2021

Chapter Four :
Diode Circuit Analysis

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4.1 The Diode Models :

Diodes have two models, these models will describe in this section:

- **The ideal model**

The ideal model of a diode is a simple switch. When the diode is **forward biased,** it acts like closed (on) switch, as shown in Fig. 4.1a. When the diode is **reverse biased,** it acts like an open (off) switch, as shown Fig. 4.1b. The barrier potential, the forward dynamic resistance, and the reverse current are all neglected. Fig. 4.2, explains the diode as switch in the electric circuits.

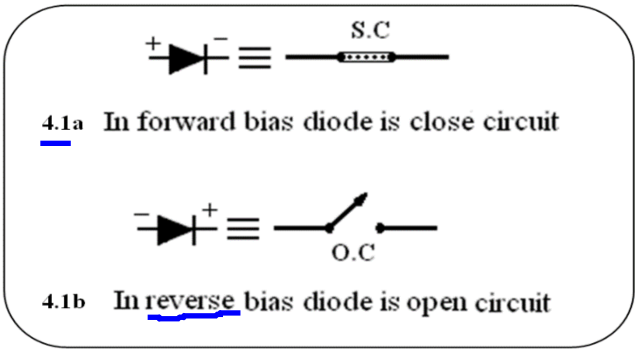


Fig. 4.1 The diode as switch.

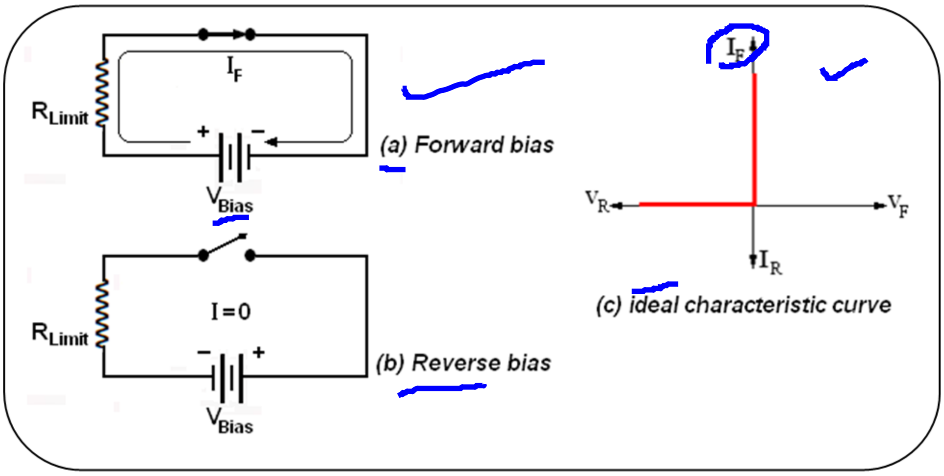


Fig. 4.2 The ideal model of a diode.

In Fig. 4.2c, the ideal V−I characteristic curve graphically depicts the ideal diode operation. In the ideal diode model: **V_F=0, I_R=0** and **V_R=V_{bias}.**

❖ The practical model.

The practical model adds the barrier potential to the ideal switch model. When the diode is **forward biased**, it is equivalent to a closed switch in series with a small equivalent voltage source equal to the barrier potential (V_F) with the positive side toward the anode, as indicated in Fig. 4.3a . This equivalent voltage source represents the fixed voltage drop V_D produced across the forward biased (***p-n***) junction of the diode and is not an active source of voltage.

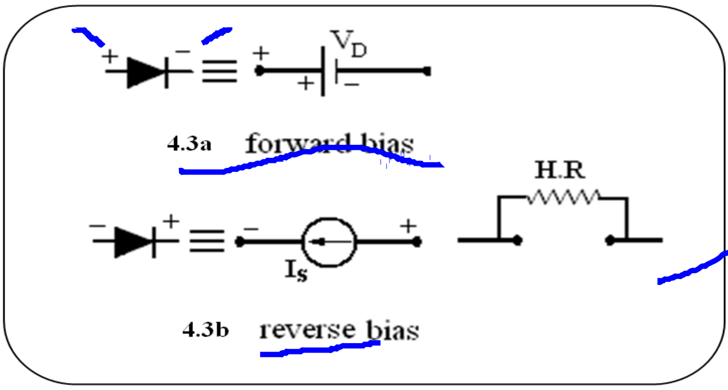
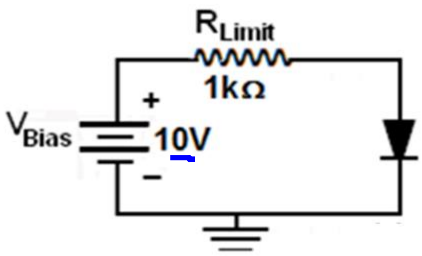


Fig. 4.3 The practical diode model.

Example : *Determine the forward voltage and forward current for the diode in figure below for each of the diode models. Also find the voltage across the limiting resistor in each case. Assume $r_d = 10\Omega$ at the determined value of forward current.*



Solution:

1- ideal model:

$$V_F = 0V$$

$$I_F = \frac{V_{bias}}{R_{Limit}} = \frac{10}{1k\Omega} = 10mA$$

$$V_{R_{limit}} = I_F \times R_{Limit} = 10mA \times 1k\Omega = 10V$$

2- Practical model:

Si

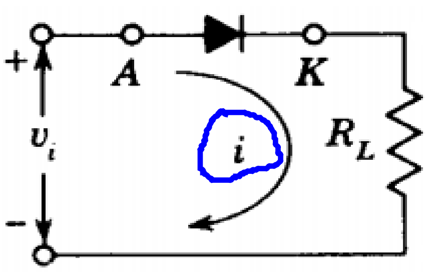
$$V_F = 0.7V$$

$$I_F = \frac{V_{Bias} - V_F}{R_{Limit}} = \frac{10V - 0.7V}{1k\Omega} = 9.3mA$$

$$V_{R_{Limit}} = I_F \times R_{Limit} = 9.3mA \times 1k\Omega = 9.3V$$

4.2 Load Line of a Diode Circuit

The basic diode circuit, indicated in Fig. 4-4, consists of the device in series with a load resistance R_L and an input-signal source v_i. This circuit is now analyzed to find the instantaneous current i and the instantaneous diode voltage v_D when the instantaneous input voltage is v_i.



vi/RL

Fig. 4.4 Basic diode circuit.

From Kirchhoff's voltage low (KVL), we can derive the equation for the load line :

$$v_D = v_i - i\,R_L \qquad \text{......... (4.1)}$$

The load line for a diode is the line on the V-I characteristic of the diode which connects between the maximum current could pass in the diode circuit and the input voltage. The load line crossing the V-I curve at a point called diode operating point (Q-point).

In order to draw the load line and determine the Q-point of the diode, we can return to load line equation (4.1)

$$when\ \ v_D = 0\ \ then\ \ i = \frac{v_i}{R_L}$$

$$when\ \ i = 0\ \ then\ \ v_D = v_i$$

Consider now that the input voltage v_i is allows to vary and equal to v_i' , then the above procedure must be repeated for each voltage value. A plot of current vs. input voltage, called the dynamic characteristic. This construction is illustrated in Fig. 4.5.

$$when\ v_D = 0\ then\ \ i = \frac{v_i'}{R_L}$$

$$when\ i = 0\ then\ \ v_D = v_i'$$

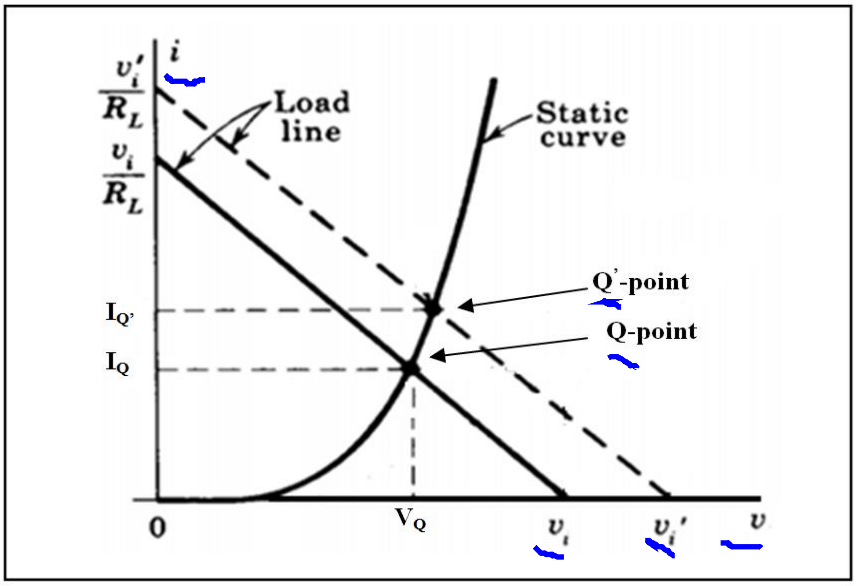


Fig. 4.5 The load line and V–I characteristics.

4.3 Types of Diodes

There are many types of diodes:

4.3.1 Varactor Diodes

Definition: is a p-n junction diode whose internal capacitance varies with the variation of the reverse voltage such type of diode is known as the varactor diode. It is used for storing the charge. The varactor diode always works in reverse bias, and it is a voltage dependent semiconductor device.

