MODULE 1

Module - 1

Semiconductor diodes and Applications

SYLLABUS:

p-n junction diode, Equivalent circuit of diode,

Zener Diode, Zener diode as a voltage regulator,

Rectification-Half wave, Full wave – Bridge & centre tapped rectifier,

Capacitor filter circuit (2.2, 2.3, 2.4 T1).

Photodiode, LED, Photocoupler (2.7.4, 2.7.5, 2.7.6 Tl)

78XX series and 7805 Fixed IC voltage regulator (8.4.4 and 8.4.5 of Tl)

TEXTBOOKS:

T1."Basic Electronics", D.P. Kothari, I. J. Nagrath, McGraw Hill Pvt Ltd, 2014.

T2. "Electronic Devices", Thomas L Floyd, Pearson Education, 9th edition 2012

The pn junction – formation and working

This shall be studied under three headings as givenbelow .

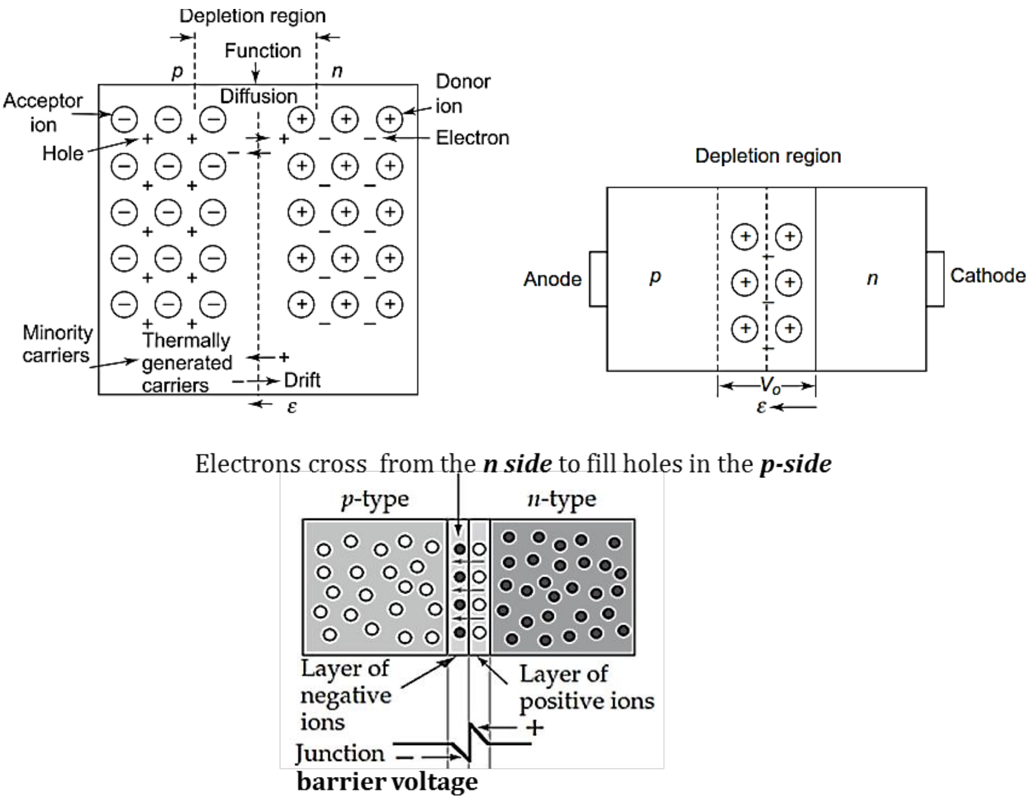
FORMATION:

1. A pn junction is formed by joining a *p-type* and ***n-type*** semiconductor. The holes are the majority charge carriers in ***p-type*** and electrons in the ***n-type*** semiconductor.
2. The majority charge carriers are **uniformly distributed in the semiconductor**.
3. Majority holes from P side diffuse into N side and vice versa as shown in Fig.1.1.

JUNCTION FORMATION AND MOVEMENT

1. The movement of majority charge carriers across the junction is called as **DIFFUSION** from a region of high carrier concentration to a region of low carrier concentration.
2. When the -ve ions are created on the ***p-type*** due to diffusion, the portion close to the junction on ***p-type*** acquires a -ve voltage. Similarly when the +ve ions are created on the n-type, the portion close to the junction on ***n-type*** acquires a +ve voltage.
3. The negative voltage on ***p-type*** repels additional electrons crossing the junction and the +ve voltage on ***n-type*** repels the additional holes crossing the junction.
4. The electric field set up by the +ve and -ve ions by diffusion of charge carriers prevents further flow of electrons and holes creating a potential difference at the junction known as **BARRIER VOLTAGE.**
5. The ***magnitude of barrier voltage depends on doping densities, electronic charge and junction temperature.***
6. The barrier voltage opposes the flow of majority carriers across the junction but assists the flow of minority carriers across the junction in in opposite direction, known as a DRIFT CURRENT.

.



7. Fig.1.1: pn junction

DEPLETION REGION

1. A region is known as **DEPLETION REGION** ***that is depleted of charge carriers is formed because of the movement of majority charge carriers across the junction that leaves a layer on each side where no charge carriers/free electrons and holes are present..***
2. On *n-type* the depletion region consists of donor impurity and on ***p-type*** the depletion region consists of acceptor impurity.
3. If the semiconductors have equal doping densities, then the depletion layers on each side have same widths.
4. It is to be noted that, In steady-state, there is no net current flow across the junction.

Summary - p–n junction

1. The majority holes from P-side **diffuse** into N-side and vice versa.
2. Recombination of electrons and holes in a narrow region on both sides of the junction results in uncovered fixed positive ions on N-side and fixed negative ions on P-side. This is the **depletion region** where no free electrons and holes are present.
3. The electric field set up by the positive and negative ions prevents further flow of electrons and holes – called **Barrier Potential**.
4. The electric field causes the movement of minority carriers in opposite direction, a **drift current.**
5. In steady-state, there is no net current flow across the junction.

Biased junction - Operation

When an external voltage is applied to a pn junction, the pn junction is said to be biased.

Forward-biased junction

1. When the positive terminal is connected to ***p-type*** and negative terminal to n-type, the electrons from the ***n-type*** are repelled from the -ve terminal and holes from the ***p-type*** are repelled from the +ve terminal as shown in Fig.1.2.
2. *This reduces the width of the depletion region and the barrier potential.*
3. When the *applied bias voltage increases the barrier voltage decreases* and it disappears. *The majority charge carriers can easily flow across the junction.*

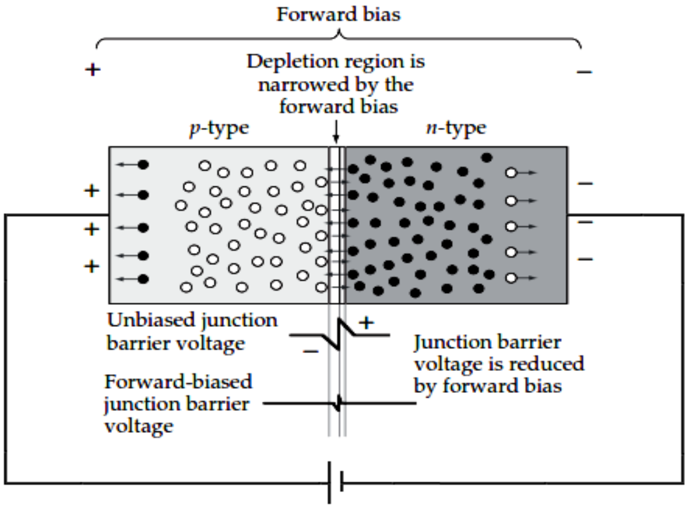


Fig.1.2: pn junction under forward bias

4. A majority charge carrier current flows and the junction is said to be forward biased.
5. *Increase in the bias voltage further from zero after the* **knee** *of the characteristics the barrier potential is overcome and allows more majority charge carriers to flow across the junction, causing a very large current for very small increments in input voltage.*

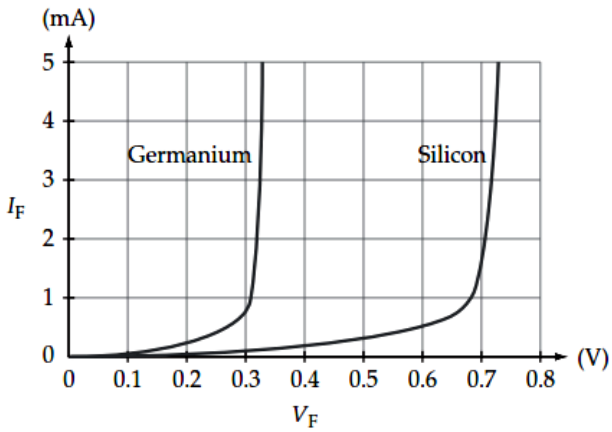


Fig.1.3: Forward -bias characteristics Si and Ge

Reverse-biased junction

1. When positive terminal connected to ***n-type*** and negative terminal to ***p-type***, the electrons from ***n-type*** are attracted to the +ve terminal and holes from the ***p-type*** are attracted to the -ve terminal as shown in Fig.1.4.
2. **This widens the depletion region and the barrier voltage increases**.
3. When barrier voltage increases there is no possibilities of majority carrier current flow across the junction and the **junction is said to be reverse biased and has a high resistance.**

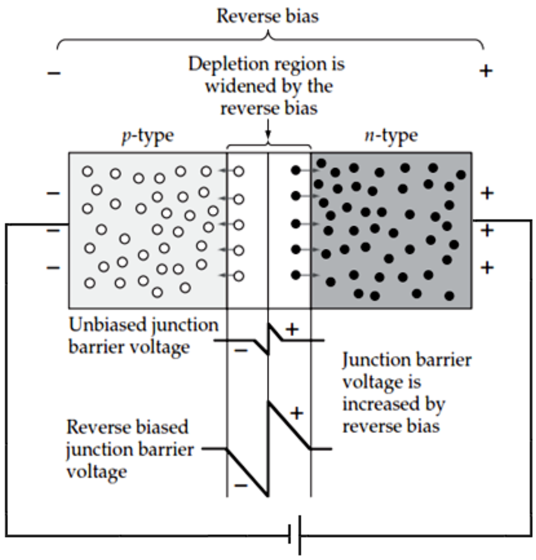


Fig.1.4: pn junction under Reverse bias

4. The *minority carriers on each side can still cross the junction or DRIFT* and their movements across the junction results in a small reverse current but stays at the saturation level.
5. ***Increase in the bias voltage further does not increase the current*** level and this current is known as **REVERSE SATURATION CURRENT due to DRIFT**, which is almost of negligible order (nA for Si and uA for Ge).

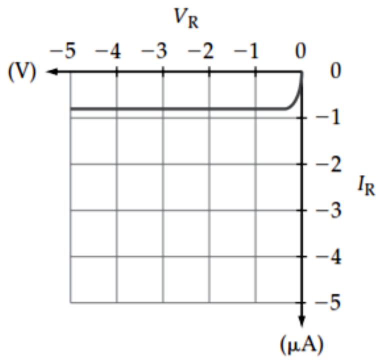


Fig.1.5: Reverse bias junction and characteristics

Summary - biasing of a p–n junction

1. A p–n junction is forward biased when **p is connected to the +ve and n to the –ve** terminal of the supply **(P-P N-N).** The **majority charge carriers current** is established **in a forward-biased** p–n junction.
2. The **depletion layer width narrows down** on application of **forward voltage**.
3. Barrier potential for Germanium is 0.3 V and for silicon is 0.7 V at room temperature. These are the voltage drops across the p–n junction when current flows.
4. When **p-connected to the -ve and n connected to the +ve** terminal of the supply, the p–n junction is said to be reverse biased **(P-N N-P).** A minutely **small**

current flows through a **reverse-biased** p–n junction due to the **minority charge carriers.**

5. The **width of the depletion layer, & the barrier potential increases** when the **junction is reverse** biased.
6. A **forward-biased** p–n junction offers ALMOST **NO resistance** to current flow while a **reverse-biased** junction offers **VERY HIGH resistance**.

LINKS TO VIDEOS

Introduction to Semiconductors https://www.youtube.com/watch?v=qAhqWeKcUAE
p-n junction diode forward and reverse biased https://www.youtube.com/watch?v=Coy-WRCfems
https://www.youtube.com/watch?v=USrY0JspDEg
Introduction to Diode: V-I characteristics of the Diode:
https://www.youtube.com/watch?v=EdUAecpYVWQ

pn-junction diode as a switch

1. A junction can be used as a switch, i.e. ON when forward biased and **OFF** when reverse biased.
2. A pn-junction provided with copper wire connecting leads becomes an electronic device known as diode.
3. The circuit symbol for a diode is an *arrowhead and a bar*. The arrowhead indicates the direction of current flow when the diode is forward bias as shown in the Fig.1.6.
4. The ***p-type*** of the diode is always the +ve terminal for forward bias and is termed as anode. The ***n-type*** of the diode is always the -ve terminal for forward bias and is termed as cathode.

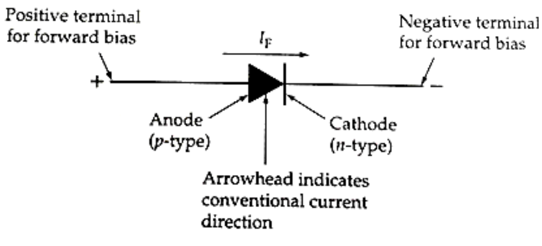


Fig.1.6: pn-junction diode

Diode relationship and VI characteristics

$$I_D = I_0\left(e^{(k\,V_D)/T_k} - 1\right)$$

where = I_0 is the reverse saturation current

k = 11,600/η *Botzman's constant* η=1 for Ge and η=2 for Si for low current, below the knee of the curve and η=1 for both Ge and Si for higher level of current beyond the knee

$T_k = T_C + 273°$, and

T_C = operating temperature (25°C)

The plots of Eq. (14.1) for Ge and Si diodes are drawn to scale in Fig. 14.5. The sharply rising part of the curve extended downward meets the VD axis, which is indicated

V_γ= V suffix **Gamma -** offset, threshold or firing potential

One may assume I_D= 0 up to V_T and then increases almost linearly at a sharp slope. The values of V_T are

V_γ =0.7V for Si diode

V_γ =0.3 V for Ge diode

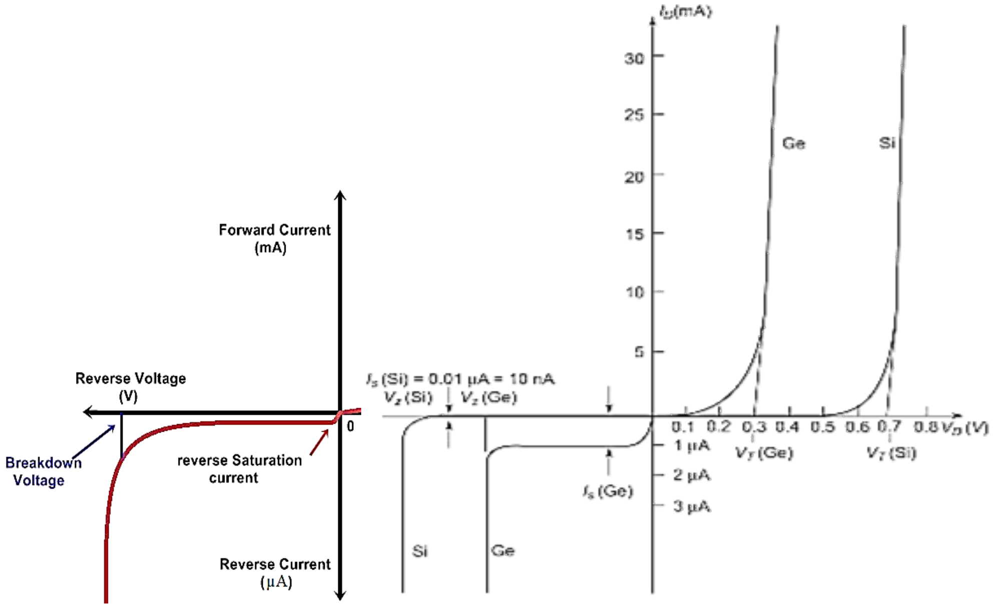


Fig.1.7: Si and Ge - pn junction diode characteristics

Problem

An Si diode has I_s = 10 nA operating at 25°C. Calculate I_D for a forward bias of 0.6 V.

Solution We take $\eta = 2$

$$T_k = 25° + 273° = 298°$$

$$k = \frac{11{,}600}{2} = 5{,}800$$

$$kV_D/T_k = \frac{5800 \times 0.6}{298} = 11.68$$

$$e^{11.68} = 117930$$

Then $I_D = 10\,(117930 - 1) = 50 \times 0.117929 \times 10^6$ nA

$= 0.586$ mA, negligible.

This justifies the choice of $\eta = 2$

Note: The diode is to conduct current much larger than this value.

So $I_D = 0.586$ mA may be approximated as zero.

Diode parameters

The diode parameters required for the construction of diode characteristics are

i. Forward voltage drop (V_F)

ii. Maximum forward current ($I_{F(max)}$)

iii. Reverse breakdown voltage (V_{BR})

i. Reverse saturation current (I_o)

ii. Dynamic resistance (r_d)

Knee Voltage / Forward Voltage (V_F also): Forward voltage drop at a given temperature is defined as the maximum forward voltage of the diode for a specific forward current, it is also given by the relation,

$$Forward\ Voltage\ Drop = \frac{Power\ Dissipated}{Forward\ DC\ Current} = \frac{P_D}{I_F}$$

Maximum Forward Current (I_{Fmax}) : Every diode has a maximum value of forward current that may be passed continuously through the diode safely is known as maximum forward current, if this value is exceeded, then the diode is destroyed due to excessive heat.

Reverse Saturation Current (I_o) : It is the maximum reverse current that flows through a reverse biased P-N junction at a given temperature, this current is only due to MINORITY CARRIERS, by DRIFT action its value is <1µA for silicon and around 100 µA for germanium diodes.

