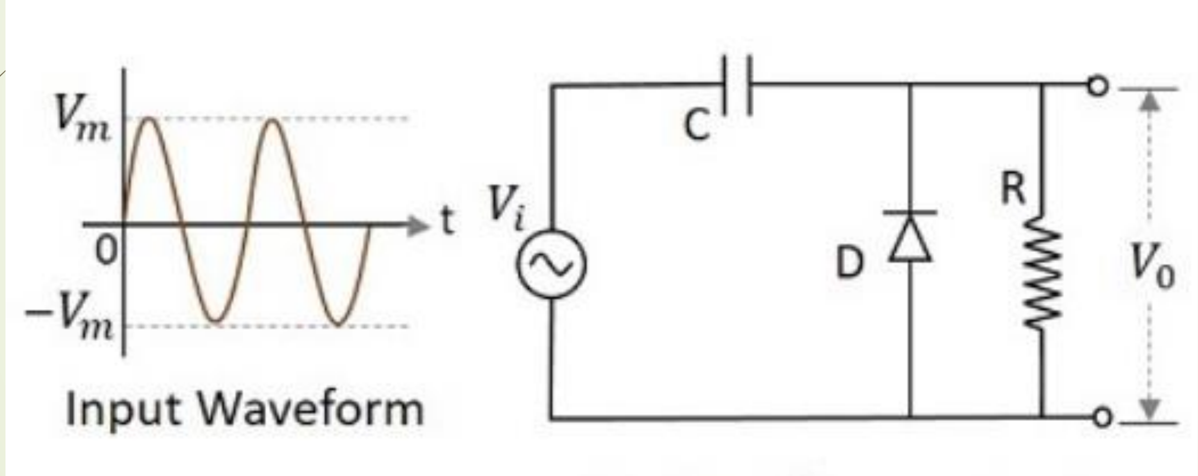
- Clamping circuits are used to shift an AC waveform up or down by adding a DC level equal to the positive or negative peak value of AC input.

Types of Clampers

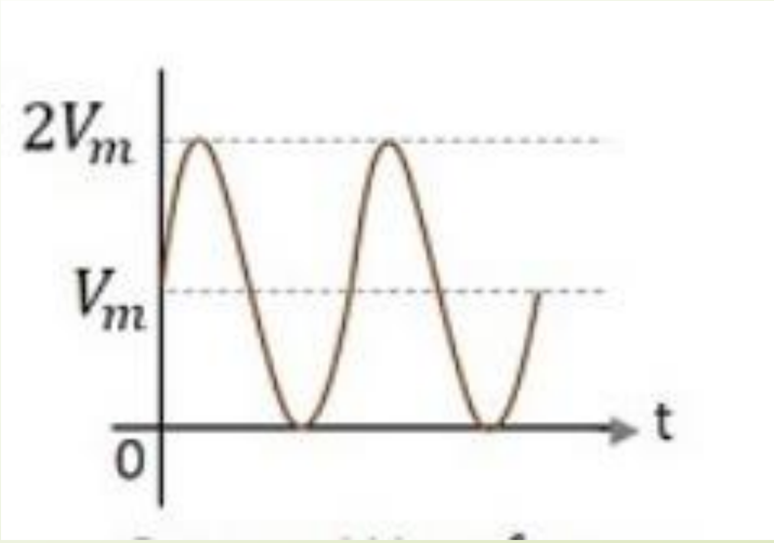
1. Positive Clamper
2. Positive clamper with positive Vr
3. Positive clamper with negative Vr
4. Negative Clamper
5. Negative clamper with positive Vr
6. Negative clamper with negative Vr

1. Positive Clamper Circuit

- A Clamping circuit restores the DC level. When a negative peak of the signal is raised above to the zero level, then the signal is said to be **positively clamped**.

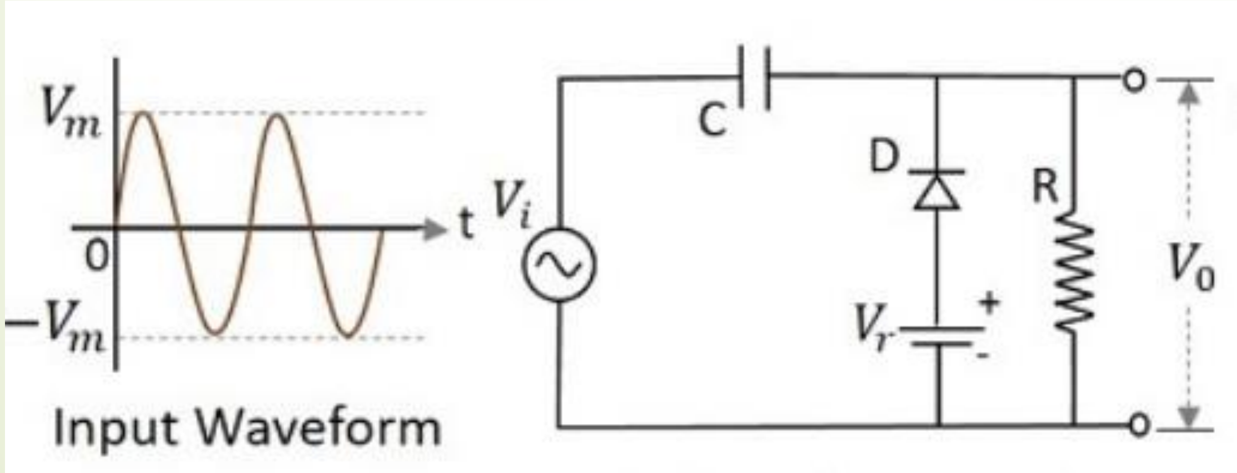


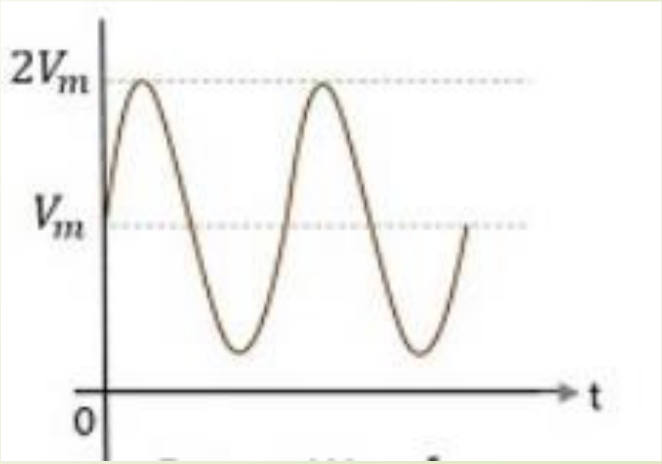
$$V_0=V_i+V_m$$



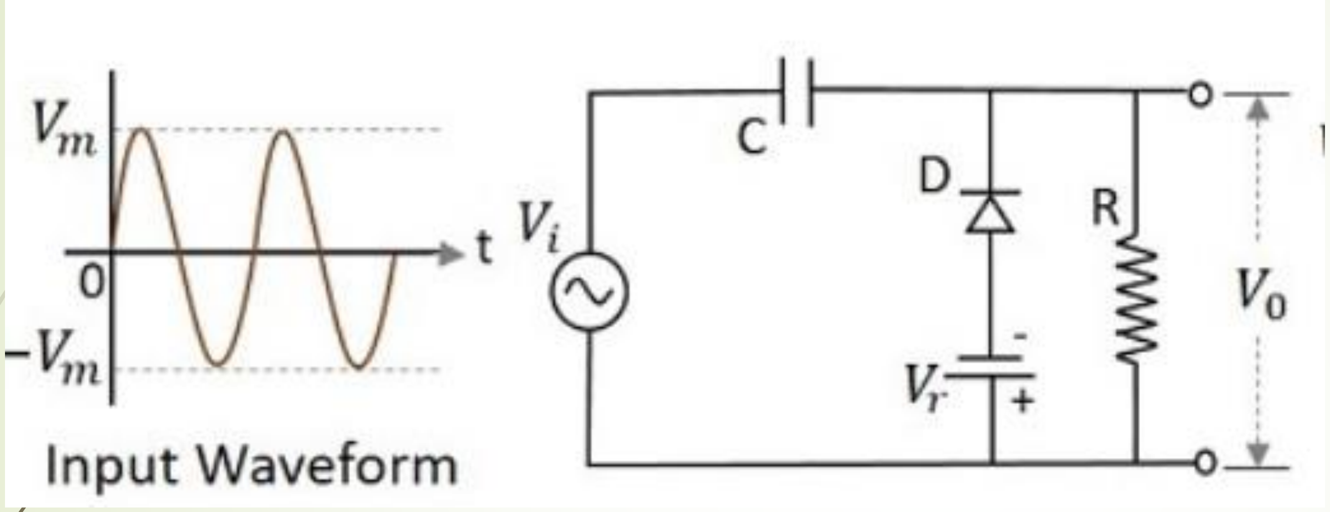
2. Positive Clamper with Positive V_r

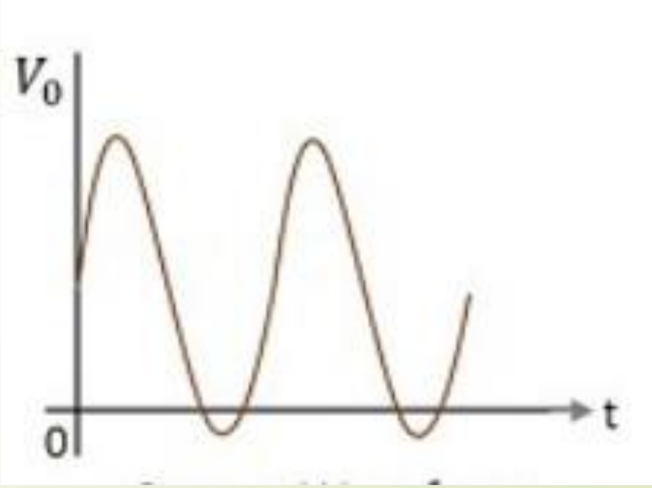
- When a Positive clamper circuit is provided with a positive reference voltage and biased accordingly, the circuit incorporates this voltage into its output, elevating the clamped level in the process.





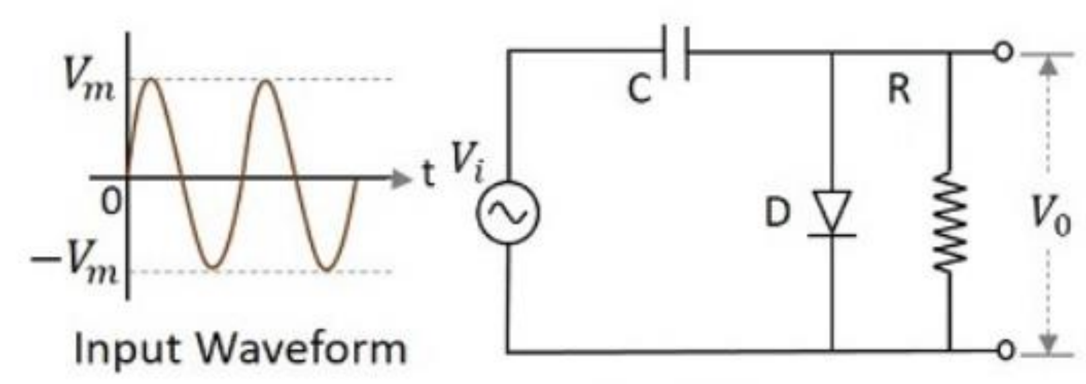
3. Positive Clamper with Negative Vr

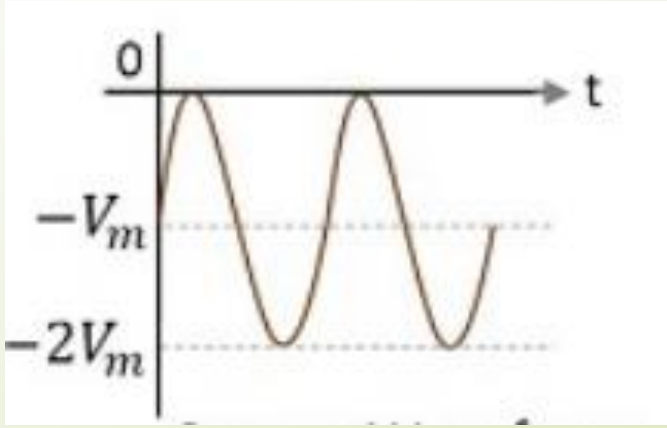




4. Negative Clamper

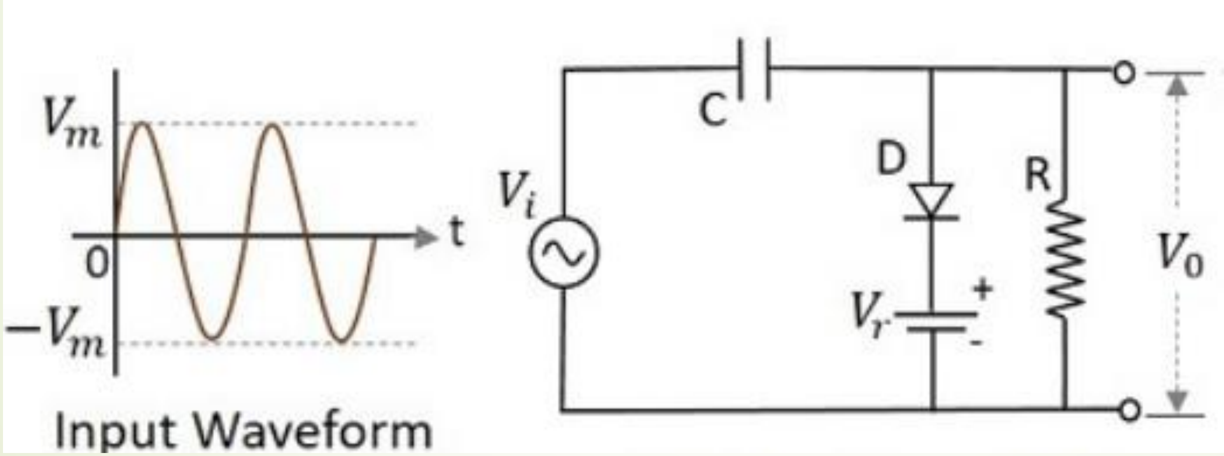
- A Negative Clamper circuit is one that consists of a diode, a resistor, and a capacitor and that shifts the output signal to the negative portion of the input signal.

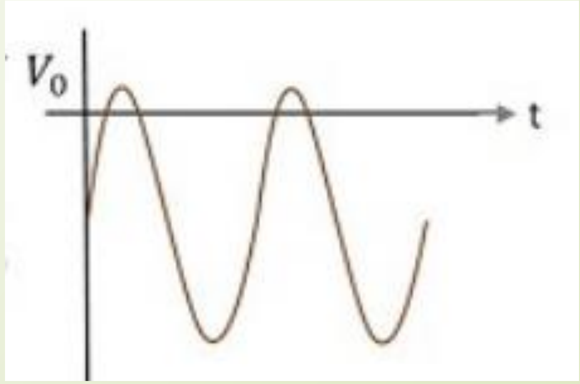




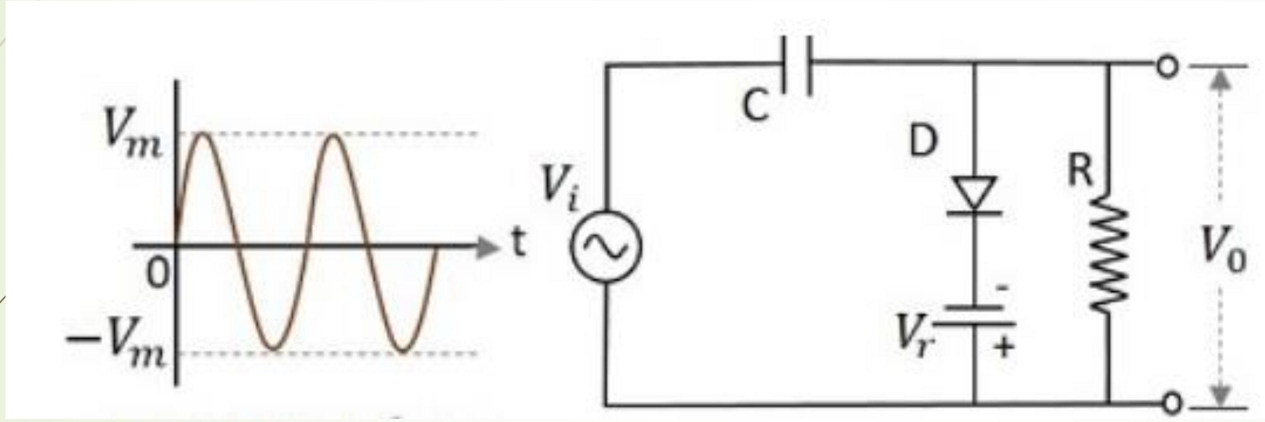
5. Negative clamper with positive V_r

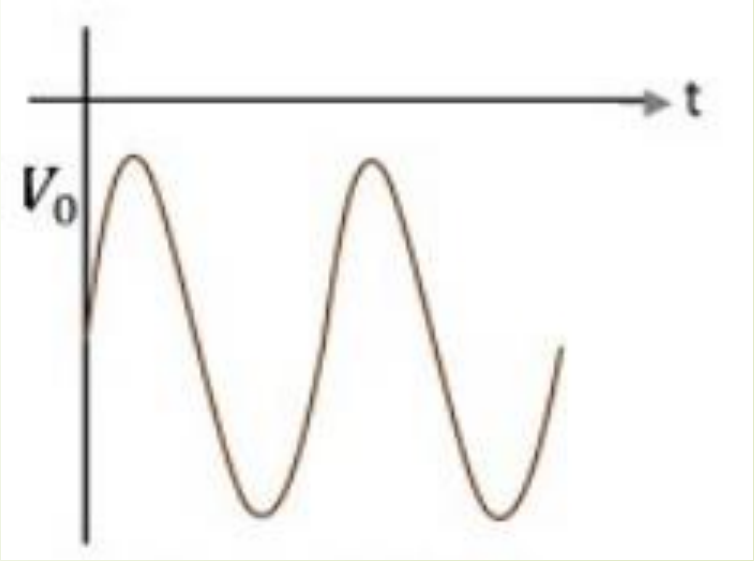
- A Negative clamper circuit if biased with some positive reference voltage, that voltage will be added to the output to raise the clamped level.





6. Negative Clamper with Negative V_r





EE/EC 3301
ANALOG ELECTRONICS

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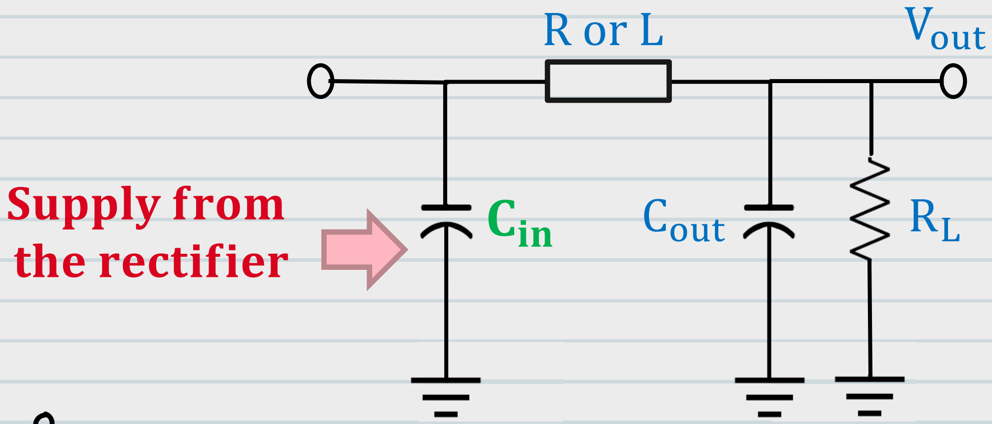
π Filter

Consists of a **shunt capacitor** at the input side, and it is followed by an L-section filter.

The capacitor is present at the input side. Called as ***capacitor input filter***.