The symbol of a varactor diode is shown in Fig. 4.6 .

Fig. 4.6 Varactor diode symbol.

The formula gives the capacitance of varactor diode:

$$C = \frac{\epsilon A}{W} \qquad \ldots\ldots\ldots (4.2)$$

In a varactor diode, the capacitance is varied when the voltage is varied. So the varactor diode is a variable capacitor. The capacitance of a varactor diode is measured in picofarads (pF).

❖ **Advantages of varactor diode :**

1- The varactor diode produce less noise as less compared to the other diode.
2- It is less costly and more reliable. وثوقي
3- The varactor diode is small in size and less in weight.

❖ **Applications of varactor diode:**

1- Varactor diode is used in frequency multipliers.
2- Varactor diode is used in parametric amplifiers. عن-اداخل-متغ
3- Its used in voltage-controlled oscillators.

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4.3.2 Schottky Diodes

Schottky diode is a metal-semiconductor junction diode that has less forward voltage drop than the p-n junction diode and can be used in high-speed switching applications.

In this diode type, metals such as aluminum or platinum replace the p-side semiconductor and the n-side is made from semiconductor such as silicon.

The circuit symbol of the Schottky diode is shown in Fig. 4.7 .

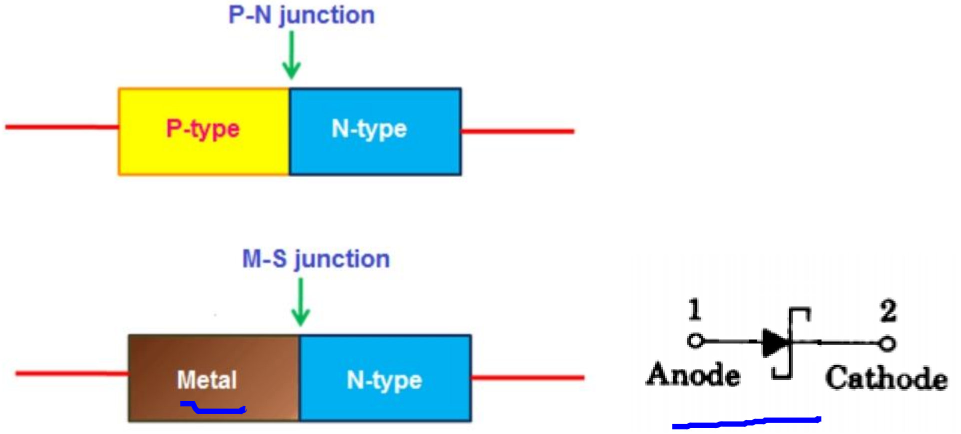

Fig. 4.7 The symbol of Schottky diode.

❖ Schottky diode V-I characteristics:

The V-I characteristics of Schottky diode is almost similar to the p-n junction diode. However, the forward voltage drop of Schottky diode is very low as compared to the p-n junction as shown in Fig. 4.8.

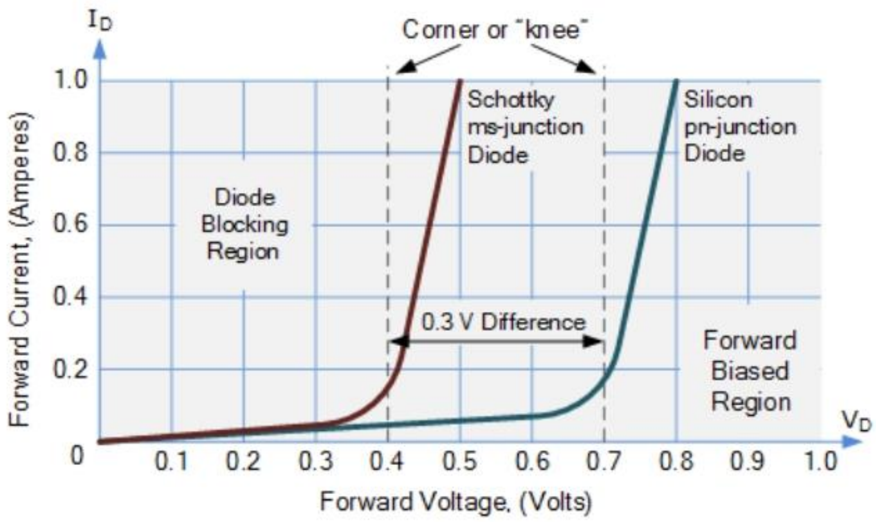

Fig. 4.8 V-I characteristics of Schottky diode.

The forward voltage drop of Schottky diode is 0.3 to 0.4 volts whereas the forward voltage drop of silicon p-n junction diode is 0.6 to 0.7 volts.

Due to this lower value, the forward current of a silicon Schottky diode can be many times larger than that of a typical p-n junction diode, depending on the metal electrode used.

❖ Advantages of Schottky diodes:

1- High efficiency.
2- Schottky diodes operate at high frequencies.
3- Schottky diode produces less unwanted noise than p-n junction diode.
4- Schottky diode has very fast switching time from ON to OFF.

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❖ **Applications of Schottky diodes:**

1- Scottky diodes are used as general purpose rectifiers.
2- Schottky diodes are used in radio frequency (RF) applications.
3- Schottky diodes are widely used in power supplies.
4- Schottky diodes are used in logic circuits.
5- Schottky diodes are used signal conditioning and switching through to TTL and CMOS logic gates due mainly to their low power and fast switching speeds.

4.3.3 Tunnel Diode

A tunnel diode (also called Esaki diode) is a heavily doped p-n junction diode with impurities(say, to 1 part in 10^3) in which the electric current decreases as the voltage increases. This new diode was announced in 1958 by Esaki, who also gave the correct theoretical explanation for diode.

The standard circuit symbol for a tunnel diode is given in Fig. 4.9.

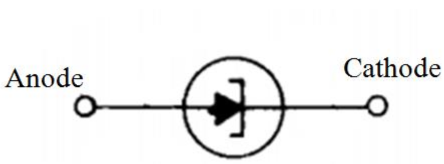


Fig. 4.9 Circuit symbol for tunnel diode.

❖ **V-I Characteristics of a Tunnel diode:**

Classically, a particle must have energy at least equal to the height of a potential energy barrier if it is to move from one side of the barrier to the other. However, for barriers as thin as those in the Esaki diode there is a large probability that an electron will penetrate through the barrier potential. This quantum mechanical behavior is referred to as tunneling, The Volt –Ampere relationship is shown in Fig. 4.10.

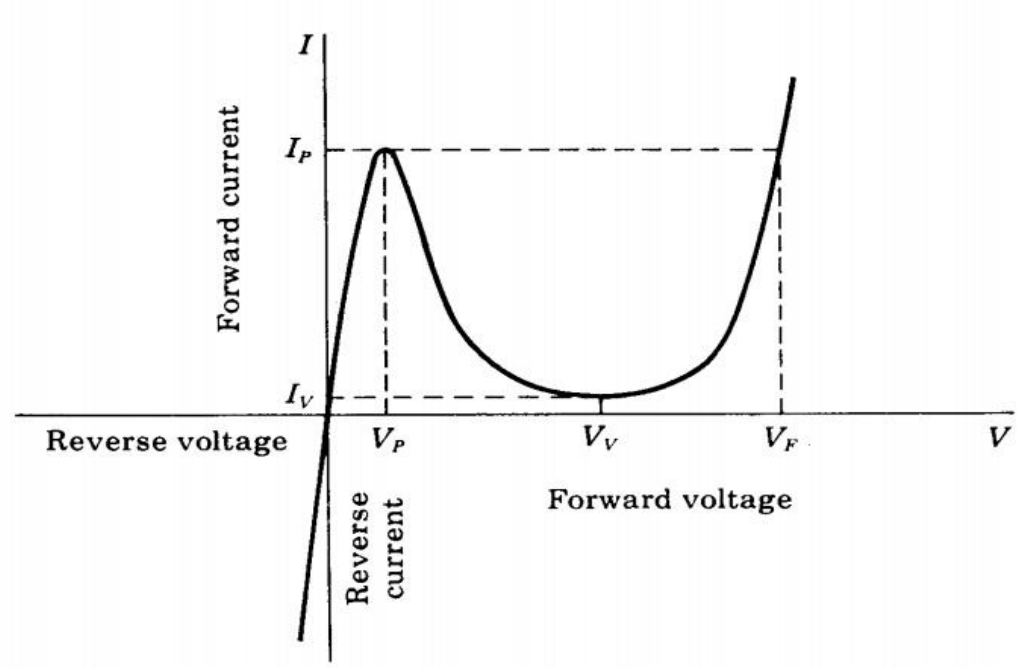


Fig. 4.10 V - I characteristics of the tunnel diode.

From Fig. 4.10, we see that the tunnel diode working in forward biased. For currents whose values are between I_v and I_p the curve is triple- valued, because each current can be obtained at three different applied voltages. This multivalued feature which makes the tunnel diode useful in pulse and digital circuits.

❖ **Advantages of tunnel diodes:**

1- Long life.
2- High speed operation.
3- Low noise.
4- Low power consumption.

❖ Applications of tunnel diodes:

1- Tunnel diodes are used as logic memory storage devices.
2- Tunnel diodes are used in relaxation oscillator circuits.
3- Used as an high-speed switch.
4- Used in FM receivers.

