Ministry of High Education and Scientific Research
Kut University Collage
Medical Instrumentation Techniques Engineering

Regulated Power Supplies (Part 1)

Third Stage
Medical Electronic System

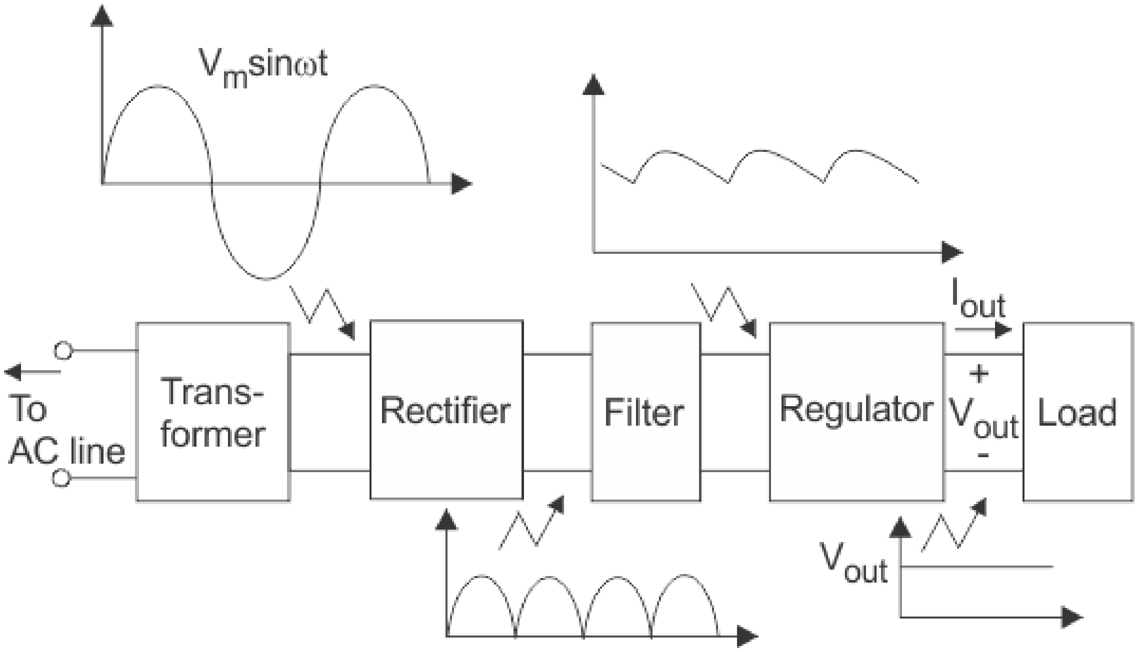
By
Ban Hamed

A **regulated power supply** converts unregulated AC (Alternating Current) to a constant DC (Direct Current). A regulated power supply is used to ensure that the output remains constant even if the input changes.
A regulated DC power supply is also known as a linear power supply, it is an embedded circuit and consists of various blocks.

The regulated power supply will accept an AC input and give a constant DC output. The figure below shows the block diagram of a typical regulated DC power supply.

The basic building blocks of a regulated DC power supply are as follows:

1. A step-down transformer
2. A rectifier
3. A DC filter
4. A regulator

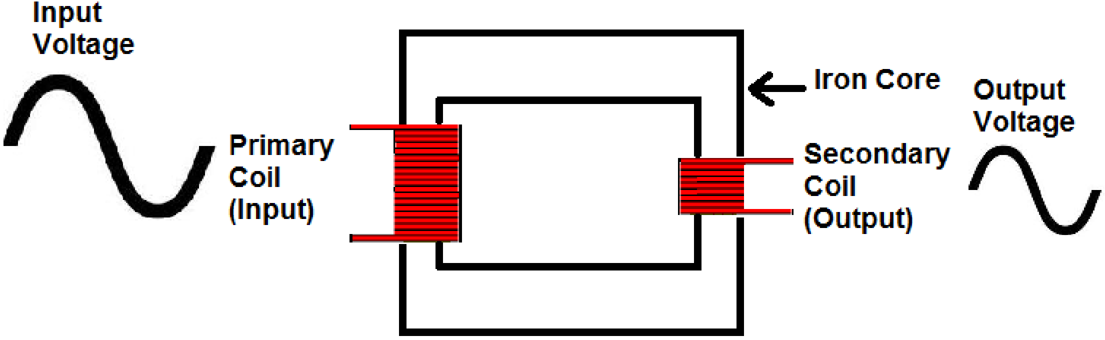


Components of typical linear power supply

Operation of Regulated Power Supply

Step Down Transformer

A step down transformer will step down the voltage from the ac mains to the required voltage level. The turn's ratio of the transformer is so adjusted such as to obtain the required voltage value. The output of the transformer is given as an input to the rectifier circuit.