Reverse Breakdown Voltage (V_{BR}): It is the maximum reverse voltage applied at which the P-N junction breaks down and reverse current rises sharply. This critical value of voltage is known as **breakdown voltage**. Breakdown voltage is around 50V for Germanium diode and 75V for Silicon diode.

Power Dissipation (P_D): The power dissipated in a diode for a given value of diode voltage (V_D) and current (I_D) $\boldsymbol{P_D = I_D * V_D}$

Static Resistance / DC Resistance (R_{DC}): It is the opposition offered by the P-N junction to the flow of DC current when in forward bias, it is measured by taking a ratio of DC voltage across diode to the resulting DC current through it. It is given by, $\boldsymbol{R_{DC} = \frac{V_F}{I_F}}$ R_{DC} varies from 40Ω to 70Ω.

1. **Calculate the forward and reverse resistances offered by a silicon diode with I_F = 100mA, V_F = 0.75V and V_R = 50V, I_R = 1µA.**

   Forward resistance is given by : $R_F = \frac{V_F}{I_F} = \frac{0.75}{100m} = 7.5\Omega$

   Reverse resistance is given by : $R_R = \frac{V_R}{I_R} = \frac{50}{1\mu} = 500M\Omega$

Dynamic Resistance (r_d) : Dynamic resistance also called incremental resistance for a diode at a given temperature is the reciprocal of the slope of the forward characteristics, given by $r_d = \left.\frac{\Delta V_F}{\Delta I_F}\right|_{at\ a\ given\ temperature\ maintained\ constant,\ or\ from\ the\ diode\ VI\ characteristics}$

ΔV_F is the change in the forward voltage and ΔI_F is the change in the forward current.

Also for any temperature T at which the junction is maintained,

$$r_{d\,at\ T} = \left.\frac{26mV}{I_F}\left(\frac{T + 273^0C}{298^0C}\right)\right|_{for\ Si}$$

Volt equivalent for Si =26mV at room temperature

r_d is often very small – few ohms

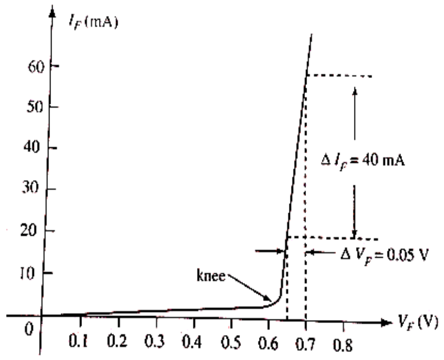


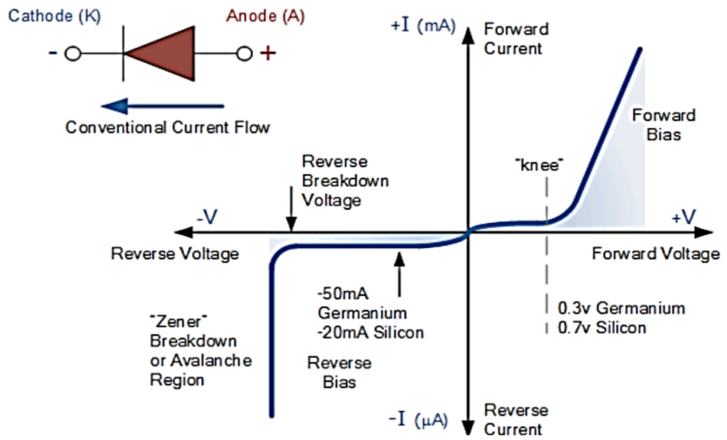
Fig.1.8: pn junction diode characteristics

Peak inverse voltage: It the maximum voltage that a diode can withstand in the reverse direction without breaking down. If this voltage is exceeded the diode may be destroyed. Diodes must have a peak inverse voltage rating that is higher than the maximum voltage that will be applied to them in a given application.

Maximum power rating: It is defined as the maximum power that a diode can dissipate without damaging it is called maximum power rating. Usually, maximum power rating is specified by the manufacturer in its data sheet. The power dissipated at the junction is equal to the product of junction current and the voltage across the junction. If the power developed across the junction is more than the maximum power dissipated by it, the junction will be over-heated and may be destroyed.

LINKS TO VIDEOS
Diode Resistance Explained (DC, AC and Average AC Resistance):
https://www.youtube.com/watch?v=hag5ss1ZxH0

Types of Break down



Zener Region As the reverse-bias voltage is raised, the diode breaks down at voltage **Vν** by **AVALANCHE PHENOMENON**.

- The maximum negative voltage that a diode can withstand at Peak Inverse Voltage (PIV rating). The avalanche breakdown occurs when a **very high reverse voltage** is applied across the diode.
- As the applied reverse voltage increases, the electric field across the junction increases, it exerts a **FORCE ON THE ELECTRONS AT THE JUNCTION AND FREES THEM FROM COVALENT BONDS.** These free electrons start moving with

high velocity across the junction and collide with the other atoms, thus creating more free electrons.

- This results in the rapid increase in net current. Both kinds of breakdowns occur in Zener diodes. The avalanche breakdown occurs because of the ionisation of electrons and hole pairs whereas the Zener breakdown in zener diode occurs because of heavy doping.

Zener Breakdown **HEAVY DOPING** of the N and P-regions can result in **low breakdown voltage** of just a few volts —10 V, —5 V. This mechanism of breakdown is different from avalanche and the type of diode called **zener** diode.

- When connected at a point in an electronic circuit, it does not allow the potential there to exceed the diode rated voltage.
- When the diode is reverse biased, the **KINETIC ENERGY OF THE ELECTRONS INCREASES** and they move at higher velocities colliding with other atoms giving rise to free electrons.
- These free electrons, in turn, give rise to a very high value of reverse saturation current. This is Zener breakdown.

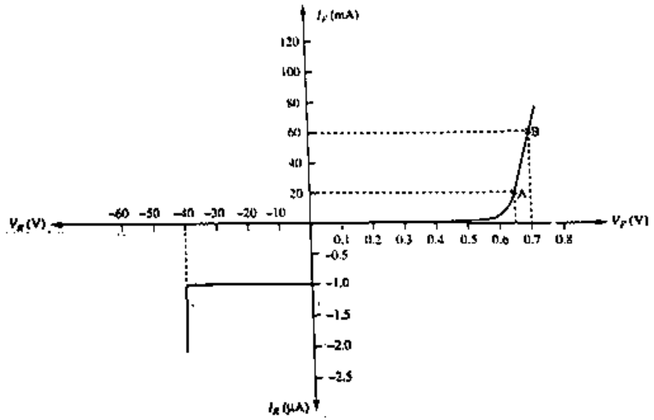
COMPARISON TABLE OF AVLANCHE ND ZENER BREAKDOWN

Avalanche Breakdown	Zener Breakdown
1. The process of applying **high voltage and increasing the free electrons** or electric current in semiconductors and insulating materials, by breaking **COVALENT BONDS**	The process in which the **electrons move across the barrier** from the valence band of p-type material to the conduction band of n-type material
2. Breakdown voltages much greater than 10 volts.	Zener breakdown voltage of 5 to 8 volts.
3. The valence electrons are pushed to conduction due to the energy imparted **by accelerated electrons,** which gain their velocity due to their collision with other atoms.	The valence electrons are pulled into conduction due to the high electric field **in the narrow depletion region.**
4. The increase in temperature **increases** the breakdown voltage.	The increase in temperature **decreases** the breakdown voltage.
5. The VI characteristic curve of the avalanche breakdown is not as sharp as the Zener breakdown.	The VI characteristics of a Zener breakdown has a sharp curve.
6. DEPLETION REGION : THICK - It occurs in diodes that are lightly doped.	THIN DEPLETION REGION Because It occurs in diodes that are **highly doped.**
7. Junction destroyed after breakdown as thr	Junction isn't destroyed, rather re used many times after breakdown
8. Positive temperature coefficient – breakdown voltage increases with temperature	-ve temperature coefficient – breakdown voltage decreases with temperature
9. Ionization occurs because of collision	Ionization occurs because of electric field

LINKS TO VIDEOS

Avalanche Breakdown and Zener Breakdown Effect (detailed) : *https://www.youtube.com/watch?v=EzlSafjMltc*

1. **Plot the forward and reverse characteristics of a diode for the following data**
    a. **Forward voltage drop = 0.6V**
    b. **Reverse breakdown voltage = 40V**
    c. **Reverse saturation current = 1µA**
    d. **Forward current = 20mA at a forward voltage of 0.65V**
    e. **Forward current = 60mA at a forward voltage of 0.7V**



Determine the dynamic resistance at a forward current of 40mA for the diode characteristics given in the Fig.1.8

$$r_d = \frac{\Delta V_F}{\Delta I_F} = \frac{0.05}{40m} = 1.25\Omega$$

Diode approximation - Equivalent circuit:

- Equivalent circuit of a device is a proper *combination of electrical elements like voltage source, current source, resistor etc to represent* the actual terminal characteristics.
- Diodes are one way devices, offering a low resistance when forward biased and a high resistance when reverse biased. Equivalent circuit for a diode can be obtained by approximating the VI characteristics by straight line segments.
- There are **3 types of equivalent circuits or approximations**

1. Ideal diode approximation

- Diodes are one way devices, offering a low resistance when forward biased and a high resistance when reverse biased.
- An **ideal diode** (or perfect diode) would have **zero forward resistance** and zero forward voltage drop. It would also have an **infinitely high reverse resistance,** which would result in zero reverse current.

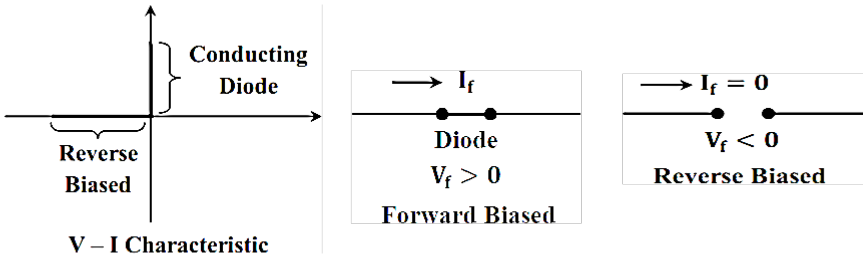


Fig.1.9: Ideal diode approximation: characteristics and equivalent circuit

2. Practical diode approximation

- Although an ideal diode does not exist, diodes can be assumed to be near-ideal devices with forward voltage drop and are called as **practical diodes.**
- For silicon diode the forward drop is 0.7V and Germanium - forward drop is 0.3V

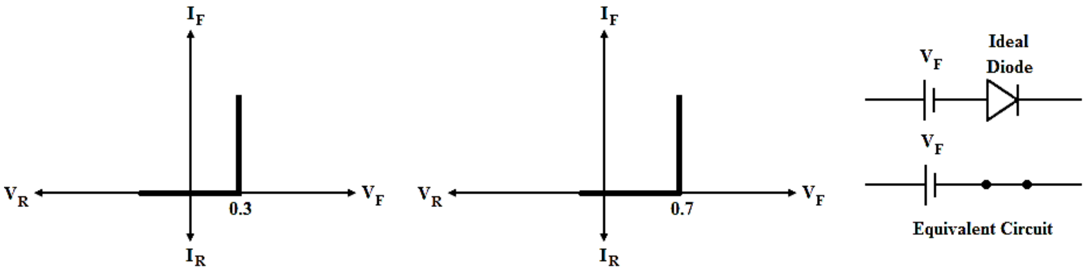
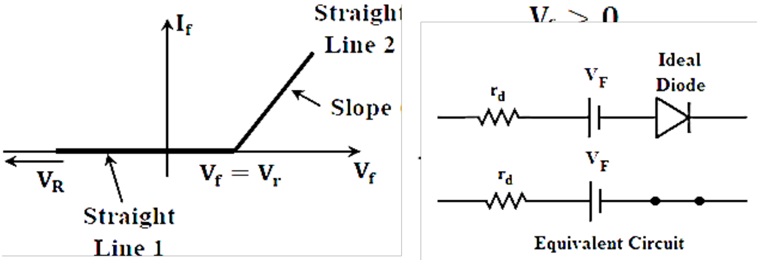


Fig.1.10: Practical diode approximation: characteristics and equivalent circuit

3 Piecewise Linear approximation

- When a forward characteristics of a diode is not available a straight line approximation called piecewise linear characteristics can be used.
- In a forward bias, diode is assumed to have a constant forward voltage drop (V_F) and negligible series resistance (dynamic resistance).
- To construct a piecewise linear characteristics, V_F is marked first on the horizontal axis (point X). Then from V_F a straight line is drawn with a **slope equal to (1/r_d) r_d -the diode dynamic resistance**



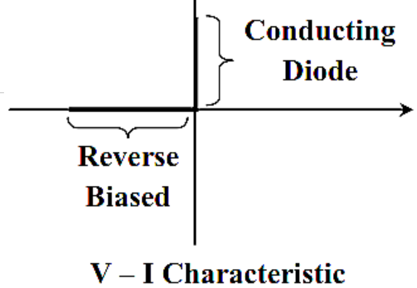


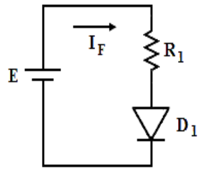
Fig.1.11: Piecewise linear approximation: characteristics and equivalent circuit

LINKS TO VIDEOS

Ideal Vs Practical Diode : https://www.youtube.com/watch?v=WX0xQWRTPjs

Problems:

1.	**Calculate the diode current for the given circuit having a silicon diode with a resistance of 4.7kΩ and E = 15V**



Applying KVL to the circuit we get : $\mathbf{E = I_F R_1 + V_F}$ (V_F= voltage drop across diode)

The diode current is taken on one side to get $\mathbf{I_F = \frac{E - V_F}{R_1}} = \frac{15-0.7}{4.7K}$

$$\mathbf{I_F = 3.04mA}$$

2. Calculate the diode current for the circuit given before having a silicon diode with a resistance of 1kΩ and E = 12V

Apply KVL on the circuit we get $E = I_F R_1 + V_F$

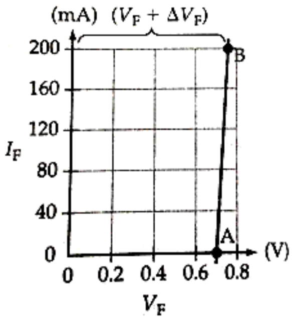
The diode current is got as $I_F = \frac{E-V_F}{R_1}$ $I_F = \frac{12-0.7}{1K}$

$$\mathbf{I_F = 11.3mA}$$

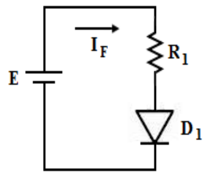
3. Construct a piecewise linear characteristics for a silicon diode which has a 0.25Ω dynamic resistance and a 200mA maximum forward current.

$r_d = \frac{\Delta V_F}{\Delta I_F}$ re arranging we get $\Delta V_F = r_d * \Delta I_F$ Hence - $\Delta V_F = 200m * 0.25 = 0.05V$

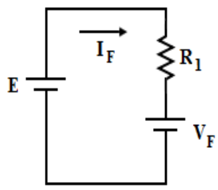
- To draw the piecewise linear characteristics mark point A at V_F = 0.7V on the horizontal axis
- At 200mA mark point B at V_F = 0.7V + 0.05V = 0.75V on the horizontal axis
- The piecewise linear characteristics for the given problem is as shown in the Figure below.



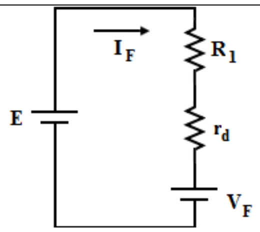
4. Calculate I_F for the diode in the given circuit assuming that V_F = 0.7V, E = 1.5V, R_1 = 10Ω and r_d = 0. What is the current if we consider r_d = 0.25Ω



- Equivalent circuit of the diode when dynamic resistance is neglected is obtained by replacing diode with a voltage cell with a voltage V_F = 0.7V



- Applying KVL on the equivalent circuit when r_d = 0 we get
  $E = I_F R_1 + V_F$ re arranging - $I_F = \frac{E-V_F}{R_1} = \frac{1.5-0.7}{10} = \mathbf{80mA}$
- Equivalent circuit of the diode with a dynamic resistance is obtained by replacing diode with a voltage cell with a voltage V_F = 0.7V and dynamic resistance r_d.