4.3.4 Zener Diodes

The Zener diode is designed for operation in the reverse breakdown region. Zener diodes like normal p-n junction diodes under forward biased condition.

The breakdown voltage of a Zener diode is set by carefully controlling the doping level during manufacture.

The standard circuit symbol for zener diode is shown in Fig. 4.11.

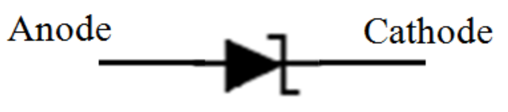


Fig. 4.11 Circuit symbol for zener diode.

❖ V-I Characteristics of a Zener diode:

The (V-I) characteristic in Fig. 4.12 shows that when a zener diode is forward biased, it works like a normal diode. However, when reverse biased voltage is applied to the zener diode, reaches reverse breakdown, its voltage remains almost constant even though the current changes significantly, and this is true in normal operating regions for rectifier diodes and for Zener diode shown as shaded areas.

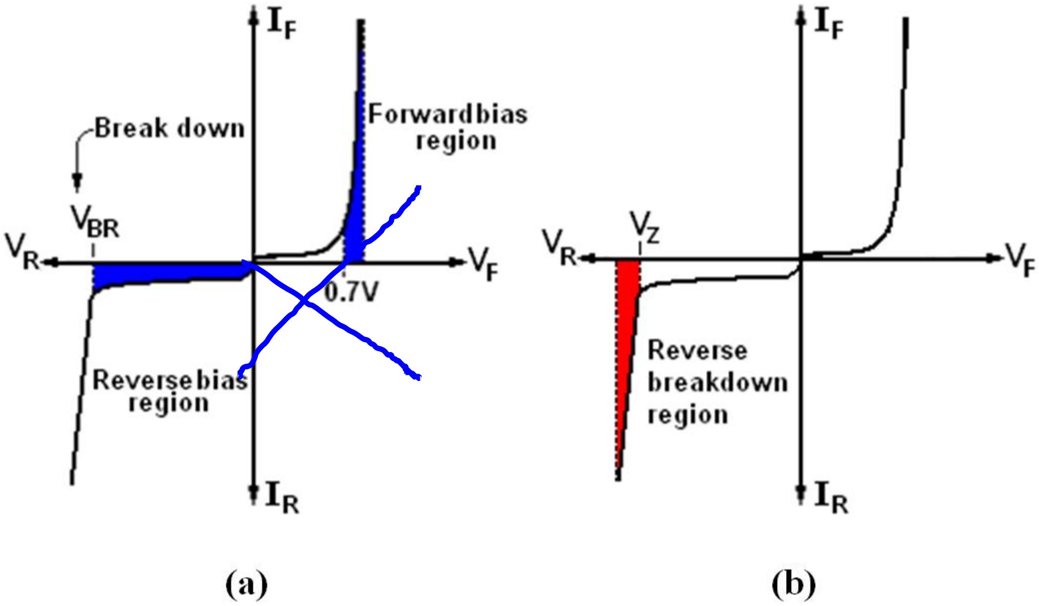


Fig. 4.12 (a) Normal operating regions for Zener diode in Forward bias.

(b) Normal operating regions for Zener diode in Reverse bias.

❖ Zener Breakdown Characteristics

From Fig. 4.13 shown below, we can be observed that, when the reverse voltage V_R, is increased, the reverse current I_R remains small up to **"knee"** of the curve**.** The reverse current is also called the Zener current I_Z.

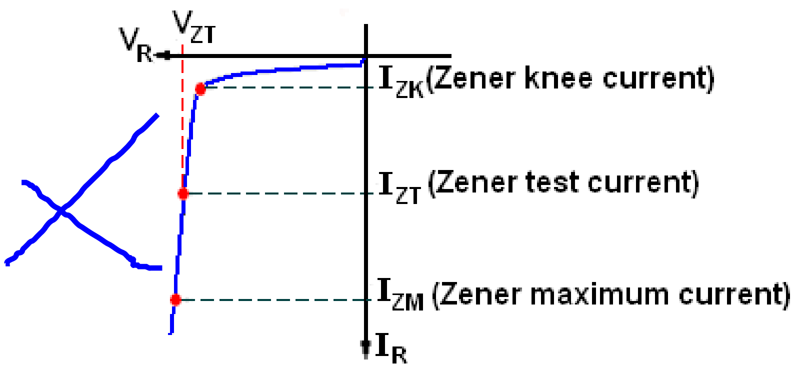


Fig. 4.13 Reverse characteristic of the Zener diode.

At **"knee"** point the breakdown effect begins; the internal Zener resistance r_Z , begins to decrease as the reverse current increases rapidly. From the bottom of the knee the Zener breakdown voltage Vz, remains essentially constant although it increases slightly as the Zener current I_Z increases.

Fig. 4.14a, represent the practical model of a zener diode. The Zener resistor is calculated from the inverse of V-I slope, as in Fig. 4.14b . So r_Z is as in following equation:

$$r_Z = \frac{\Delta V_Z}{\Delta I_Z} \qquad \ldots\ldots..(4.3)$$

In most cases, you can assume that r_Z is constant over the full linear range of Zener current values and is purely resistive.

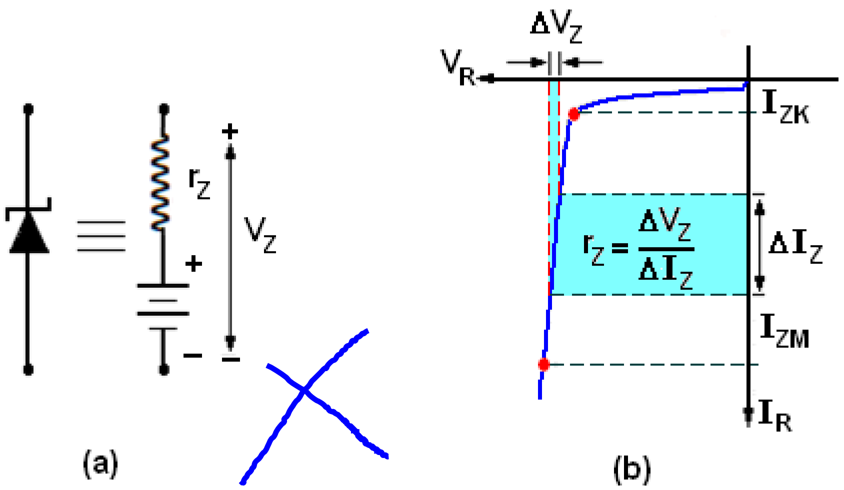


Fig. 4.14 (a) Zener diode equivalent circuit model.
(b) Characteristic curve.

❖ Advantages of Zener diodes:

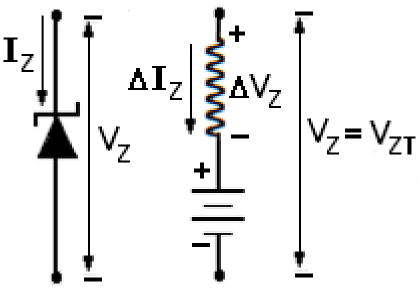
1- Power dissipation capacity is very high.
2- High accuracy.
3- Small size.
4- Low cost.

❖ Applications of Zener diodes:

1- It is used as voltage regulation.
2- It is used in switching operations.
3- It is used in clipping and clamping circuits.
4- It is used in various protection circuits.

Example : *Zener diode has $r_Z = 3.5\Omega$. The data sheet gives $V_{ZT} = 6.8V$ at $I_{ZT} = 37mA$ and $I_{ZK} = 1mA$. What is the voltage across the zener terminals when the current is 50mA, and then 25mA?*

Solution:



For $I_Z = 50mA$;

$\Delta I_Z = I_Z - I_{ZT} = 50 - 37 = 13mA.$

I_Z is a 13mA increase above $I_{ZT} = 37mA$.

$\Delta V_Z = \Delta I_Z \times r_Z = 13 \times 3.5 = 45.5mV.$

The change in Zener voltage when I_Z becomes 50mA is:

$V_Z = 6.8 + \Delta V_Z = 6.8v + 45.5mv = 6.85V.$

For $I_Z = 25mA$:

$\Delta I_Z = I_Z - I_{ZT} = 25 - 37 = -12mA.$

I_Z is a 12mA decrease below $I_{ZT} = 37mA$.

$\Delta V_Z = \Delta I_Z \times r_Z = -12 \times 3.5 = -42mV.$

The change in Zener voltage when I_Z becomes 25mA is:

$V_Z = 6.8 + \Delta V_Z = 6.8v - 42mv = 6.76V.$

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4.4 Diode Applications

Many types of diodes are used for a wide range of applications. Before taking a look at various applications of diodes, let us quickly take a peek at a small list of common applications of diodes:

1- Rectifiers.
2- Clipper circuits.
3- In voltage divider bias.
4- Clamping circuits.
5- In logic gates.

4.4.1 Diode as Rectifiers

The most common and important application of a diode is the rectification of AC power to DC power. Using the diodes, we can construct different types of rectifier circuits. The basic types of these rectifier circuits are :

1- Half wave rectifier.
2- Full wave rectifier.
3- Center tapped full wave rectifier.
4- Full bridge rectifier.