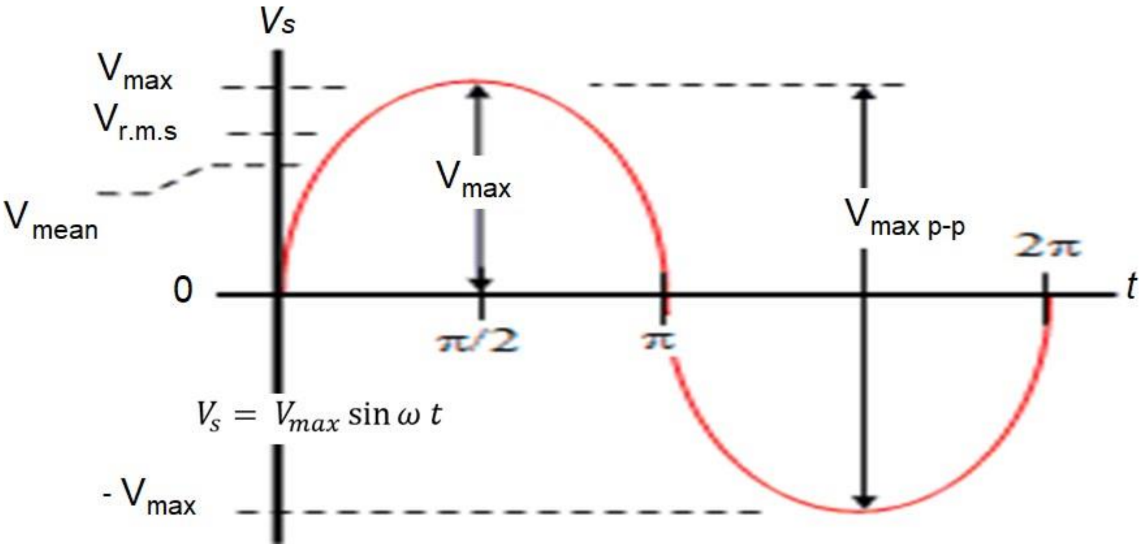
Step Down Transformer

$$\boxed{\therefore \frac{V_{s1\,max}}{V_{s2\,max}} = \frac{n_1}{n_2}}$$

Rectification

Rectifier is an electronic circuit consisting of **diodes** which carries out the rectification process. Rectification is the process of converting an alternating voltage or current into corresponding direct (DC) quantity. The input to a rectifier is AC whereas its output is unidirectional pulsating DC.

There are a number of ways in which the amplitude of a sinewave is referenced, usually as peak voltage (V_{pk}, V_p or V_{max}) peak-to-peak voltage ($V_{p.p}$), average voltage (V_{avg}), and root-mean-square voltage (V_{rms}). Peak voltage and peak-to-peak voltage are apparent by looking at the above plot. Root-mean-square and average voltage are not so apparent.



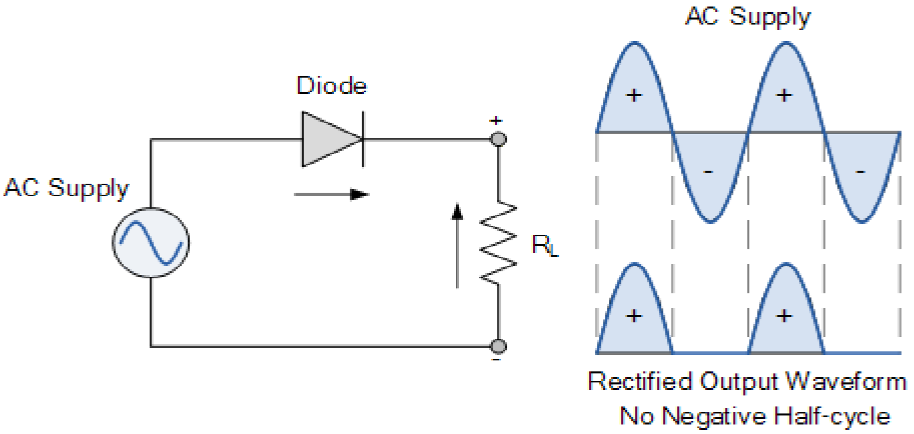
As the name implies, V_{rms} is calculated by taking the square root of the mean average of the square of the voltage in an appropriately chosen interval. In the case of symmetrical waveforms like the sinewave, a quarter cycle faithfully represents all four quarter cycles of the waveform. Therefore, it is acceptable to choose the first quarter cycle, which goes from 0 radians (0°) through p/2 radians (90°).

V_{rms} is the value indicated by the vast majority of AC voltmeters. It is the value that, when applied across a resistance, produces that same amount of heat that a direct current (DC) voltage of the same magnitude would produce. For example, 1 V applied across a 1 Ω resistor produces 1 W of heat. A 1 V_{rms} sinewave applied across a 1 Ω resistor also produces 1 W of heat. That 1 V_{rms} sinewave has a peak voltage of √2 V (≈1.414 V), and a peak-to-peak voltage of 2√2 V (≈2.828 V).

Average voltage or mean voltage (V_{mean}) is calculated by taking the average of the voltage in an appropriately chosen interval.

Therefore, it is acceptable to choose the first quarter cycle, which goes from 0 radians (0°) through p/2 radians (90°).
As with the V_{rms} formula, a full derivation for the V_{mean} formula is given here as well.

Although **a <u>half wave rectifier</u>** could technically be used, its power losses are significant compared to **a <u>full wave rectifier</u>**.