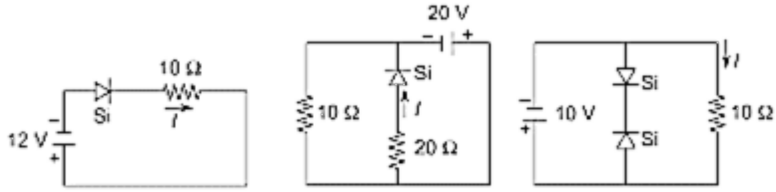


- Applying KVLon the equivalent circuit when r_d = 0.25Ω we get

$$E = I_F R_1 + I_F r_d + V_F$$

$$I_F = \frac{E - V_F}{R_1 + r_d} = \frac{1.5 - 0.7}{10 + 0.25} = \mathbf{78mA}$$

5. For the diode in the circuits given below , find I



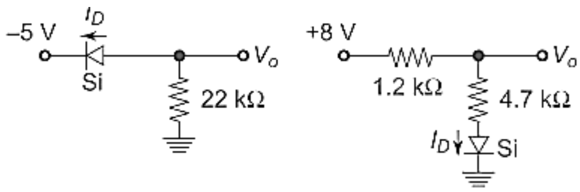
(a) (b) (c)

a. Reverse biased by 12 V hence doesn't conduct **I=0**

b. Voltage across thediode here is 20V independent of 10 ohm res. Diode conducts as per the equivalent circuit, we have I=$\frac{20-0.7}{20}$=**0.965A**

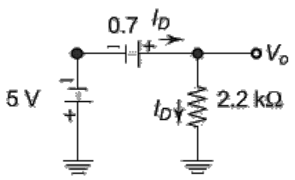
c. Both diodes are in opposition hence no current flows in left loop, I=$\frac{10}{10} = \mathbf{-1A}$

6. For the following ckts determine I_D and V_o using the approximate model



(a) (b)

a) Re drawing we get



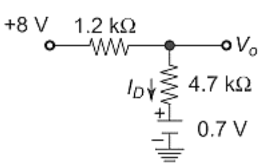
$$I_D = \frac{5-0.7}{2.2} = \frac{4.3}{2.2} = 1.95 \text{ mA}$$

$$V_o = 2.2\, I_D = 2.2 \times \frac{4.3}{2.2} = 4.3 \text{ V}$$

or directly,

$$V_o = 5 - 0.7 = 4.3 \text{ V}$$

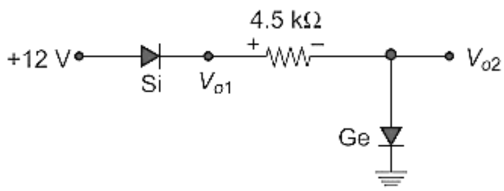
b) Redrawing :



$$I_D = \frac{8-0.7}{1.2+4.7} = \frac{7.3}{5.9} = 1.237 \text{ mA}$$

$$V_o = 4.7 \times 1.237 + 0.7 = 6.51 \text{ V}$$

7. For the network determine V_{o1} & V_{o2} using the approximate model

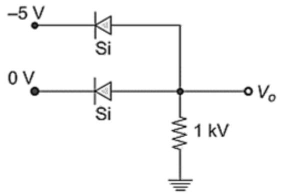


$$V_{o2} = 0.3 \text{ V or } V_T(\text{Ge}) = 0.3 \text{ V when conducting}$$

$$V_{o1} = 12 - 0.7 = 11.3 \text{ V}$$

Note the result does not depend on 4.5 kΩ.

8. **Determine V_o** for the negative logic OR gate



For given input voltages we see that

only top diode conducts V_0=-5+0.7=-4.3V

Rev biased lower diode remains OFF

Now we give -5V to any or both inputs we get an output of -4.3 V (HIGH)

Output becomes Zero if noth inputs are given 0 volts

LINKS TO VIDEOS

PROBLEM: HOW TO SOLVE THE DIODE CIRCUITS: https://www.youtube.com/watch?v=jkEVGQ2lneI
Diode Equivalent Circuits: https://www.youtube.com/watch?v=06Or9jeeZPM
PROBLEM: SERIES DIODE CONFIGURATION : https://www.youtube.com/watch?v=rl9FdHTVOWY
PROBLEM: PARALLEL AND SERIES-PARALLEL CONFIGURATION OF DIODES : https://www.youtube.com/watch?v=4D0it39f2lQ

Rectifiers

- A rectifier is an electrical device that converts an Alternating Current (AC) into a Direct Current (DC) by using one or more P-N junction diodes.
- The rectifiers are mainly classified into two types:
  i. Half wave rectifier
  ii. Full wave rectifier
- Half wave rectifiers use one diode, while a full wave rectifier uses multiple diodes.

Half-wave rectifier

- Half-wave rectifiers allows only one half-cycle (+ve half-cycle) of the AC voltage through it and will block the other half-cycle (-ve half-cycle) of the AC voltage as shown in the Fig.1.12.

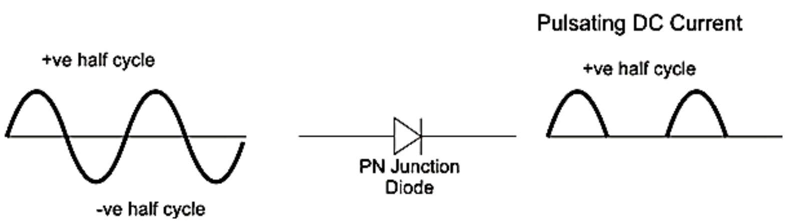


Fig.1.12: Half wave rectifier operation

Operation of a half wave rectifier

- Fig.1.13 shows the circuit diagram of a rectifier using a step down transformer.

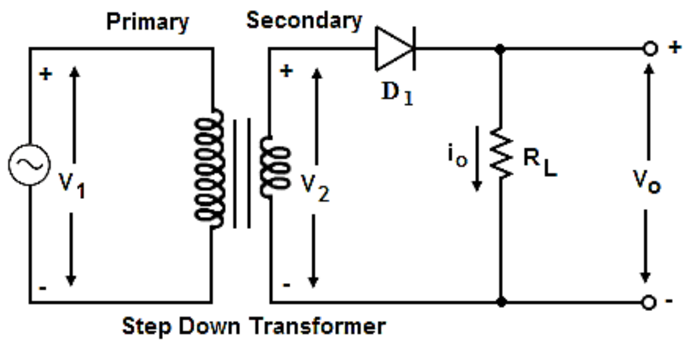


Fig.1.13: Half-wave rectifier

- The step down transformer reduces the AC supply voltage to the required level.
- The AC voltage to be rectified is applied across the primary of the transformer and the voltage across the secondary of the transformer is available for rectification.
- Half-wave rectifier rectifies only one half cycle of the AC input.
- Let the voltage applied across the primary of the transformer be $\mathbf{v_1 = V_m sin\omega t}$

  where $\mathbf{V_m}$ is the peak value
- The voltage across the secondary of the transformer available for rectification is given by

  $\mathbf{v_2 = \frac{N_2}{N_1} V_m sin\omega t}$ where $\frac{N_2}{N_1}$ is the turns ratio of the transformer

  N_1: number of turns in the primary coil
  N_2: number of turns in the secondary coil
- **If $N_2 = N_1$** $\mathbf{v_2 = V_m sin\omega t}$

Half wave rectifier waveforms

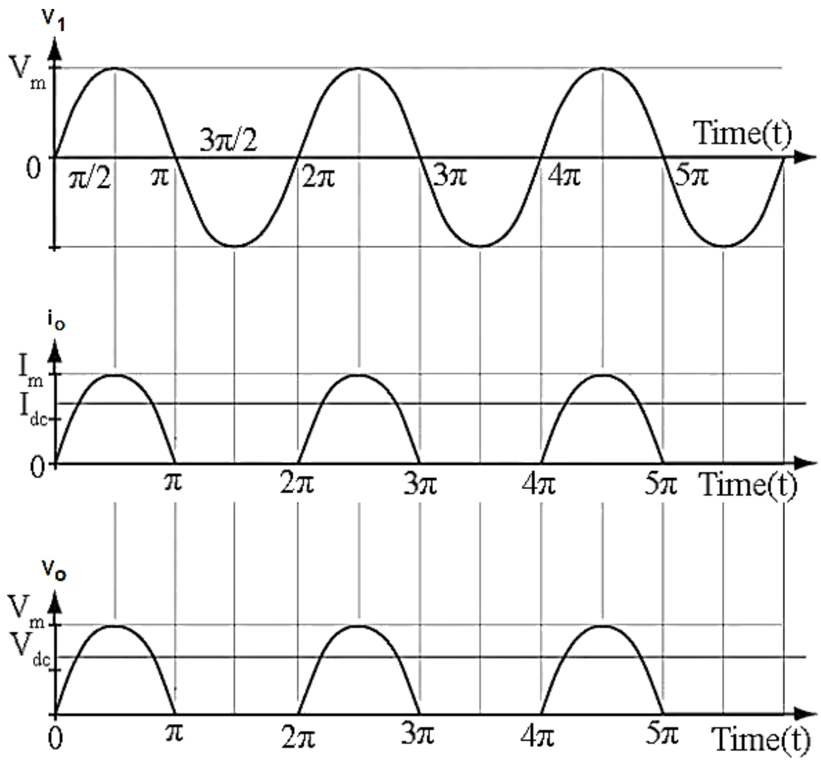


Fig.1.14: Half-wave rectifier waveform

- During the +ve half cycle the diode conducts and the current $\mathbf{i_o}$ flows through the load. The load voltage $\mathbf{v_o = i_o R_L}$.
- During the -ve half cycle the diode gets reverse biased and the current $\mathbf{i_o}$ is zero. The load voltage $v_o = 0$.

Hence during a total cycle the output waveform has only 1 +ve sinusoidal waveform corresponding to the time when the diode turns ON

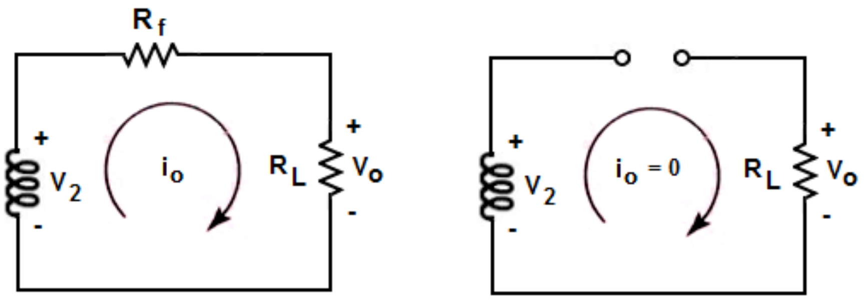


Fig.1.15: Equivalent circuit to find half-wave rectifier current

- From the circuit shown in the Fig.1.15 $\mathbf{i_o = \frac{v_2}{R_f+R_L}}$

$$i_o = \frac{V_m \sin\omega t}{R_f + R_L}$$

$$\boxed{i_o = I_m \sin\omega t}$$

Where $I_m = \frac{V_m}{R_f+R_L}$ is the peak load current

Average DC load current

$$I_{DC} = \frac{\text{Area under one cycle of } i_o}{\text{Period of } i_o}$$

$$I_{DC} = \int_0^{2\pi} i_o d\omega t \Big/ 2\pi \quad = \quad \int_0^{2\pi} \frac{I_m \sin\omega t \, d\omega t}{2\pi}$$

$$I_{DC} = \frac{1}{2\pi}\left[\int_0^{\pi} I_m \sin\omega t \, d\omega t + \int_{\pi}^{2\pi} 0 \, d\omega t\right]$$

$$I_{DC} = \frac{I_m}{2\pi}[-\cos\omega t]_0^{\pi}$$

$$\boxed{\mathbf{I_{dc} = \frac{I_m}{\pi}}}$$

Average DC load voltage

$$V_{DC} = I_{DC} R_L$$

$$V_{DC} = \left(\frac{I_m}{\pi}\right) R_L = \frac{1}{\pi}\left(\frac{V_m}{R_f+R_L}\right) R_L$$

$$V_{DC} = \frac{V_m}{\pi}\left(\frac{R_L}{R_f+R_L}\right) = \left(\frac{V_m/\pi}{\frac{R_f+R_L}{R_L}}\right)$$

$$\mathbf{V_{dc}} = \left(\frac{\mathbf{V_m/\pi}}{\mathbf{1+\frac{R_f}{R_L}}}\right)$$

RMS load current

$$I_{RMS} = \sqrt{\frac{\text{Area under one cycle of } i_o^2}{\text{Period of } i_o}}$$

$$I_{RMS} = \sqrt{\int_0^{2\pi}\frac{i_o^2 d\omega t}{2\pi}} = \sqrt{\frac{1}{2\pi}\left[\int_0^{\pi} I_m^2 \sin^2\omega t\, d\omega t + \int_{\pi}^{2\pi} 0\, d\omega t\right]}$$

$$I_{RMS} = I_m\sqrt{\frac{1}{2\pi}\int_0^{\pi}\frac{1}{2}(1-\cos 2\omega t)\, d\omega t + 0} = I_m\sqrt{\frac{1}{4\pi}\left[\int_0^{\pi} d\omega t - \int_0^{\pi}\cos 2\omega t\, d\omega t\right]}$$

$$I_{RMS} = \frac{I_m}{2}\sqrt{\frac{1}{\pi}\left[(\omega t)_0^{\pi} - \left(\frac{\sin 2\omega t}{2}\right)_0^{\pi}\right]} = \frac{I_m}{2}\sqrt{\frac{1}{\pi}\left[(\pi-0) - \frac{1}{2}(\sin 2\pi - \sin 0)\right]}$$

$$\mathbf{I_{rms}} = \frac{\mathbf{I_m}}{\mathbf{2}}$$

RMS load voltage

$$V_{RMS} = I_{RMS} R_L$$

$$V_{RMS} = \left(\frac{I_m}{2}\right) R_L = \frac{1}{2}\left(\frac{V_m}{R_f+R_L}\right) R_L$$

$$\mathbf{V_{rms}} = \frac{\mathbf{V_m/2}}{\mathbf{1+\frac{R_f}{R_L}}}$$

Rectifier efficiency

The ratio of the DC output power to the AC input power supplied to the rectifier.

denoted by η_r. $\quad \eta_r = \frac{P_{dc}}{P_i}$

- DC output power is given by $\mathbf{P_{dc} = I_{dc}^2 R_L}$

  For half wave rectifier, I_{DC} is given by $\mathbf{I_{dc} = \frac{I_m}{\pi}}$

  DC output power can be expressed as $P_{DC} = \frac{I_m^2}{\pi^2} R_L$

- AC input power is given by $P_i = I_{RMS}^2 (R_f + R_L)$

  For half wave rectifier, I_{RMS} is given by $\mathbf{I_{rms} = \frac{I_m}{2}}$

Therefore AC input power is $$\mathbf{P_i = \frac{I_m^2}{4}(R_f + R_L)}$$

- Therefore efficiency can be expressed as

$$\mathbf{\eta_r = \frac{\frac{I_m^2}{\pi^2}R_L}{\frac{I_m^2}{4}(R_f + R_L)} = \frac{0.406R_L}{(R_f + R_L)}}$$

$$\eta_r = \frac{0.406}{\frac{(R_f + R_L)}{R_L}} = \frac{0.406}{1 + \frac{R_f}{R_L}}$$

$$\%\eta_r = \frac{40.6}{1 + \frac{R_f}{R_L}}$$

If diode is ideal, $R_f = 0$ then

$$\%\boldsymbol{\eta}_{\mathbf{r\ max}} = \mathbf{40.6}$$

Ripple factor

The ratio of RMS value of AC component present in the rectified output to the DC component of the rectified output. It is denoted by γ

$$\boldsymbol{\gamma} = \frac{V_{AC}}{V_{DC}}$$

- The output of the rectifier is a pulsating DC and has two component
  1. AC component of RMS value V_{AC}
  2. DC component V_{DC}
- Total power output is the sum of powers of DC and ac components

$$\begin{bmatrix}\text{total RMS value of}\\ \text{rectifed output}\end{bmatrix}^2 = [\text{DC value}]^2 + \begin{bmatrix}\text{RMS value of}\\ \text{AC component}\end{bmatrix}^2$$

$$V_{RMS}^2 = V_{DC}^2 + V_{AC}^2$$

- Dividing throughout by V_{DC}^2 we get

$$\mathbf{\frac{V_{RMS}^2}{V_{DC}^2} = 1 + \frac{V_{AC}^2}{V_{DC}^2}} \quad \text{implies} \quad \left(\frac{V_{RMS}}{V_{DC}}\right)^2 = 1 + \left(\frac{V_{AC}}{V_{DC}}\right)^2 \quad | \quad \text{but} \frac{V_{AC}}{V_{DC}} = \gamma$$

$$\left(\frac{V_{RMS}}{V_{DC}}\right)^2 = 1 + \gamma^2 \quad \text{rearranging we get} \quad \gamma^2 = 1 - \left(\frac{V_{RMS}}{V_{DC}}\right)^2$$

$$\therefore \boldsymbol{\gamma} = \sqrt{\left(\frac{\mathbf{V_{RMS}}}{\boldsymbol{V_{DC}}}\right)^2 - \mathbf{1}}$$

we know that $\mathbf{V_{RMS} = \frac{V_m/2}{1+\frac{R_f}{R_L}}}$ and $\mathbf{V_{DC} = \left(\frac{V_m/\pi}{1+\frac{R_f}{R_L}}\right)}$, hence by substitution we get

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

$$\boxed{\therefore \gamma_{HWR} = 1.21}$$

$$\gamma = 1.21 = \frac{V_{AC}}{V_{DC}}$$

$$\mathbf{V_{ac} = 1.21V_{dc}}$$

Clearly we see that in the half wave rectifier the AC or the ripple component is 121% of the DC component, which is much more than the acceptable levels..

Hence half wave rectifier is NOT recommended for practical applications.

Peak Inverse Voltage

The maximum REVERSE voltage that can be applied for the diode.

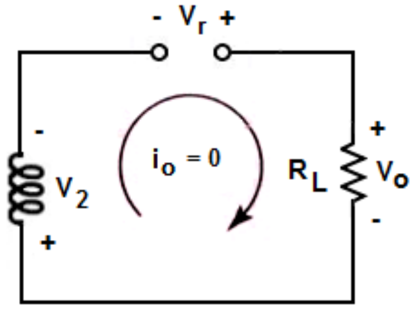


Fig.1.16: Equivalent circuit to find Peak Inverse Voltage

- Applying KVL in the above figure $\mathbf{v_2 - v_r + i_o R_L = 0}$
- since $i_o = 0$ we infer $v_r = v_2 = V_m \sin\omega t$

  hence $PIV = V_{r\,max} = V_m$ when $\sin\omega t = 1$

For a HWR circuit, as during reverse bias the max voltage appearing across it is the entire secondary voltage – the diode chosen should be such that it can withstand the given value of $\mathbf{V_m}$, and still operate.