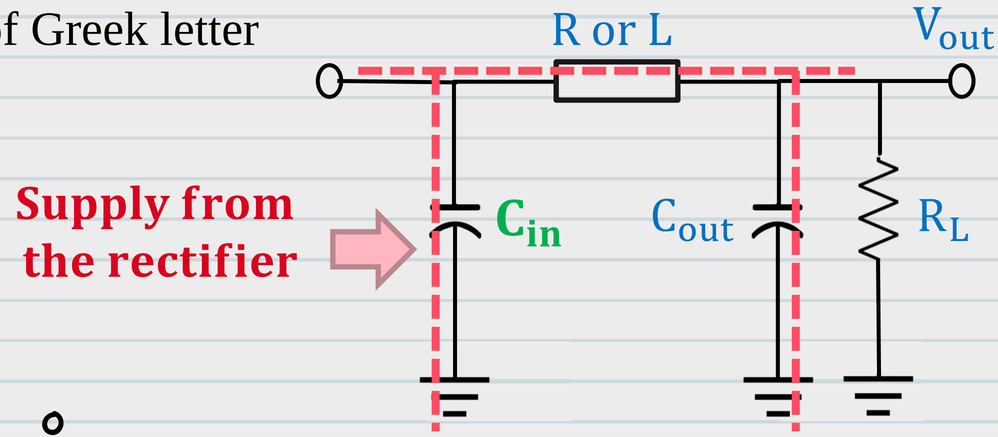
Pi Filter

π Filter

Consists of a **shunt capacitor** at the input side, and it is followed by an L-section filter.

The capacitor is present at the input side. Called as ***capacitor input filter***.

The construction arrangement of all the components resembles the shape of Greek letter ***Pi (π)***. Called as ***Pi filter***.



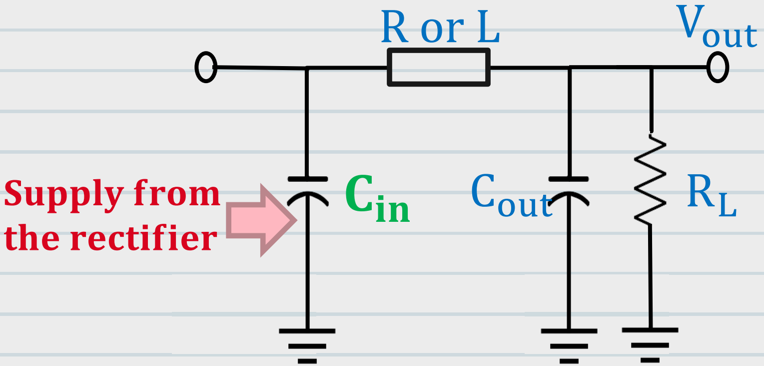
Pi Filter

The output from the rectifier is directly given across capacitor.

The pulsating DC output voltage is filtered first by the capacitor connected at the input side and then by resistor or coil and then by another shunt capacitor.

C_{in} – Low reactance to the AC component
and high (infinite) resistance to the DC component.
(by passes AC comp to the GND, provides
DC comp to the R or L.)

C_{out} – Bypasses AC comp to the GND,
provides DC comp across the R_L.

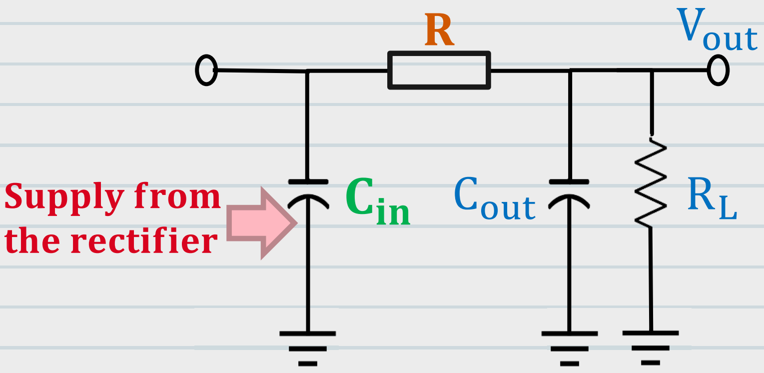


Pi Filter

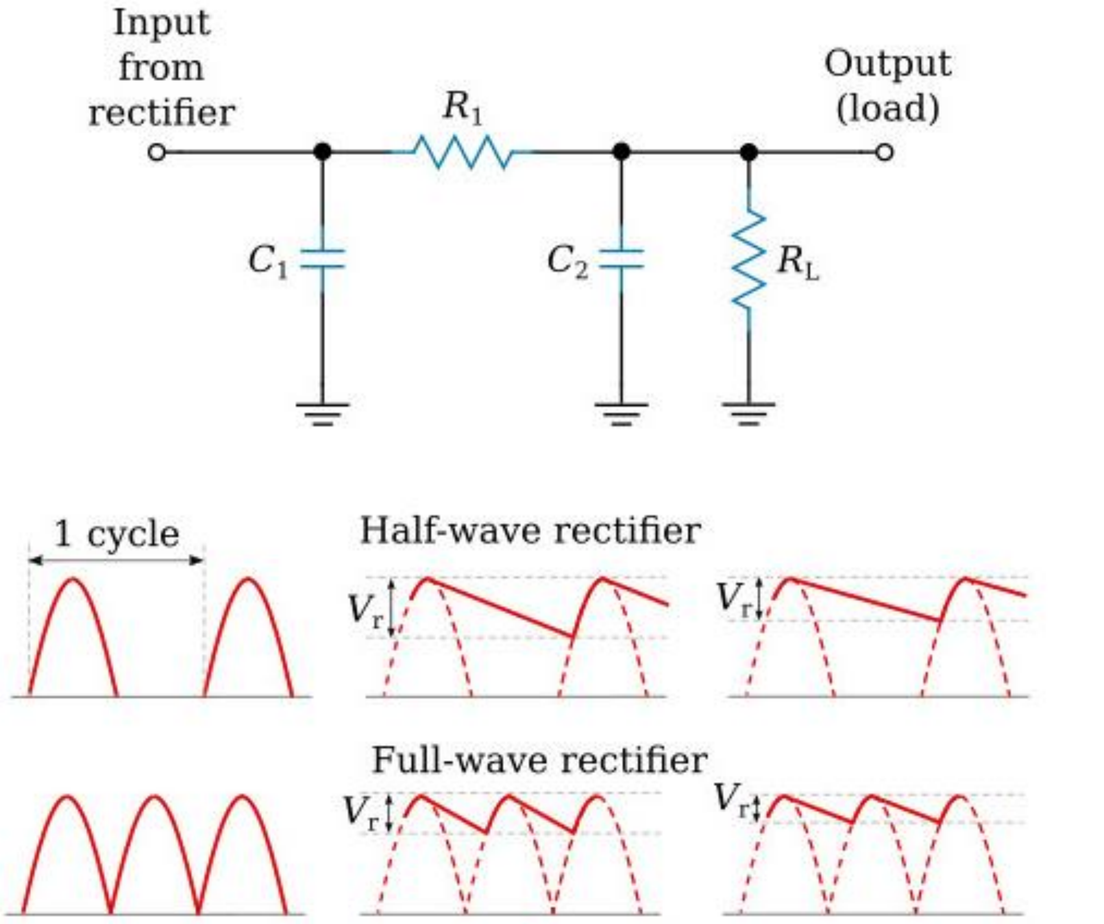
Rectifier with RC – π Filter

Low pass RC filter section added to get greater reduction in ripple.

The capacitor – resistor – capacitor combination is called as ***RC – π filter***.



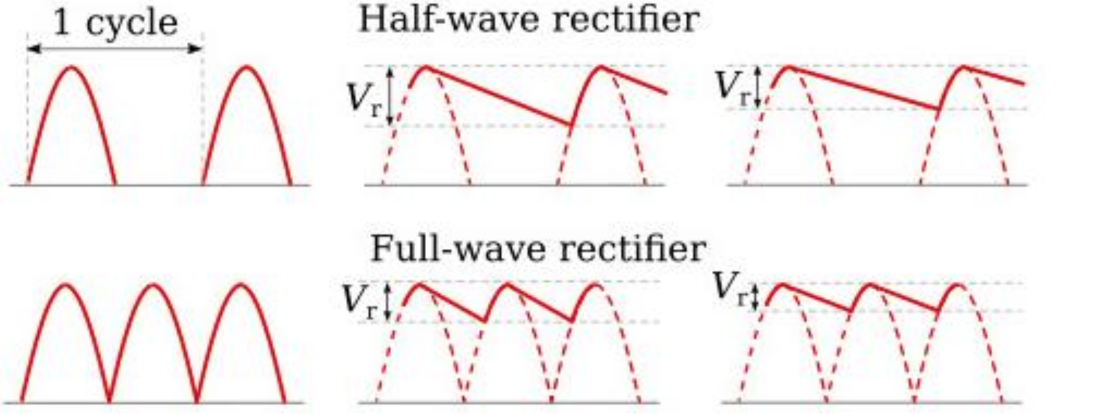
RC – Pi Filter



(A) Unfiltered output from rectifier (B) Voltage across capacitor C_1 (C) Voltage across capacitor C_2

C_1 is used to reduce the percentage of ripple to a relatively low value (view B). This voltage is passed on to the $R_1 - C_2$ network, which reduces the ripple even further.

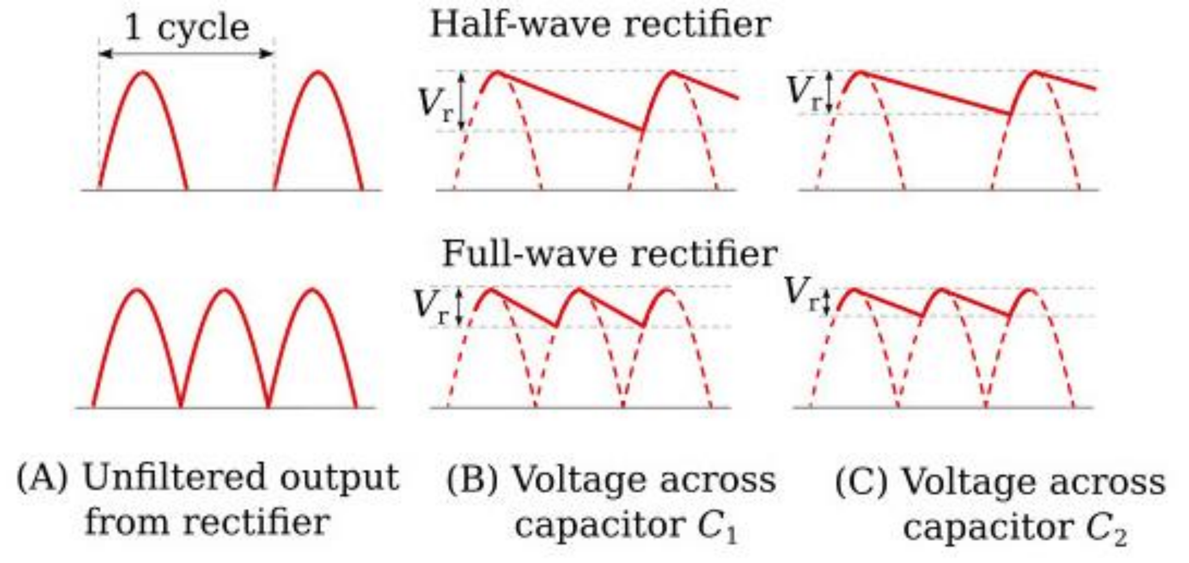
C_2 offers an infinite impedance to the DC component of the output voltage. Thus, the DC voltage is passed to the load.



(A) Unfiltered output from rectifier (B) Voltage across capacitor C_1 (C) Voltage across capacitor C_2

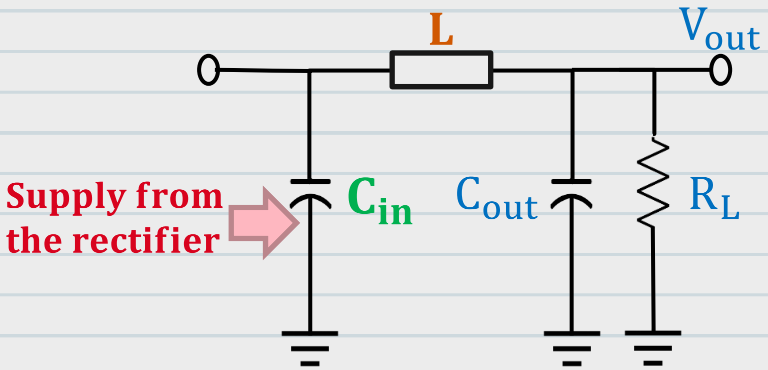
∴ Most of the ripple voltage is dropped across R_1. Only a trace of the ripple voltage can be seen across C_2 and the R_L (view C).

The RC filter is extremely popular because smaller capacitors can be used with good results.

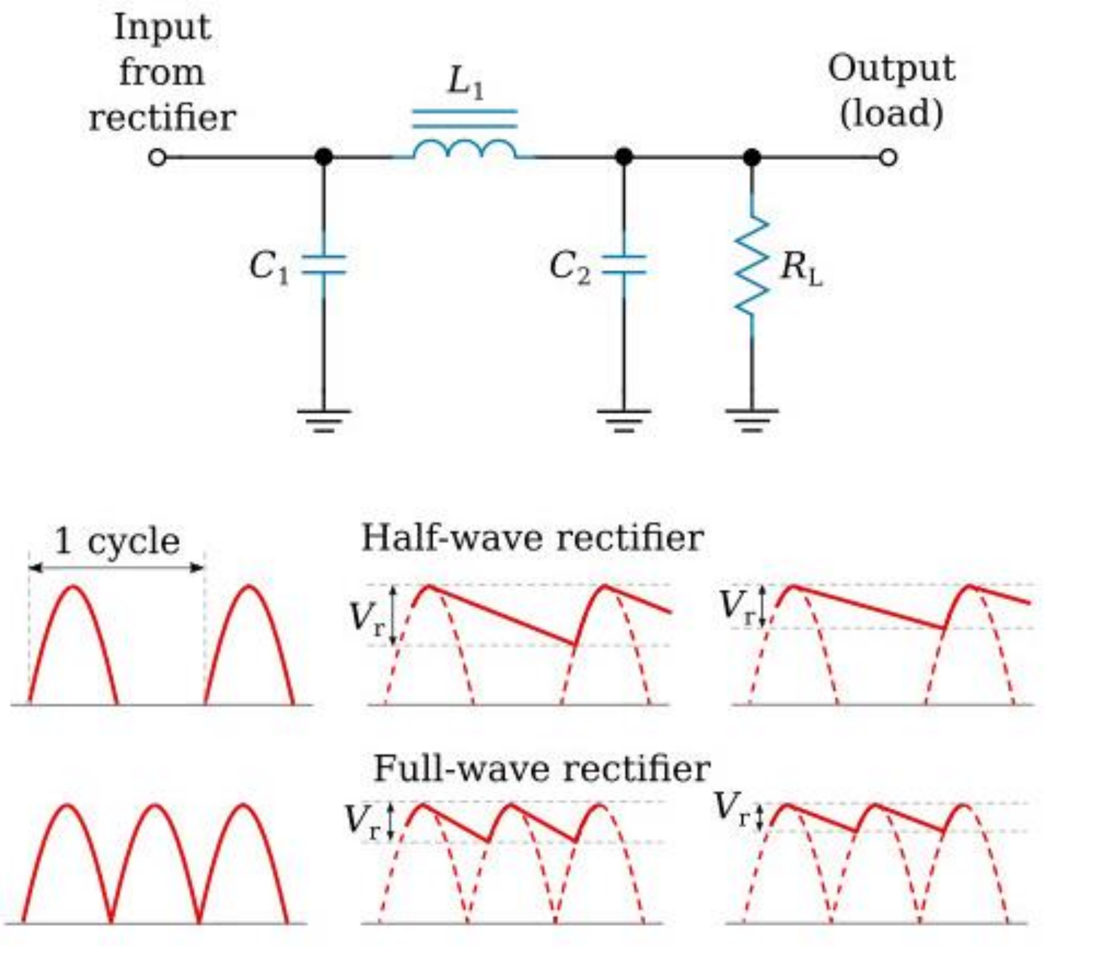


Rectifier with LC – π Filter

R replaced by an *L* (***Inductor***) and one of the most commonly used filters.