The output DC voltage of a half wave rectifier, given a sinusoidal input, can be calculated with the following ideal equations:

$$\boxed{v_{s\,rms} = \frac{V_{s\,max}}{\sqrt{2}}}$$

V_{av} or V_{dc} or V_{lmean}

$$= \frac{1}{T}\int_0^T f(t)dt$$

$$= \frac{1}{2\pi}\int_0^\pi V_{s\,max} sin\theta d\theta$$

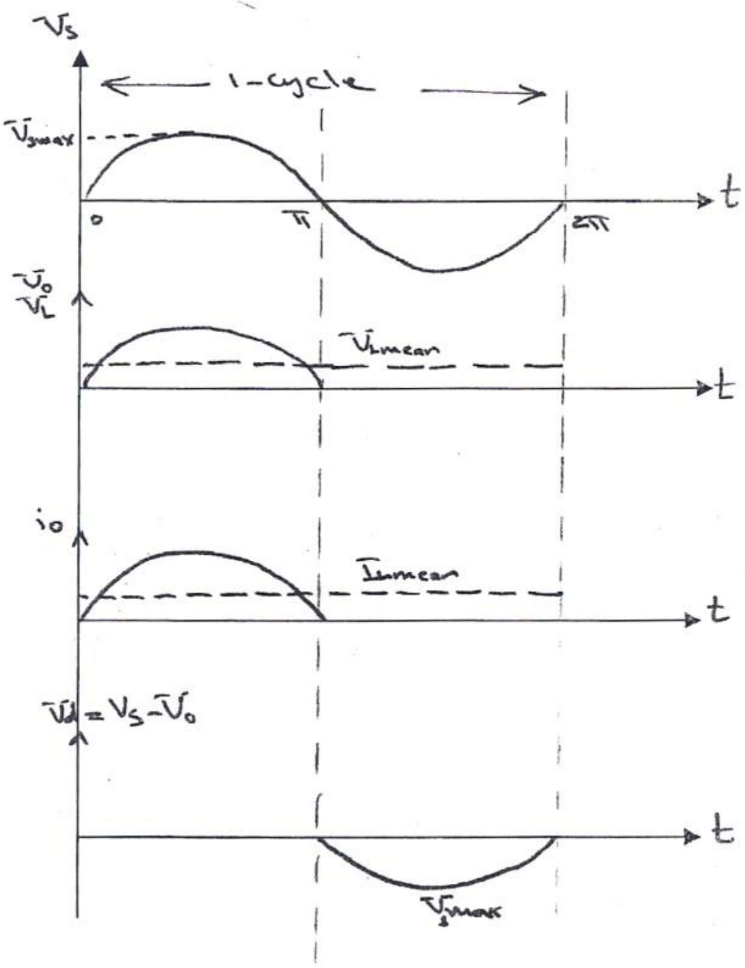
$$= \frac{V_{s\,max}}{2\pi}\int_0^\pi sin\theta d\theta$$

$$= \frac{V_{s\,max}}{2\pi}[-cos\theta]_0^\pi$$

$$= -\frac{V_{s\,max}}{2\pi}[cos\pi - cos0]$$

$$\boxed{\therefore\ V_{lmean} = \frac{V_{s\,max}}{\pi}}$$

$$\boxed{\therefore\ I_{lmean} = \frac{V_{lmean}}{R}}$$



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

$$v_{0\,rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} V_{smax}{}^{2}\sin^2\theta d\theta}$$

$$\boxed{\sin^2\theta = \frac{1}{2}(1 - \cos2\theta)}$$

$$= V_{smax}\sqrt{\frac{1}{2\pi}\int_0^{\pi}\frac{1}{2}(1 - \cos2\theta)}$$

$$= V_{smax}\sqrt{\frac{1}{4\pi}\int_0(1 - \cos2\theta)d\theta} = V_{smax}\sqrt{\frac{1}{4\pi}\int_0^{\pi}1d\theta - \frac{1}{2}\int_0^{\pi}\cos2\theta\, d\theta}$$

$$= V_{smax}\sqrt{\frac{1}{4\pi}\left[\theta - \frac{\sin2\theta}{2}\right]_0^{\pi}}$$

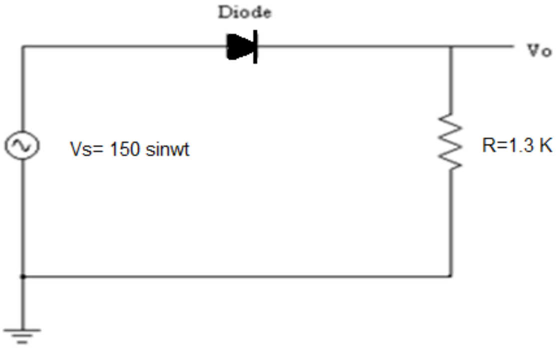
$$= V_{smax}\sqrt{\frac{1}{4\pi}\left[- \frac{\sin2\pi}{2} - 0 + \frac{\sin2\times0}{2}\right]}$$

$$= V_{smax}\sqrt{\frac{1}{4\pi}[\pi]} =$$

$$\boxed{v_{0\,rms} = \frac{V_{smax}}{2}} \qquad \boxed{\therefore\ i_{0\,rms} = \frac{v_{o\,rms}}{R}}$$

Rectification efficiency (f) $= \frac{P_{dc}}{P_{ac}} = \frac{I_{mean}.V_{mean}}{i_{rms}.v_{rms}}$

Ex1: For the 1-φ half wave rectifier circuit shown in Figure below, $R = 1.3K\Omega$, $V_s = 150\ sinwt$. Calculate V_{Lmean}, I_{Lme}, $v_{s_{r.m.s}}, v_{o_{r.m.s}}, i_{o_{r.m.s}}, form\ factor\ (FF) and\ ripple\ factor\ (RF)$.