LINKS TO VIDEOS

Half wave Rectifier Explained: https://www.youtube.com/watch?v=Ll0IOk_Ltfc

Problems

1. A sinusoidal voltage of peak value 40V and frequency 50Hz is applied to a half wave rectifier having a load resistor of 800Ω and R_f of the diode is 8Ω. Calculate

  a. Peak, DC and RMS value of load current
  b. DC output power
  c. ac input power
  d. rectifier efficiency

Peak current is given by $I_m = \frac{V_m}{R_f+R_L} = \frac{40}{8+800} = \mathbf{49.5mA}$

DC current is given by $I_{DC} = \frac{I_m}{\pi} = \frac{49.5m}{\pi} = \mathbf{15.75mA}$

RMS current is given by $I_{rms} = \frac{I_m}{2} = \frac{49.5m}{2} = \mathbf{24.75mA}$

DC output power is given by $\mathbf{P_{dc} = I_{dc}^2 R_L}$

$$P_{DC} = (15.75m)^2 * 800$$

$$\mathbf{P_{dc} = 198.45mW}$$

AC input power is given by $\mathbf{P_i = I_{rms}^2 (R_f + R_L)}$

$$P_i = (24.75m)^2 * (8 + 800)$$

$$\mathbf{P_i = 494.95mW}$$

Rectifier efficiency $\mathbf{\eta_r} = \frac{\mathbf{P_{dc}}}{\mathbf{P_i}} * 100\%$

$$\eta_r = \frac{198.45m}{494.95m} * 100\%$$

$$\mathbf{\eta_r = 40.09\%}$$

2. The input to a half wave rectifier is given through a 10:1 transformer from a supply of 230sin314t. If R_f = 50Ω and R_L = 500Ω determine

a. DC load voltage

b. RMS load voltage

c. PIV

d. rectifier efficiency

e. DC power delivered to load

f. freq of output waveform

Secondary voltage is given by $v_2 = \frac{N_2}{N_1} V_m \sin\omega t = \frac{1}{10} * 230\sin314t$

$$\mathbf{v_2 = 23\sin314t}$$

Frequency of the output waveform is given by $\mathbf{f = \frac{\omega}{2\pi}} = \frac{314}{2\pi}$ =**50Hz**

DC load voltage is given by $V_{DC} = \left(\frac{V_m/\pi}{1+\frac{R_f}{R_L}}\right) = \frac{23/\pi}{1+\frac{50}{100}}$ =**6.66V**

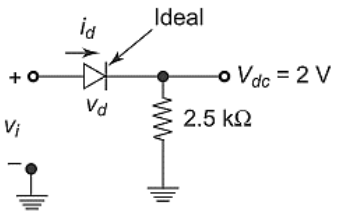
RMS load voltage is given by $V_{RMS} = \frac{V_m/2}{1+\frac{R_f}{R_L}} = \frac{23/2}{1+\frac{50}{100}}$ =**10.45V**

PIV ACross the diode is given by PIV = V_m = **23V**

DC output power is given by $P_{DC} = \frac{V_{DC}^2}{R_L} = \frac{(6.66)^2}{500}$ **P_dc=88.mW**

Rectifier efficiency $\%\eta_r = \frac{40.6}{1+\frac{R_f}{R_L}} = \frac{40.6}{1+\frac{50}{100}}$ =**36.91**

sketch v_i, v_d and i_d if the input is sinusoidal of 50 Hz. what if V_d =0,7V

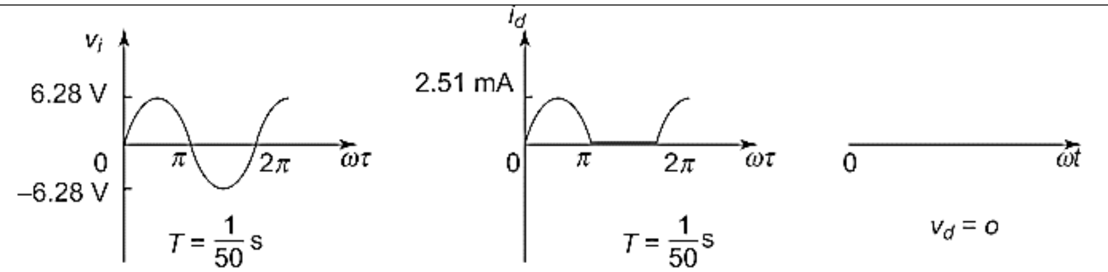


$$V_{dc} = \frac{V_m}{\pi} = 2\text{V}$$

$$v_i \text{ peak} = V_m = 2\pi \text{ V}$$

$$i_d \text{ peak} = I_m = \frac{2\pi}{2.5} = 2.51 \text{ mA}$$

$$v_d = 0, \text{ diode is ideal}$$



if the diode has $V_T = 0.7$ V.

$$v_d = \frac{V_m - V_T}{\pi} = 2 \text{ V, it is an approximation as output voltage is not exactly sinusoidal.}$$

$$v_i \text{ peak} = V_m = 2\pi + 0.7 = 6.98 \text{ V}$$

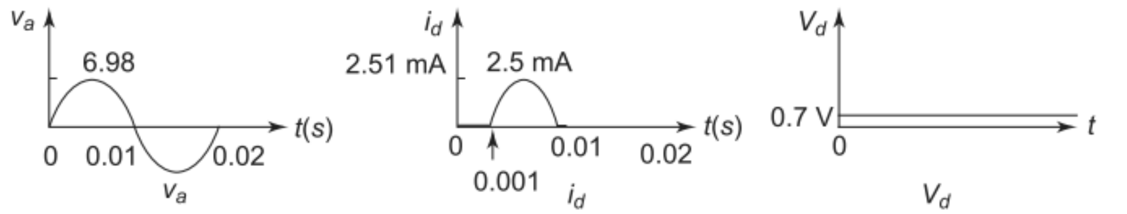
For $v_i < V_T = 0.7$ V, $i_d = 0$ at time t_1,

$$6.98 \sin 2\pi f t_1 = 0.7 \text{ V},$$

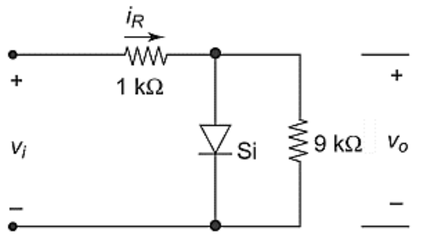
$$t_1 = 0.0011 \text{ s}$$

$$i_d \text{ peak}, I_m = \frac{V_m - V_T}{2.5} = \frac{2\pi}{2.5} = 2.51 \text{ mA}$$

v_i in sinusoidal with peak 6.98 V, $f = 50$ Hz



5. For a sinusoidal input of 10 V peak, sketch i_R and v_o in the network



For Si, $V_T = 0.7$ V

During positive half-cycle, the diode does not conduct up to 0.7 V.

$$v_i \Rightarrow 0 - 0.7 \text{ V}$$

$$v_o = \left(\frac{9}{10}\right) v_i$$

$$= 0.9\, v_i \text{ up to } 0.7 \text{ V}$$

$$i_R = 0.1\, v_i \text{ up to } 0.07 \text{ mA}$$

For $v_i \geq 0.7$ V, diode voltage remains constant on both halves of the cycle.

$$v_o = 0.7 \text{ V},$$

$$i_R = \frac{v_i - 0.7}{1}$$

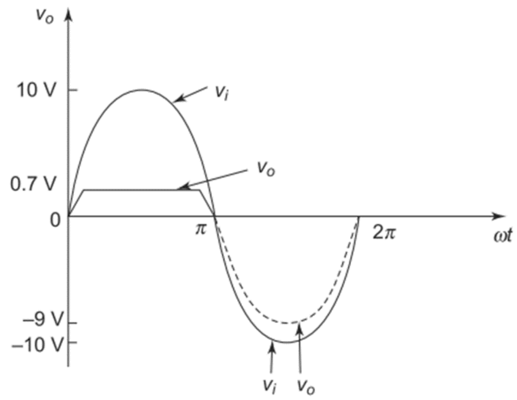
$$= (v_i - 0.7) \text{ mA}$$

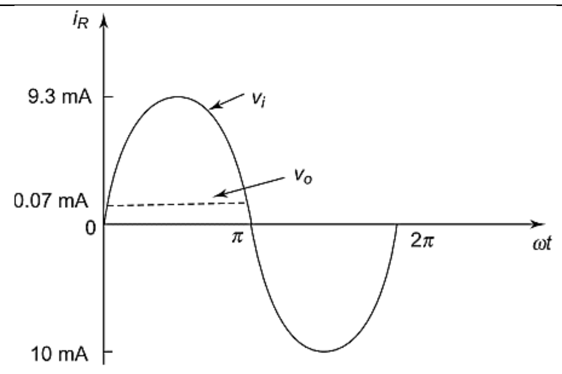
$$i_R \text{ (peak)} = (10 - 0.7) = 9.3 \text{ mA}$$

During negative half-cycle, the diode open circuits

$$i_R \text{ (peak)} = \frac{10}{1} = 10 \text{ mA}$$

$$v_o = 0.9\, v_i \text{ peak} = 9 \text{ V}$$





LINKS TO VIDEOS

Introduction to Rectifier : https://www.youtube.com/watch?v=Xmu31a-59vw
Half Wave Rectrifier (HWR) : https://www.youtube.com/watch?v=AspBbh_jOuk
RMS Load Voltage and Current : https://www.youtube.com/watch?v=XTfWAYuyfVU
Ripple Factors (RF): https://www.youtube.com/watch?v=SgK_kyIlbrk&t=152s
Effeciency and PIV: https://www.youtube.com/watch?v=XLBtAmcXYKA

Full wave rectifier - center-tapped – operation and waveforms

- The step down transformer reduces the AC supply voltage to the required level and the AC voltage to be rectified is applied across the primary of the transformer such that the voltage across the secondary is available for rectification.
- Full-wave rectifier rectifies both cycles of the ac input.
- Let **voltage applied across the primary** of the transformer be $\mathbf{v_1 = V_m sin\omega t}$
  where $\mathbf{V_m}$ is the peak value
- The voltage across the secondary of the transformer available for rectification is given by $\mathbf{v_2 = \frac{N_2}{N_1} V_m sin\omega t}$ where $\frac{N_2}{N_1}$ is the turns ratio of the transformer
- If $N_2 = N_1$ $v_2 = V_m sin\omega t$

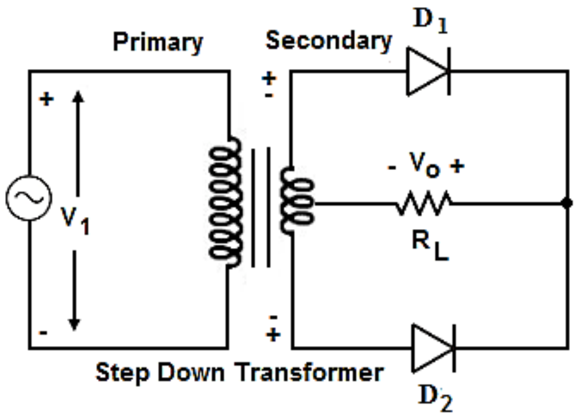


Fig.1.17: Full-wave rectifier

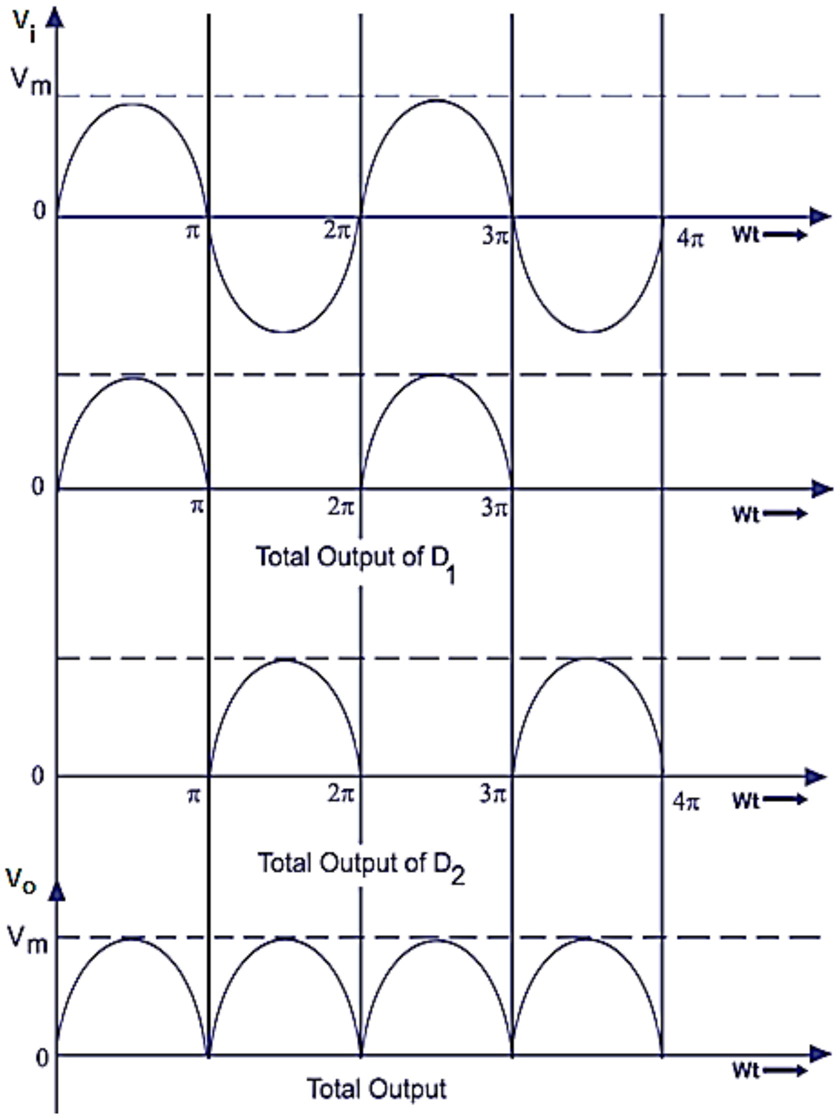


Fig.1.17: Full-wave rectifier waveform

- During the **positive half cycle diode D_1 conducts** and **diode D_2 remains OFF** and the current $\mathbf{i_o = i_{D1}}$ flows through the load. The load voltage $\mathbf{v_o = i_oR_L}$.
- During the **negative half cycle diode D_2 conducts and diode D_1 remains OFF** and the current $\mathbf{i_o = i_{D2}}$ flows through the load. The load voltage $\mathbf{v_o = i_oR_L}$.

Hence during a total cycle the output waveform has 2 positive sinusoidal waveforms as opposed to just one in a half wave rectifier HWR

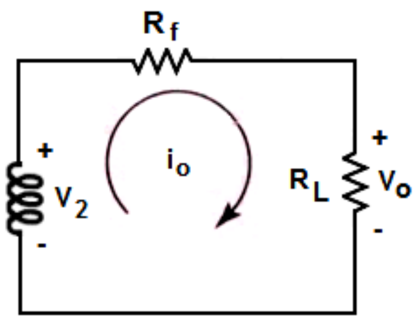


Fig.1.18: Equivalent circuit to find full-wave rectifier current

From the circuit shown in the Fig.1.18

$$i_o = \frac{v_2}{R_f+R_L} \quad = \frac{V_m \sin\omega t}{R_f+R_L}$$

$i_o = I_m \sin\omega t$ Where $I_m = \frac{V_m}{R_f+R_L}$ is the peak load current

Average DC load current

$$I_{dc} = \frac{\textbf{Area under one cycle of } i_o}{\textbf{Period of } i_o}$$

$$I_{DC} = \int_0^{\pi} \frac{i_o d\omega t}{\pi} \quad = \frac{1}{\pi}\int_0^{\pi} I_m \sin\omega t \, d\omega t$$

$$I_{DC} = \frac{I_m}{\pi}[-\cos\omega t]_0^{\pi}$$

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

Average DC load voltage

$$V_{dc} = I_{dc}R_L$$

$$V_{DC} = \left(\frac{2I_m}{\pi}\right)R_L \quad = \frac{2}{\pi}\left(\frac{V_m}{R_f+R_L}\right)R_L$$

$$V_{dc} = \frac{2V_m}{\pi}\left(\frac{R_L}{R_f+R_L}\right) \quad = \left(\frac{2V_m/\pi}{\frac{R_f+R_L}{R_L}}\right)$$

$$V_{dc} = \left(\frac{2V_m/\pi}{1+\frac{R_f}{R_L}}\right)$$

RMS load current

$$I_{RMS} = \sqrt{\frac{\textbf{Area under one cycle of } i_o^2}{\textbf{Period of } i_o}}$$

$$I_{RMS} = \sqrt{\frac{1}{\pi}\int_0^{\pi} i_o^2 d\omega t} \quad = \sqrt{\frac{1}{\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \, d\omega t}$$

$$I_{RMS} = I_m\sqrt{\frac{1}{\pi}\int_0^{\pi}\frac{1}{2}(1-\cos 2\omega t)\, d\omega t}$$

$$I_{RMS} = I_m\sqrt{\frac{1}{2\pi}\left[\int_0^{\pi} d\omega t - \int_0^{\pi}\cos 2\omega t \, d\omega t\right]}$$

$$I_{RMS} = I_m\sqrt{\frac{1}{2\pi}\left[(\omega t)_0^{\pi} - \left(\frac{\sin 2\omega t}{2}\right)_0^{\pi}\right]}$$

$$I_{RMS} = I_m\sqrt{\frac{1}{2\pi}\left[(\pi-0)-\frac{1}{2}(\sin 2\pi-\sin 0)\right]} = I_m\sqrt{\frac{1}{2\pi}\left[(\pi)-\frac{1}{2}(0)\right]} = I_m\sqrt{\frac{\pi}{2\pi}}$$

$$\mathbf{I_{RMS} = \frac{I_m}{\sqrt{2}}}$$

RMS load voltage

$$\mathbf{V_{RMS} = I_{RMS}R_L}$$

$$V_{RMS} = \left(\frac{I_m}{\sqrt{2}}\right)R_L = \frac{1}{\sqrt{2}}\left(\frac{V_m}{R_f+R_L}\right)R_L$$

$$\mathbf{V_{RMS} = \frac{V_m/\sqrt{2}}{1+\frac{R_f}{R_L}}}$$

Rectifier efficiency

The ratio of the DC output power to the AC input power supplied to the rectifier. denoted by η_r.