4.4.1.1 Half Wave Rectifier

Fig. 4.15, illustrates the process called half wave rectification. The diode connection to an Ac source and to a load resistor R_L will form a half-wave rectifier.

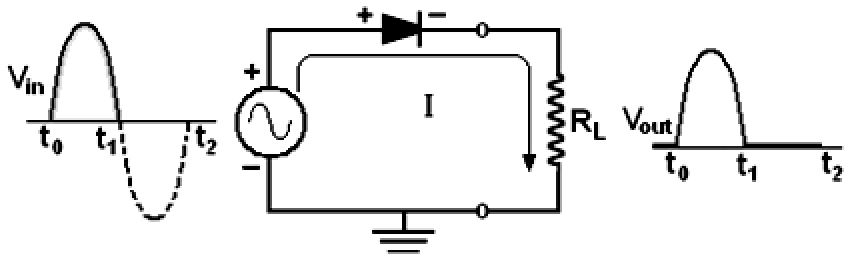


Fig. 4.15 Half-wave rectifier circuit with I/P and O/P waveform.

When the input voltage (**V_{in}**) goes positive during the time duration between ***t_0*** to ***t_1***, as shown in Fig. 4.15, the diode will biased forward and conducts current through the load resistor. The current produces an output voltage across the load R_L which has the same shape as the positive half cycle of the input voltage.

As the input voltage goes negative, during the second half of the input voltage cycle (***t_1*** to ***t_2***), the diode will biased reverse. As a result there is no current will pass through the load R_L and the voltage across the load resistor is 0V.

The net result is that only the positive half cycles of the ac input voltage appear across the load as shown in Fig. 4.16. Since the output does not change polarity, it is a **pulse dc voltage**.

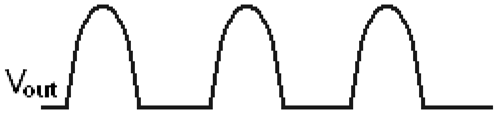


Fig. 4.16 Half-wave output voltage for three input cycles.

When **the practical diode model** is used with the barrier potential of (**V_D**) taken into account. During the positive half cycle, the input voltage must overcome the barrier potential before the diode becomes forward biased. This result in a half wave output with a peak value that is less than the peak value of the input by (**V_D**), as shown in Fig. 4.17.

$$\mathbf{V_{p\,(out)} = V_{p\,(in)} - V_D}$$

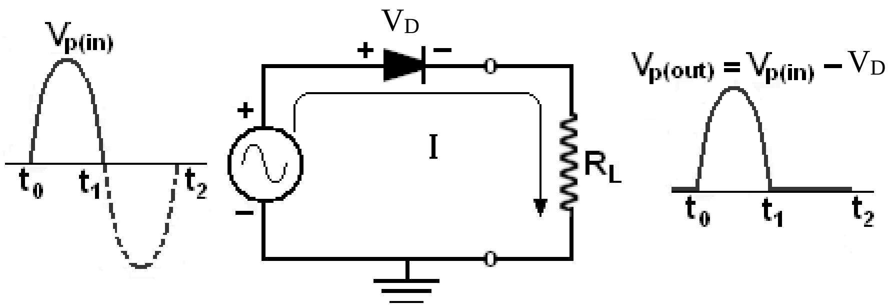


Fig. 4.17 Half wave rectifier circuit.

The **mean value** of the output voltage (V_{avg} or V_{dc}) can be calculated mathematically by the area under the curve over a full cycle, as shown in Fig. 4.18, dividing by 2π, the number of radians in a full cycle, where V_p is the peak value of the voltage:

$$V_{dc} = V_{avg} = \frac{V_p}{\pi}$$

The root mean square value of the output voltage (V_{rms}) is given as:

$$V_{rms} = \frac{V_p}{\sqrt{2}} = 0.707\, V_p$$

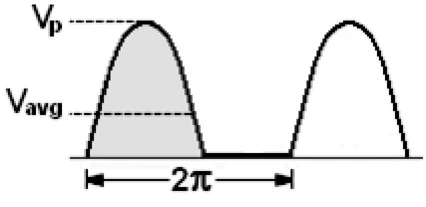


Fig. 4.18 Average value of the half wave rectified signal.

Example : *What is the average value of the half wave rectified voltage if* $V_p = 50V$*?*

Solution:

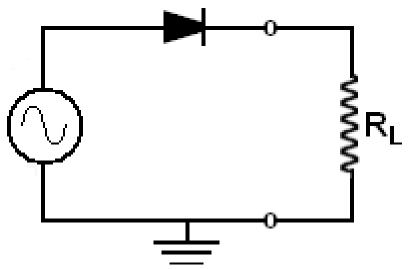
$$V_{dc} = V_{avg} = \frac{V_p}{\pi} = \frac{50}{\pi} = 15.9V$$

Notice that V_{avg} is 31.8 % of V_p

Example : *What are the output voltages of the silicon rectifier diode circuit shown in figure below, if the input voltages are?*

a. $V_{P(in)} = 5V$?

b. $V_{P(in)} = 100V$?



Solution:

a. The peak output voltage is:
$V_{p(out)} = V_{p(in)} - 0.7V = 5 - 0.7 = 4.3V$

b. The peak output voltage is:
$V_{p(out)} = V_{p(in)} - 0.7V = 100 - 0.7 = 99.3V$

❖ Half Wave Rectifier with Transformer Coupled Input Voltage.

A transformer is often used to couple the ac input voltage from the source to the rectifier, as shown in Fig. 4.19.

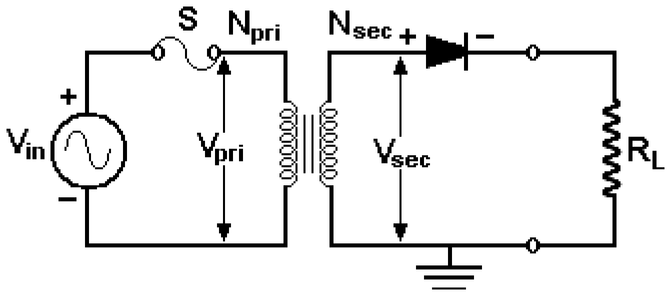


Fig. 4.19 Half wave rectifier with transformer coupled input voltage.

Transformer coupling provides two advantages:

1. It allows the source voltage to be stepped up or stepped down as needed.
2. The Ac source is electrically isolated from the rectifier, thus preventing a shock hazard in the secondary circuit.

The turn's ratio (n) is equal to the ratio of secondary turns ($N_{secondary}$) to the primary turns ($N_{primary}$):

$$n = \frac{N_{secondary}}{N_{primary}}$$

$$V_{secondary} = n \times V_{primary}$$

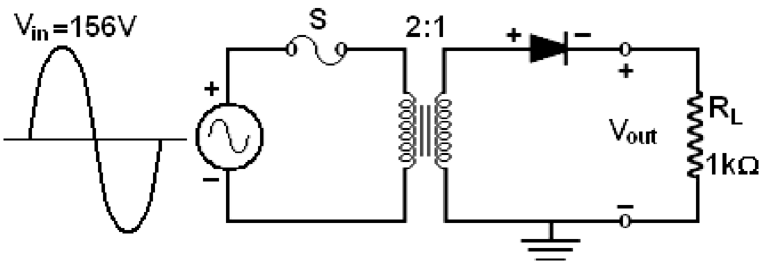
If $n > 1$, the secondary voltage is greater than the primary voltage.

If $n < 1$, the secondary voltage is less than the primary voltage.

The peak secondary voltage, $V_{p(secondary)}$ in a transformer coupled half wave rectifier is equal to $V_{p(in)}$. Therefore:

$$V_{p(out)} = V_{p(secondary)} - V_D$$

Example: *Determine the peak value of the output voltage of the circuit below?*



Solution:

$V_{p(pri)} = V_{p(in)} = 156V$

The peak secondary voltage is:

$V_{p(sec)} = nV_{p(pri)} = 0.5 \times 156V = 78V$

The rectified peak output voltage is:

$V_{p(out)} = V_{p(sec)} - 0.7V = 78 - 0.7 = 77.3V$

Where$V_{p(sec)}$is the input to the rectifier.

4.4.1.2 Full Wave Rectifier

A full-wave rectifier allows unidirectional (one-way) current through the load during the entire 360^o of the input cycle, whereas a half-wave rectifier allow current through the load only during one-half of the cycle. The result of full-wave rectification is an output voltage with a frequency twice the input frequency that pulsate every half-cycle of the input, as shown in Fig. 4.20.

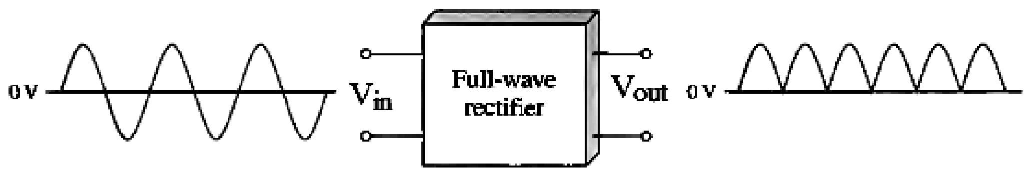


Fig. 4.20 Full wave rectifier.