Solution: <u>الحل بعد االشتقاق</u>

$$V_{lmean} = \frac{V_{s\,max}}{\pi} = \frac{150}{3.14} = 47.7\ V$$

$$I_{lmean} = \frac{V_{lmean}}{R} = \frac{47.7}{1.3k} = 36.7\ mA$$

$$v_{s\,rms} = \frac{V_{s\,max}}{\sqrt{2}} = \frac{150}{\sqrt{2}} = 106.06\ V$$

$$v_{o\,rms} = \frac{V_{s\,max}}{2} = \frac{150}{2} = 75\ V$$

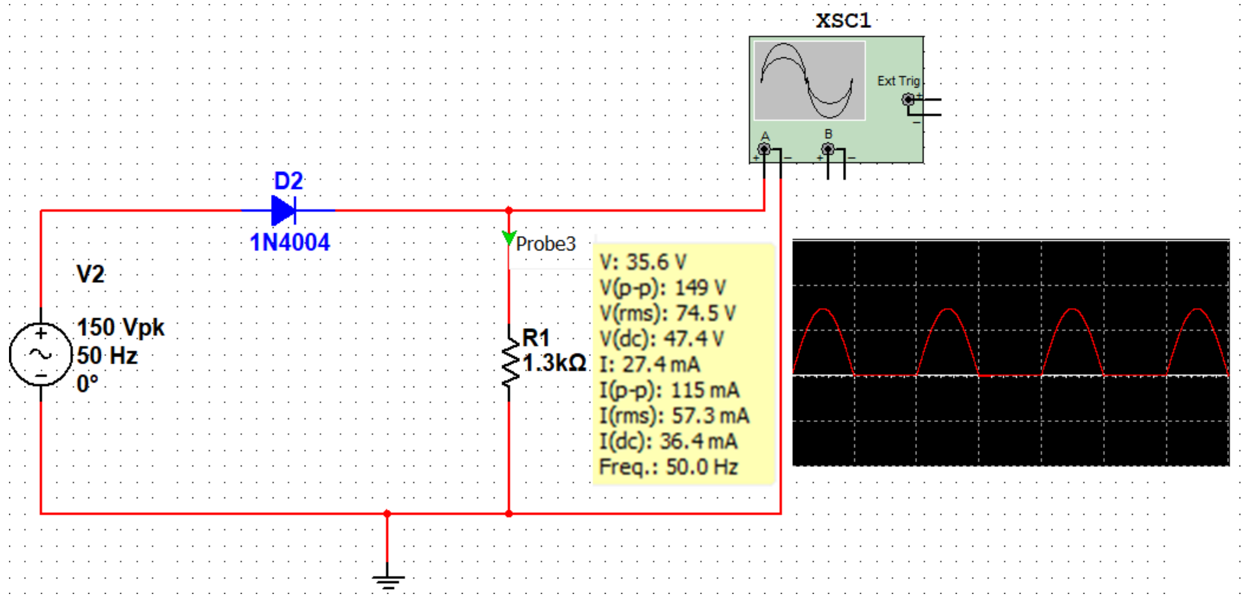
$$i_{o\,rms} = \frac{v_{o\,rms}}{R} = \frac{75}{1.3k} = 57.7\ mA$$

$$FF = \frac{v_{o\,rms}}{V_{lmean}} = \frac{75}{47.7} = 1.57$$

$$RF = \sqrt{\frac{V_{o\,rms}{}^2 - V_{lmean}{}^2}{V_{lmean}{}^2}} = \sqrt{\frac{(75)^2 - (47.7)^2}{(47.7)^2}} = 1.213$$

Rectification efficiency (f**)** $= \frac{P}{P_{ac}} = \frac{I_{lmean}.V_{lmean}}{i_{o\,rms}.v_{o\,rms}} = \frac{36.7m\times 47.7}{57.7m\times 75} = 0.4 = 40\%$

The Answer with MULTISIM



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V: 35.6 V
V(p-p): 149 V
V(rms): 74.5 V
V(dc): 47.4 V
I: 27.4 mA
I(p-p): 115 mA
I(rms): 57.3 mA
I(dc): 36.4 mA
Freq.: 50.0 Hz
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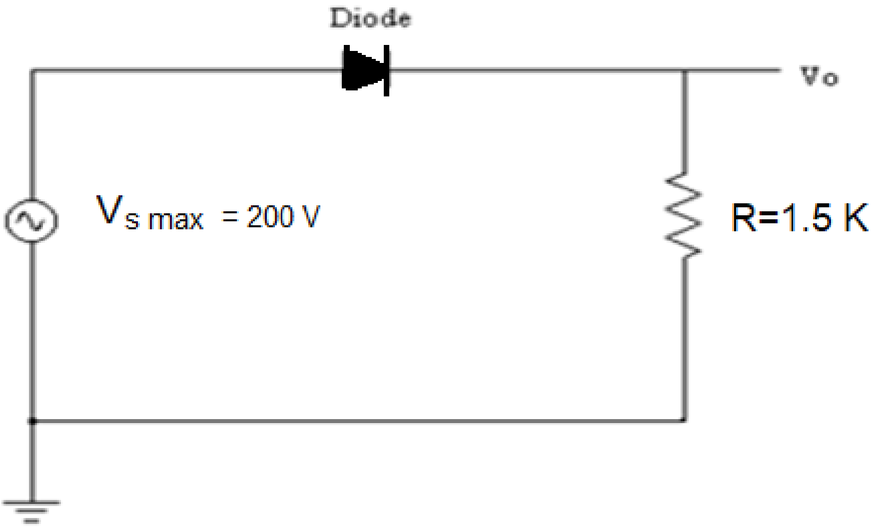
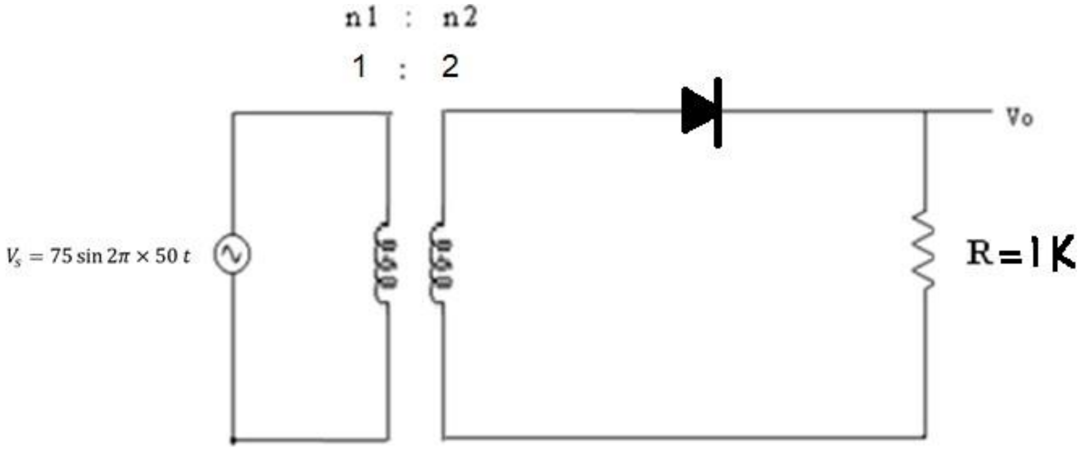
Ex2: (H.W) For the 1-φ half wave rectifier circuit shown in Figure below, $R = 10\Omega$, $V_s = 200$ volt. Determine V_{Lmean}, I_{Lmean}, $v_{s_{r.m.s}}$, $v_{o_{r.m.s}}$, $i_{o_{r.m.s}}$, $FF\ and\ RF$.