LC – Pi Filter



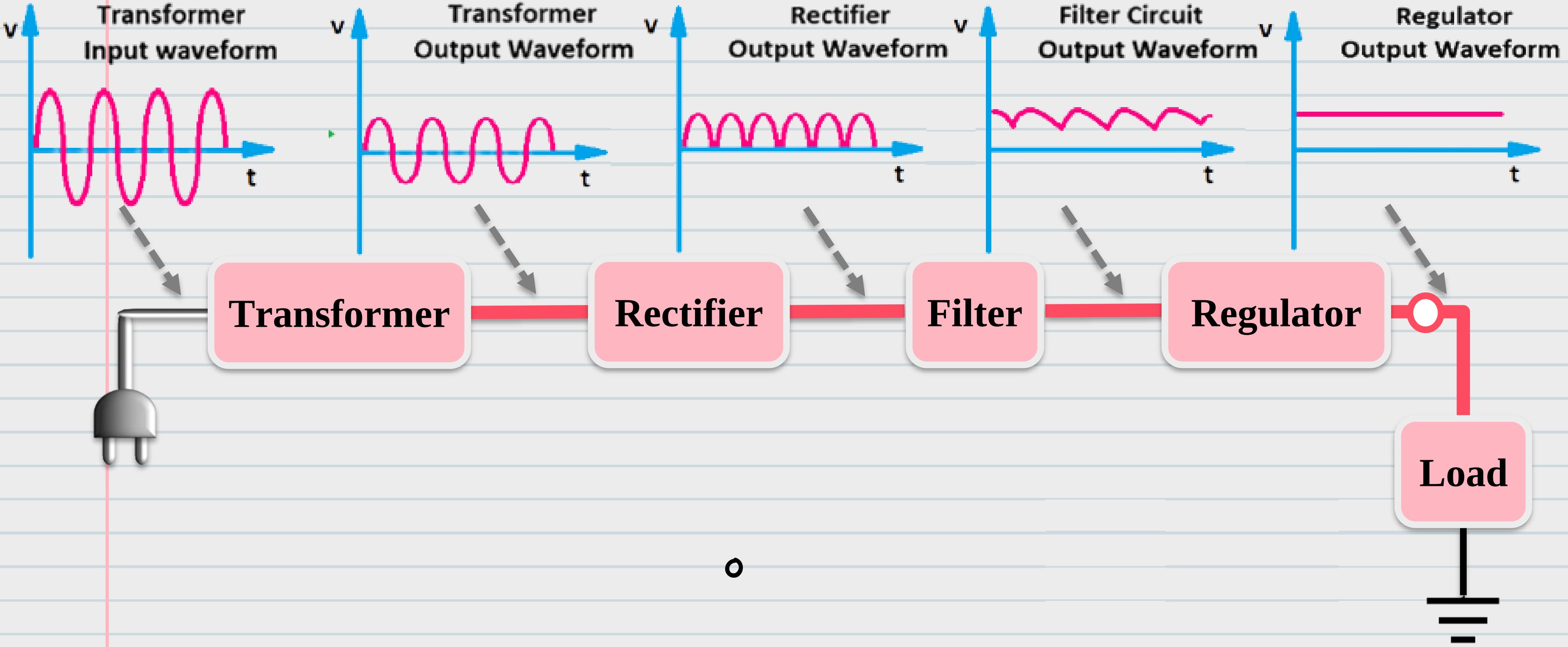
(A) Unfiltered output from rectifier

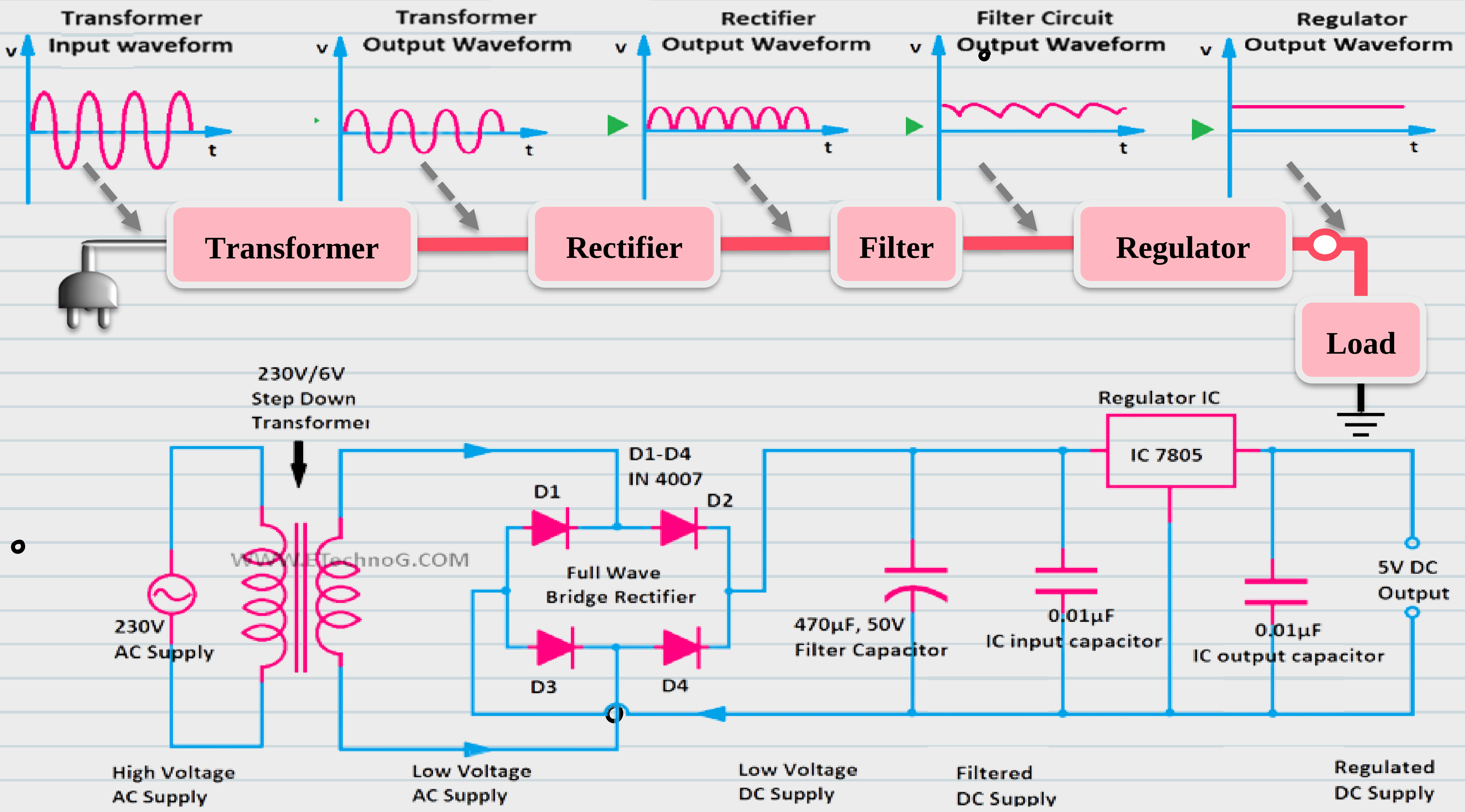
(B) Voltage across capacitor C_1

(C) Voltage across capacitor C_2

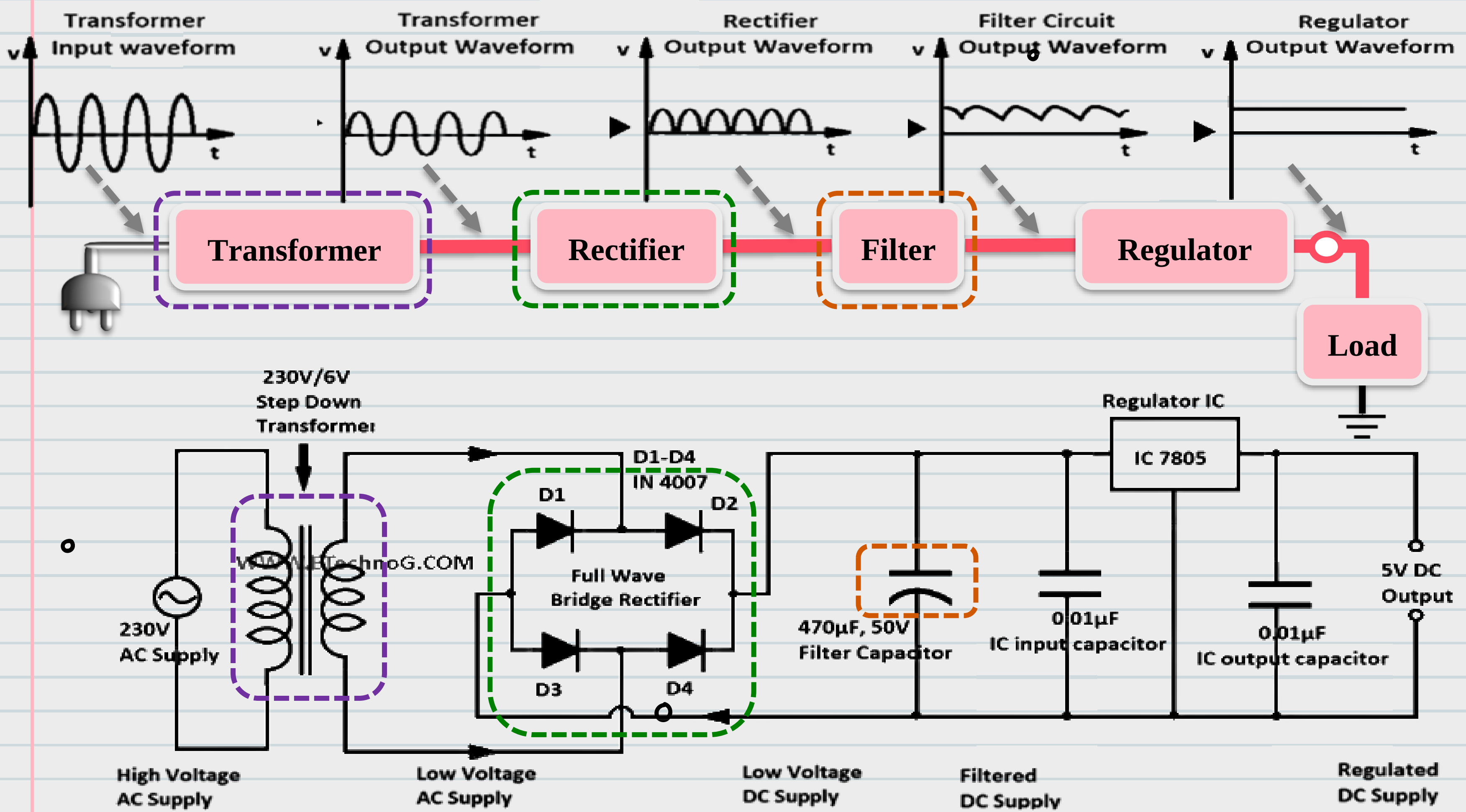
DC Power Supplies and Regulation

DC Power Supply





Transformer Input waveform
Transformer Output Waveform
Rectifier Output Waveform
Filter Circuit Output Waveform
Regulator Output Waveform
v
t
Transformer
Rectifier
Filter
Regulator
Load
230V/6V Step Down Transformer
D1-D4 IN 4007
D1
D2
D3
D4
Full Wave Bridge Rectifier
WWW.ETechnoG.COM
230V AC Supply
Regulator IC
IC 7805
470µF, 50V Filter Capacitor
0.01µF IC input capacitor
0.01µF IC output capacitor
5V DC Output
High Voltage AC Supply
Low Voltage AC Supply
Low Voltage DC Supply
Filtered DC Supply
Regulated DC Supply



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Low Voltage DC Supply
Filtered DC Supply
Regulated DC Supply

Regulation

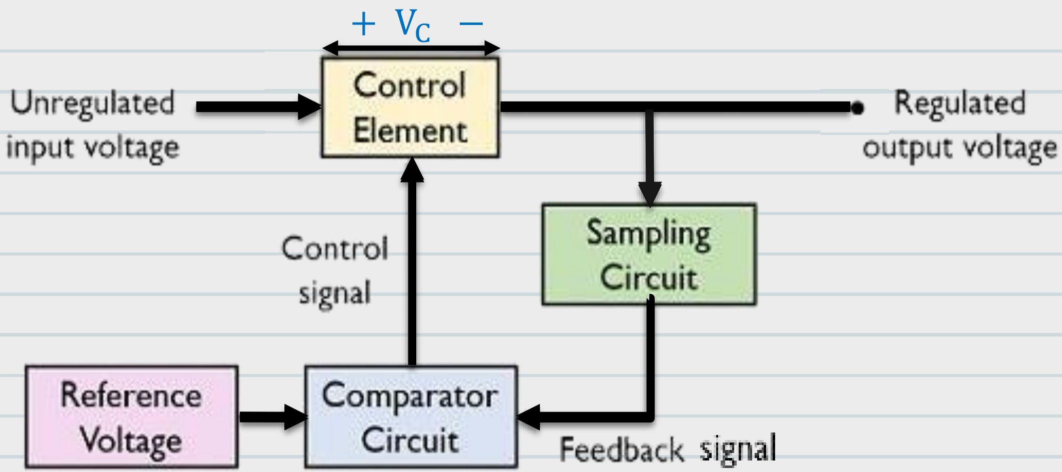
The last and most important block of the regulated power supply.

Ensures a steady constant voltage supply through all operational conditions. (Maintain/ regulate/ stabilize output voltage during the variations in loads.)

Voltage fluctuations damage to electrical machinery.

Disturbances such as power sags and surges affect sensitive electronics devices.

The regulator circuit uses different types of regulating components and devices such as a Series inductor, Zener Diode, IC 78XX series, IC 317, etc.



The unregulated dc voltage is the input to the circuit.

Control element controls the amount of input voltage that is going to the output side.

Sampling circuit provides the necessary feedback signal.

Comparator circuit compares the feedback signal with the reference voltage to generate the appropriate control signal.

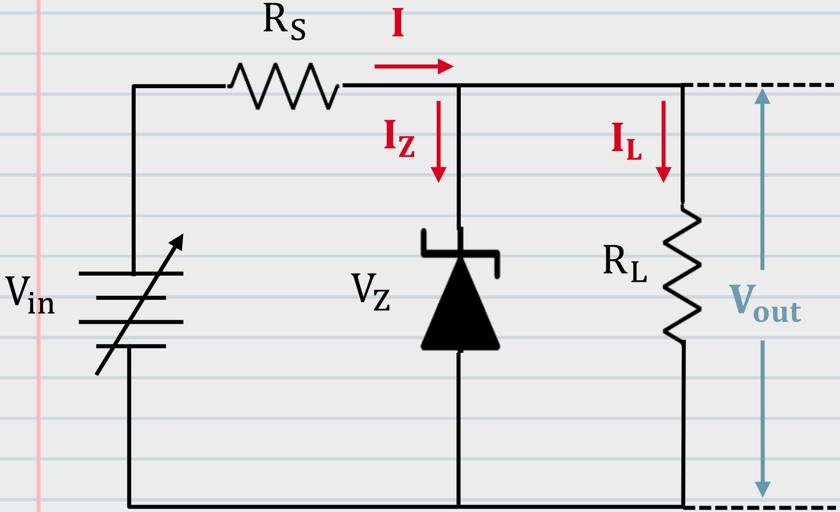
Thus depending upon the value of control signal, the voltage ***Vc,*** across the control element is adjusted in order to maintain the output voltage constant.

Used for both fixed as well as variable load conditions.

Two types of Regulation:

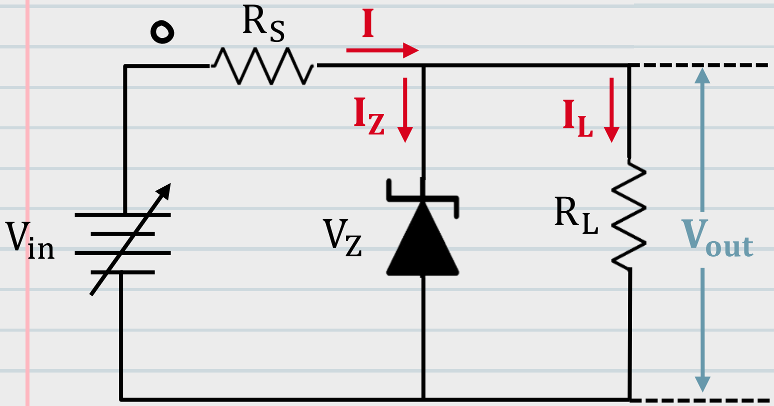
1. Line Regulation
2. Load Regulation

1. Line Regulation



$$\boxed{V_O = V_Z = \text{Constant}}$$

Series resistance, R_S and load resistance, R_L are fixed.
Input voltage, V_{in} is changing.
Output voltage, V_{out} remains the same as long as the input voltage is maintained above a ***minimum value***.



Considering the voltage across the R_S,

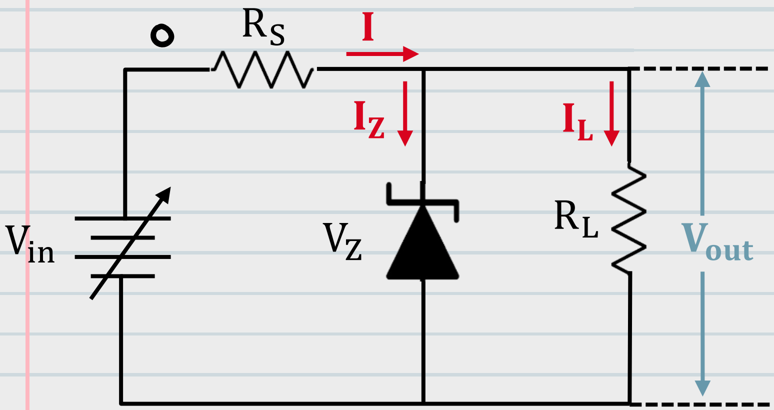
$$V_{Rs} = I\,R_S \longrightarrow (1)$$

$$V_{Rs} = \{V_{in}\} - [V_{out}] \longrightarrow \{V_{in}\}\ \alpha\ \{\{V_{Rs}\}\}$$

$$(1) \longrightarrow \{V_{Rs}\} = I\,[R_S] \longrightarrow \{V_{Rs}\}\ \alpha \{\{I\}\}$$

$$\{V_{in}\}\ \alpha\ \{V_{Rs}\}\ \alpha\ \{\{I\}\} \longrightarrow \boxed{\{V_{in}\}\ \alpha\ \{\{I\}\}}$$

V_{in}: Varying $\longrightarrow$ I : Varying

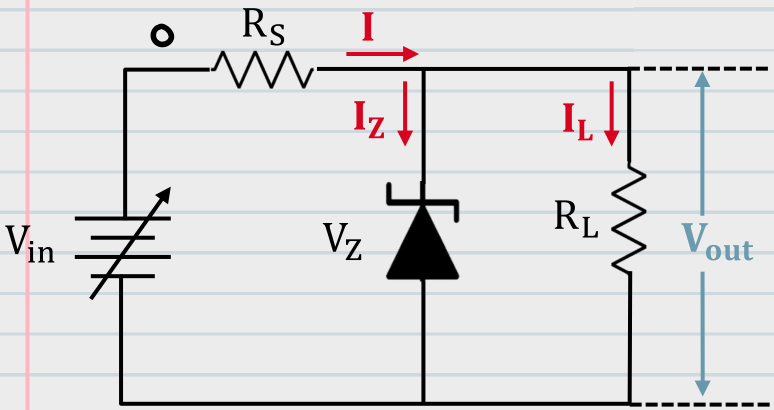


Considering the output voltage V_{out},

$$V_{out} = I_L R_L \quad (2)$$

- $[V_{out}] = I_L [R_L] \longrightarrow [V_{out}] = [I_L][R_L]$

R_L: Fixed $\longrightarrow$ I_L: Constant



Considering the current I,

$$I = I_Z + I_L \quad \text{——— } (3)$$

$$I = I_Z + [\, I_L \,] \longrightarrow I \propto I_Z$$

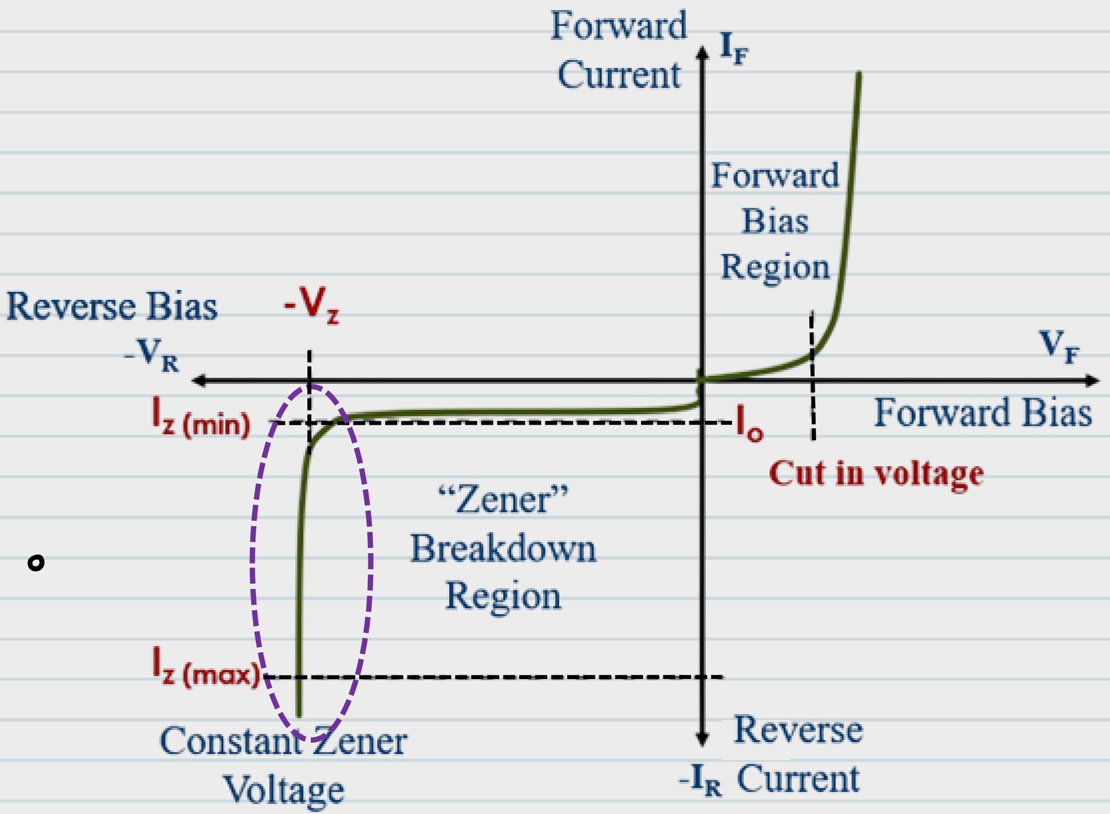
According to (1),

$$V_{in} : \text{Varying} \longrightarrow I : \text{Varying}; \; \{V_{in}\} \; \alpha \; \{\{I\}\}$$

According to (3),

$$\textit{when}, I: \text{Varying} \longrightarrow I_Z: \text{Varying}; \; \{I\} \; \alpha \; \{\{I_Z\}\}$$

Limitation of the I_Z;



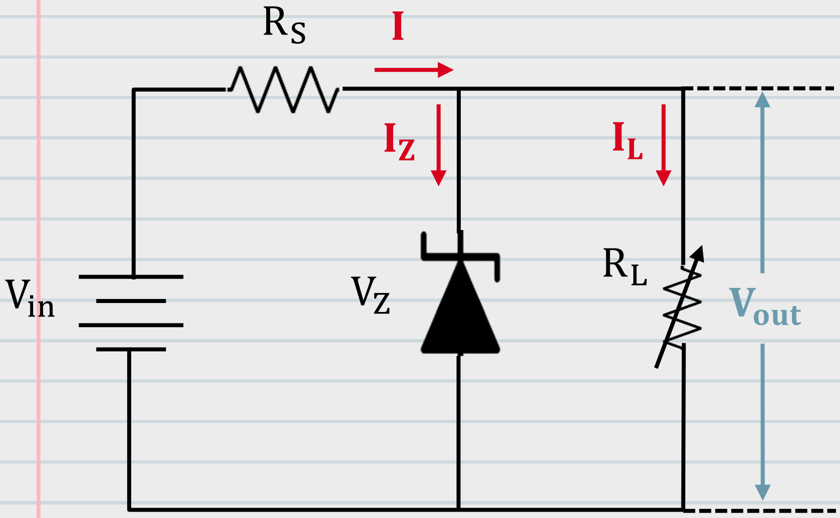
∴ If I_Z vary within the minimum and maximum current for the Zener diode; then V_Z can be kept constant.