The average or dc value for a full wave rectified sinusoidal voltage is twice that of the half wave, as shown in the following formula:

$$V_{dc} = V_{avg} = \frac{2V_p}{\pi}$$

V_{avg} is approximately 63.7% of V_p for a full wave rectified voltage.

$$V_{rms} = \frac{V_p}{\sqrt{2}} = 0.707\ V_p$$

❖ **The Center Tapped Full Wave Rectifier.**

A center tapped rectifier use two diodes connected to the secondary of a center tapped transformer as shown in Fig. 4.21. The input voltage is coupled through the transformer to the center tapped secondary. Half of the total secondary voltage appears between the center tap and each end of the secondary winding as shown.

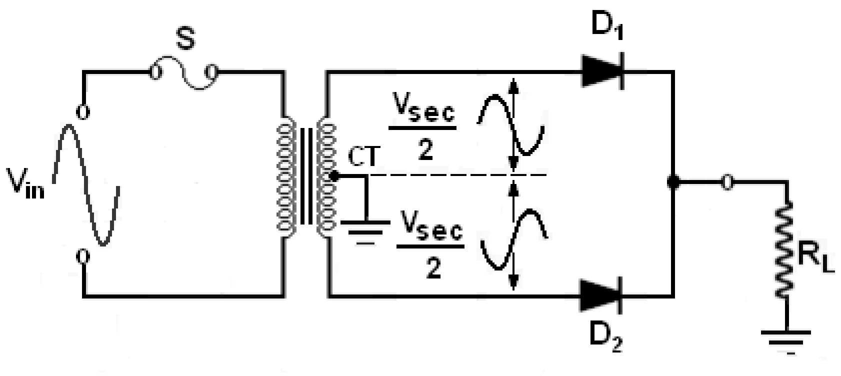
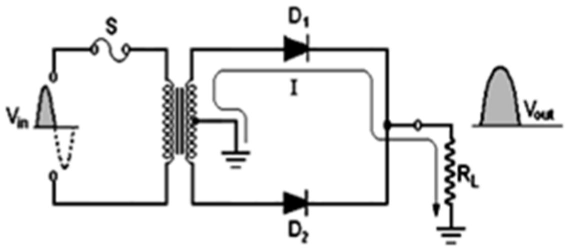


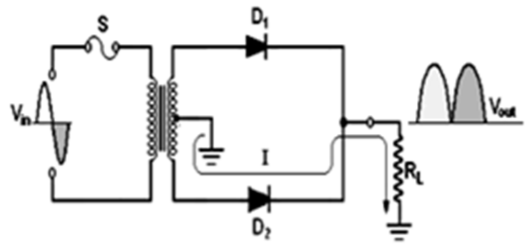
Fig. 4.21 A center-tapped full wave rectifier.

For a positive half cycle of the input voltage, the polarities of the secondary voltages are as shown in Fig. 4.22a. This condition forward biases diode $\mathbf{D_1}$ and reverse biases diode **D_2** . The current path is through **D_1** and the load resistor **R_L** as indicated.

For a negative half cycle of the input voltage, the voltage polarities on the secondary are as shown in Fig. 4.22b. This condition reverses biases **D_1** and forward biases **D_2**. The current path is through **D_2** and **R_L** as indicated. Because the output current during through the load, the output voltage developed across the load resistor is a full wave rectified Dc voltage as shown.



(a) During positive half cycles.



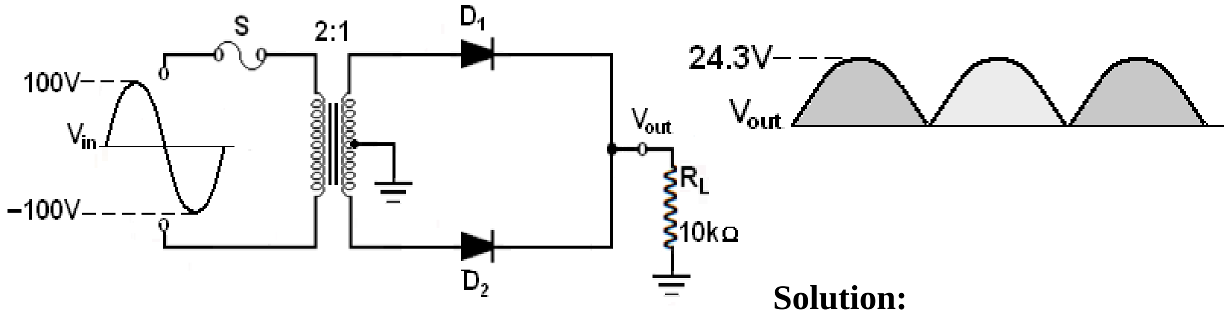
(b) During negative half cycles.

Fig. 4.22 Basic operation of a center tapped full wave rectifier.

The output voltage of a center tapped full wave rectifier is always one half of the **total secondary voltage** less the diode drop, no matter what is the turn's ratio.

$$V_{out} = \frac{V_{sec}}{2} - V_D$$

Example : *Show the voltage waveforms across each half of the secondary winding and across R_L when a 100V peak sine wave is applied to the primary winding in figure below?*



Solution:

The transformer turns ratio n = 0.5.

The total peak secondary voltage is:

$V_{p(sec)} = n\, V_{p(pri)} = 0.5 \times 100 = 50V$

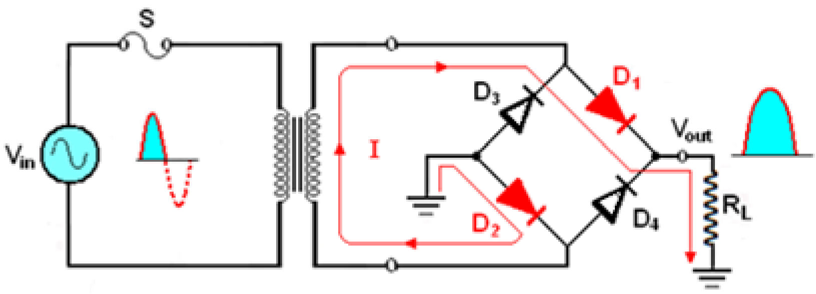
There is a 25V peak across each half of the secondary with respect to ground. The output load voltage:

$25 - 0.7 = 24.3V$

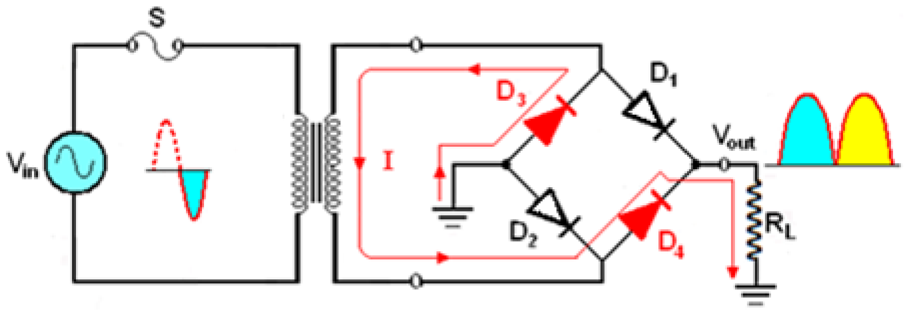
❖ The Bridge Full Wave Rectifier

The bridge rectifier uses four diodes connected as shown in Fig. 4.23. When the input cycle is positive, as shown in Fig. 4.23a, diodes $\mathbf{D_1}$ and $\mathbf{D_2}$ are forward biased and conduct current in the direction shown by arrow.

A voltage is developed across $\mathbf{R_L}$ that looks like the positive half of the input cycle. During this time, diodes $\mathbf{D_3}$ and $\mathbf{D_4}$ are reverse biased. When the input cycle is negative as in Fig. 4.23b, diodes $\mathbf{D_3}$ and $\mathbf{D_4}$ are forward biased and conduct current in the same direction through $\mathbf{R_L}$ as during the positive half cycle.



(a) During the positive half cycle of the input.



(b) During the negative half cycle of the input.

Fig. 4.23 Operation of a bridge rectifier.

During the negative half cycle, $\mathbf{D_1}$ and $\mathbf{D_2}$ are reverse biased. A full wave rectified output voltage appears across $\mathbf{R_L}$ as a result of this action.

The output voltage of the bridge full wave rectifier :

During the positive half cycle of the total secondary voltage, diodes D_1 and D_2 are forward biased. Neglecting the diode drops, the secondary voltage appears across the load resistor. The same is true when D_3 and D_4 are forward biased during the **negative half cycle**.

$$V_{p(out)} = V_{p(sec)}$$

It can be seen in Fig. 4.24. Two diodes are always in series with the load resistor during both the positive and negative half cycles. If these diode drops are taken into account, the output voltage is:

$$V_{p(out)} = V_{p(sec)} - 2V_D$$

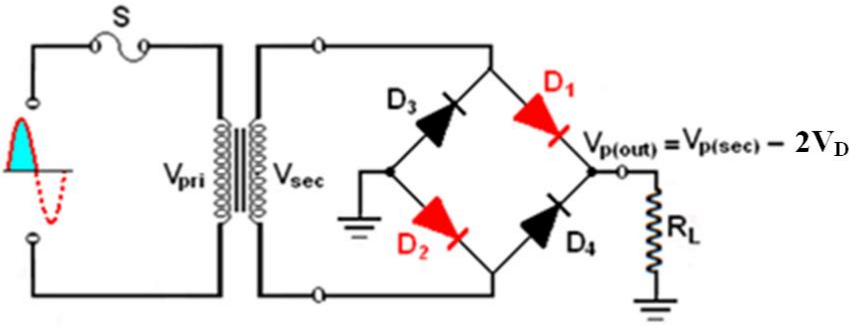


Fig. 4.24 Bridge operation during a positive half cycle of the primary and secondary voltages.