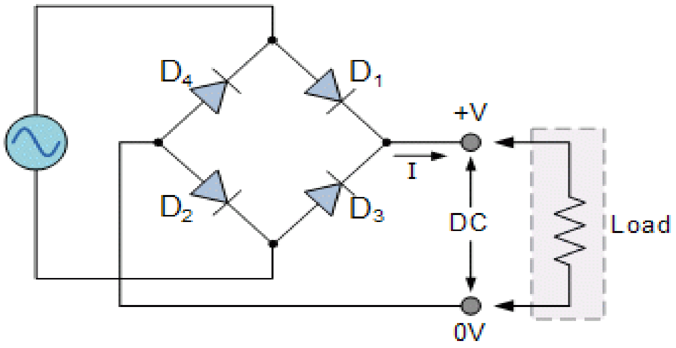


Ex3 (H.W): For the 1-φ half wave rectifier circuit shown in Figure below, has a purety resistor load of R=1K, determine

1. Efficiency.
2. FF.
3. RF.

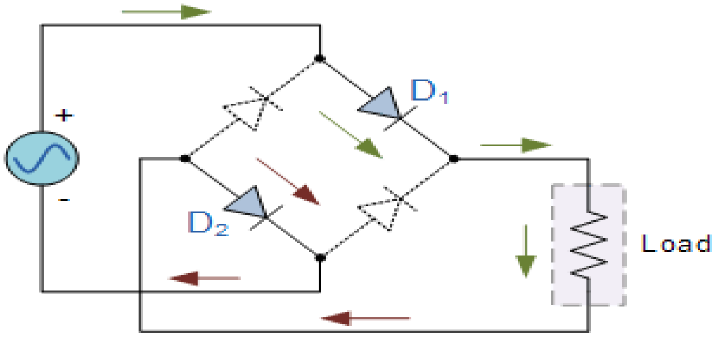


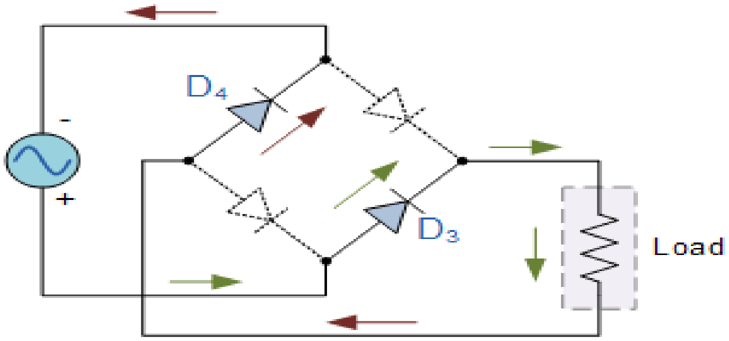
A full wave rectifier or a **bridge rectifier** is used to rectify both the half cycles of the ac supply (full wave rectification). The figure below shows a full wave bridge rectifier.



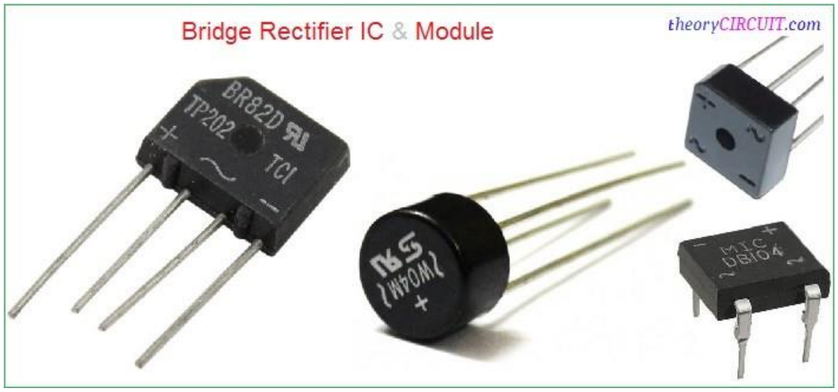
A bridge rectifier consists of four **p-n junction diodes** connected in the manner shown above. In the positive half cycle of the supply, the voltage induced across the secondary of the **electrical transformer** i.e. VMN is positive. Therefore point E is positive with respect to F. Hence, diodes D_3

and D_2 are reversed biased and diodes D_1 and D_2 are forward biased. The **diode** D_3 and D_4 will act as open switches (practically there is some **voltage drop**) and diodes D_1 andD_2 will act as closed switches and will start conducting.