$$\boldsymbol{\eta_r = \frac{P_{dc}}{P_i}}$$

DC output power is given by $P_{DC} = I_{DC}^2 R_L$

For Full wave rectifier, I_{DC} is given by $I_{DC} = \frac{2I_m}{\pi}$

Hence DC output power becomes $P_{DC} = \frac{4I_m^2}{\pi^2}R_L$

AC input power is given by $P_i = I_{RMS}^2(R_f+R_L)$

For full wave rectifier, $\mathbf{I_{RMS}}$ is given by $\mathbf{I_{RMS} = \frac{I_m}{\sqrt{2}}}$

AC input power is hence : $P_i = \frac{I_m^2}{2}(R_f+R_L)$

Rectification efficiency hence becomes

$$\eta_r = \frac{\frac{4I_m^2}{\pi^2}R_L}{\frac{I_m^2}{2}(R_f+R_L)} = \frac{8}{\pi^2}\frac{R_L}{(R_f+R_L)} = \frac{0.812}{\frac{(R_f+R_L)}{R_L}} = \frac{0.812}{1+\frac{R_f}{R_L}}$$

$$\%\boldsymbol{\eta_r = \frac{81.2}{1+\frac{R_f}{R_L}}}$$

If diode are ideal, $R_f = 0$ then $\%\eta_{r\,max} = 81.2$

Ripple factor

The ratio of RMS value of AC component present in the rectified output to the DC component of the rectified output. It is denoted by $\boldsymbol{\gamma = \frac{V_{AC}}{V_{DC}}}$

The output of the rectifier is a pulsating DC and has two component

1. AC component of RMS value V_{AC}
2. DC component V_{DC}

Total power output is the sum of powers of DC and ac components

$$\begin{bmatrix}\text{total RMS value of} \\ \text{rectifed output}\end{bmatrix}^2 = [\text{DC value}]^2 + \begin{bmatrix}\text{RMS value of} \\ \text{AC component}\end{bmatrix}^2$$

$$\mathbf{V_{RMS}^2 = V_{DC}^2 + V_{AC}^2}$$

Dividing throughout by V_{DC}^2 we get

$$\frac{\mathbf{V_{RMS}^2}}{\mathbf{V_{DC}^2}} = \mathbf{1} + \frac{\mathbf{V_{AC}^2}}{\mathbf{V_{DC}^2}} \quad \text{implies} \quad \left(\frac{V_{RMS}}{V_{DC}}\right)^2 = 1 + \left(\frac{V_{AC}}{V_{DC}}\right)^2 \quad | \quad \text{but} \frac{V_{AC}}{V_{DC}} = \gamma$$

$$\left(\frac{V_{RMS}}{V_{DC}}\right)^2 = 1 + \gamma^2 \quad \text{rearranging we get} \quad \gamma^2 = 1 - \left(\frac{V_{RMS}}{V_{DC}}\right)^2$$

$$\therefore \boldsymbol{\gamma} = \sqrt{\left(\frac{\mathbf{V_{RMS}}}{\mathbf{V_{DC}}}\right)^2 - \mathbf{1}}$$

We know that. $V_{RMS} = \dfrac{V_m/\sqrt{2}}{1+\frac{R_f}{R_L}}$ and $V_{DC} = \left(\dfrac{2V_m/\pi}{1+\frac{R_f}{R_L}}\right)$ substituting these values in the equation we get $\boldsymbol{\gamma} = \sqrt{\left(\frac{\boldsymbol{\pi}}{\mathbf{2\sqrt{2}}}\right)^2 - \mathbf{1}}$

$$\boldsymbol{\gamma = 0.483}$$

$$\gamma = 0.483 = \frac{V_{AC}}{V_{DC}} \quad \text{hence} \quad V_{AC} = 0.483V_{DC}$$

INFERENCE :

In full wave rectifier the ripple component is 48.3% of the DC component. As the ripple content is less THAN the DC value **FWR gives more DC output voltage than a HWR**

Peak Inverse Voltage

the maximum reverse voltage that can be applied for the diode.

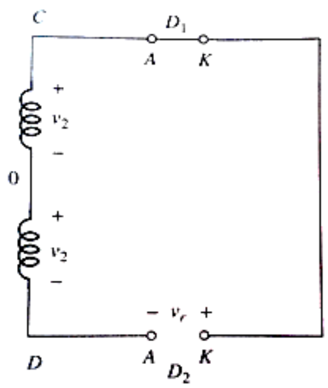


Fig.1.19: Equivalent circuit to find Peak Inverse Voltage

- Applying KVL to the circuit in Fig.1.19, we get, $v_2 + v_2 - v_r = 0$ where $v_2 = V_m \sin\omega t$

hence $\mathbf{v_r = 2v_2 = 2V_m \sin\omega t}$

$\boxed{\mathbf{PIV = v_{r\,max} = 2V_m}}$ when $\sin\omega t = 1$

- For a center tapped circuit, if any one diode doesn't conduct during reverse bias the max voltage appearing across it is **2 times the entire secondary voltage –** the diode chosen should be such that it can withstand the given value of **2*V_m**, **which is VERY MUCH below its PIV** and still operate, which is difficult to do .
- This is a draw back of centre tapped transformer based FWR

Full wave bridge rectifier – operation and waveform

- Fig.1.20 shows the circuit diagram of a full wave bridge rectifier. It uses FOUR diodes connected in the form of a bridge.
- The AC voltage to be rectified is applied across primary of the transformer and the voltage across the secondary is available for rectification.
- Full wave bridge rectifier rectifies BOTH cycles of the AC input.
- Let the voltage applied across the primary of the transformer be $\mathbf{v_1 = V_m sin\omega t}$ where $\mathbf{V_m}$ is the peak value
- The voltage across the secondary of the transformer available for rectification is given by $\mathbf{v_2 = \frac{N_2}{N_1} V_m sin\omega t}$ where $\frac{N_2}{N_1}$ is the turns ratio of the transformer
- If $N_2 = N_1$ $v_2 = V_m \sin\omega t$

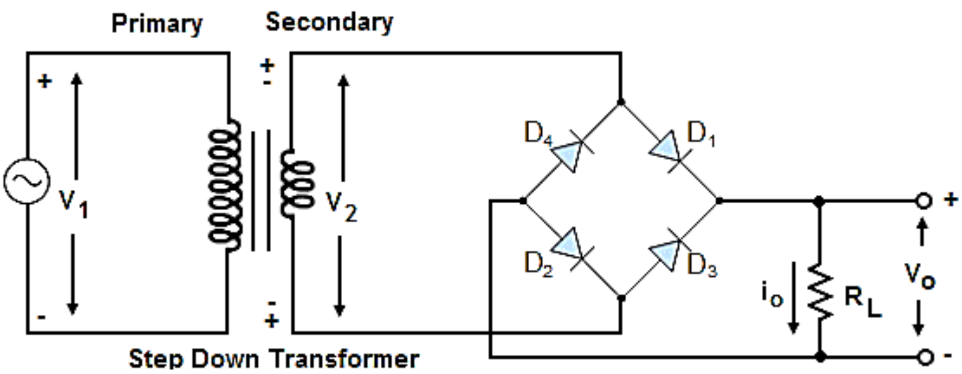


Fig.1.20: Full-wave bridge rectifier

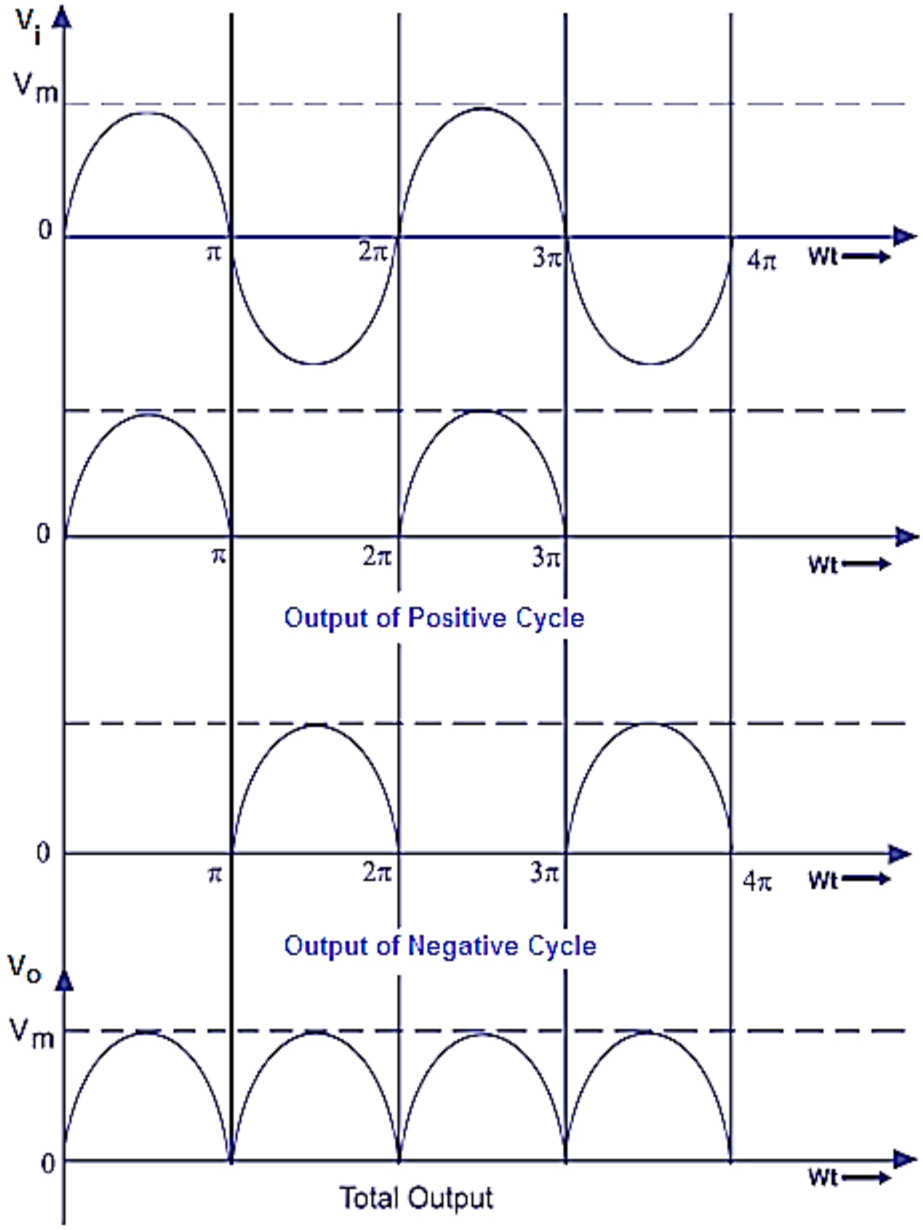


Fig.1.21: Full-wave bridge rectifier waveform

- During the **positive half cycle the diode D_1 and D_2 are forward biased** and **D_3 and D_4 are reverse biased** and the current $\mathbf{i_o = i_{D1} = i_{D2}}$ flows through the load. The load voltage $\mathbf{v_o = i_o R_L}$.

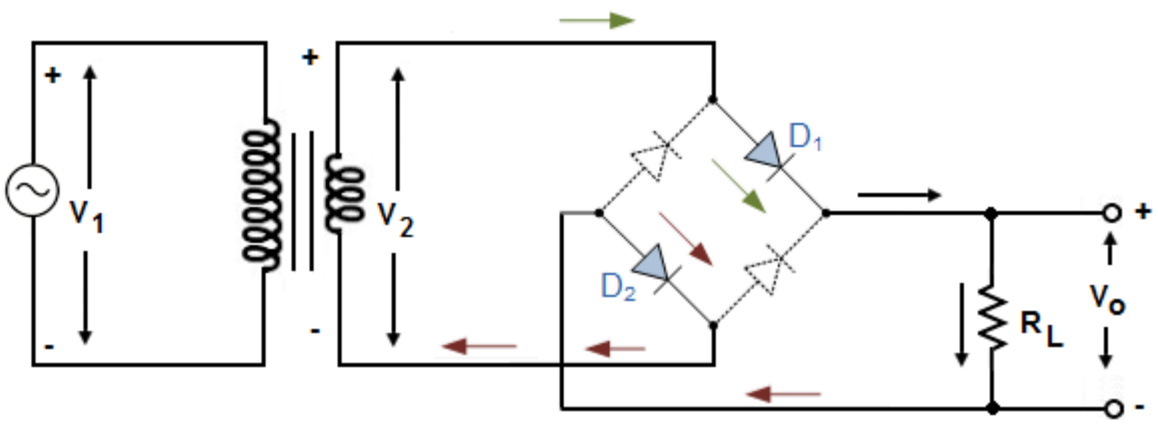


Fig.1.22: Equivalent circuit during positive cycle

- During the **negative half cycle the diode D_3 and D_4 are forward biased** and **D_1 and D_2 are reverse biased** and the **current $i_o = i_{D3} = i_{D4}$** flows through the load. The load voltage $v_o = i_oR_L$.

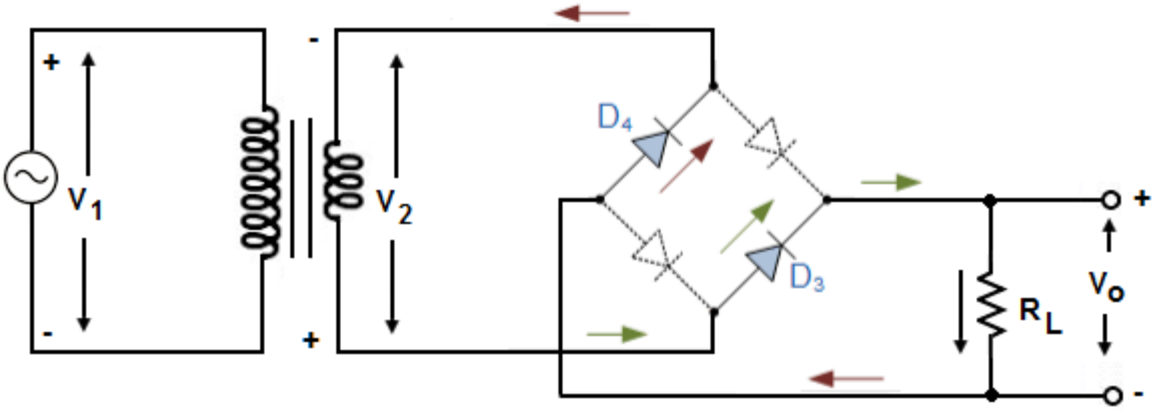


Fig.1.23: Equivalent circuit during negative cycle

- Applying KVL to the circuit shown in Fig.1.22, we get

$$-v_2 + i_oR_f + i_oR_L + i_oR_f = 0$$

$$i_o(2R_f + R_L) = v_2$$ re arranging and substituting for v_2, we get

$$\mathbf{i_o = \frac{V_m \sin\omega t}{2R_f+R_L}} \qquad i_o = I_m \sin\omega t \quad \text{where } I_m = \frac{V_m}{2R_f+R_L}$$ is the peak load current

Average DC load current

$$\mathbf{I_{DC} = \frac{\text{Area under one cycle of } i_o}{\text{Period of } i_o}}$$

$$I_{DC} = \int_0^{\pi} \frac{i_o d\omega t}{\pi}$$

$$I_{DC} = \frac{1}{\pi}\int_0^{\pi} I_m \sin\omega t \, d\omega t = \frac{I_m}{\pi}[-\cos\omega t]_0^{\pi}$$

$$\mathbf{I_{DC} = \frac{2I_m}{\pi}}$$

Average DC load voltage

$$\mathbf{V_{DC} = I_{DC}R_L}$$

$$V_{DC} = \left(\frac{2I_m}{\pi}\right) R_L = \frac{2}{\pi}\left(\frac{V_m}{2R_f+R_L}\right) R_L$$

$$\mathbf{V_{DC} = \frac{2V_m}{\pi}\left(\frac{R_L}{2R_f+R_L}\right) = \frac{2V_m}{\pi}\left(\frac{1}{\frac{2R_f+R_L}{R_L}}\right)}$$

$$\mathbf{V_{DC} = \left(\frac{2V_m/\pi}{1+\frac{2R_f}{R_L}}\right)}$$

RMS load current

$$\mathbf{I_{RMS} = \sqrt{\frac{Area\ under\ one\ cycle\ of\ i_o^2}{Period\ of\ i_o}}}$$

$$I_{RMS} = \sqrt{\frac{\int_0^{\pi} i_o^2 d\omega t}{\pi}}$$

$\mathbf{I_{RMS}} = \sqrt{\frac{\int_0^{\pi} I_m^2 \sin^2\omega t\, d\omega t}{\pi}} = \mathbf{I_m}\sqrt{\frac{1}{\pi}\int_0^{\pi}\frac{1}{2}(1-\cos 2\omega t)\, d\omega t}$ as WKT $\mathbf{\sin^2\omega t = \frac{1}{2}(1-\cos 2\omega t)}$

$$I_{RMS} = I_m\sqrt{\frac{1}{2\pi}\left[\int_0^{\pi} d\omega t - \int_0^{\pi}\cos 2\omega t\, d\omega t\right]}$$

$$I_{RMS} = I_m\sqrt{\frac{1}{2\pi}\left[\ \omega t|_0^{\pi} \quad - \left.\frac{\sin 2\omega t}{2}\right|_0^{\pi}\right]}$$

$$I_{RMS} = I_m\sqrt{\frac{1}{2\pi}\left[(\pi - 0) - \frac{1}{2}(\sin 2\pi - \sin 0)\right]}$$

$$\mathbf{I_{RMS} = \frac{I_m}{\sqrt{2}}}$$

RMS load voltage

$$\mathbf{V_{RMS} = I_{RMS} R_L}$$

$$V_{RMS} = \left(\frac{I_m}{\sqrt{2}}\right) R_L = \frac{1}{\sqrt{2}}\left(\frac{V_m}{2R_f+R_L}\right) R_L$$

$$\mathbf{V_{RMS} = \frac{V_m/\sqrt{2}}{1+\frac{2R_f}{R_L}}}$$

Rectifier efficiency

The ratio of the DC output power delivered to the load to the AC input power supplied from the secondary of the transformer. It is denoted by $\boldsymbol{\eta_r = \frac{P_{DC}}{P_i}}$