<u>Example :</u> *Determine the peak output voltage for the bridge rectifier? The transformer is specified to have a 12 Vrms secondary voltage for the standard 110V across the primary.*

Solution:

The peak output voltage (taking into account the two diode drops) is

$$V_{rms} = \frac{V_{p(sec)}}{\sqrt{2}}$$

$$V_{P(sec)} = \sqrt{2} \times 12 = 17V$$

$$V_{P(out)} = V_{P(sec)} - 1.4 = 17 - 1.4 = 15.6V$$

❖ Ripple Factor.

The ripple factor is an indication of the effectiveness of the filter and is defined as:

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

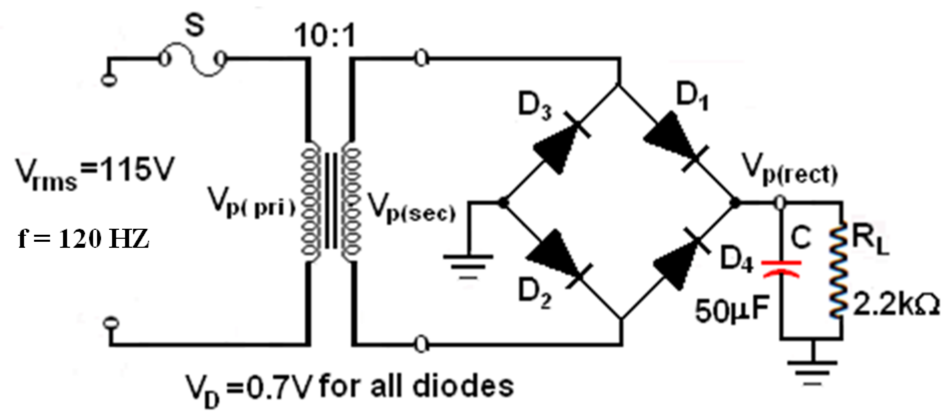
$$V_{r\,(p-p)} \cong \frac{1}{f R_L C} V_{p(rect)}$$

$$V_{dc} \cong \left(1 - \frac{1}{2 f R_L C}\right) V_{p(rect)}$$

Where: $V_{r\,(p-p)}$: is the peak to peak voltage.

V_{dc}: is the dc (average) value of the filter's output voltage.

Example: *Determine the ripple factor for the filtered rectifier with a load as indicated in figure below?*



Solution:

For full wave rectifier :

$$V_{rms} = \frac{V_p}{\sqrt{2}} \quad \rightarrow \quad V_{p(pri)} = \sqrt{2} \times V_{rms}$$

$$V_{p(pri)} = \sqrt{2} \times 115 = 163v$$

$$n = N_2/N_1 = 1/10 = 0.1$$

$$\therefore V_{p(sec)} = nV_{p(pri)} = 0.1 \times 163 = 16.3v$$

The unfiltered peak full wave rectifier voltage is:

$$V_{p(rect)} = V_{p(sec)} - 2V_D = 16.3 - 2 \times 0.7 = 14.9V$$

The frequency of a full wave rectifier voltage is 120Hz. So the ripple voltage is:

$$V_r \cong \left(\frac{1}{fR_LC}\right) V_{p(rect)} = \left(\frac{1}{120 \times 2.2 \times 10^3 \times 50 \times 10^{-6}}\right) \times 14.9 = 1.13V$$

$$V_{dc} \cong \left(1 - \frac{1}{2fR_LC}\right) V_{p(rect)}$$

$$V_{dc} = \left(1 - \frac{1}{2 \times 120 \times 2.2 \times 10^3 \times 50 \times 10^{-6}}\right) \times 14.9 = 14.3V$$

$$r = \frac{V_r}{V_{d.c}} = \frac{1.13}{14.3} = 0.079$$

$$\therefore r = 7.9\%$$

4.4.2 Diode Clipping Circuits

The clipper circuit is used to clip off portions of signal voltages above or below certain levels without disturbing the remaining part of the input voltage waveform. Based on the diode configuration in the circuit, these clippers are divided into:

1- Positive clippers.
2- Negative clippers.
3- Positive biased clippers.
4- Negative biased clippers.

❖ **Positive clippers.**

Fig. 4.25, shows a diode clipper that clips the positive part of the input voltage. As the input voltage goes positive, the diode becomes forward biased and conducts the current. So point A is limited to (+ V_D), when the input go back below V_D, the diode is reverse biased and appears as an open the output voltage is look like the negative part of the input voltage, but with magnitude determined by the voltage divider formed by R_1 and the load resistance R_L.

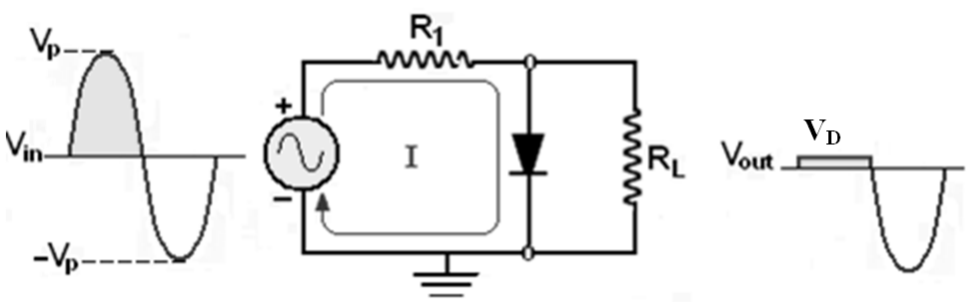


Fig. 4.25 circuit for the positive clipper.

$$V_{out} = \left(\frac{R_L}{R_L + R_1}\right) V_{in} \qquad \text{if } R_1 \ll R_L \;\rightarrow\; V_{out} = V_{in}$$

❖ **Negative clippers.**

If the diode turns around as in Fig. 4.26, the negative part of the input voltage is clip off. When the diode is forward biased during the negative part of the input voltage, point A is held at (**-V_D**) by the diode drop.

When the input voltage goes above (**-V_D**), the diode is no longer forward biased; and a voltage appears across $\mathbf{R_L}$ proportional to the input voltage.

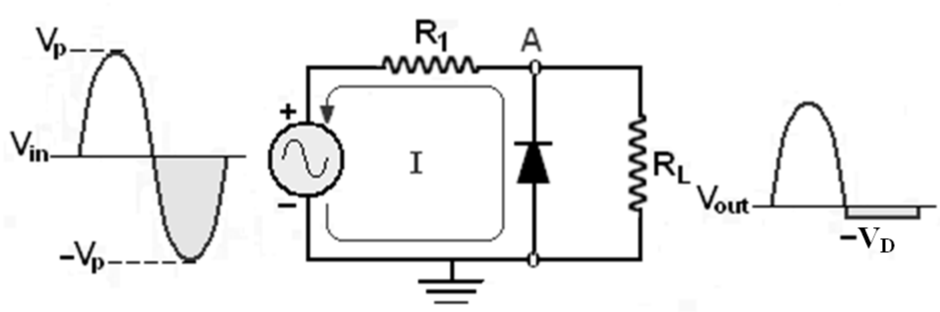
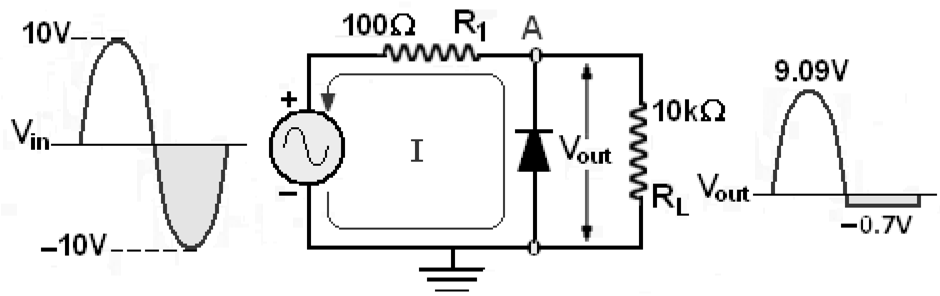


Fig. 4.26 circuit for the negative clipper.

Example: *Determine the output voltage waveform to the circuit shown in figure below? Assume V_D=0.7 Volt.*



Solution:

The diode is forward biased and conduct when the input voltage goes below $-0.7V$ the peak output voltage across R_L determine as follow:

$$V_{pout} = \left(\frac{R_L}{R_L + R_1}\right) V_{pin} = \frac{10 \times 10^3}{100 + 10 \times 10^3} \times 10 = 9.09V$$

❖ **Positive biased clippers.**

The level to which an AC voltage is limited can be adjusted by adding a bias voltage V_B, in series with the diode, as shown Fig. 4.27.