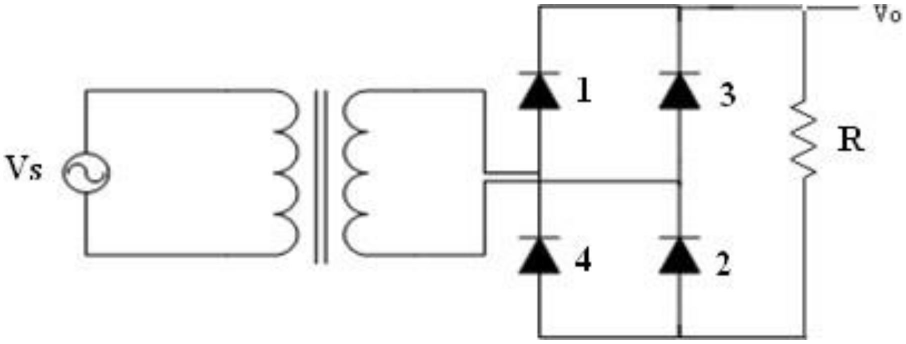




Hence a rectified waveform appears at the output of the rectifier as shown in the first figure. When voltage induced in secondary i.e. VMN is negative than D_3 and D_4 are forward biased with the other two reversed biased and a positive **voltage** appears at the input of the filter.



Ex4: For the 1-φ full wave rectifier circuit shown in Figure below, $R = 10k\Omega$, $V_{smax} = 200$ volt. Determine V_{Lmean}, I_{Lmean}, , $v_{o_{r.m.s}}$, $i_{o_{r.m.s}}$, RF and rectifier efficiency.



$$V_{lmean} = \frac{1}{2\pi}\int_0^{\pi} V_{s\,max} sin\theta d\theta \times 2$$

$$= \frac{V_{s\,max}}{\pi}\int_0^{\pi} sin\theta d\theta$$

$$= \frac{V_{s\,max}}{\pi}[-cos\theta]_0^{\pi}$$

$$= -\frac{V_{s\,max}}{\pi}[cos\pi - cos0]$$

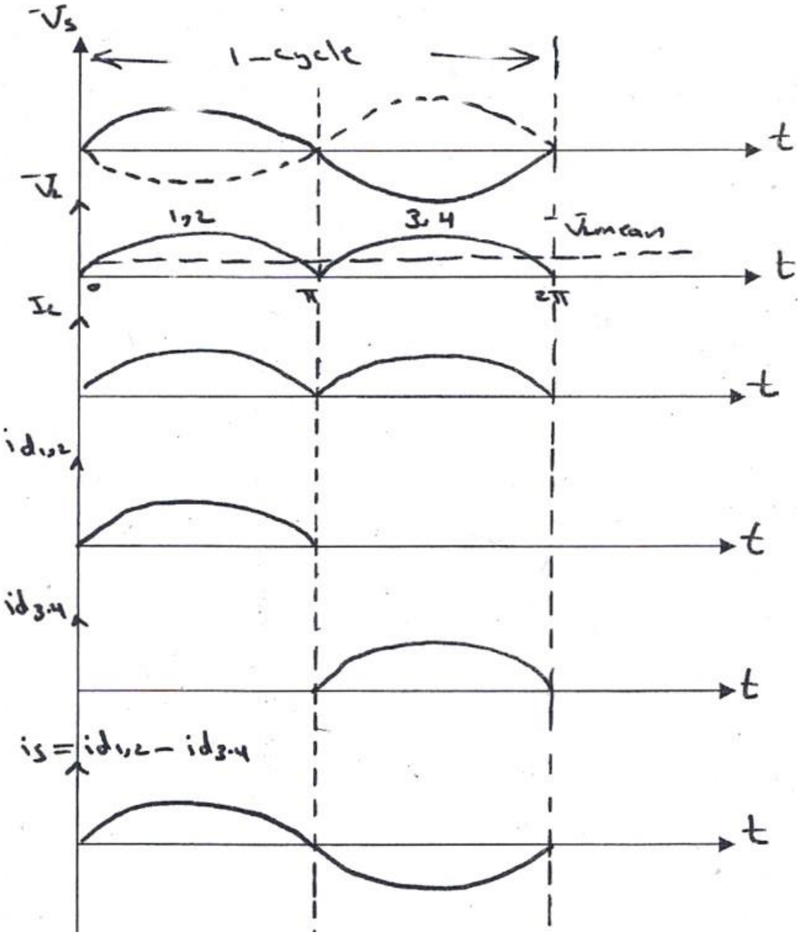
$$\boxed{\therefore\ V_{lmean} = \frac{2}{max}}$$

$$V_{lmean} = \frac{2 \times 200}{3.14} = 127.3\ V$$

$$\boxed{\therefore\ I_{lmean} = \frac{V_{lmean}}{R}}$$

$$= \frac{172.3}{10k} = 12.7\ mA$$

$$\boxed{v_{s\,rms} = \frac{V_{s\,max}}{\sqrt{2}}}$$



$$v_{0\,rms} = \sqrt{\frac{1}{2\pi}\int_{0}^{\pi} V_{smax}{}^{2} sin^{2}\theta d\theta \times 2}$$