- DC output power is given by $P_{DC} = I_{DC}^2 R_L$

  For full wave rectifier, I_{DC} is given by $I_{DC} = \frac{2I_m}{\pi}$

  Hence DC output power : $P_{DC} = \frac{4I_m^2}{\pi^2} R_L$

- AC input power is given by $P_i = I_{RMS}^2 (2R_f + R_L)$

  For full wave rectifier, I_{RMS} is given by $I_{RMS} = \frac{I_m}{\sqrt{2}}$

  Hence AC input power can be expressed as $P_i = \frac{I_m^2}{2}(2R_f + R_L)$

- Therefore efficiency can be expressed as $\eta_r = \dfrac{\frac{4I_m^2}{\pi^2}R_L}{\frac{I_m^2}{2}(2R_f+R_L)} = \dfrac{8}{\pi^2}\dfrac{R_L}{(2R_f+R_L)}$

$$\eta_r = \frac{0.812}{\frac{(2R_f + R_L)}{R_L}} = \frac{0.812}{1+\frac{2R_f}{R_L}}$$

$$\boldsymbol{\%\eta_r = \frac{81.2}{1+\frac{2R_f}{R_L}}}$$

- If diodes are ideal, $R_f = 0$ then $\%\eta_{r\,max} = 81.2$

Ripple factor

The ratio of RMS value of AC component present in the rectified output to the DC component of the rectified output. It is denoted by $\boldsymbol{\gamma = \frac{V_{AC}}{V_{DC}}}$

- The output of the rectifier is a pulsating DC and has two component
  i. AC component of RMS value V_{AC}
  ii. DC component V_{DC}
- Total power output is the sum of powers of DC and AC components

$$\begin{bmatrix}\text{total RMS value of}\\ \text{rectifed output}\end{bmatrix}^2 = [\text{DC value}]^2 + \begin{bmatrix}\text{RMS value of}\\ \text{AC component}\end{bmatrix}^2$$

$$V_{RMS}^2 = V_{DC}^2 + V_{AC}^2$$

- Dividing throughout by V_{DC}^2 we get

$$\frac{V_{RMS}^2}{V_{DC}^2} = 1 + \frac{V_{AC}^2}{V_{DC}^2} \quad \text{implies} \quad \left(\frac{V_{RMS}}{V_{DC}}\right)^2 = 1 + \left(\frac{V_{AC}}{V_{DC}}\right)^2 \quad | \quad \text{but}\ \frac{V_{AC}}{V_{DC}} = \gamma$$

$$\left(\frac{V_{RMS}}{V_{DC}}\right)^2 = 1+\gamma^2 \quad \text{re arranging we get} \quad \gamma^2 = 1 - \left(\frac{V_{RMS}}{V_{DC}}\right)^2$$

$$\therefore \boldsymbol{\gamma = \sqrt{\left(\frac{V_{RMS}}{V_{DC}}\right)^2 - 1}}$$

$$V_{RMS} = \frac{V_m/\sqrt{2}}{1+\frac{2R_f}{R_L}} \quad \& \quad \boldsymbol{V_{DC} = \left(\frac{2V_m/\pi}{1+\frac{2R_f}{R_L}}\right)}$$

- Therefore $\boldsymbol{\gamma = \sqrt{\left(\frac{\pi}{2\sqrt{2}}\right)^2 - 1} = 0.483}$

$$\gamma = 0.483 = \frac{V_{AC}}{V_{DC}}$$

$$V_{AC} = 0.483V_{DC}$$

INFERENCE :

In full wave rectifier the ripple component is 48.3% of the DC component. As the ripple content is less THAN the DC value **FWR gives more DC output voltage than a HWR**

Peak Inverse Voltage

The maximum reverse voltage that can be applied TO the diode.

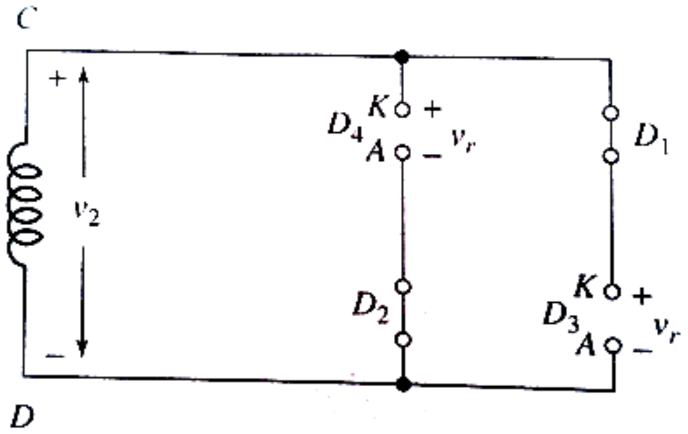


Fig.1.23: Equivalent circuit to find Peak Inverse Voltage

- Applying KVL to the circuit in Fig.1.23 we get, $v_2 - v_r = 0$ where $v_2 = V_m \sin\omega t$

  hence $\mathbf{v_r = v_2 = V_m \sin\omega t}$ $\boxed{\mathbf{PIV = v_{r\,max} = V_m}}$ when $\sin\omega t = 1$

- Tthe diode chosen should be such that it can withstand the given value of $\mathbf{V_m}$, **which is VERY MUCH below its PIV** and still operate.

Comparison of rectifiers

Parameter	Have-wave Rectifier	Full-wave centre tapped - Rectifier	Full-wave Bridge Rectifier
Peak Current I_m	$\frac{V_m}{R_f + R_L}$	$\frac{V_m}{R_f + R_L}$	$\frac{V_m}{2R_f + R_L}$
DC load Current I_{DC}	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
RMS load Current I_{RMS}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
DC load Voltage V_{DC}	$\frac{V_m/\pi}{1 + \frac{R_f}{R_L}}$	$\frac{2V_m/\pi}{1 + \frac{R_f}{R_L}}$	$\frac{2V_m/\pi}{1 + \frac{2R_f}{R_L}}$
RMS load Voltage V_{RMS}	$\frac{V_m/2}{1 + \frac{R_f}{R_L}}$	$\frac{V_m/\sqrt{2}}{1 + \frac{R_f}{R_L}}$	$\frac{V_m/\sqrt{2}}{1 + \frac{2R_f}{R_L}}$
Efficiency η_r	$\frac{0.406}{1 + \frac{R_f}{R_L}}$	$\frac{0.812}{1 + \frac{R_f}{R_L}}$	$\frac{0.812}{1 + \frac{2R_f}{R_L}}$
Ripple Factor γ	**1.21**	**0.483**	**0.483**
Peak Inverse Voltage PIV	V_m	$2V_m$	V_m

LINKS TO VIDEOS:

Half wave Rectifier Explained: https://www.youtube.com/watch?v=Ll0IOk_Ltfc
Full wave Rectifier Explained: https://www.youtube.com/watch?v=74QrYyYsftY
Full Wave Bridge Rectifier: https://www.youtube.com/watch?v=Kl8IOESVWlM
Full Wave Center-Tapped Rectifier: https://www.youtube.com/watch?v=CGZ0yHaAmjs
Full Wave Rectifier (DC Load Current & Load Voltage):
https://www.youtube.com/watch?v=XI4mHDveD7g
PROBLEM E RMS AND DC VALUES IN HWR, FWR: https://www.youtube.com/watch?v=A2SMI31EgMA
Calculation of Ripple Factor and Ripple Voltage for HWR and FWR:
https://www.youtube.com/watch?v=ruEYtTYePRk
PROBLEM: DIODE RECTIFIER CIRCUITS : https://www.youtube.com/watch?v=UQVAFcCLoKo

Capacitor filter circuit

- Capacitor filter is used to reduce the ripple content present in the rectified output. It is done by connecting a capacitor in parallel with R_L.
- Fig.1.24 shows the half wave rectifier with capacitor filter.

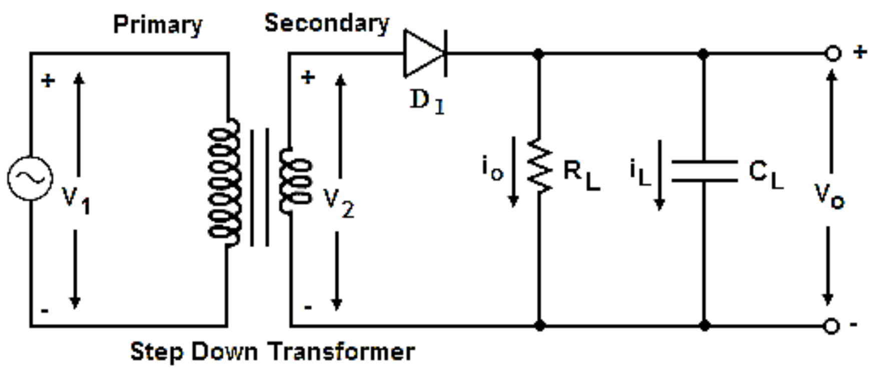


Fig.1.24: Half-wave rectifier with capacitor filter

- During positive half cycle of the AC supply, the diode conducts (on state) and charges the capacitor to the peak value of V_m of the transformer secondary voltage.
- When the transformer secondary voltage falls below V_m the diode stops conducting (**OFF** state).
- As a result, capacitor discharges through R_L and the voltage on capacitor decreases.

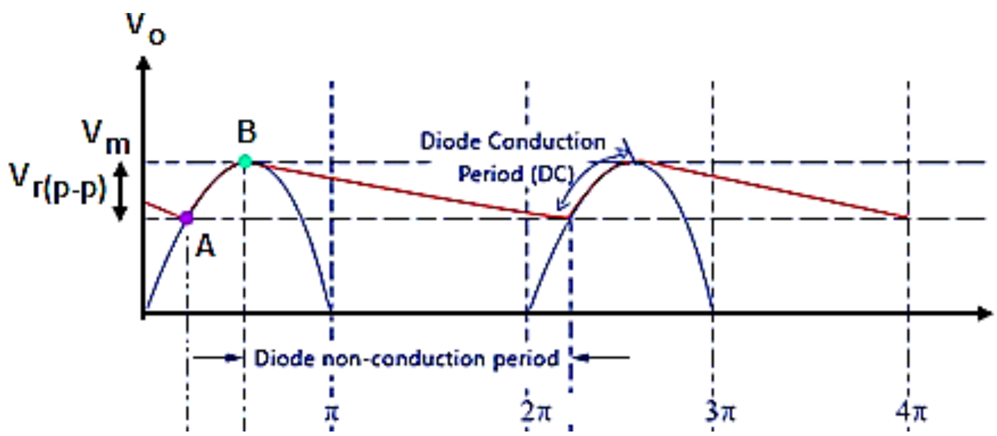


Fig.1.25: Output voltage waveform of Half-wave rectifier with and without capacitor filter

- The capacitor discharges until the diode starts conducting again and charges the capacitor in the next positive half-cycle of AC supply.

  $V_{r(p-p)}$ is peak-peak ripple voltage on capacitor

  t_c is charging time of capacitor

  t_d is discharging time of capacitor

  $T = t_c + t_d$ time period of output waveform

- In the Fig.1.25 the dotted line shows the output of the rectifier without capacitor filter, where V_o varies between **zero and V_m.**
- When the filter is connected the output V_o varies between $V_m - V_{r(p-p)}$ **and** V_m.
- Similarly the waveform obtained from a full-wave rectifier with capacitor filter is as shown in the Fig.1.27.

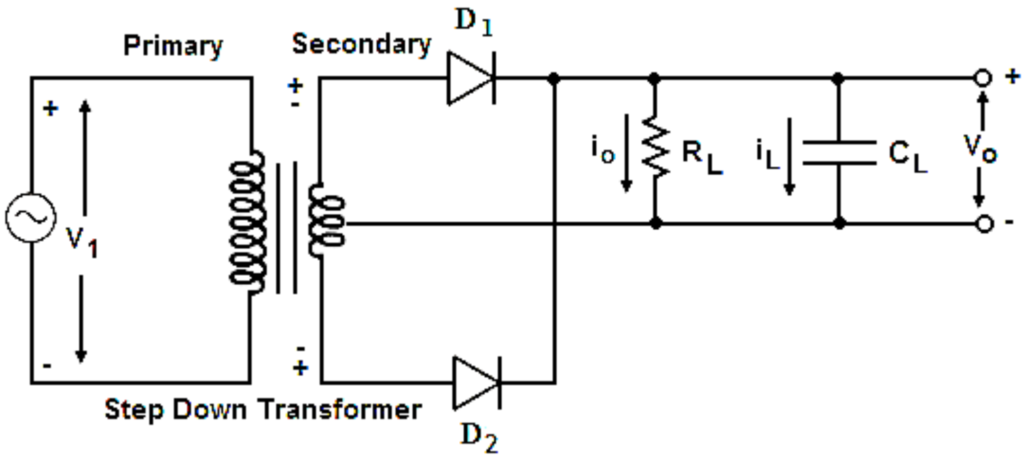


Fig.1.26: Full-wave rectifier with capacitor filter

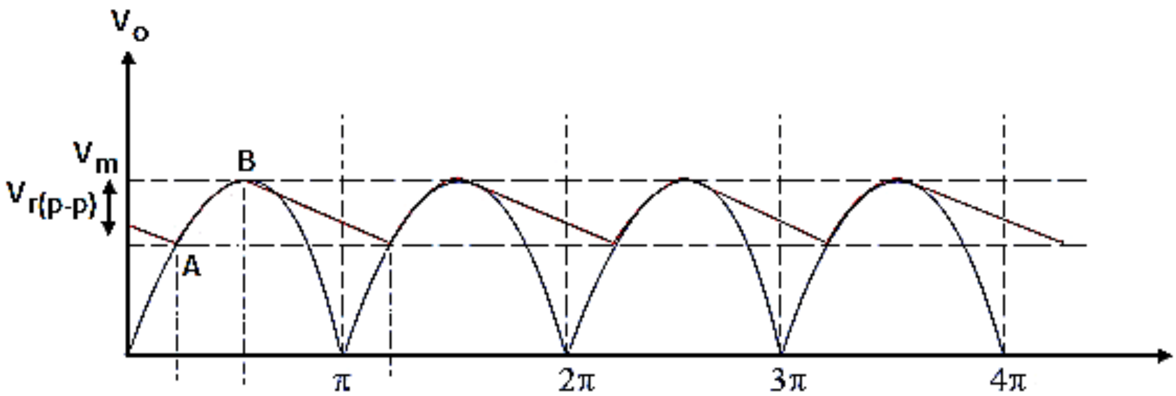


Fig.1.27: Output voltage waveform of full-wave rectifier with and without capacitor filter

- Similarly the waveform obtained from a full-wave bridge rectifier with capacitor filter is as shown in the Fig.1.29.

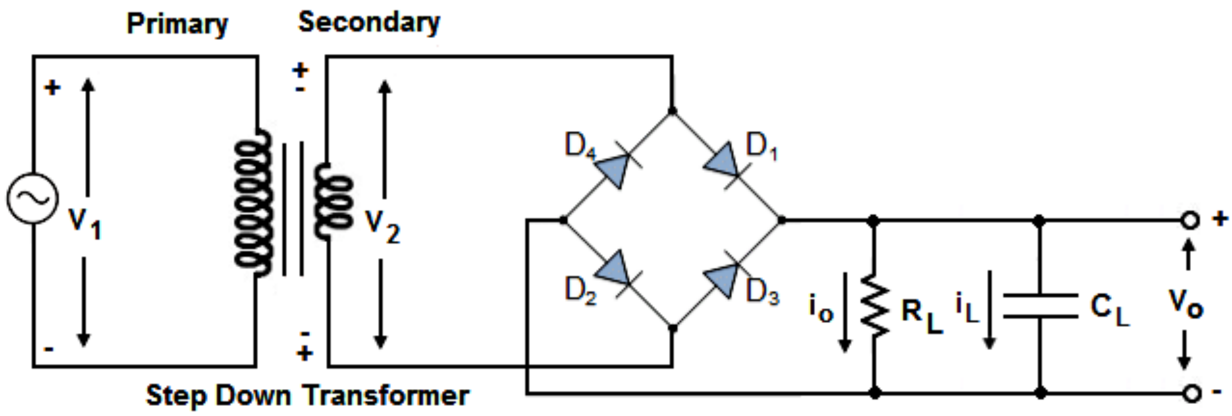


Fig.1.28: Full-wave bridge rectifier with capacitor filter

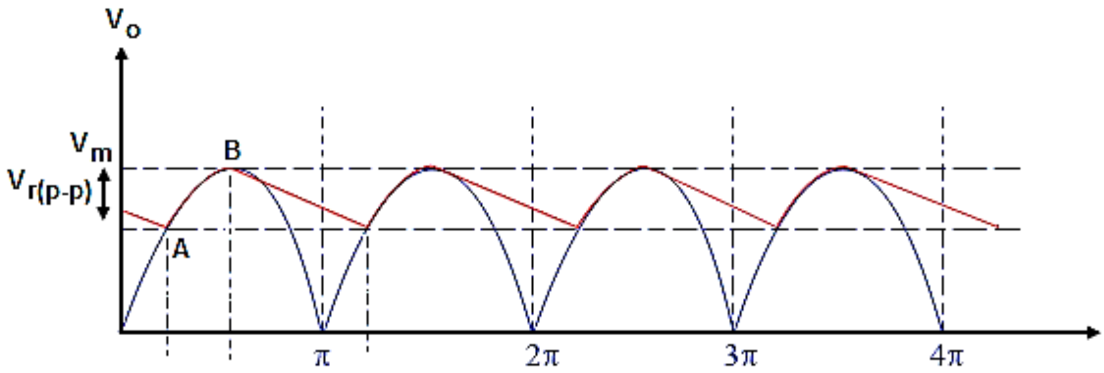
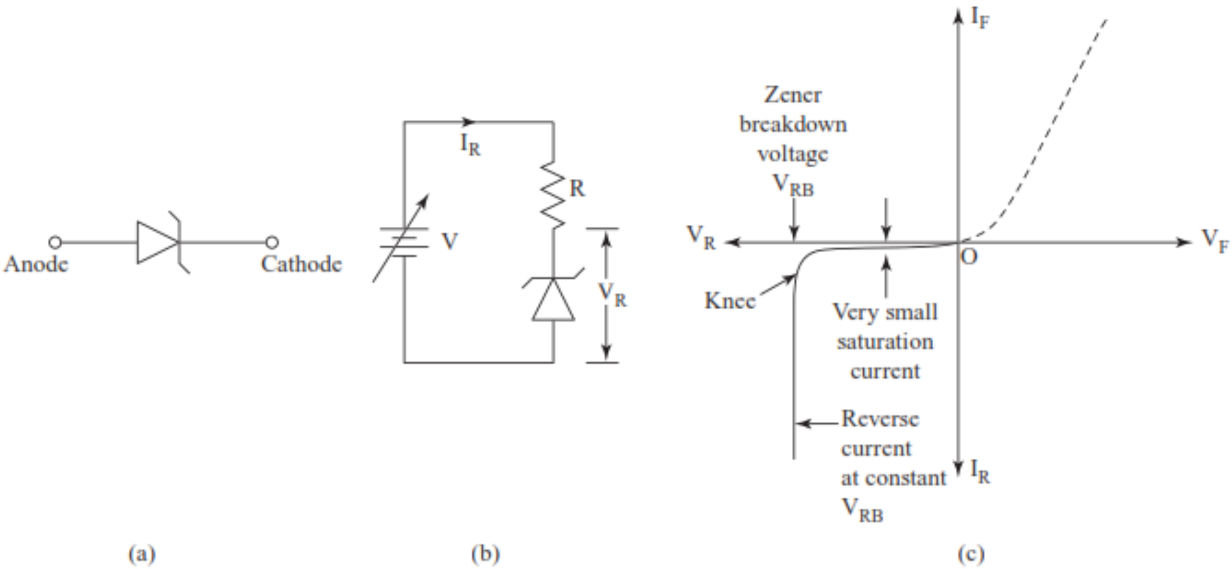