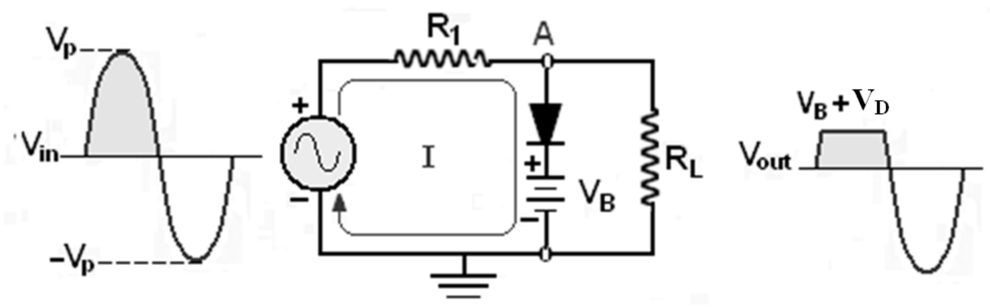


Fig. 4.27 Positive biased clipper.

The voltage at point **A** is equal to $(V_B + V_D)$ before the diode will become forward biased and conduct. Once the diode begins to conduct, the voltage at point **A** is limited to $(V_B + V_D)$ so that all input voltage above this level is clipped off.

❖ **Negative biased clippers**

To obtain negative biased clipper circuit, the diode and bias voltage must connect as shown in Fig. 4.28. In this case, the voltage at point **A** must go below $(-V_B - V_D)$ to forward bias the diode an initiate limiting action as shown.

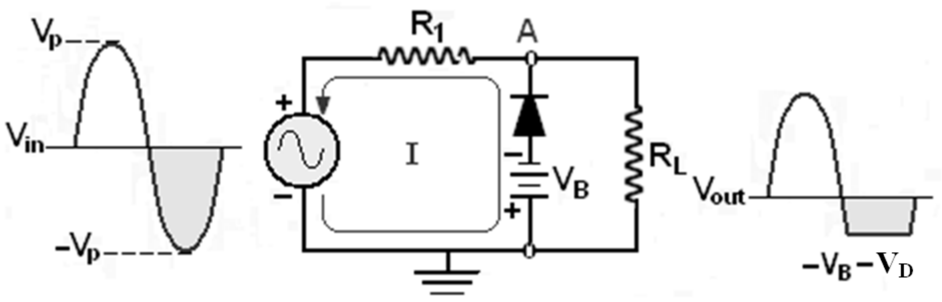
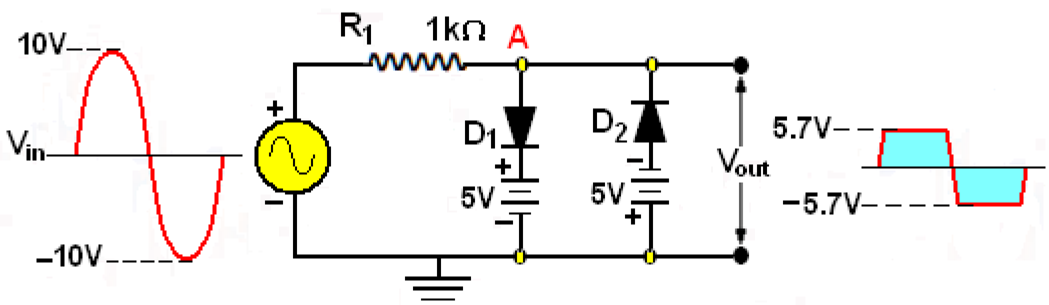


Fig. 4.28 Negative biased clipper.

Example: *Figure below shows a circuit combining a positive clipper with a negative clipper. Determine the output voltage waveform?*



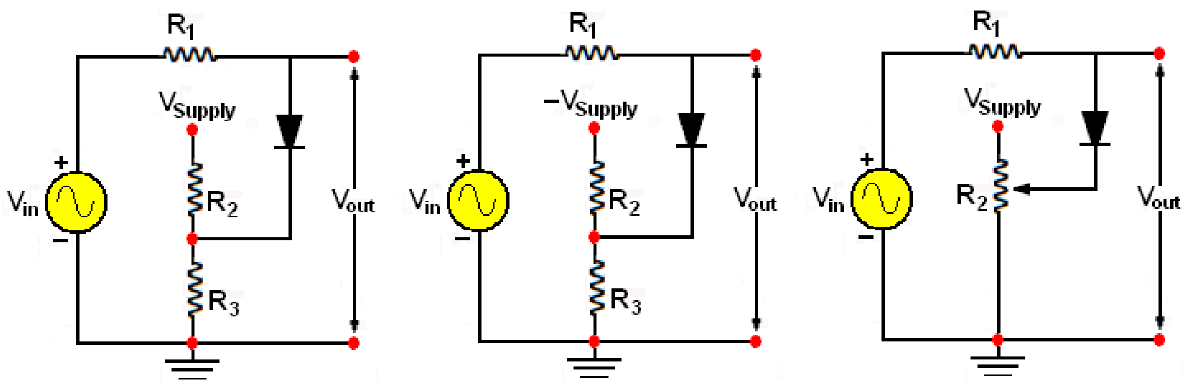
Solution:

*When the voltage at point **A** reaches* $+5.7V$, *diode* D_1 *conducts and limits the waveform to* $+5.7V$. *Diode* D_2 *does not conduct until the voltage reaches* $-5.7V$. *Therefore positive voltage above* $+5.7V$ *and negative voltage below* $-5.7V$ *are clipped off. Output voltage waveform is shown in figure below.*

4.4.3 Voltage Divider Bias

The bias voltage sources that have been used to explain the basic operation of diode limiter can be replaced by a resistive voltage divider that derives the desired bias voltage from the dc supply voltage, as shown in Fig. 4.29. The bias voltage is set by the resistor values according to the voltage divider formula.

$$V_{Bias} = \left(\frac{R_3}{R_2 + R_3}\right) V_{Supply}$$

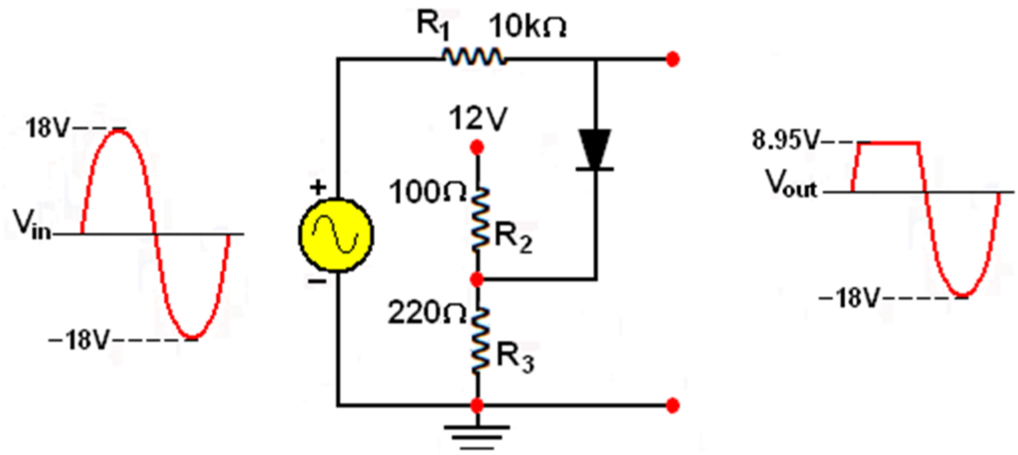


(a) Positive limit (b) Negative limiter (c) Variable positive limiter

Fig. 4.29 Diode limiters implemented with voltage divider bias.

A positively biased limiter is shown in Fig. 4.29a, a negatively biased limiter is shown in Fig.4.29b, and a variable positive bias circuit using a potentiometer voltage divider is shown in Fig. 4.29c. The bias resistors must be small compared to R, so that the forward current through the diode will not affect the bias voltage.

Example: *Describe the output voltage waveform for the diode limiter in figure below:*



Solution:

The circuit is a positive limiter. Use the voltage divider formula to determine the bias voltage:

$$V_{Bias} = \left(\frac{R_3}{R_2 + R_3}\right) V_{Supply}$$

$$V_{Bias} = \left(\frac{220}{100 + 220}\right) 12 = 8.25V$$

The positive part of the output voltage waveform is limited to:

$$V_{Bias} + 0.7V = 8.25 + 0.7 = 8.95V$$

4.4.4 Diode Clampers

A clamper adds a DC level to an AC voltage. Clampers are sometimes known as DC restorers.

❖ **Negative clamper**

The negative clamper achieved by turn the diode, as in Fig. 4.30. The capacitor voltage reverses and circuit becomes a negative clamper. The clamping is less than perfect because the positive peak has a reference level of V_D instead of 0 volt.