$$= V_{smax}\sqrt{\frac{1}{\pi}\int_{0}^{\pi}\frac{1}{2}(1 - cos2\theta)d\theta}$$

$$\boxed{sin^{2}\theta = \frac{1}{2}(1 - cos2\theta)}$$

$$= V_{smax}\sqrt{\frac{1}{2\pi}\int_{0}^{\pi}(1 - cos2\theta)} = V_{smax}\sqrt{\frac{1}{2\pi}\int_{0}^{\pi} 1 d\theta - \frac{1}{2}\int_{0}^{\pi} cos2\theta\, d\theta}$$

$$= V_{smax}\sqrt{\frac{1}{2\pi}\left[\theta - \frac{sin2\theta}{2}\right]_{0}^{\pi}}$$

$$= V_{smax}\sqrt{\frac{1}{2\pi}\left[- \frac{sin2\pi}{2} - 0 + \frac{sin2 \times 0}{2}\right]}$$

$$= V_{smax}\sqrt{\frac{1}{2\pi}[\pi]} = \quad \boxed{v_{0\,rms} = \frac{V_{smax}}{\sqrt{2}}}$$

$$= \frac{200}{\sqrt{2}} = 141.4\, V$$

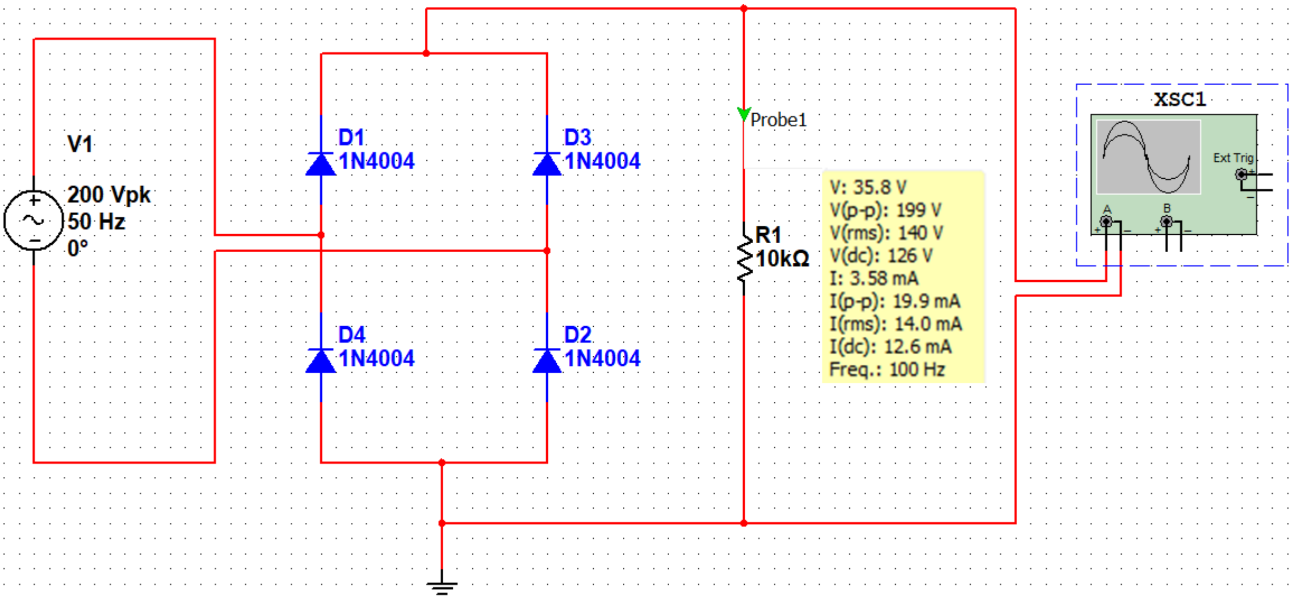
$$\boxed{\therefore\ i_{0\,rms} = \frac{v_{o\,rms}}{R}}$$

$$= \frac{141.4}{10k} = 14.14\, mA$$

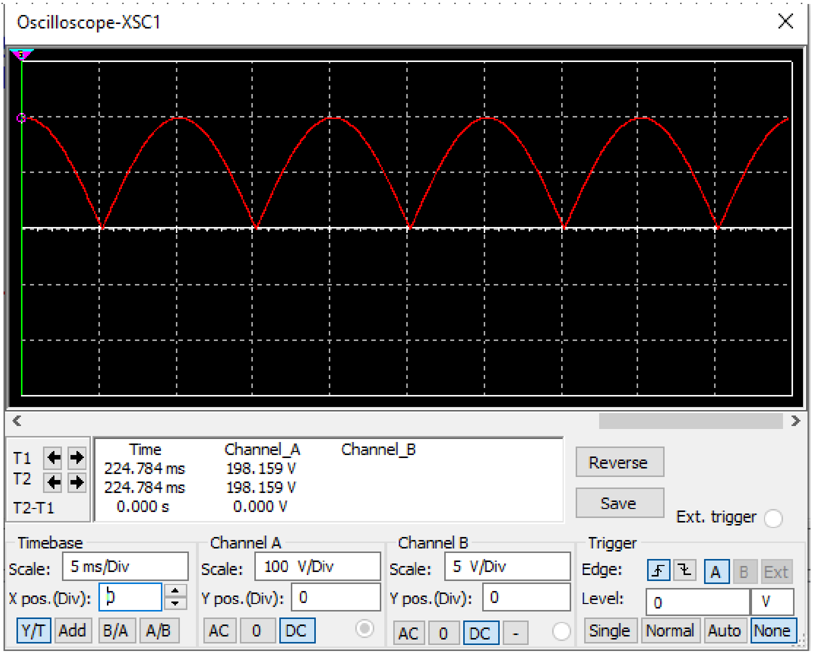
$$RF = \sqrt{\frac{V_{o\,rms}{}^{2} - V_{lmean}{}^{2}}{V_{lmean}{}^{2}}} = \sqrt{\frac{(141.4)^{2} - (127.3)^{2}}{(127.3)^{2}}} = 0.48$$