Fig.1.29: Output voltage waveform of full-wave bridge rectifier with and without capacitor filter

LinkS TO VIDEOS:

Peak Detector Circuit Explained : https://www.youtube.com/watch?v=w4531AVjBYY

Zener diode voltage regulator



(a) Symbol of a zener diode; (b) zener diode circuit; (c) V–I characteristic

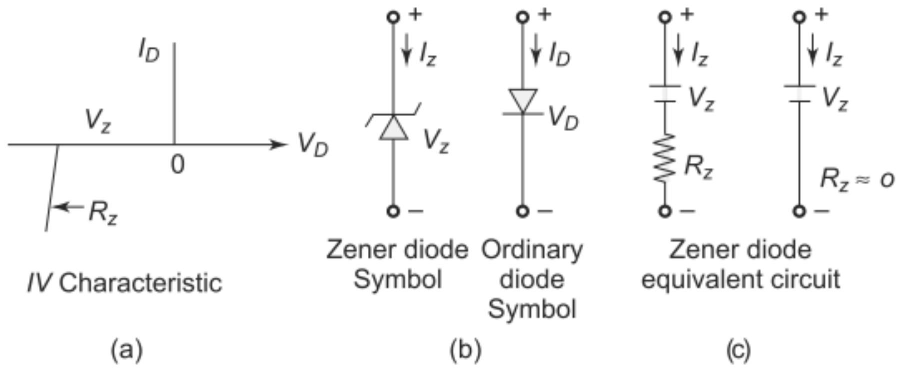


Figure 1Zener diode equivalent representation

- The output of a rectifier with capacitor filter varies with the changes in the load current and line voltage hence it is called as variable DC or unregulated DC.
- A voltage regulator **is a circuit which accepts unregulated DC input and provides a constant DC output voltage irrespective of the changes in the load current and line voltage** as shown in Fig.1.30.
- Zener diode operates in the reverse break down region and has a **constant voltage V_Z** across its terminal.
- The input voltage **V_i must be greater than the zener breakdown voltage V_Z**.

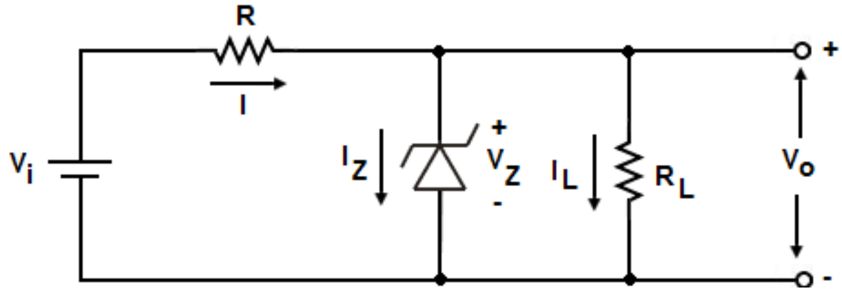


Fig.1.30: Zener diode voltage regulator

- Voltage across R_L is equal to the voltage across the zener diode since R_L and zener diode are in parallel. $\mathbf{V_o = V_Z}$
- From the Figure supply current $\mathbf{I = I_Z + I_L}$

  re arranging we have $\mathbf{I_Z = I - I_L}$
- Supply current can also be expressed as

$$\mathbf{I = \frac{V_i - V_o}{R}}$$

- Therefore current through the zener diode can be expressed as

$$\mathbf{I_Z = \frac{V_i - V_o}{R} - I_L}$$

- V_i varies between $V_{i_{min}}$ and $V_{i_{max}}$ and I_L varies between $I_{L_{min}}$ and $I_{L_{max}}$. Therefore minimum current through the zener diode is given by

$$\mathbf{\frac{V_{i_{min}} - V_o}{R} - I_{L_{max}} > I_{Z_{min}}}$$

- Maximum current through the zener diode is given by

$$\frac{V_{i_{max}} - V_o}{R} - I_{L_{min}} < I_{Z_{max}}$$

- Maximum allowable power dissipation in the Zener is

$$P_D = I_{L_{max}} V_Z$$

LINKS TO VIDEOS:

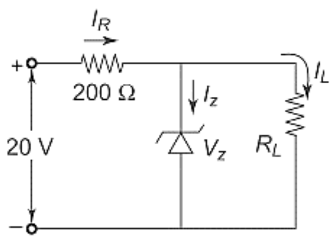
Introduction to Zener Diodes: https://www.youtube.com/watch?v=JdL3DnnFHXw
Effects of Temperature on Zener Voltage https://www.youtube.com/watch?v=JffJpym7K8Y
ZENER DIODE REGULATOR (PART 1): https://www.youtube.com/watch?v=6xGCOrPBL4s

Problem

1.

For V_Z=10V, R_Z=0; P_{Zmax}=350mW , find the following:

(a) For R_L = 180 Ω, determine all currents and voltages.
(b) Repeat part (a) for R_L = 450 Ω.
(c) Find the value of R_L for the zener to draw maximum power.
(d) Find the minimum value of R_L for the zener to be just in on-state.



a)Find I_R I_L I_Z and V_Z

As R_L is small assume that the Zener does not conduct implies $\boldsymbol{I_Z=0}$

$\boldsymbol{I_R = I_L} = \frac{20}{200+180} = \mathbf{52.6}\boldsymbol{mA}$

V_S=$\boldsymbol{V_L}$=20-200$*$ I_R $=20 - 200 * 52.6m = \mathbf{9.48}\boldsymbol{V} < 10V \therefore$ assumption that I_Z is zero is correct.

b)R_L=450Ω implies Zener conducts so $\boldsymbol{V_L}$=$\boldsymbol{V_Z}$=**10V** *as per the given data*

$$\boldsymbol{I_L} = \frac{10}{450} = \mathbf{22.2mA}$$

$$\boldsymbol{I_R} = \frac{20-10}{200} = \mathbf{50}\boldsymbol{mA}$$

$$\boldsymbol{I_Z=I_R - I_L} = 30mA - 22.2\ mA = \mathbf{27.8\ mA}$$

$$\boldsymbol{P_Z= I_L * V_Z} = \mathbf{27.8*10=278mW< 350mW}$$

c) When zener draws max power,

$$I_Z = \frac{p_z}{V_z} = \frac{350}{10}m = 35mA$$

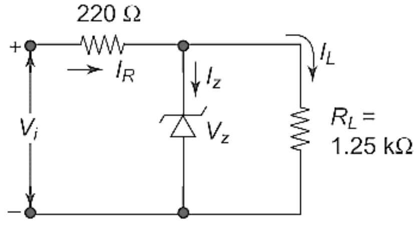
$$I_R = \frac{20-10}{200} = 50mA$$

$$\boldsymbol{I_L=I_Z - I_R} = 15Ma$$

$$R_L = \frac{V_R = V_L}{I_L} = \frac{10}{50m} = \mathbf{200\Omega}$$

2 Determine the range of V_i in which the zener operates

For V_Z=20V, P_{Zmax}=1200mW ,



a. When the zener just starts conducting, I_z=0

V_z=20V; $I_R = I_L = \frac{20}{1.25}$=16mA

$V_i = V_Z + I_R * 220 = 20 + 16m * 220 = \mathbf{23.52V}$

b. When the zener current is max $I_z = I_{z\ max}$

$I_{z\ max} = \frac{P_{Zmax}}{V_Z} = \frac{1200}{20} = 60mA \quad I_L$=16mA

$I_R = I_L + I_{Zmax} = 16+60 = 76mA$

$V_i = V_Z + I_R * 220 = 20 + 76m * 220 = $ **36.72V**

Hence observed that for V_i ranging from 23.52 V to 36.72V V_L shall remain constant at 20V

3. Design a Zener diode voltage regulator to meet the following requirements

Unregulated DC input voltage, $V_i = 13 - 17V$

Load current, $I_L = 10mA$

Regulated output voltage, $V_o = 10V$

Minimum zener current, $I_{Z_{min}} = 5mA$

Maximum power dissipation in zener, $P_{D_{max}} = 500mA$

Maximum power dissipation is $\mathbf{P_{D_{max}} = P_D = I_{L_{max}} V_Z}$

$$I_{Z_{max}} = \frac{P_D}{V_Z} = \frac{500m}{10} = 50mA$$

Maximum current through the zener diode is $\frac{V_{i_{max}} - V_o}{R} - I_{L_{min}} < I_{Z_{max}}$

$$\frac{17-10}{R} - 0 < 50m$$

$$R > \frac{7}{50m}$$

$$R = 140\Omega$$

Minimum current through the zener diode is

$$\frac{V_{i_{min}} - V_o}{R} - I_{L_{max}} > I_{Z_{min}}$$

$$\frac{13-10}{R} - 10m > 5m$$

$$R < \frac{3}{15m}$$

$$R = 200\Omega$$

Combining above we can write

$$140\Omega < R < 200\Omega$$

$$R = \frac{140+200}{2} = 170\Omega$$

$$R_L = \frac{V_o}{I_L} = \frac{10}{10m} = 1k\Omega$$

4. A 24V, 600mW Zener diode is used for providing a 24V stabilized supply to a variable load. If the input voltage is 32V, calculate

i. The value of series resistance required

ii. Diode current when the load is 1200Ω

Since no variation in input, $V_{i_{max}} = V_{i_{min}} = V_i = 32V$

$$I_{Z_{max}} = \frac{P_D}{V_Z} = \frac{600m}{24} = 25mA$$

$$\frac{V_{i_{max}} - V_o}{R} - I_{L_{min}} < I_{Z_{max}}$$

But $I_{L_{min}} = 0$ hence $\frac{32-24}{R} - 0 < 25m$

$$R > \frac{8}{25m} \quad \text{implies } R = 320\Omega$$

$$I_L = \frac{V_o}{R_L} = \frac{24}{1200} = 20mA$$

Diode current is given by

$$I_Z = \frac{V_i - V_o}{R} - I_L$$

$$I_Z = \frac{32-24}{320} - 20m$$

$$I_Z = 5mA$$

5. **A 9V reference source is to be designed using a zener diode and a resistor connected in series to a 30V supply. Select suitable components and calculate the circuit current when the supply drops to 27V. Take I_{ZT} = 20mA**

Since load current is not given it is unloaded voltage regulator. I_{ZT} is the test current which lies between $I_{L_{min}}$ and $I_{Z_{max}}$ $V_o = V_Z = 9V$

$$I = I_Z = \frac{V_i - V_o}{R}$$

$$R = \frac{V_i - V_o}{I_{ZT}} = \frac{30-9}{20m} = 1.05k\Omega$$

When V_i = 27V

$$I_Z = \frac{V_i - V_o}{R} = \frac{27-9}{1.05k} = 17.14mA$$

LINKS TO PROBLEMS:
PROBLEM: ZENER DIODE REGULATOR (2):
https://www.youtube.com/watch?v=LtWMuoQKMIc
PROBLEM: ZENER DIODE REGULATOR (3):
https://www.youtube.com/watch?v=HBaddgGeIrM
PROBLEM: ZENER DIODE REGULATOR (4):
https://www.youtube.com/watch?v=_Glio3MxT2Q
PROBLEMS: ZENER DIODE (PART 1): https://www.youtube.com/watch?v=rE4wC7h8uWo
PROBLEMS: ZENER DIODE (PART 2): https://www.youtube.com/watch?v=dKw6lBy8Xzc

Photodiode

- It is a semiconductor device that converts light into an electrical current.

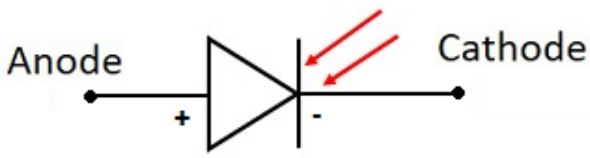


Fig.1.31: Photodiode

- A photodiode is a PN junction (silicon / germanium) operates in **reverse bias region** as shown in Fig.1.32.

- When a light is made to **illuminate the PN junction, covalent bonds are ionized.** This generates hole and electron pairs.
- **Photocurrents are produced** due to generation of electron-hole pairs that are formed **when photons of energy more than 1.1eV hits the diode.**
- When the photon enters the depletion region of diode, it hits the atom with high energy. This results in release of electron from atom structure. After the electron release, free electrons and hole are produced.
- Due to the electric filed, electron hole pairs moves away from the junction. Hence, **holes move to anode and electrons move to cathode to produce photo current.**
- The **photon absorption intensity and photon energy are directly proportional to each other.** When energy of photon is less, the absorption will be more.

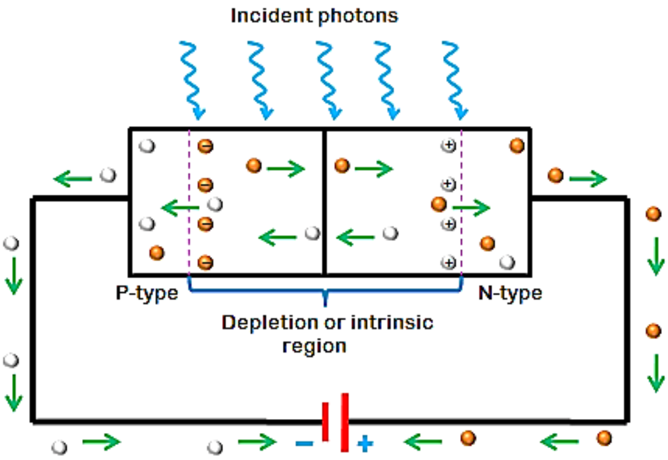


Fig.1.32: Photodiode under reverse bias

LINKS TO VIDEOS: Photodiode What, How it Works Explained: https://www.youtube.com/watch?v=kry1aGCU2Go

Light Emitting Diode (LED)

1. **Light-emitting diode (LED) is a two terminal p-n junction semiconductor diode which emits light when activated.**
2. When a suitable current is applied to the terminals, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called **electroluminescence.**
3. The process of light emission in pn junctions is illustrated in Fig.1.33.
4. **The metal contact of p material is made much small** to permit the emergence of maximum number of photons so that in an LED, the light lumens generated per watt of electric power is high. Intensity of light increases almost linearly with forward current, depending on the material used.

5. The voltage levels of LEDs are **1.7V to 3.3V** which is compatible with solid state circuits. The response time is short and light contrast is good. **LEDs emit red, green, orange or blue.**
6. LEDs are used in several display applications, such as 8 segment display of numbers 0 to 9, LED TVs.