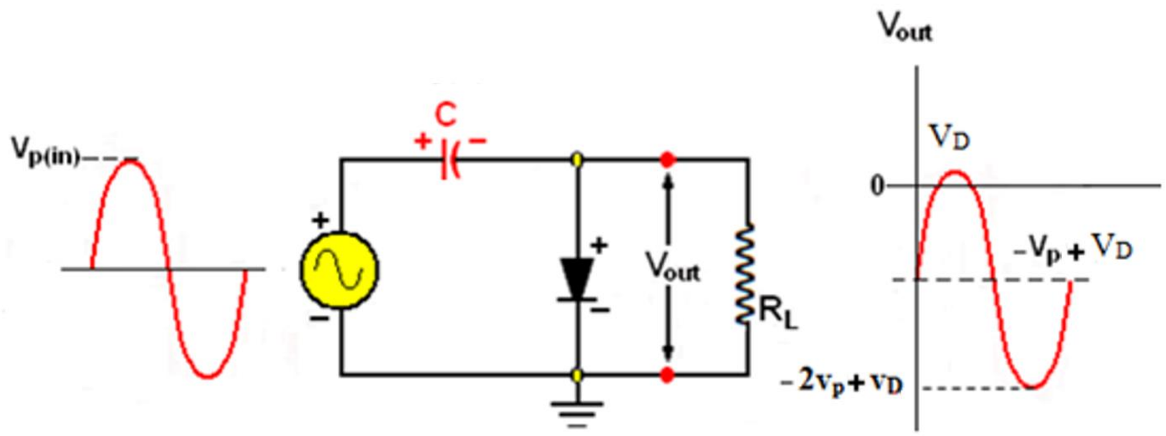


Fig. 4.30 Negative clamper.

❖ **Positive Clamper**

Fig. 4.31, shows a diode clamper that inserts a positive dc level in the output waveform. The operation can be seen by considering the first negative half cycle for input voltage, when input voltage initially goes negative, the diode is forward biased allowing the capacitor to charge near the peak of the input $(V_p - V_D)$.

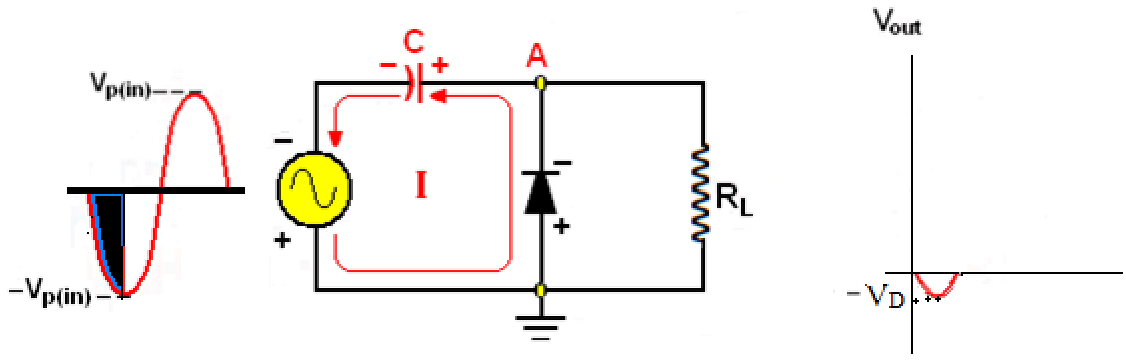


Fig. 4.31 Charge the capacitor.

Just above the negative peak the diode is reverse biased. This is because the diode cathode is held near the $(V_p - V_D)$ by charge on the capacitor. The capacitor can only discharge through the high resistance R_L.

The net effect of the clamping action is that the capacitor retains a charge approximately equal to the peak value of the input less the diode drop V_D, as shown in Fig. 4.32. The capacitor voltage acts essentially as a battery in series with input signal.

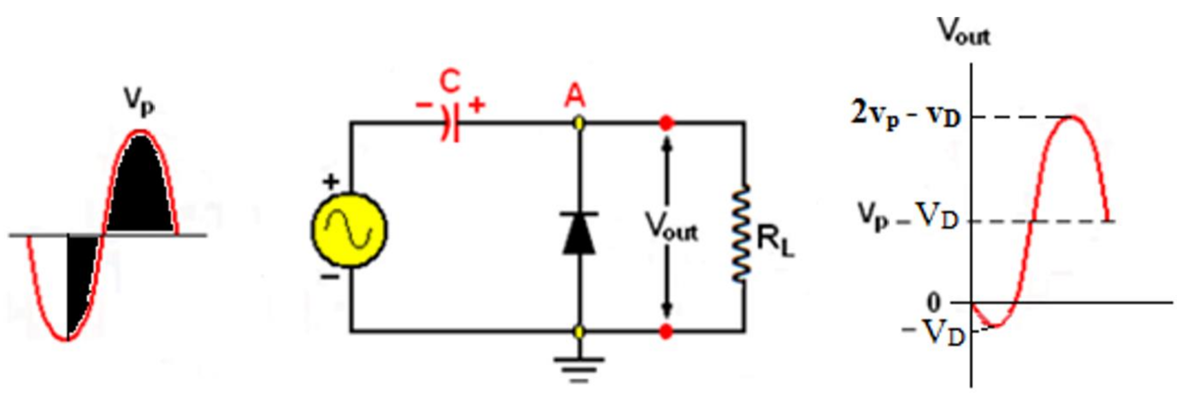
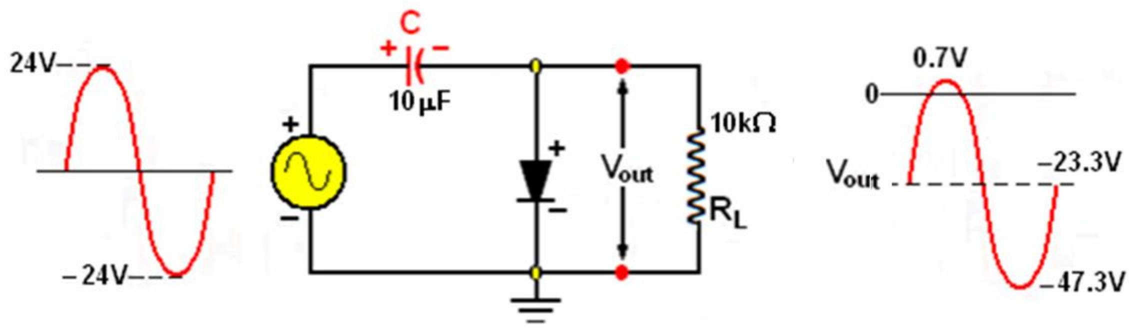


Fig. 4.32 Discharge the capacitor.

Example: *What is the output voltage that you would expect to observe across R_L in the clamper circuit?*



Solution:

Negative dc value equal to the input peak less the diode drop V_D.

$V_{dc} = -V_p + V_D$

$V_{dc} = -(V_p - V_D) = -(24 - 0.7) = -23.3v$

$V_{out} = -2V_p + V_D$

$= -48 + 0.7 = -47.3v$

4.4.5 Diode logic gates

It is possible to implement the digital logic gates by using diodes and resistors, if we suppose the **0 volt** mean **low** level and the **5volt** mean **high** level we can say that:

❖ **OR gate**

The circuit in Fig. 4.33, is diode logic OR gate, has two inputs $(V_A \,\&\, V_B)$ with one output (V_y).

a) If $V_A = V_B = 5$ volt (high) or one of them equal to 5volt (high)
The diode will be conduct $\rightarrow V_y = 5$ volt mean high

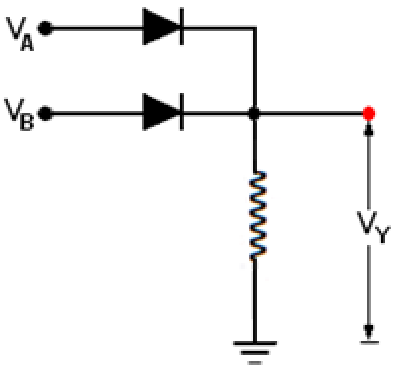
b) If $V_A = V_B = 0$ volt (low).
The diodes will be cut off → $V_y = 0$ volt mean (low).

This circuit implements the logic OR function, which is in Boolean notation, is expressed as:

$Y = A + B$

A	B	A+B
0	0	0
0	1	1
1	0	1
1	1	1

OR gate truth table



OR gate circuit

Fig. 4.33 OR gate implemented by diodes.

❖ **AND gate**

The circuit in Fig. 4.34, is diode logic AND gate, has two inputs (V_A & V_B) with one output (V_y).

a) If $V_A = V_B = 0$ volt (low) or one of them equal to 0 volt (low)

The diode will be forward biased and the current has a path to the ground from any conduct diode coming from the supply voltage (V_{CC}) and off $V_y = 0$ volt mean (low).

b) If $V_A = V_B = 5$volt (high).

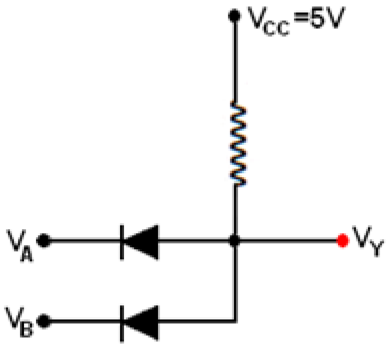
The diodes will be cut off and the supply voltage (V_{CC}) charge the V_y by 5 volt (high). And this achieved the (4^{th}) level from the table.

This circuit implements the logic AND function, which is in Boolean notation, is expressed as:

$$Y = A \times B$$

A	B	AXB
0	0	0
0	1	0
1	0	0
1	1	1

AND gate truth table



AND gate circuit

Fig. 4.34 AND gate implemented by diodes.