$$\mathbf{I_{Zmin} < I_Z < I_{Zmax}}$$

$$\Downarrow$$

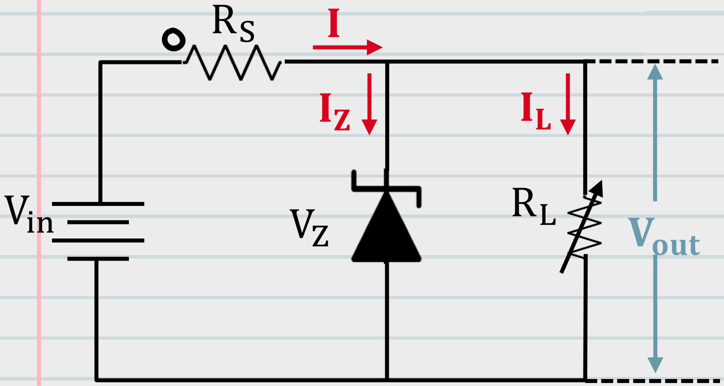
$$[\ \mathbf{V_Z}\ ]$$

2. Load Regulation



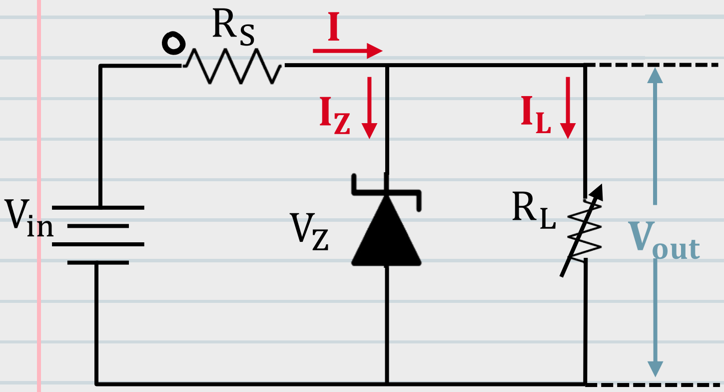
$$V_O = V_Z = \text{Constant}$$

Series resistance, R_S and Input voltage, V_{in} are fixed.
Load resistance, R_L is changing.
Output voltage, V_{out} remains the same as long as the input voltage is maintained above a ***minimum value***.



$$V_O = V_Z = \text{Constant}$$

V_{in}: Fixed $\longrightarrow$ I : Fixed



$V_O = V_Z = \text{Constant}$

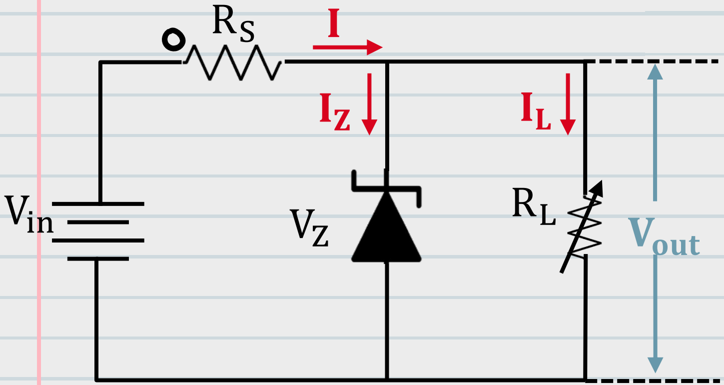
V_{in}: Fixed $\longrightarrow$ I : Fixed

Considering the output voltage V_{out},

$$V_{out} = I_L R_L \text{ ——— } (2)$$

$$[V_{out}] = I_L \{R_L\} \longrightarrow \{R_L\} \propto \{\{I_L\}\}$$

R_L: Varying $\longrightarrow$ I_L: Varying



$$V_O = V_Z = \text{Constant}$$

V_{in}: Fixed $\longrightarrow$ I : Fixed

R_L: Varying $\longrightarrow$ I_L: Varying

I_L: Varying $\longrightarrow$ I_Z: Varying

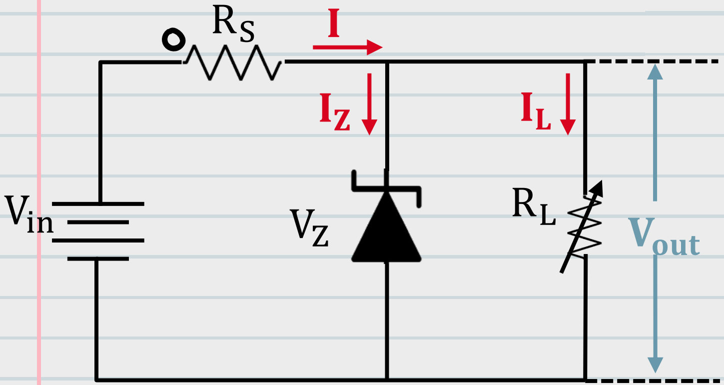
Considering the current I,

$$I = I_Z + I_L \quad \text{——} \quad (3)$$

$$[I] = I_Z + \{I_L\} \longrightarrow \{I_L\} \ \alpha \ \{\{I_Z\}\}$$

when,

I_L : Varying $\longrightarrow$ I_Z: Varying



$$V_O = V_Z = \text{Constant}$$

V_{in}: Fixed ⟶ I : Fixed

R_L: Varying ⟶ I_L: Varying

I_L: Varying ⟶ I_Z: Varying

Same as before, to keep $\mathbf{V_Z}$ constant;

$$I_{Zmin} < I_Z < I_{Zmax}$$

⇓

[V_Z]

Line Regulation vs Load Regulation

Line regulation

The ability of the power supply to maintain its specified output voltage over **changes in the input line voltage**.

Expressed as percent of change in the output voltage relative to the change in the input line voltage.

Load regulation

The ability of the power supply to maintain its specified output voltage given **changes in the load**. (Power is regulated)

This does not mean the ***tolerance*** applies when there are sudden changes in load, it means over the permissible load range the regulation can change by this amount.

Both values apply to the output. This means the worst case value you need to use is both of the line and load tolerance percentages added together.

Line Regulation

Can express as;

$$\boxed{\textbf{\textit{Line Regulation (in \%)}} = \frac{\Delta V_{out}}{\Delta V_{in}} \times 100\%}$$

$$\boxed{\textbf{\textit{Line Regulation (in \% / V)}} = \frac{\Delta V_{out}/V_{out}}{\Delta V_{in}} \times 100\%}$$

For ideal power supply,

Line Regulation = 0 %

Example 01:

The input of a certain regulator increases by 3.5 V. As a result, the output voltage increases by 0.042 V. The nominal output is 20 V. Determine the line regulation.

Example 01:

The input of a certain regulator increases by 3.5 V. As a result, the output voltage increases by 0.042 V. The nominal output is 20 V. Determine the line regulation.

$$\mathit{Line\ Regulation\ (in\ \%)} = \frac{\Delta V_{out}}{\Delta V_{in}} \times 100\% \quad = \frac{0.042\ V}{3.5\ V} \times 100\%$$

$$= \underline{\underline{1.2\ \%}}$$

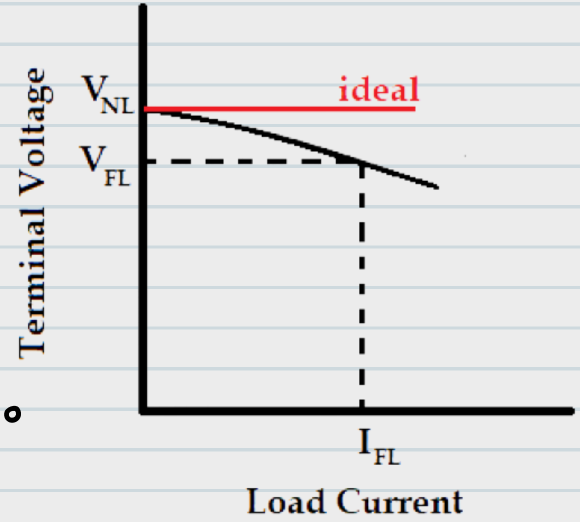
- $$\mathit{Line\ Regulation\ (in\ \%\ /\ V)} = \frac{\Delta V_{out}/V_{out}}{\Delta V_{in}} \times 100\% \quad = \frac{0.042\ V/20\ V}{3.5\ V} \times 100\%$$

$$= \underline{\underline{0.06\ \%/\ V}}$$

Load Regulation

For ideal power supply,

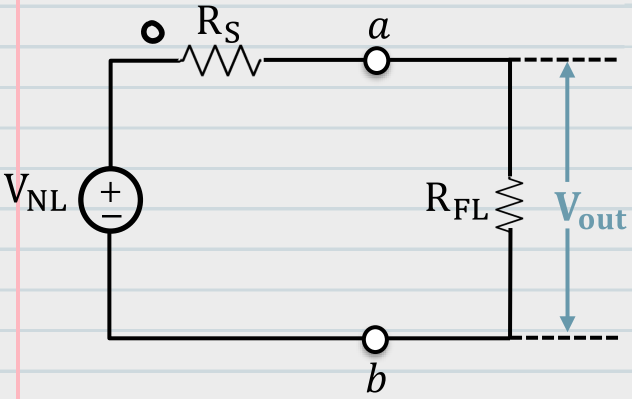
Line Regulation = 0 %



$$\boxed{\textit{Load Regulation (in \%)} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%}$$

V_{NL} – No-load output voltage (open circuit)

V_{FL} – Full-load output voltage (maximum current)



$$V_O = V_{FL} = \frac{R_{FL}}{(R_{FL} + R_S)} V_{NL} \text{ ——— } (1)$$

Load Regulation,

$$\text{Load Regulation (in \%)} = \frac{V_{NL} - V_{FL}}{V_{FL}} \text{ x } 100\%$$

From, (1)

$$= \frac{V_{NL} - \left[\frac{R_{FL}}{(R_{FL}+R_S)} V_{NL}\right]}{\left[\frac{R_{FL}}{(R_{FL}+R_S)} V_{NL}\right]} \text{ x } 100\%$$

$$= \frac{R_S}{R_{FL}} \text{ x } 100\%$$

$$\boxed{\textbf{\textit{Load Regulation (in \%)}} = \frac{\mathbf{R_S}}{\mathbf{R_{FL}}} \textbf{ x 100\%}}$$

Voltage Regulators

Two types of Voltage Regulators:

1. Linear Voltage Regulators
2. Switching Voltage Regulators

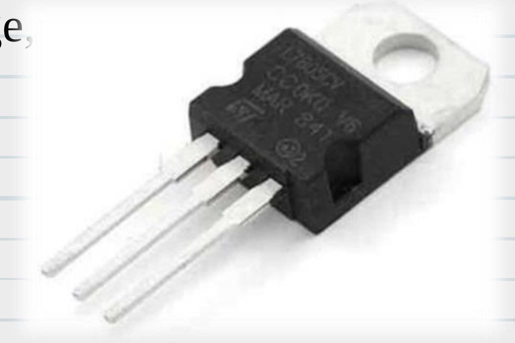
1. Linear Voltage Regulators

Similar to Voltage Divider.

The resistance of the linear voltage regulator changes with the load and gives a constant voltage output.

Example: LM7805

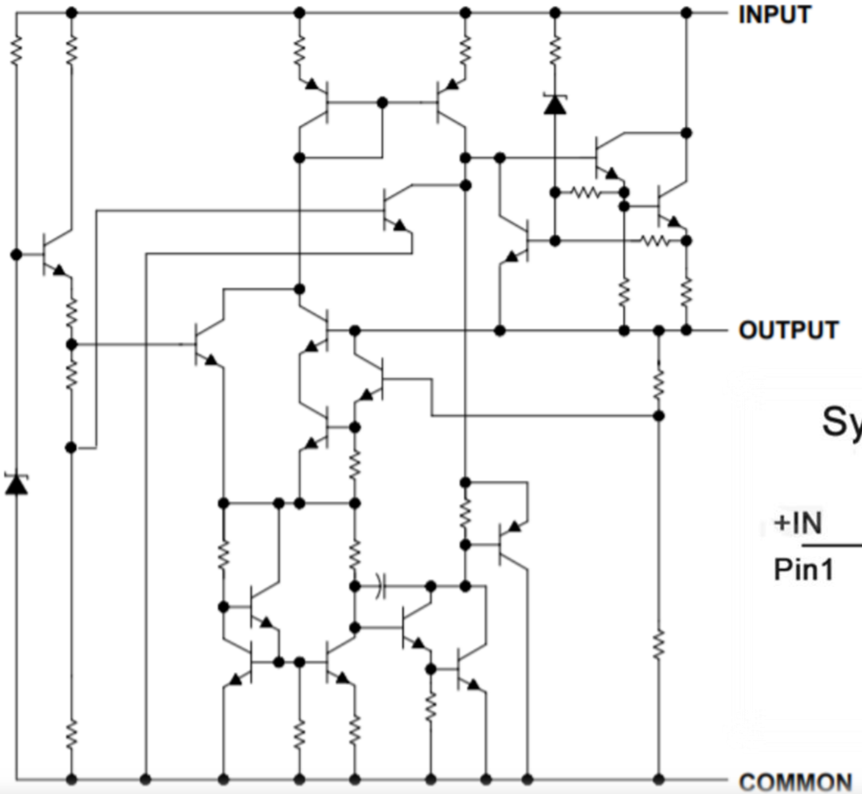
- **LM78XX**: Voltage regulators that output positive voltage,
  “XX” = voltage output.
- **LM79XX**: Voltage regulators that output negative voltage,
  “XX” = voltage output.



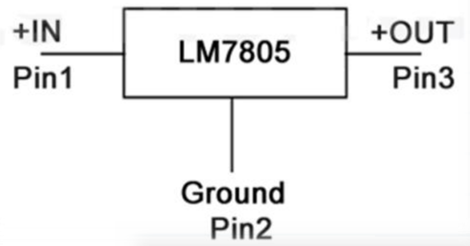
μA7800 SERIES
POSITIVE-VOLTAGE REGULATORS

SLVS056J – MAY 1976 – REVISED MAY 2003

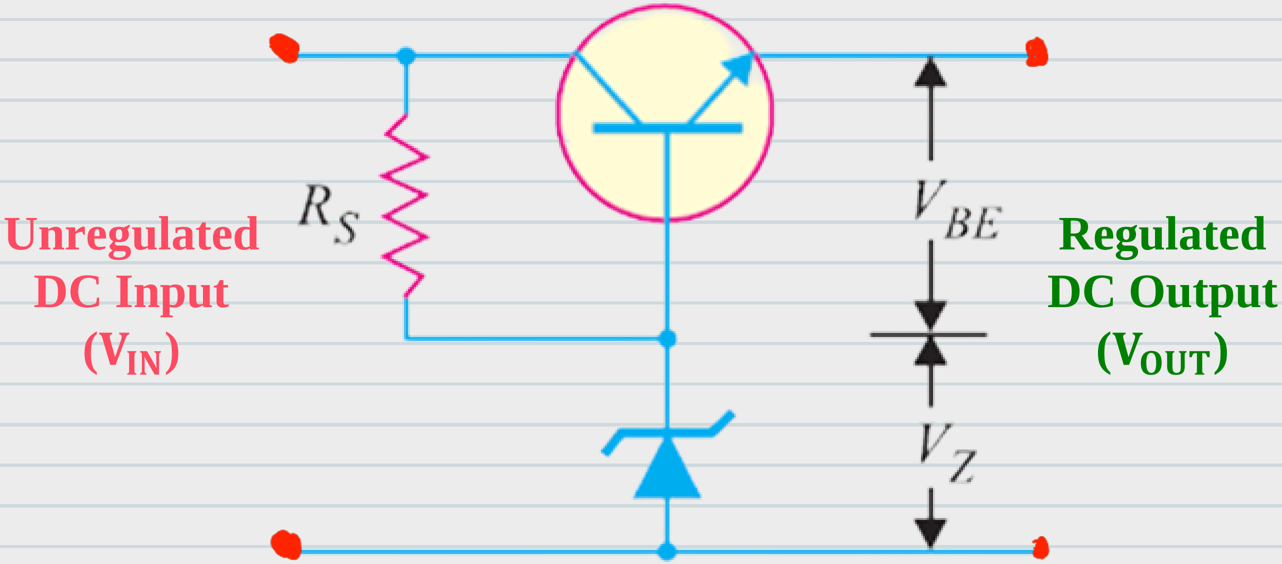
schematic



Symbol In Diagram



1. Linear Voltage Regulators

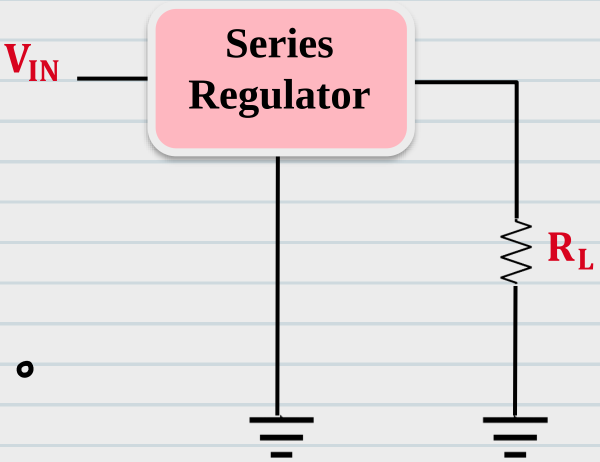


1. Linear Voltage Regulators

Two types of Linear Voltage Regulators:

a. Series Voltage Regulator
b. Shunt Voltage Regulator (i. e. Parallel by pass)

a. Series Voltage Regulators



Connected in series with the load.

Does not have an effective voltage regulation at high load currents.

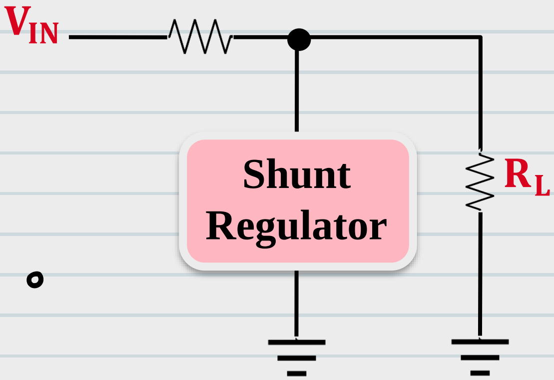
Suitable for heavy loads.

In the series voltage regulator,

Therefore, it is ***high current, low voltage*** device.

Has good efficiency for higher load currents.

b. Shunt Voltage Regulators



Connected in parallel/shunt with the load.

Has good voltage regulation even at high load currents.

Suitable for light loads.

In the shunt voltage regulator,

Therefore, it is a ***high voltage, low current*** device.

Has good efficiency for low load current.

BASIS OF COMPARISON	SERIES VOLTAGE REGULATOR	SHUNT VOLTAGE REGULATOR
Connection	Series voltage regulator is connected in series with the load.	Shunt voltage regulator is connected in parallel/shunt with the load.
High Load Currents	Series voltage regulator does not have an effective voltage regulation at high load currents.	Shunt voltage regulator has good voltage regulation even at high load currents.
Suitability	The regulator is suitable for heavy loads.	The regulator is suitable for light loads.
Output DC	In the series voltage regulator, the output DC voltage is not constant.	In the shunt voltage regulator, the output DC voltage is constant.
Control Element	In the series voltage, the control element has to carry the load current. Therefore, it is high current low voltage device.	In the shunt voltage, the control element has to bear the load voltage across it. Therefore, it is a high voltage low current device.
Efficiency	Series voltage regulator has good efficiency for higher load currents.	Shunt voltage regulator has good efficiency for low load current.

Linear Voltage Regulators:

Advantages:

- Cheap
- Fast response time
- Lower electromagnetic Interference and noise
- Good for constant output voltage for low power applications

Disadvantages:

- Low efficiency
- High heat → need heat sink and space
- Output < input

Switching Regulator Circuit

Rapidly switches a series device on/off.

Switch’s duty cycle sets the amount of charge transferred to the load.