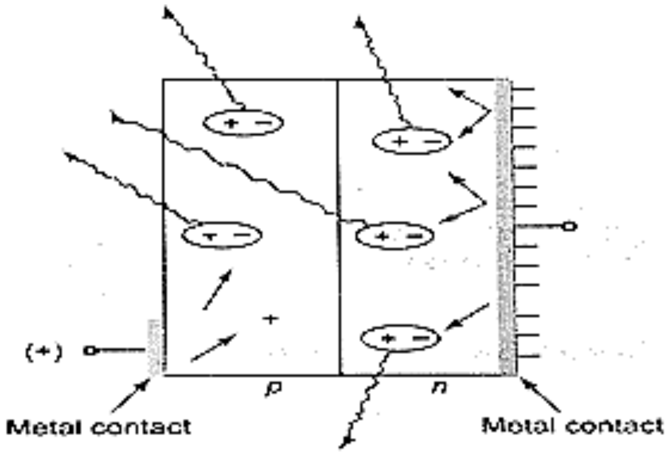


Fig.1.33: Light emission in PN junction

LED - Working, Advantages and Types: https://www.youtube.com/watch?v=kaKLmKhUrf4

Photo Coupler

1. **Photo coupler is a package of an LED and photodiode where circuits are electrically isolated** as shown in Fig.1.34.
2. The LED is forward biased and the photodiode is reverse biased. The output is available across R_2

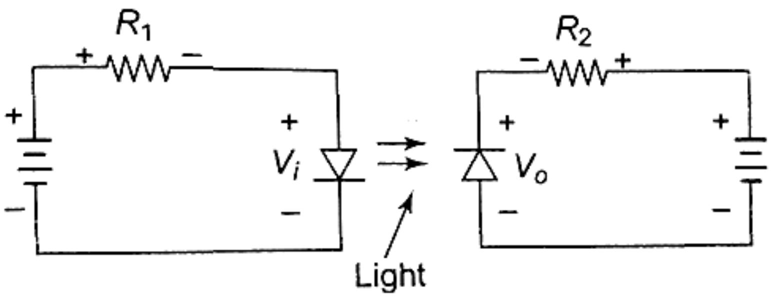


Fig.1.34: Photo coupler

3. The output signal of one circuit can be controlled by varying input signal in another circuit, where the two circuits are ELECTRICALLY ISOLATED**.**
4. A powerful light emitting diode (LED) is connected across a variable voltage source. By adjusting the input voltage V_i across the LED, the intensity of the light emitted from the LED can be controlled. The variable source and the LED form the input circuit of the photocoupler.
5. A photodiode is present in front of the LED so that the light from the LED directly strikes the junction of the photodiode. The photodiode is in reverse biased

condition. The reverse biased circuit of the photodiode forms the output circuit of the system.

6. Initially, no voltage is applied to the LED; hence the LED does not glow. In this condition there would be only **dark current** flowing through the output circuit. Dark current is the reverse saturation current of the reverse biased photodiode when it entire dark.
7. If the voltage across the LED increased, the LED starts glowing and at same time intensity of the light increases with increasing input voltage across the LED. With increasing light intensity, the reverse current in the photodiode increases, since the reverse current in a photodiode is linearly proportional to the intensity of light falling on the photodiode junction. Also, if the **intensity of light in the input is decreased, the output photodiode current will also decrease**.
8. The key advantage of the photocoupler is the isolation between two circuits.

LM 78XX series Voltage Regulator

1. LM78XX is a family of self-contained fixed linear voltage regulator integrated circuits commonly used in electronic circuits requiring a regulated power supply due to their ease-of-use and low cost.
2. For ICs within the 78XX family, the XX is replaced with two digits (XX = 05, 06, 08, 10, 12, 15, 18 or 24), indicating the output voltage (for example, the 7805 has a 5-volt output, while the 7812 produces 12 volts).
3. They are +ve voltage regulators; they produce a voltage that is +ve relative to a common ground.
4. LM78XX ICs have three terminals and support an input voltage anywhere from around 2.5 volts over the intended output voltage up to a maximum of 35 to 40 volts depending on the model, and typically provide 1 or 1.5 amperes of current.

7805 Fixed IC Voltage Regulator

5. This fixed linear voltage regulator has Pin 1 - input, Pin 2 - output and Pin 3 - connected ground. The LM7805 has an output voltage of +5V and a maximum load current over 1 A.

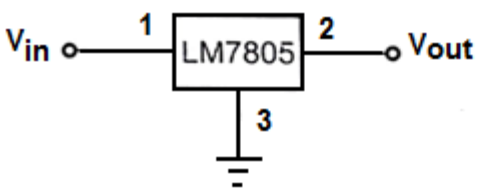


Fig.1.35: 7805 Fixed IC Voltage Regulator

PIN 1: Input

This pin is used to apply the input voltage which can be in the range of 7V to 35V.

PIN 2: Ground

This pin is connected to ground.

PIN 3: Output

6. This pin is used to take the regulated output. It will be 5V
7. The output of the rectifier is an unregulated DC Voltage, therefore two capacitors are required to obtain a regulated DC voltage and are connected as shown in the Fig.1.36.

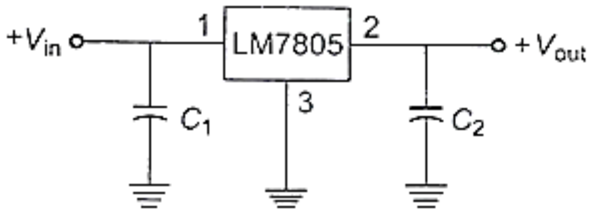


Fig.1.36: LM7805 with capacitor

8. Capacitor C_2 at the output side is used to avoid transient changes in the voltages due to changes in load and a Capacitor C_1 at the input side of regulator is used to avoid ripples if the filtering is far away from regulator.

78XX Voltage Regulator: ***https://www.youtube.com/watch?v=rPb0p7N1O00***

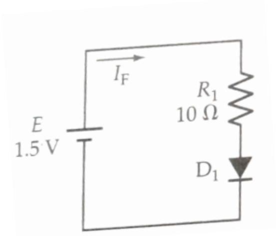
Question Bank

1. Explain the operation of pn junction diode under forward and reverse bias condition
2. List the diode parameters required for the construction of diode characteristics
3. Define the following terms

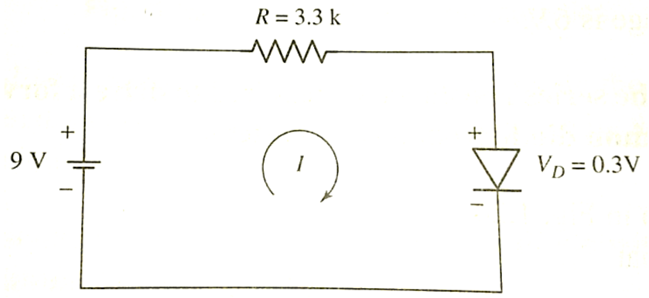
a. Dynamic resistance b. Rev, saturation current c. Rev. breakdown voltage

4. Explain the characteristics of an ideal diode
5. Explain the piecewise-linear characteristics of a diode
6. Draw the DC equivalent circuit of a diode and explain
7. Explain the operation of zener diode along with its characteristics
8. Define rectifier? What are the different types of rectifiers?
9. With circuit diagram explain the operation of half wave rectifier. Draw the input and output waveforms.
10. With circuit diagram explain the operation of center tapped full wave rectifier. Draw the input and output waveforms.
11. With circuit diagram explain the operation of full wave bridge rectifier. Draw the input and output waveforms.
12. Explain the operation of half wave rectifier with capacitor filter.
13. Explain the operation of full wave rectifier with capacitor filter.
14. Explain the operation of full wave bridge rectifier with capacitor filter.
15. Explain how zener diode can be used as voltage regulator

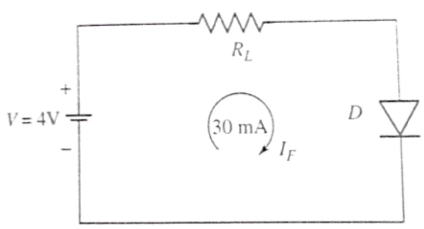
16. Explain the operation of 7805 fixed IC voltage regulator.
17. Write a short note on (i) Light emitting diode (ii) Photo coupler (iii) Photo diode
18. Plot the forward and reverse characteristics of a diode for the following data
    a. Forward voltage drop = 0.6V
    b. Reverse breakdown voltage = 100V
    c. Reverse saturation current = 1μA
    d. Forward current = 100mA at a forward voltage of 0.65V
    e. Forward current = 250mA at a forward voltage of 0.7V
19. Determine the dynamic resistance at a forward current of 20mA for the diode characteristics given in the Fig.1.6
20. Construct a piecewise linear characteristics for a silicon diode which has a 0.2Ω dynamic resistance and a 200mA maximum forward current.
21. Calculate I_F for the diode in the given circuit assuming that V_F = 0.7V and r_d = 0. What is the current if we consider r_d = 0.2Ω

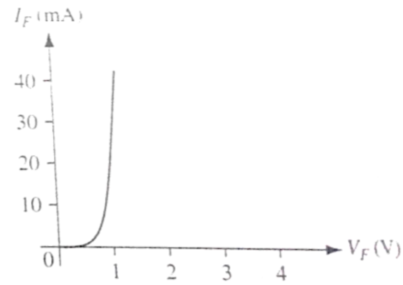


22. Calculate the diode current for the circuits given below



23. Using the device characteristics in the Figure below, determine the required load resistance for the circuit given in the Figure to give I_F = 30mA





24. A sinusoidal voltage of peak value 40V and frequency 50Hz is applied to a half wave rectifier having a load resistor of 800Ω and R_f of the diode is 8Ω. Calculate
    a. Peak, DC and RMS value of load current
    b. DC output power
    c. AC input power
    d. rectifier efficiency
25. The input to a half wave rectifier is given through a 2:1 transformer from a supply of 240V, 50Hz. If R_f = 0 and R_L = 500Ω determine
    a. DC load voltage
    b. RMS load voltage
    c. PIV
    d. rectifier efficiency
    e. DC power delivered to load
    f. freq of output waveform

26. A sinusoidal voltage of peak value 40V and frequency 50Hz is applied to a full wave rectifier having a load resistor of 800Ω and R_f of the diode is 8Ω. Calculate
    a. Peak, DC and RMS value of load current
    b. DC output power
    c. AC input power
    d. rectifier efficiency
27. The input to a full wave rectifier is given through a 10:1 transformer from a supply of 230sin314t. If R_f = 50Ω and R_L = 500Ω determine
    a. DC load voltage
    b. RMS load voltage
    c. PIV
    d. rectifier efficiency
    e. DC power delivered to load
    f. freq of output waveform
28. A sinusoidal voltage of peak value 40V and frequency 50Hz is applied to a full wave bridge rectifier having a load resistor of 800Ω and R_f of the diode is 8Ω. Calculate
    a. Peak, DC and RMS value of load current
    b. DC output power
    c. AC input power
    d. rectifier efficiency
29. The input to a full wave bridge rectifier is given through a 10:1 transformer from a supply of 230sin314t. If R_f = 50Ω and R_L = 500Ω determine
    a. DC load voltage
    b. RMS load voltage
    c. PIV
    d. rectifier efficiency
    e. DC power delivered to load
    f. freq of output waveform
30. Design a Zener diode voltage regulator to meet the following requirements
    a. DC input voltage, V_i = 20V
    b. Load current, I_L = 20mA
    c. DC output voltage, V_o = 10V
    d. Minimum zener current, $I_{Z_{min}}$ = 10mA
    e. Maximum zener current, $I_{Z_{max}}$ = 100mA
31. Design a Zener diode voltage regulator to meet the following requirements
    a. DC input voltage, V_i = 10V ± 2V
    b. Load current, I_L = 10mA
    c. DC output voltage, V_o = 5V
    d. Minimum zener current, $I_{Z_{min}}$ = 5mA
    e. Maximum power dissipation, $P_{Z_{max}}$ = 400mW

Problems on rectifiers

Q1. The applied input a.c. power to a half-wave rectifier is 100 watts. The d.c. output power obtained is 40 watts. (i) What is the rectification efficiency ?

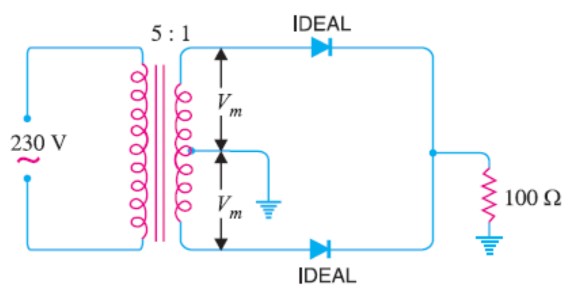
Q2. An a.c. supply of 230 V is applied to a half-wave rectifier circuit through a transformer of turn ratio 10 : 1. Find (i) the output d.c. voltage and (ii) the peak inverse voltage. Assume the diode to be ideal

Q3. A crystal diode having internal resistance $r_f = 20\Omega$ is used for half-wave rectification. If the applied voltage $v = 50 \sin \omega t$ and load resistance $R_L = 800\ \Omega$, find : (i) Im, Idc, Irms (ii) a.c. power input and d.c. power output (iii) d.c. output voltage (iv) efficiency of rectification.

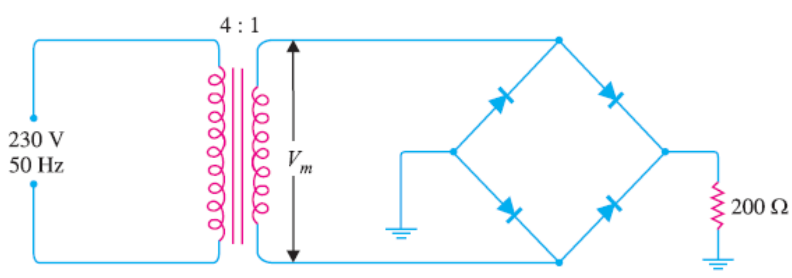
Q4. A half-wave rectifier is used to supply 50V d.c. to a resistive load of 800 Ω. The diode has a resistance of 25 Ω. Calculate a.c. voltage required.

Q5. A full-wave rectifier uses two diodes, the internal resistance of each diode may be assumed constant at 20 Ω. The transformer r.m.s. secondary voltage from centre tap to each end of secondary is 50 V and load resistance is 980 Ω. Find : (i) the mean load current (ii) the r.m.s. value of load current.

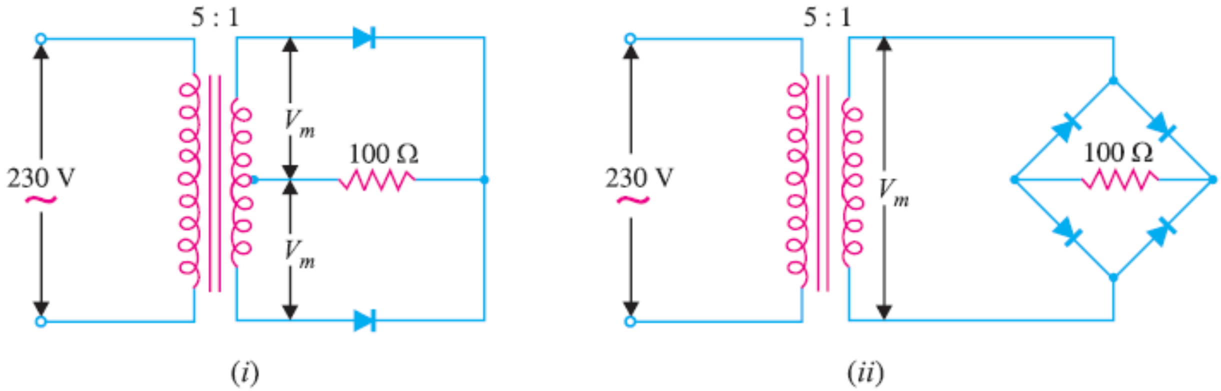
Q6. In the centre-tap circuit shown , the diodes are assumed to be ideal i.e. having zero internal resistance. Find :(i) d.c. output voltage(ii) peak inverse voltage (iii) rectification efficiency.



Q7. In the bridge type circuit shown , the diodes are assumed to be ideal. Find : (i) d.c. output voltage (ii) peak inverse voltage (iii) output frequency. Assume primary to secondary turns to be 4.

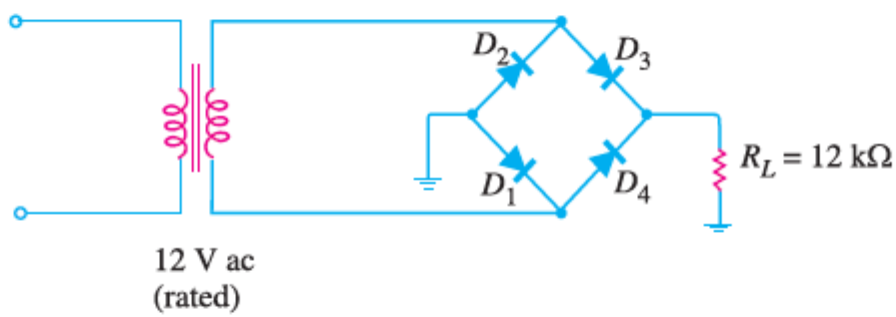


Q8. **Show the centre-tap and bridge type circuits having the same load resistance and transformer turn ratio. The primary of each is connected to 230V, 50 Hz supply. (i) Find the d.c. voltage in each case. (ii) PIV for each case for the same d.c. output. Assume the diodes to be ideal.**



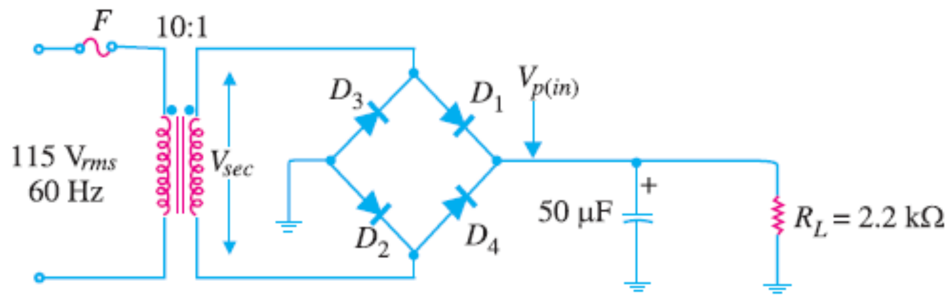
Q9. The four diodes used in a bridge rectifier circuit have forward resistances which may be considered constant at 1Ω and infinite reverse resistance. The alternating supply voltage is 240 V r.m.s. and load resistance is 480 Ω. Calculate (i) mean load current and (ii) power dissipated in each diode.

Q10. The bridge rectifier shown uses silicon diodes. Find (i) d.c. output voltage (ii) d.c. output current. Use simplified model for the diodes



Q11. **A power supply A delivers 10 V dc with a ripple of 0.5 V r.m.s. while the power supply B delivers 25 V dc with a ripple of 1 mV r.m.s. Which is better power supply ?**

Q12. For the circuit shown, find the output d.c. voltage


F
10:1
115 V_rms
60 Hz
V_sec
D_3
D_1
V_p(in)
D_2
D_4
50 μF
+
R_L = 2.2 kΩ