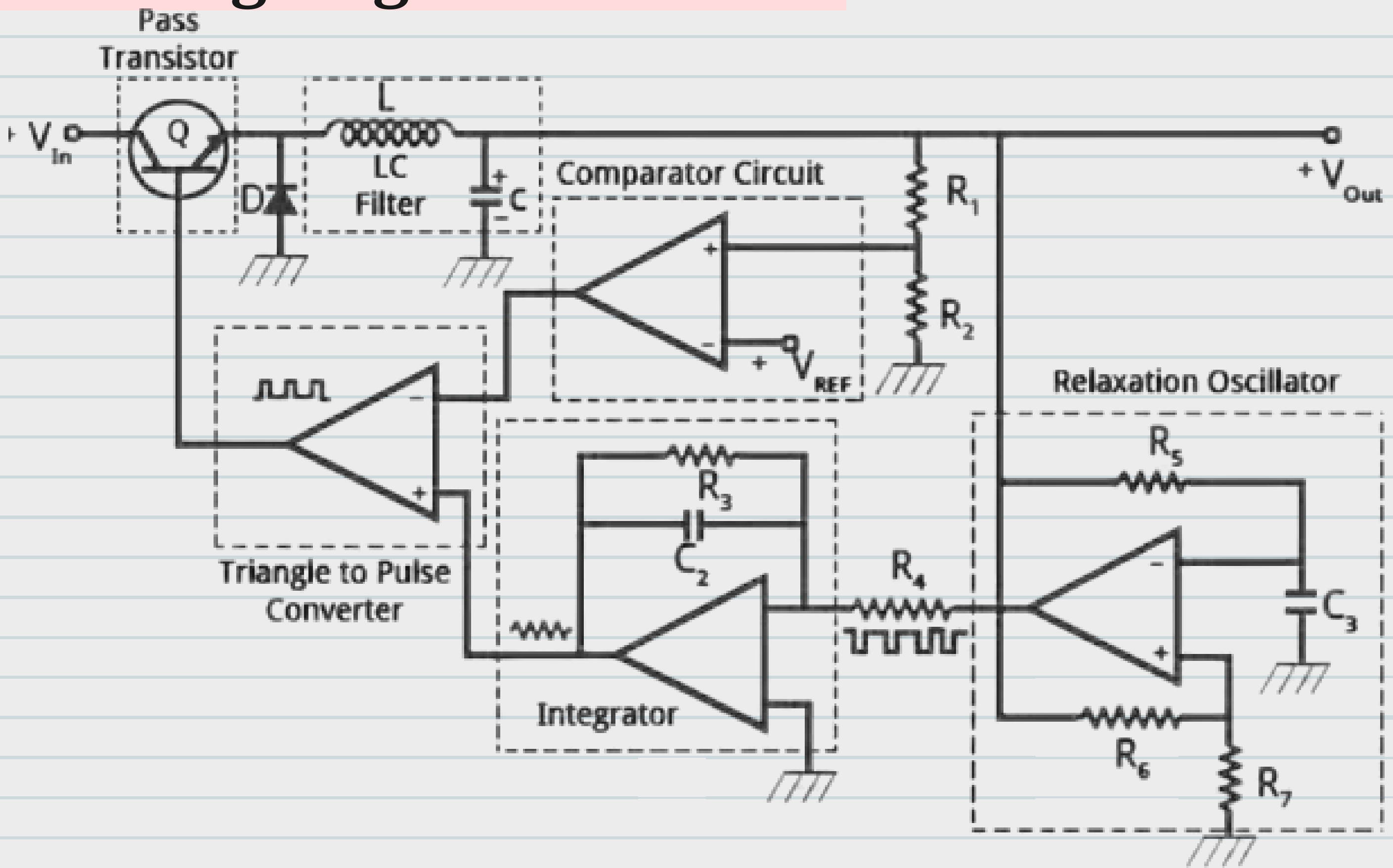
Controlled by a feedback mechanism similar to that of a linear regulator.

Series element is either fully conducting or fully switched off $\longrightarrow$ efficient.

Efficient transfer of power to the load (transistor is not always conducting).

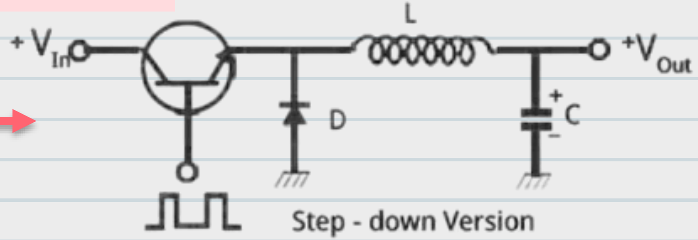
Voltage is passed in pulses, then smoothened and filtered.

Switching Regulator Circuit

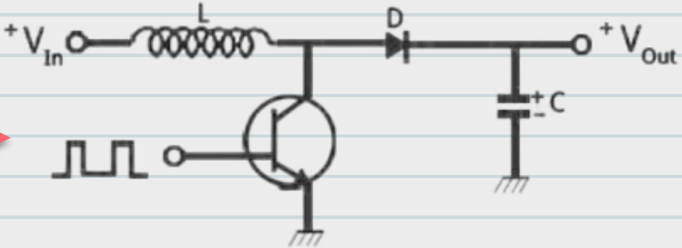


Switching Regulator Configurations

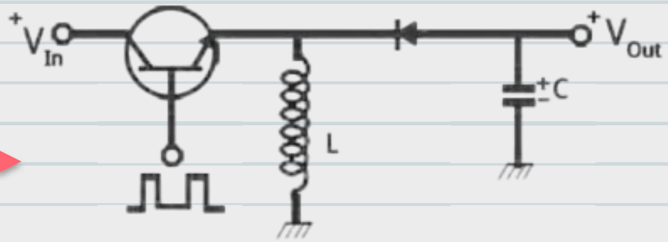
1. Step Down
2. Step Up
3. Inverter



Step - down Version



Step - up Version



Polarity Inverting Configuration

Switching Regulators

Good for high current applications (since less power is dissipated).

Voltage regulation is achieved by the on and off action, limiting the amount of current flow based on the varying line and load conditions.

Switching Regulator Circuit

Advantages:

Power conversion efficiency is high (even 90% possible).

Heat sinks not needed.

Useful when input/output voltages are very different.

Disadvantages:

Expensive.

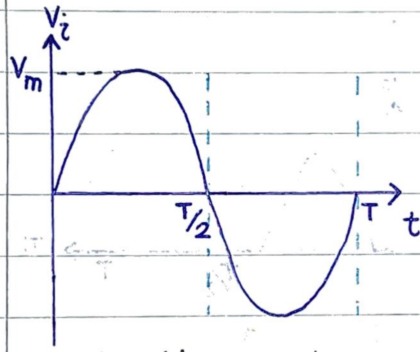
High electromagnetic interference and noise.

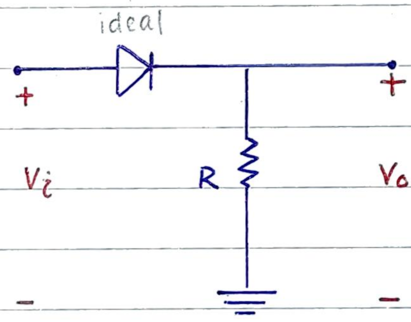
Complex circuits.

THANK YOU!

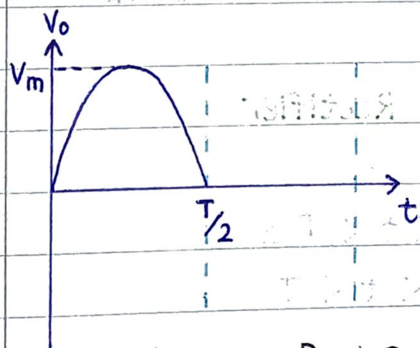
Half - wave Rectification

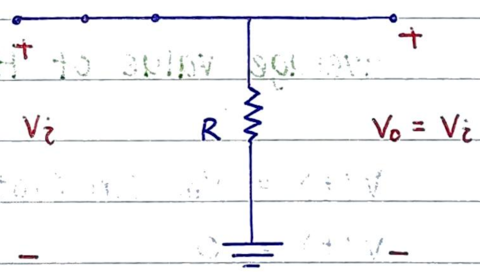
The process of removing one - half the input signal to establish a dc level is called half wave rectification



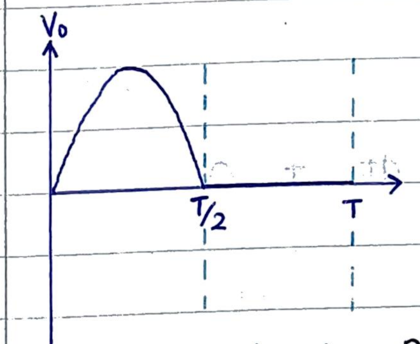


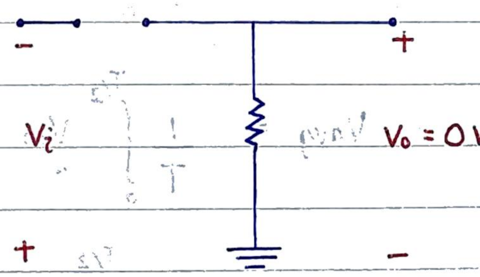
$V_i = V_m \sin \omega t$





Conduction Region $(0 \rightarrow T/2)$





Non - conduction Region $(T/2 \rightarrow T)$

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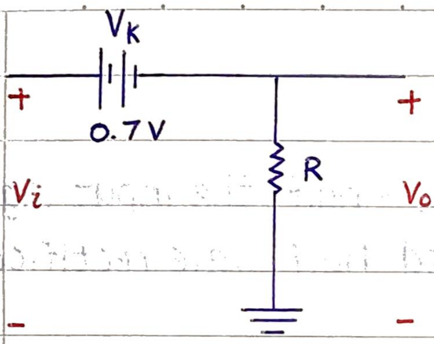

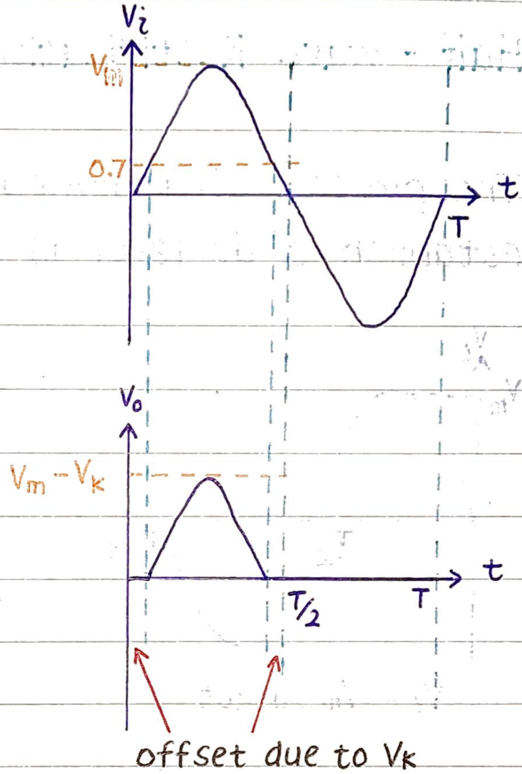

Average value of Half-wave Rectifier

$V(t) = V_m \sin(\omega t)$; $0 < t < T/2$

$V(t) = 0$; $T/2 < t < T$

$$V_{avg} = \frac{1}{T}\int_0^T V(t)\,dt$$

$$V_{avg} = \frac{1}{T}\int_0^{T/2} V_m \sin(\omega t)\,dt + 0$$

$$V_{avg} = \frac{V_m}{T}\int_0^{T/2} \sin(\omega t)\,dt$$

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$$V_{avg} = \frac{V_m}{T}\left[\frac{-\cos \omega t}{\omega}\right]_0^{T/2} \qquad \omega = \frac{2\pi}{T}$$

$$= \frac{V_m}{T \times \frac{2\pi}{T}}\left[-\cos\left(\frac{2\pi}{T} \times t\right)\right]_0^{T/2}$$

$$= \frac{V_m}{2\pi}\left[-\cos \pi - (-\cos 0)\right]$$

$$= \frac{V_m}{2\pi}\left[-(-1) - (-1)\right]$$

$$\boxed{V_{avg} = \frac{V_m}{\pi}}$$

Bridge Network

RMS value of Half-wave Rectifier

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v^2(t)\, dt}$$

$$V_{rms}^2 = \frac{1}{T}\int_0^{T/2} V_m^2 \sin^2(\omega t)\, dt \qquad \sin^2\theta = \frac{1 - \cos 2\theta}{2}$$

$$= \frac{V_m^2}{T}\int_0^{T/2} \frac{1 - \cos(2\omega t)}{2}\, dt$$

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$$V_{rms}^2 = \frac{V_m^2}{2T}\left[t - \frac{\sin(2\omega t)}{2\omega}\right]_0^{T/2}$$

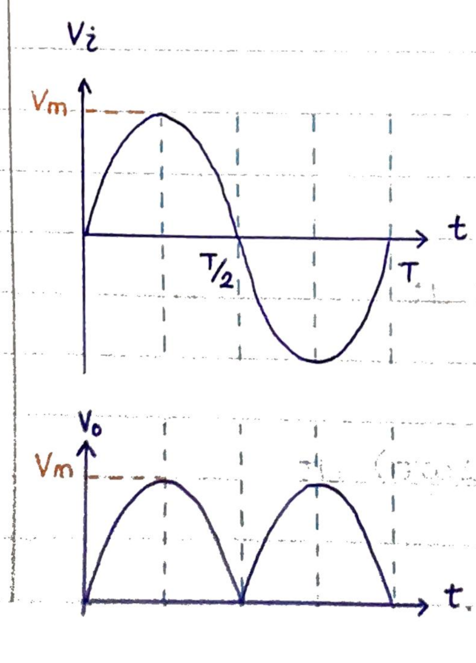
$$= \frac{V_m^2}{2T}\left[\frac{T}{2} - \frac{\sin\left(\frac{4\pi}{T}\times\frac{T}{2}\right)}{2\omega} - 0 + \frac{\sin(0)}{2\omega}\right]$$

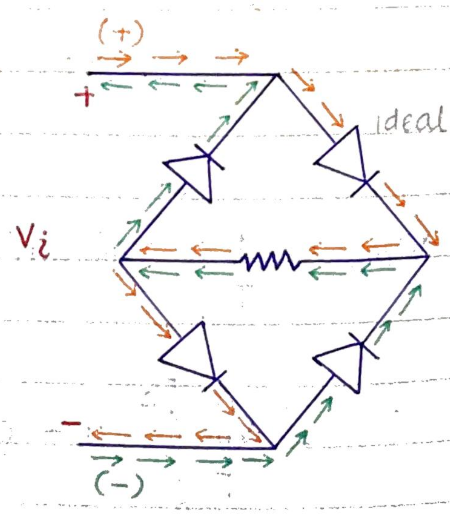
$$= \frac{V_m^2}{4}$$

$$\boxed{V_{rms} = \frac{V_m}{2}}$$

Full-wave Rectification

Bridge Network





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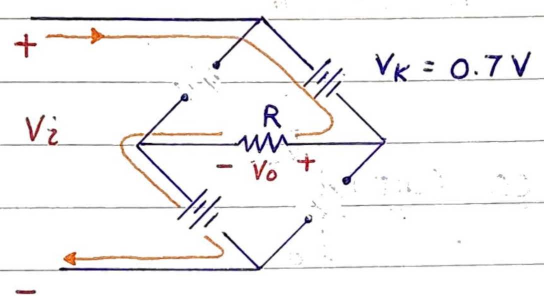
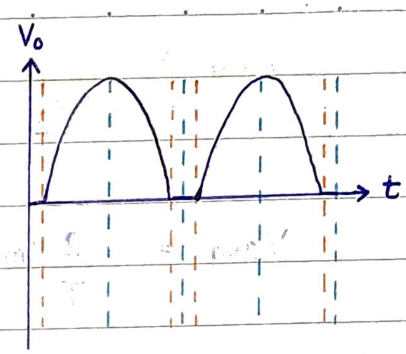
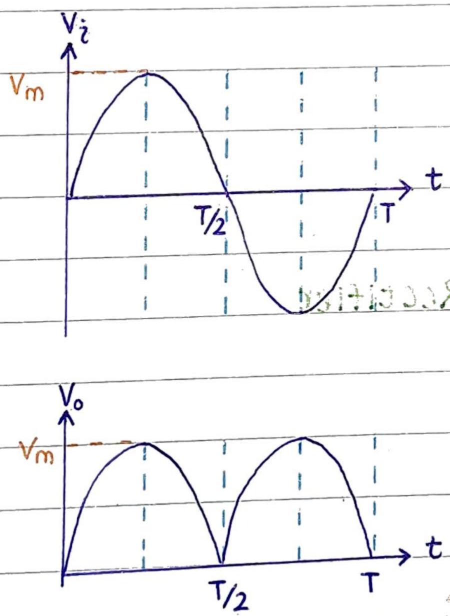
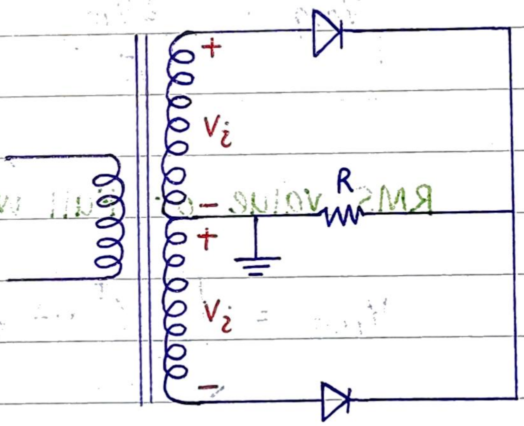




Center - Tapped Transformer





Average value of Full wave Rectifier

$$V(t) = V_m \sin(\omega t) \; ; \quad 0 < t < T/2$$

$$V_{avg} = \frac{1}{T}\int_0^T V(t)\, dt$$

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$$V_{avg} = \frac{1}{T/2} \int_0^{T/2} V_m \sin(\omega t)\, dt \qquad \omega = \frac{2\pi}{T}$$

$$V_{avg} = \frac{2V_m}{T} \left[-\frac{\cos(\omega t)}{\omega} \right]_0^{T/2}$$

$$= \frac{V_m}{\pi} \left(-(-1) + 1 \right)$$

$$\boxed{V_{avg} = \frac{2V_m}{\pi}}$$

RMS value of Full wave Rectifier

$$V_{rms} = \sqrt{\frac{1}{T} \int_0^{T} V^2(t)\, dt}$$

$$V^2_{rms} = \frac{1}{T/2} \int_0^{T/2} V^2(t)\, dt$$

$$V^2_{rms} = \frac{1}{T/2} \int_0^{T/2} V_m^2 \sin^2(\omega t)\, dt \qquad \sin^2\theta = \frac{1 - \cos 2\theta}{2}$$

$$= \frac{2V_m^2}{T} \int_0^{T/2} \left[\frac{1 - \cos(2\omega t)}{2}\right] dt$$

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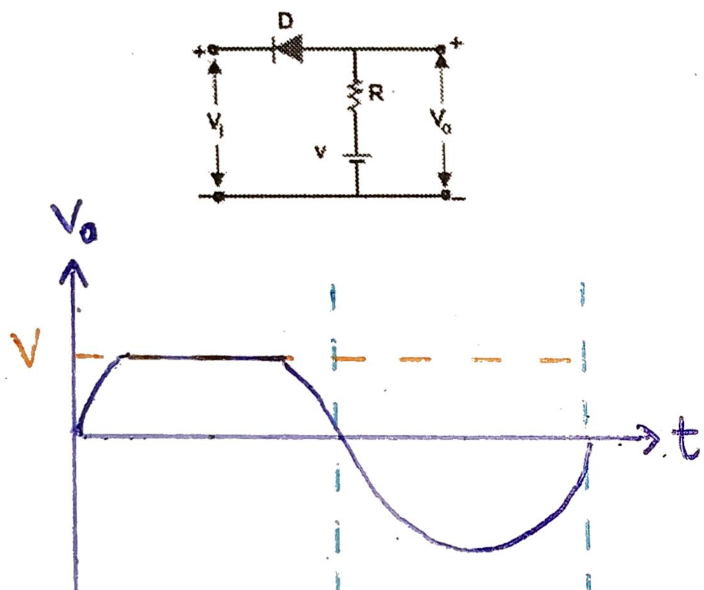
$$V^2_{rms} = \frac{V_m^2}{T}\left[\frac{T}{2} - \frac{\sin(\overset{2\pi}{2\omega t})}{2\omega} + \frac{\sin(0)}{2\omega}\right]$$

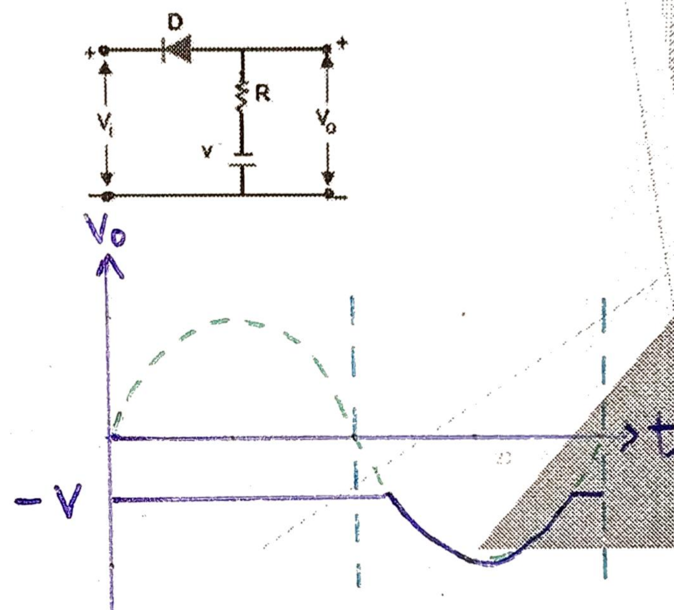
$$\boxed{V_{rms} = \frac{V_m}{\sqrt{2}}}$$

Parameters	Half-wave Rectifier	Center tapped full wave Rectifier	Full wave Bridge Rectifier
Peak inverse voltage	V_m	$2V_m$	V_m
Output frequency	f	$2f$	$2f$
Average DC value	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
RMS value	$\frac{V_m}{2}$	$\frac{V_m}{\sqrt{2}}$	$\frac{V_m}{\sqrt{2}}$

Series-positive Clipper With Bias

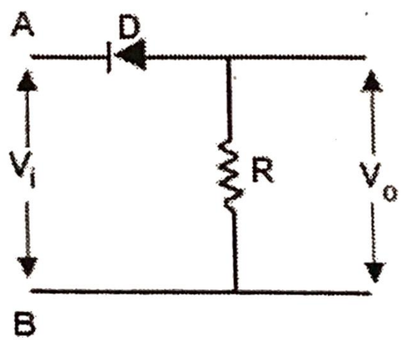
- The clipping takes place during the positive cycle only when the input voltage is greater than the battery voltage (i.e. $V_i > V$). The chipping level can be shifted up or down by varying the bias voltage (V)



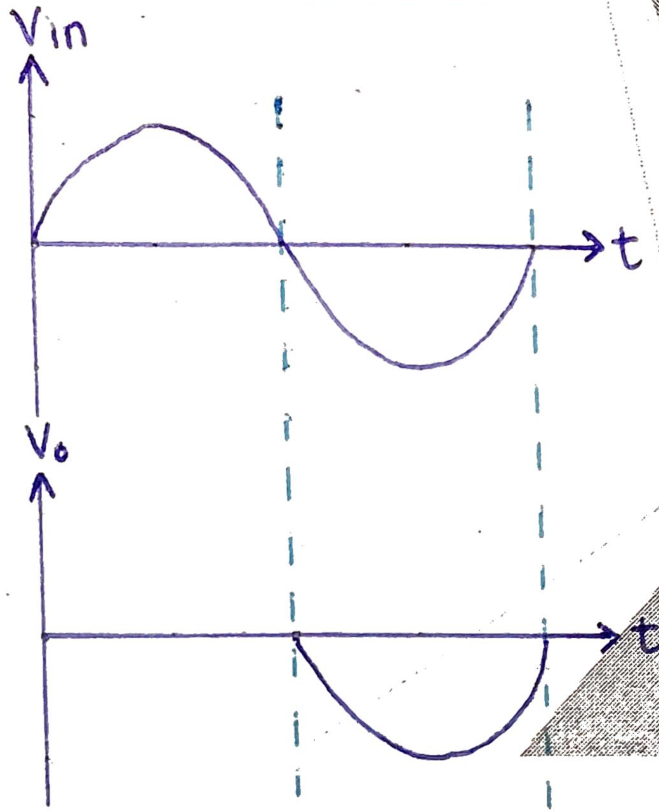


Series positive Clipper

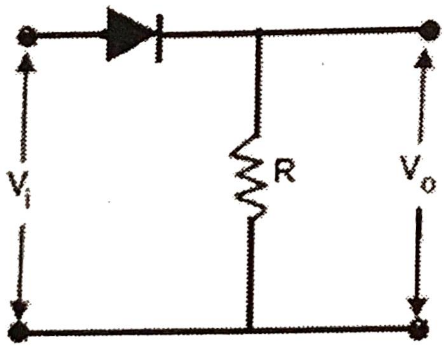
- In a series positive clipper, a diode is connected in series with the output

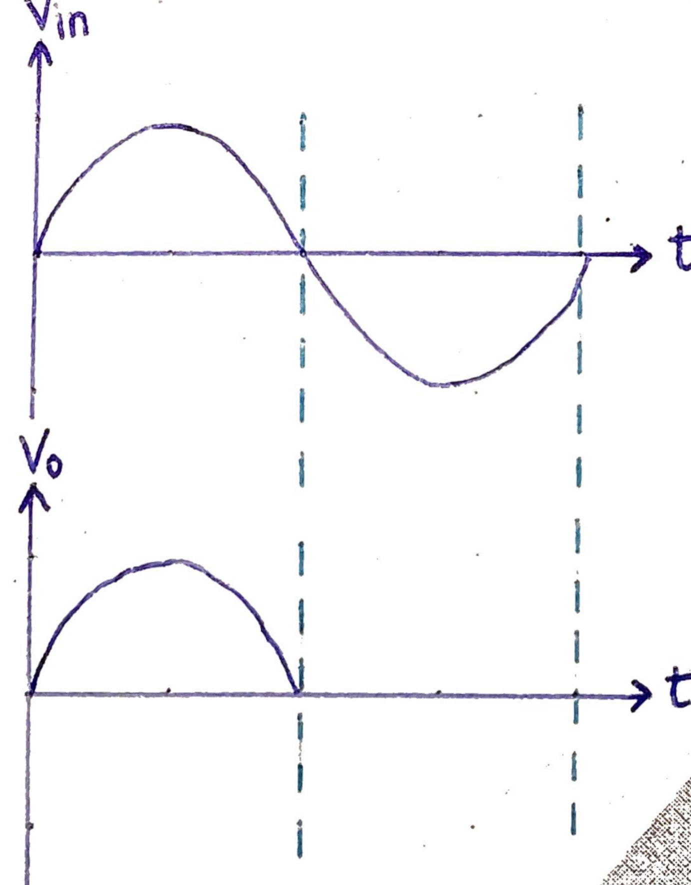


(a) Positive Clipper

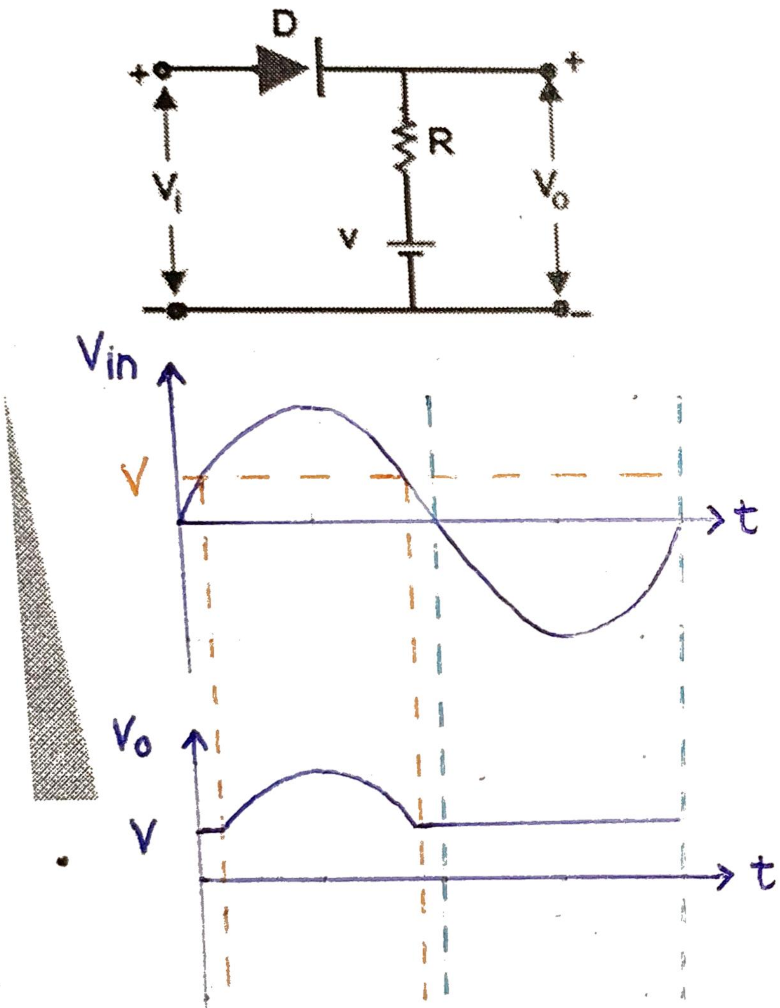


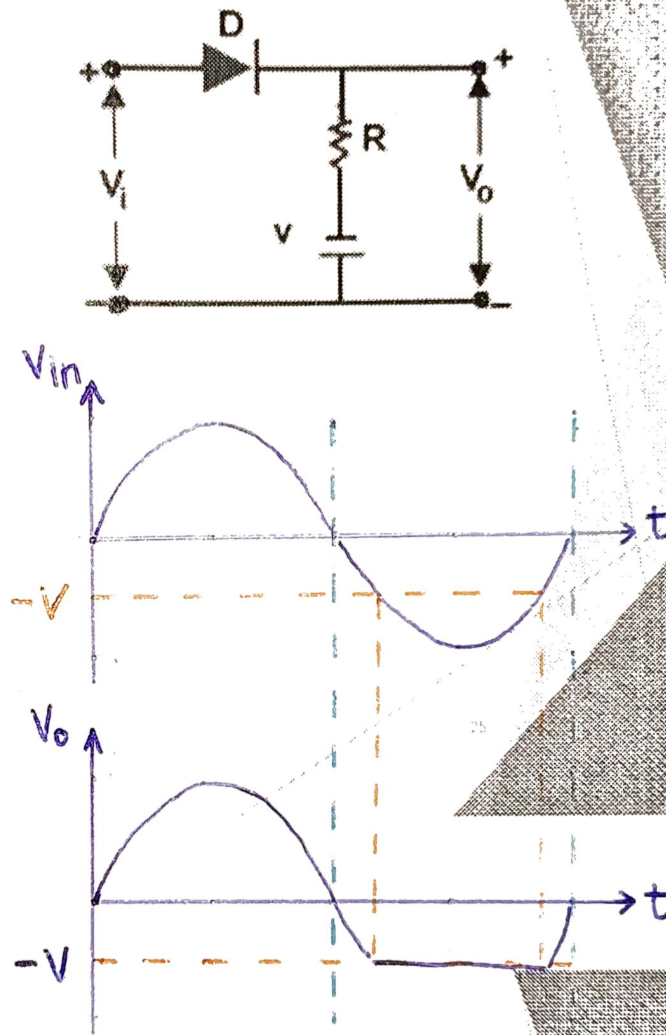
Series Negative Clipper



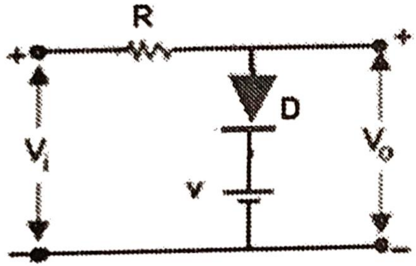


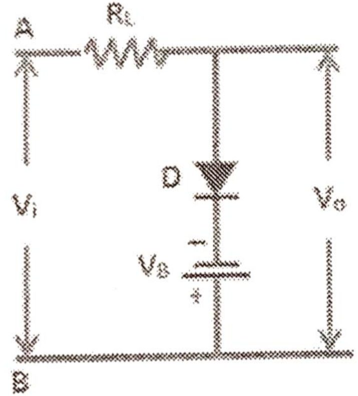
Series-negative Clipper With Bias

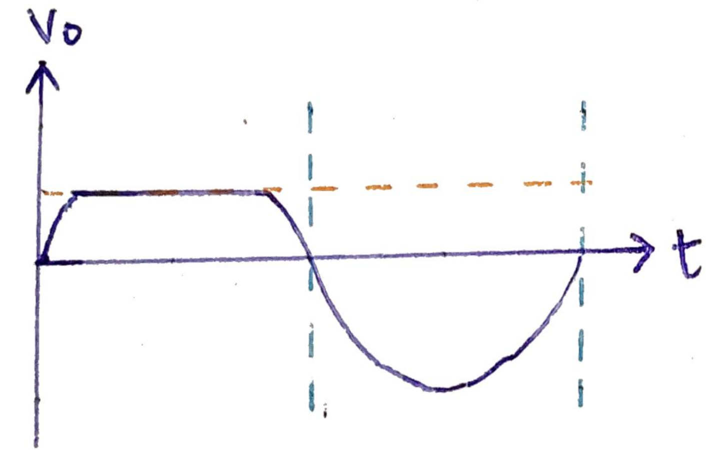


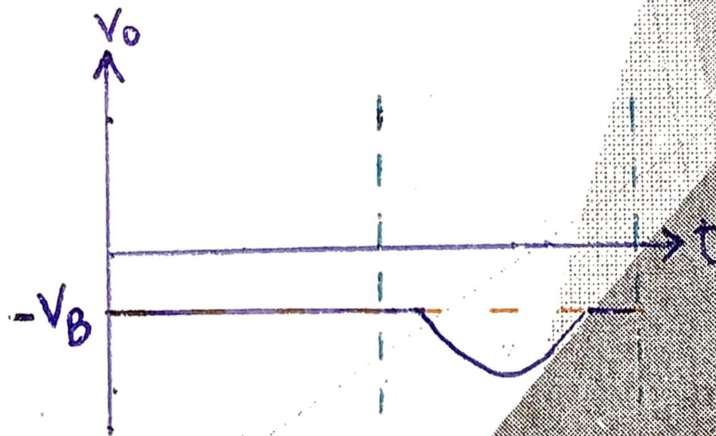


Shunt Or Parallel Positive Clipper With Bias



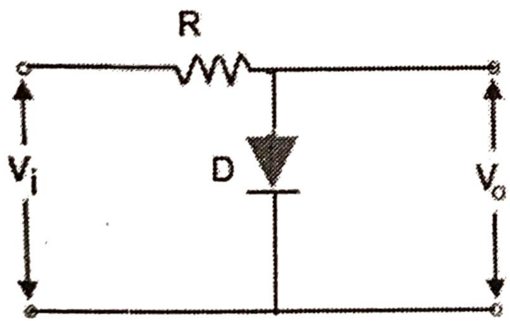


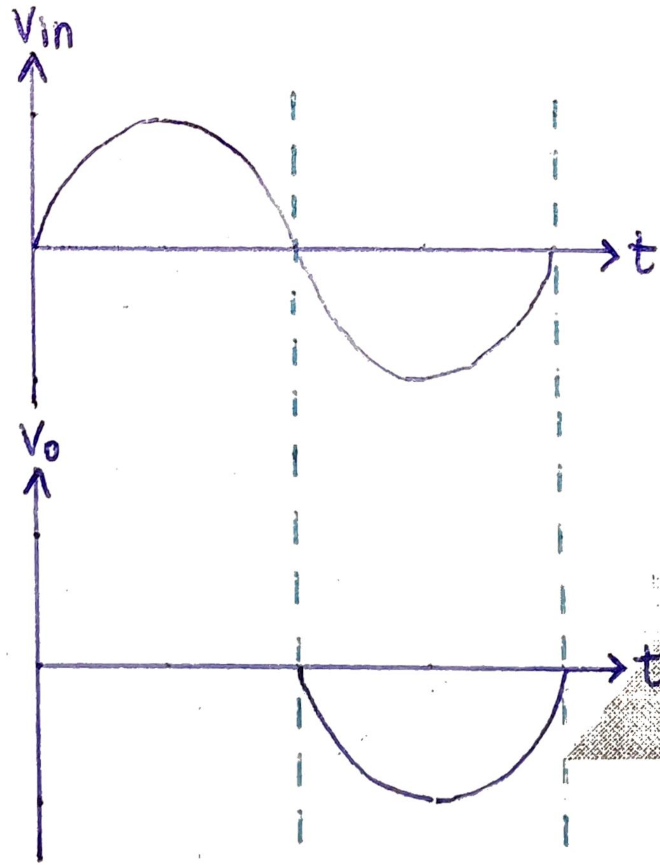




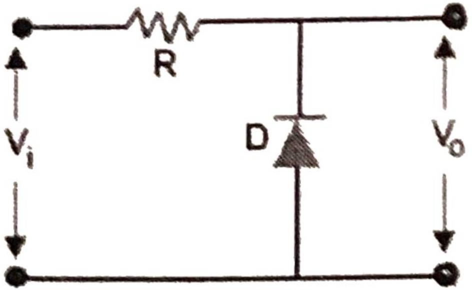
Shunt Or Parallel Positive Clipper

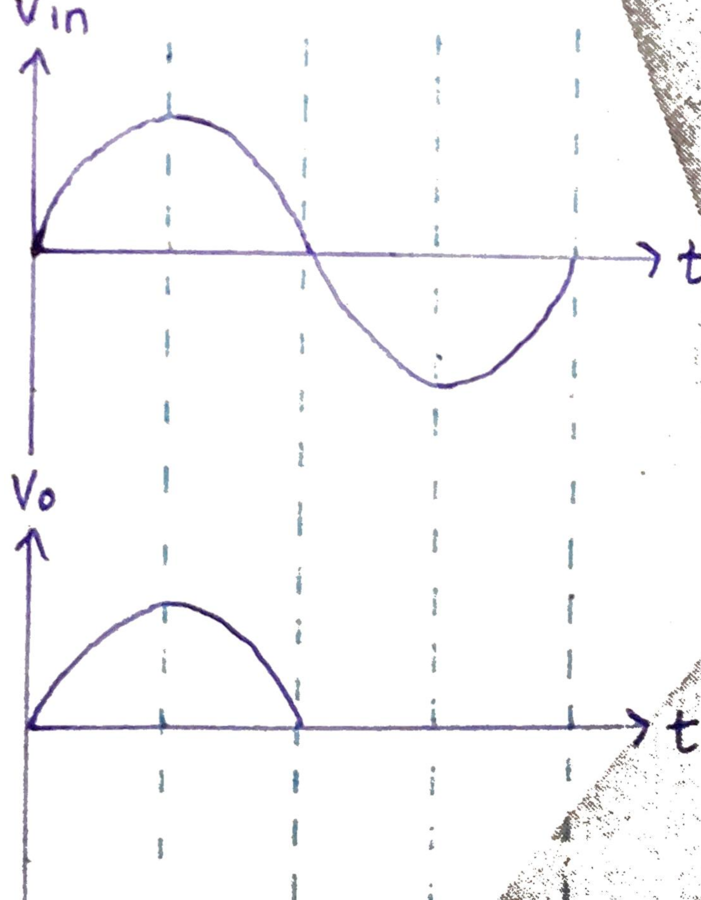
In shunt clipper, the diode is connected in parallel with the output load.



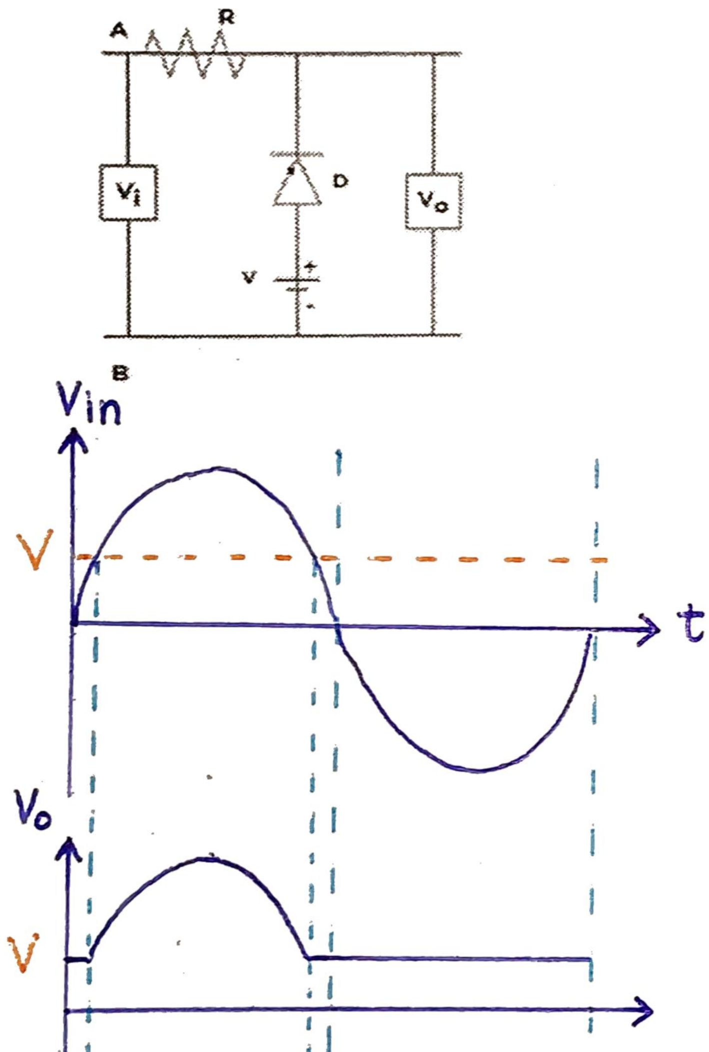


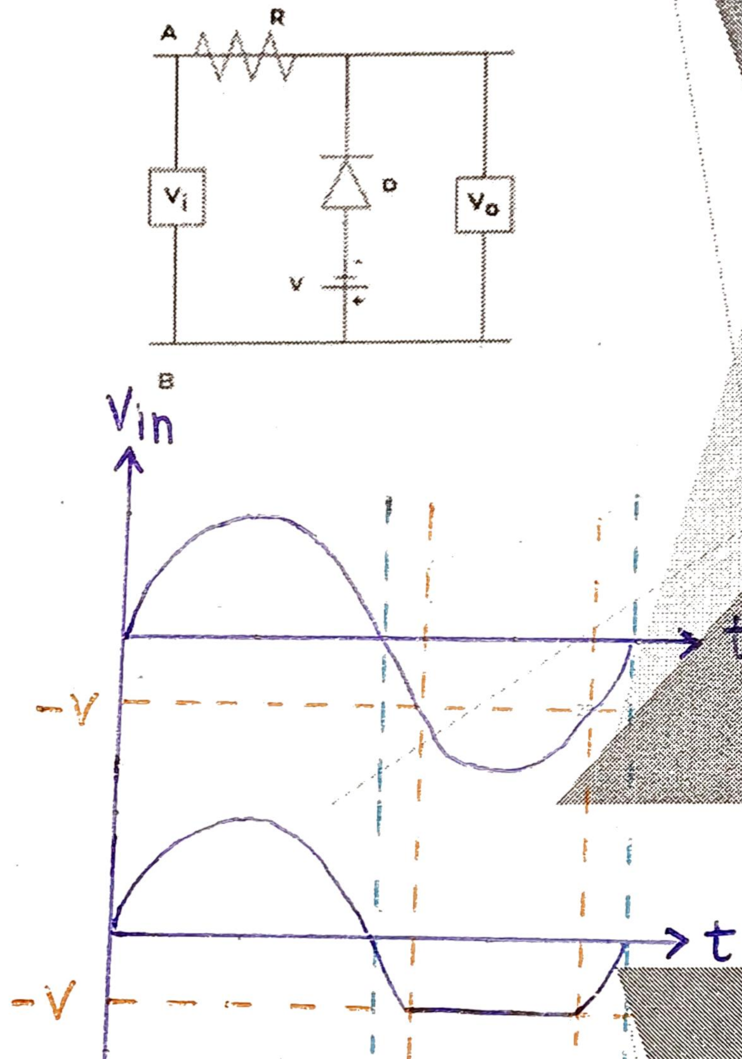
Shunt Or Parallel Negative Clipper



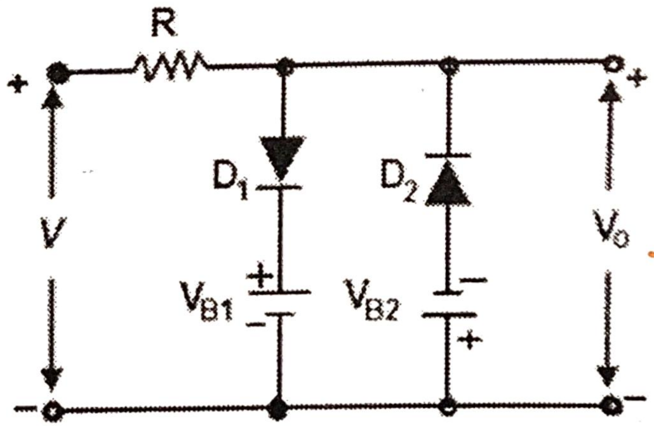


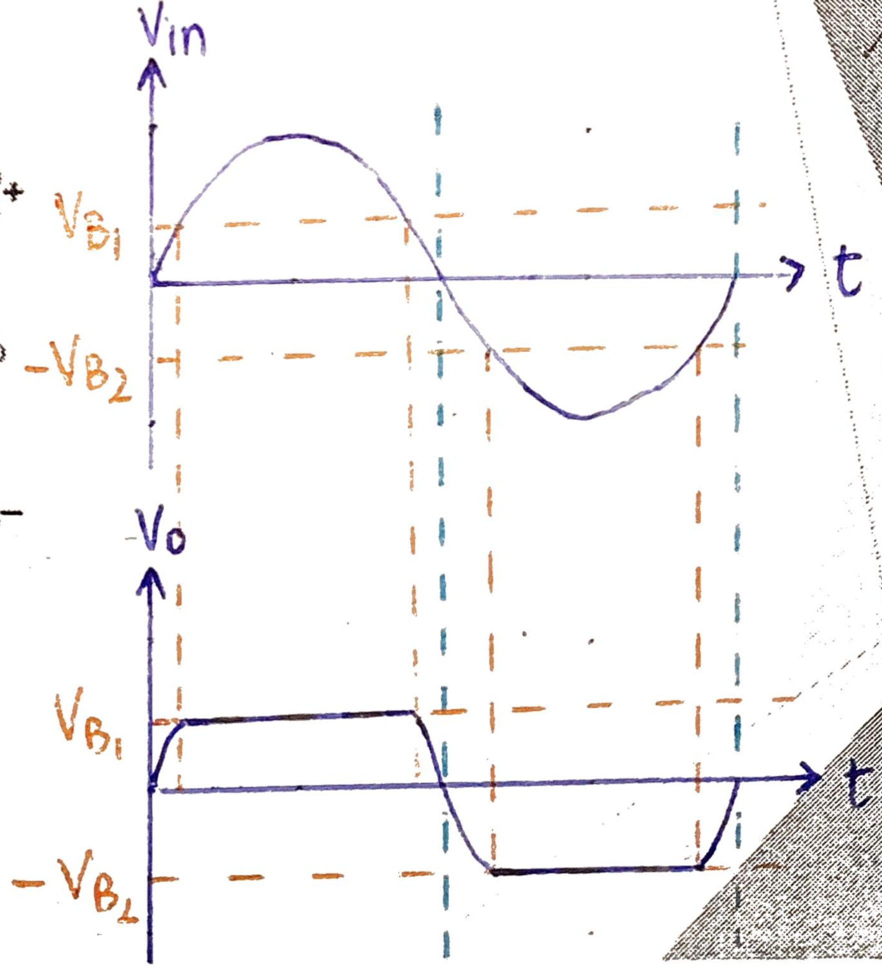
Shunt Or Parallel Negative Clipper With Bias





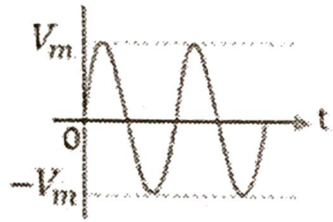
Dual (Combination) Diode Clipper



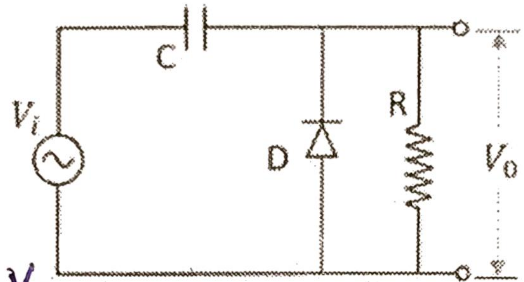


1. Positive Clamper Circuit

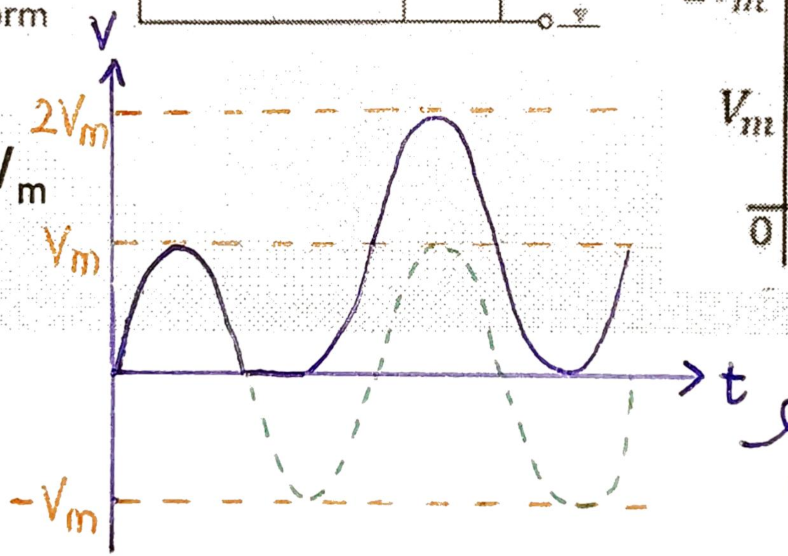
➡ A Clamping circuit restores the DC level. When a negative peak of the signal is raised above to the zero level, then the signal is said to be **positively clamped.**

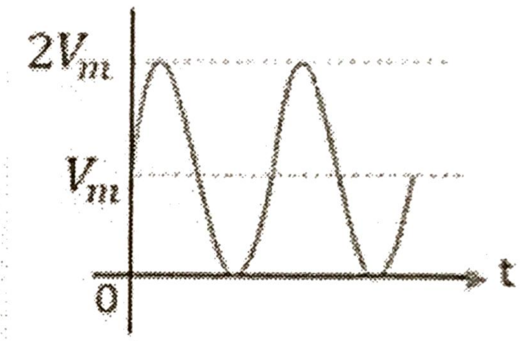


Input Waveform



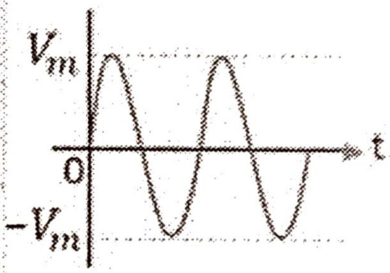
$$V_0 = V_i + V_m$$



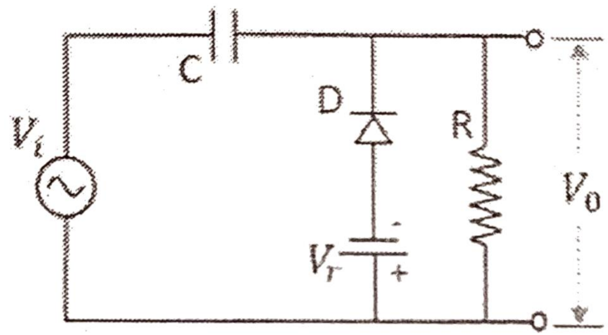


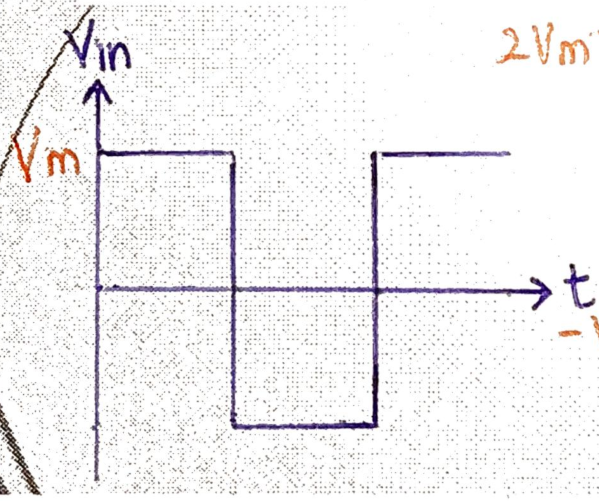
delay circuit
(D/JK Flip flop)

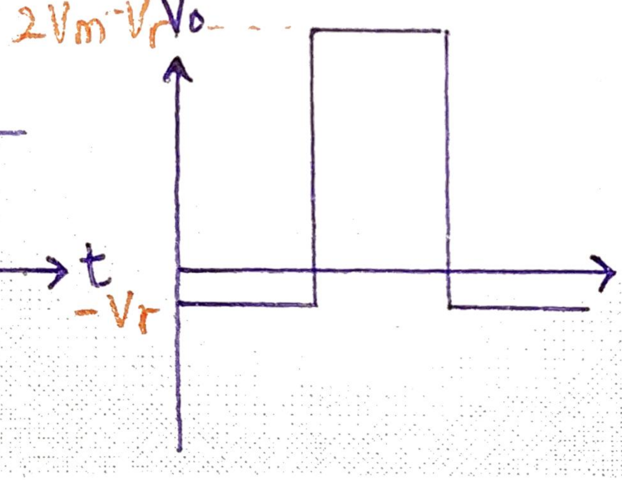
3. Positive Clamper with Negative Vr

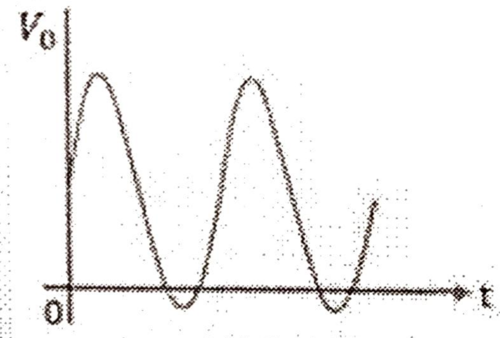


Input Waveform



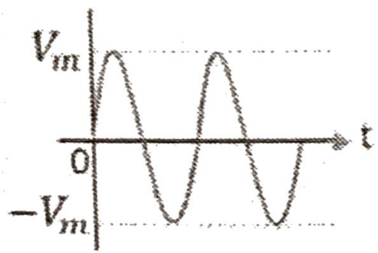




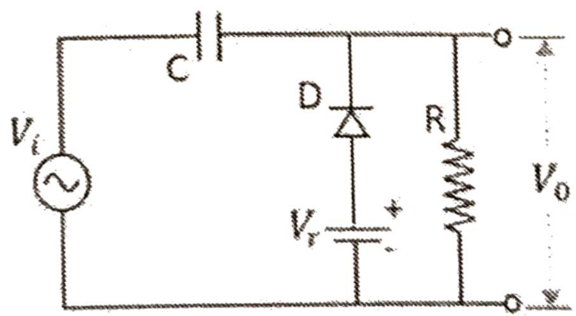


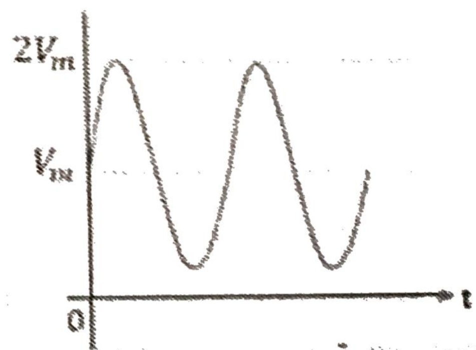
2. Positive Clamper with Positive V_r

- When a Positive clamper circuit is provided with a positive reference voltage and biased accordingly, the circuit incorporates this voltage into its output, elevating the clamped level in the process.



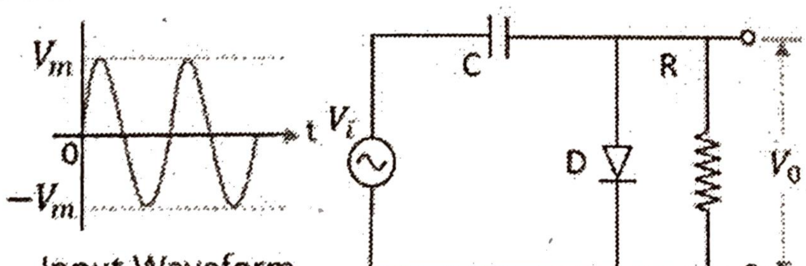
Input Waveform



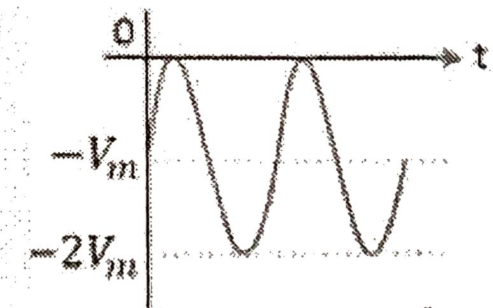


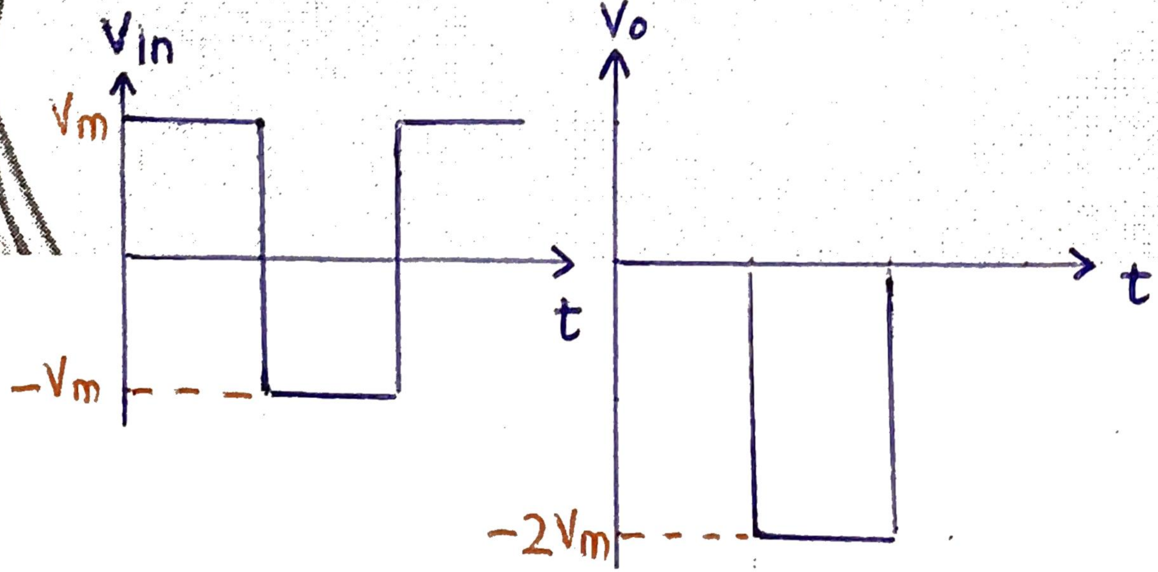
4. Negative Clamper

- A Negative Clamper circuit is one that consists of a diode, a resistor, and a capacitor and that shifts the output signal to the negative portion of the input signal.



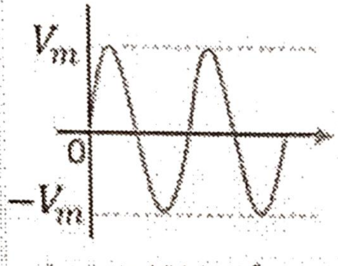
Input Waveform



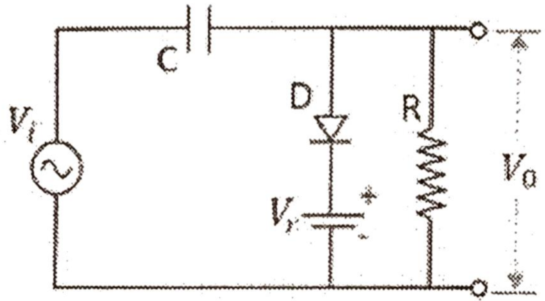


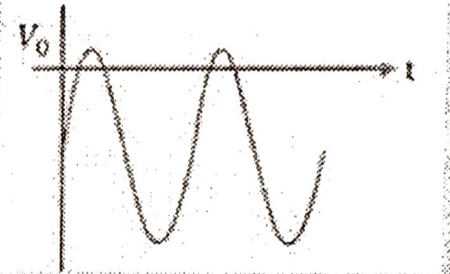
5. Negative clamper with positive V_r

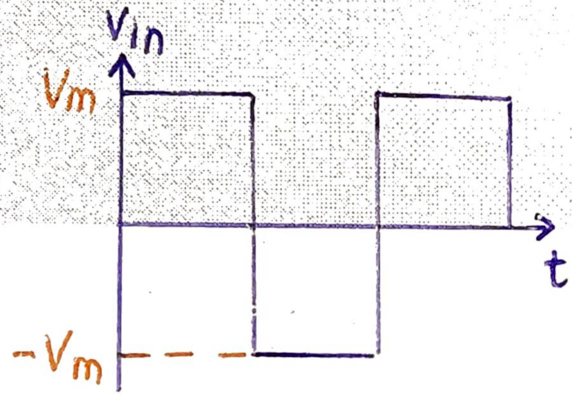
- A Negative clamper circuit if biased with some positive reference voltage, that voltage will be added to the output to raise the clamped level.

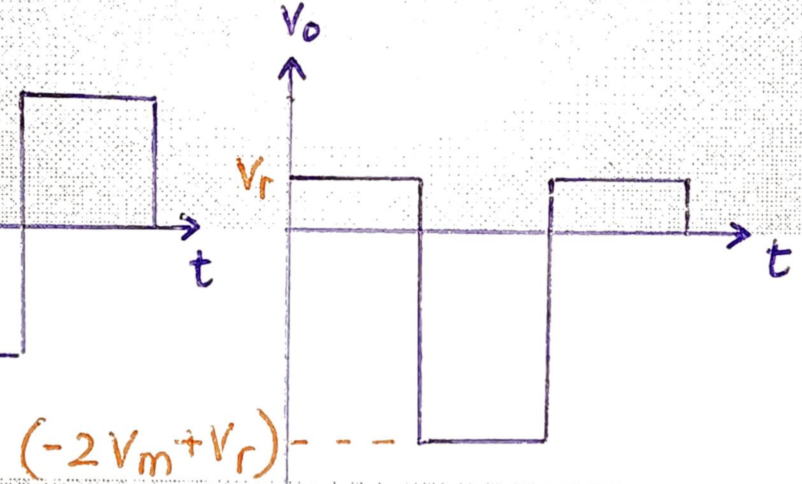


Input Waveform

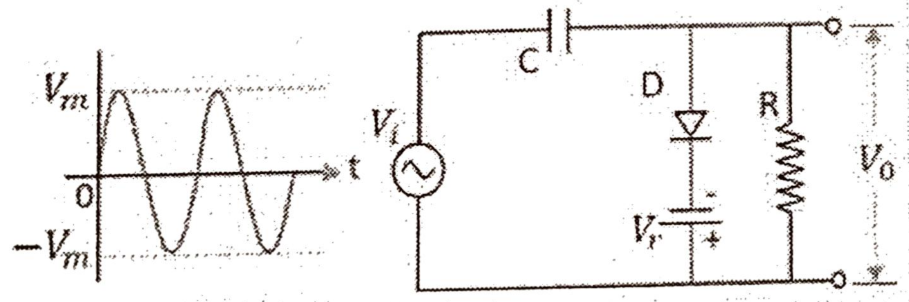


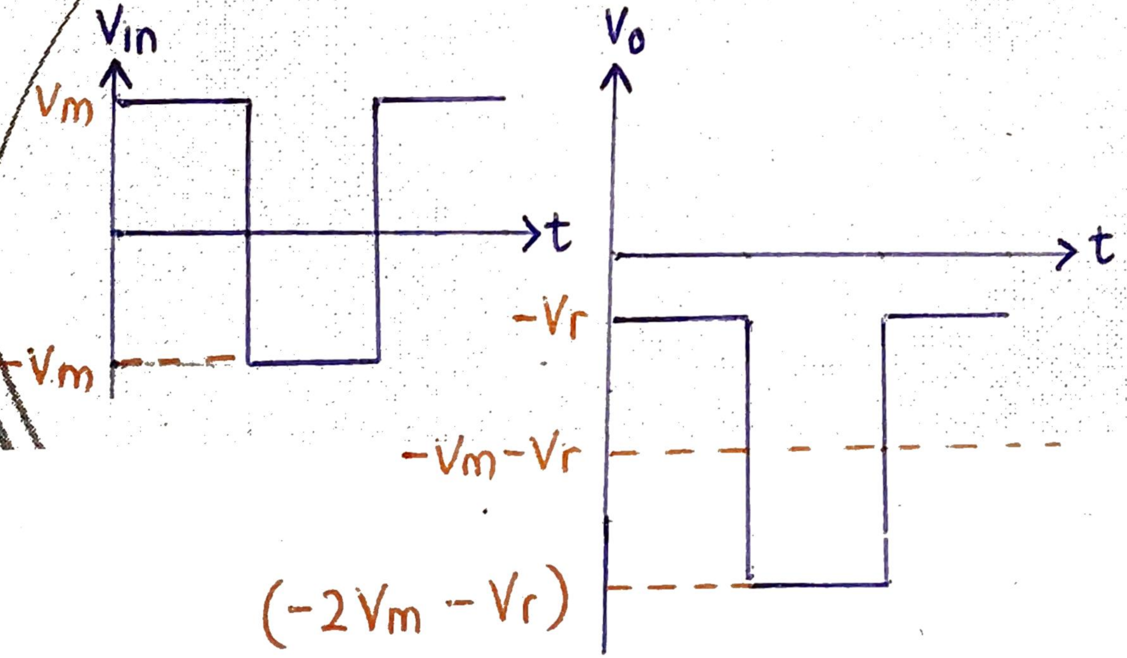


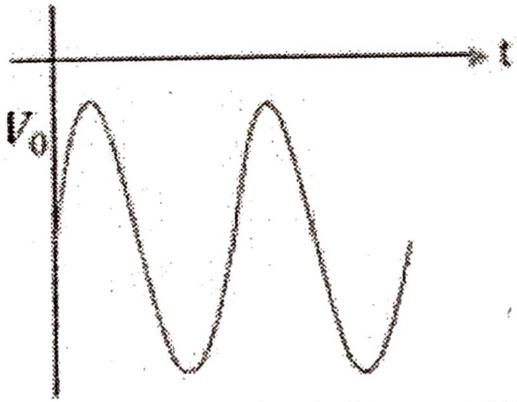




6. Negative Clamper with Negative V_r



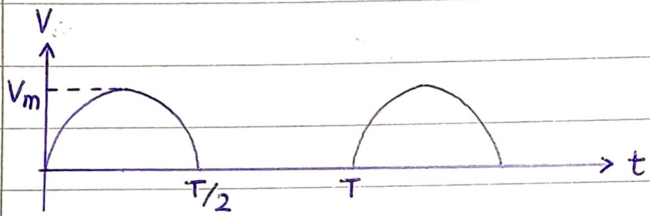




DATE

Ripple factor

Ripple factor of Half wave rectifier



$$\text{Ripple Factor } (r) = \frac{V_{r\,rms}}{V_{dc}} = 1.21$$

$$V^2_{rms} = V^2_{r\,rms} + V^2_{dc} \qquad V_{dc} = \frac{V_m}{\pi}$$

$$V_{rms} = \sqrt{V^2_{r\,rms} + V^2_{dc}} \qquad V_{rms} = \frac{V_m}{2}$$

$$V_{r\,rms} = \sqrt{V^2_{rms} - V^2_{dc}}$$

$$= \sqrt{\frac{V_m^2}{4} - \frac{V_m^2}{\pi^2}}$$

$$V_{r\,rms} = V_m\sqrt{\frac{1}{4} - \frac{1}{\pi^2}} = 0.386\,V_m$$

$$r = \frac{V_{r\,rms}}{V_{dc}} = \frac{0.386\,V_m}{V_m/\pi} = 1.211$$

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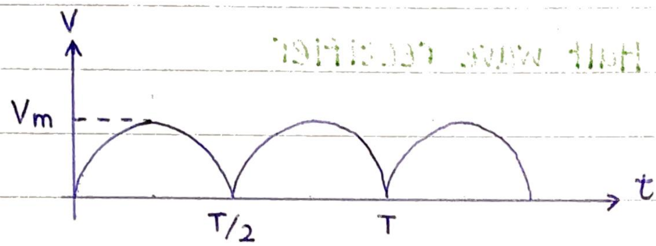
Ripple factor of Full wave rectifier



Ripple factor (r) $= \dfrac{V_{rrms}}{V_{dc}} = 0.483$

$$V_{rrms} = \sqrt{V_{rms}^2 - V^2_{dc}}$$

$$V_{dc} = \frac{2V_m}{\pi}$$

$$= \sqrt{\frac{V_m^2}{2} - \frac{4V_m^2}{\pi^2}}$$

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

$$= V_m\sqrt{\frac{1}{2} - \frac{4}{\pi^2}}$$

$$V_{rrms} \simeq 0.308\ V_m$$

$$r = \frac{V_{rrms}}{V_{dc}}$$

$$= \frac{0.308\ V_m}{2V_m/\pi}$$

$$= 0.483$$

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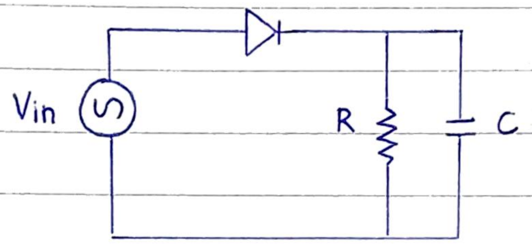
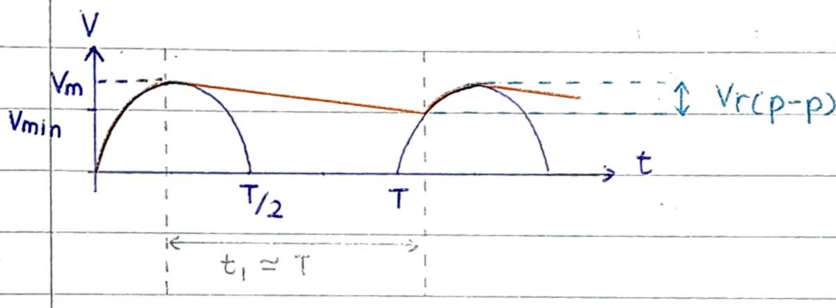
Half wave rectifier with RC filter





Voltage across the capacitor during discharging

$$V_{C(t)} = V_m e^{-t/RC}$$

$$V_{min} = V_m e^{-T/RC}$$

$$= V_m \left(1 - \frac{T}{RC}\right) \qquad (RC \gg T)$$

$$V_{max} = V_m$$

$$V_{r(p-p)} = V_{max} - V_{min}$$

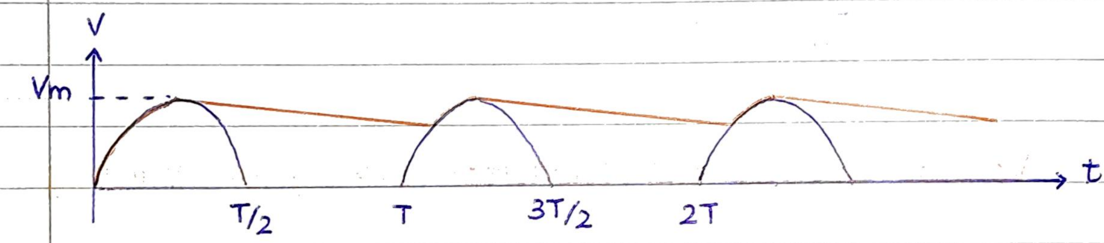
$$V_{r(p-p)} = V_m - V_m + V_m \frac{T}{RC}$$

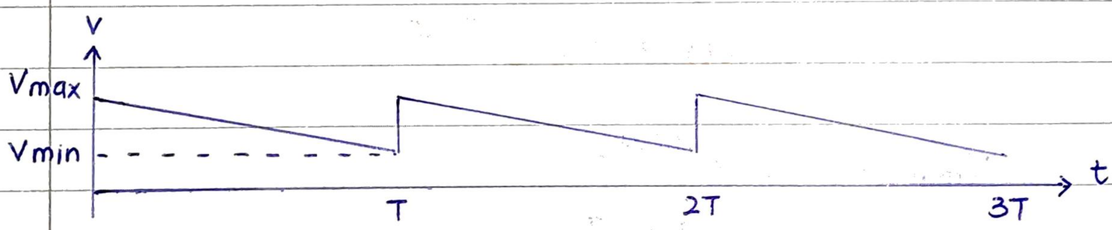
$$V_{r(p-p)} = \frac{V_m T}{RC} = \frac{V_m}{fRC}$$

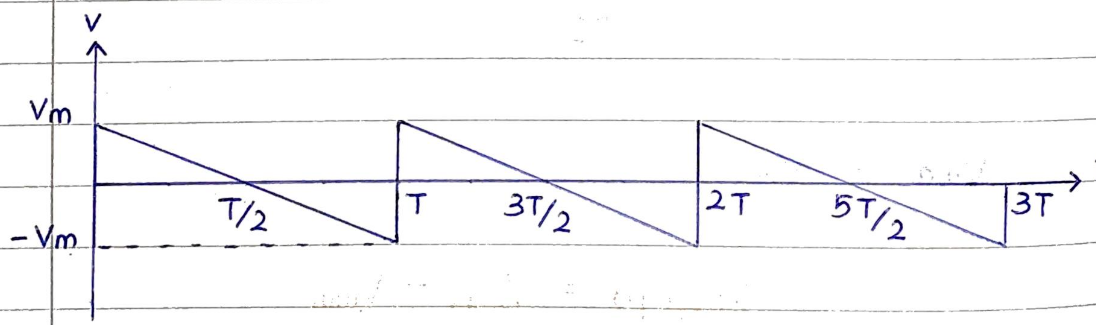
$$V_{dc} = V_m - \frac{V_{r(p-p)}}{2}$$

$$\therefore \quad V_{r(p-p)} = \frac{V_{dc}}{RfC} \qquad I_{dc} = \frac{V_{dc}}{R}$$

$$V_{r(p-p)} = \frac{I_{dc}}{fC}$$







$$V(t) = V_m - \frac{2V_m}{T} \times t \quad ; \quad 0 < t < T$$

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$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V^2(t)\,dt}$$

$$V^2_{rms} = \frac{1}{T/2}\int_0^{T/2} V^2(t)\,dt$$

$$= \frac{2}{T}\int_0^{T/2}\left(V_m - \frac{2V_m}{T}\times t\right)^2 dt$$

$$= \frac{2V_m^2}{T}\int_0^{T/2}\left[1 - \frac{4t}{T} + \frac{4t^2}{T^2}\right] dt$$

$$= \frac{2V_m^2}{T}\left[t - \frac{2t^2}{T} + \frac{4t^3}{3T^2}\right]_0^{T/2}$$

$$= \frac{2V_m^2}{T}\left[\frac{T}{2} - \frac{T}{2} + \frac{T}{6}\right]$$

$$V^2_{rms} = \frac{V_m^2}{3}$$

$$\boxed{V_{rms} = \frac{V_m}{\sqrt{3}}} \longrightarrow V_{rms} = \frac{2V_m}{2\sqrt{3}}$$

$$\boxed{V_{rms} = \frac{V_{r(p-p)}}{2\sqrt{3}}}$$

$$r = \frac{V_{r\,rms}}{V_{dc}}$$

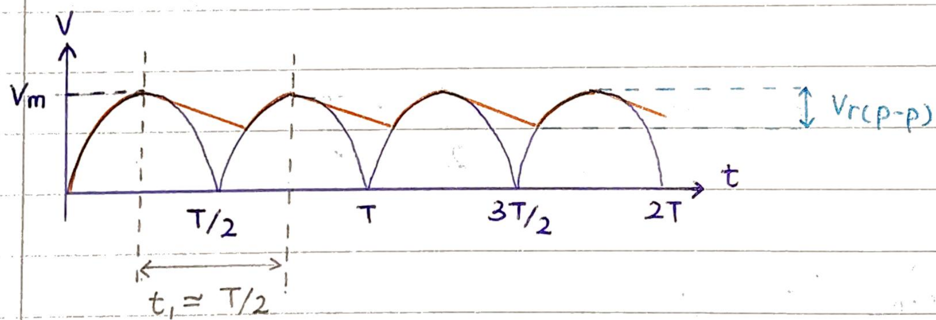
$$= \frac{V_{r(p-p)}/2\sqrt{3}}{V_m - \frac{V_{r(p-p)}}{2}}$$

$$= \frac{\left(\frac{V_m}{2\sqrt{3}Rfc}\right)}{V_m - \frac{V_m}{2fRC}} \quad (RC >>> T)$$

$$\frac{V_m}{2fRC} \to 0$$

$$\boxed{r = \frac{1}{2\sqrt{3}Rfc}}$$

Full wave rectifier with RC filter



$$V_{c(t)} = V_m e^{-t/RC}$$

$$V_{min} = V_m e^{-T/2RC}$$

$$V_{min} = V_m \left(1 - \frac{T}{2RC}\right)$$

$$V_{max} = V_m$$

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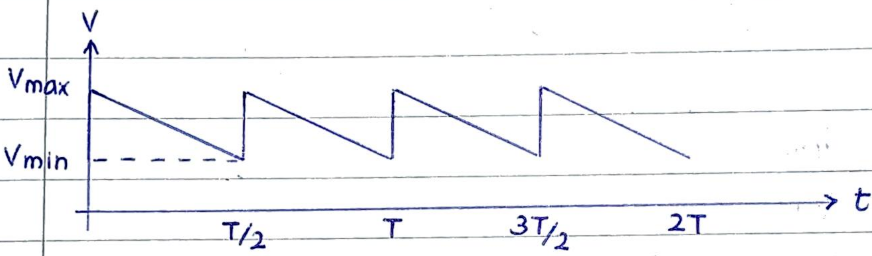
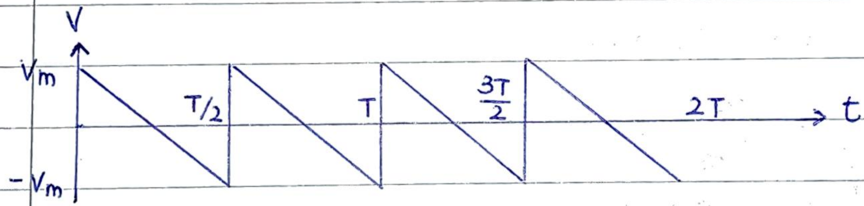
$$V_{r(p-p)} = V_{max} - V_{min}$$

$$= V_m - V_m + \frac{V_m T}{2RC}$$

$$\boxed{V_{r(p-p)} = \frac{V_m}{2fRC}} \qquad V_{r(p-p)} = \frac{I_{dc}}{2fC}$$





$$V(t) = V_m - \frac{4V_m}{T} \times t \qquad 0 < t < T/2$$

$$V^2_{rms} = \frac{1}{T/4} \int_0^{T/4} V^2(t)\, dt$$

$$= \frac{4}{T} \int_0^{T/4} \left(V_m - \frac{4V_m t}{T} \right)^2 dt$$

$$= \frac{4}{T} \int_0^{T/4} V_m^2 \left(1 - \frac{8t}{T} + \frac{16t^2}{T^2} \right) dt$$

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$$V^2_{rms} = \frac{4V_m^2}{T}\left[\frac{T}{4} - \frac{4}{T}\left(\frac{T}{4}\right)^2 + \frac{16}{3T^2}\left(\frac{T}{4}\right)^3\right]$$

$$= \frac{4V_m^2}{4}\left[1 - 1 + \frac{1}{3}\right]$$

$$V_{rms} = \frac{V_m}{\sqrt{3}} = \frac{V_{r(p-p)}}{2\sqrt{3}}$$

$$r = \frac{V_{rrms}}{V_{dc}}$$

$$= \frac{V_{r(p-p)}/2\sqrt{3}}{V_m - \frac{V_{r(p-p)}}{2}}$$

$$= \frac{\left(\frac{V_m}{2\sqrt{3}fRC}\right)}{\left(V_m - \cancel{\frac{V_m}{2fRC}}^{\,0}\right)}$$

$$\boxed{r = \frac{1}{4\sqrt{3}fRC}}$$

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