Rectification efficiency (f) $= \frac{c}{P_{ac}} = \frac{I_{lmean}\cdot V_{lmean}}{i_{o\,rms}\cdot v_{o\,rms}} = \frac{12.7m\times 127.3}{14.14m\times 141.4} = 0.8 = 80\%$

The Answer with MULTISIM



V: 35.8 V
V(p-p): 199 V
V(rms): 140 V
V(dc): 126 V
I: 3.58 mA
I(p-p): 19.9 mA
I(rms): 14.0 mA
I(dc): 12.6 mA
Freq.: 100 Hz



	Time	Channel_A	Channel_B
T1	224.784 ms	198.159 V	
T2	224.784 ms	198.159 V	
T2-T1	0.000 s	0.000 V	

Timebase
Scale: 5 ms/Div
X pos.(Div): 0

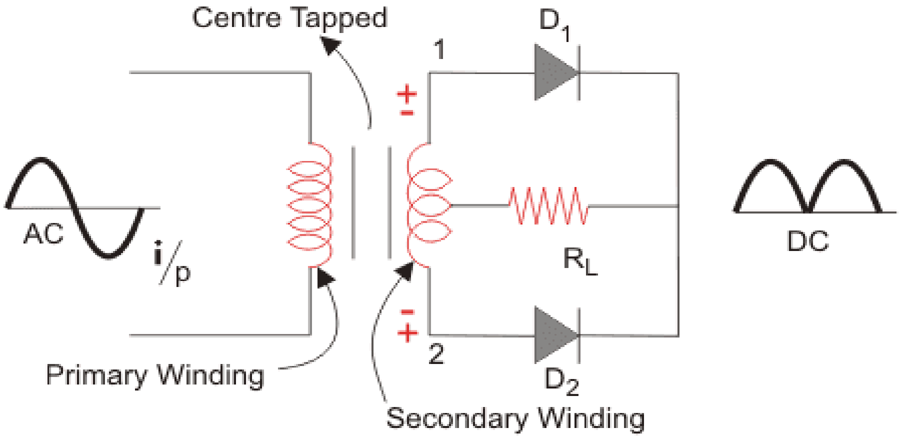
Channel A
Scale: 100 V/Div
Y pos.(Div): 0

Channel B
Scale: 5 V/Div
Y pos.(Div): 0

Trigger
Edge:
Level: 0 V

Ex5 (H.W): For the 1-φ full wave rectifier circuit, $R = 1k\Omega$, $V_s = 100\sin wt$. Determine $V_{Lme}, I_{Lmean}, , v_{o_{r.m.s}}$ $and\ i_{o_{r.m.s}}$

A **center-tapped rectifier** is a type of full-wave rectifier that uses two diodes connected to the secondary of a center-tapped transformer, as shown in Below Figure. 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.

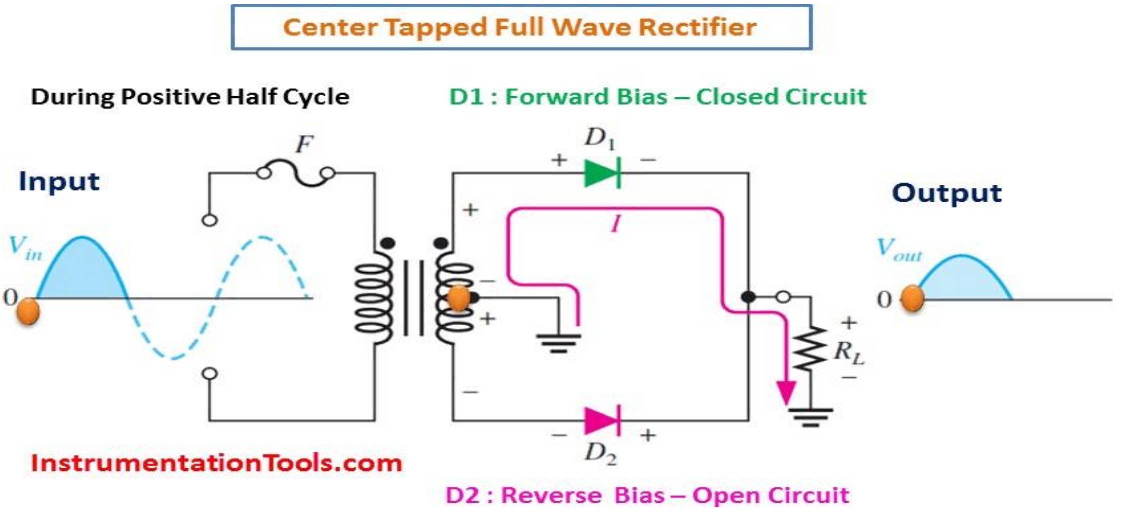


Centre Tapped Full Wave Rectifier

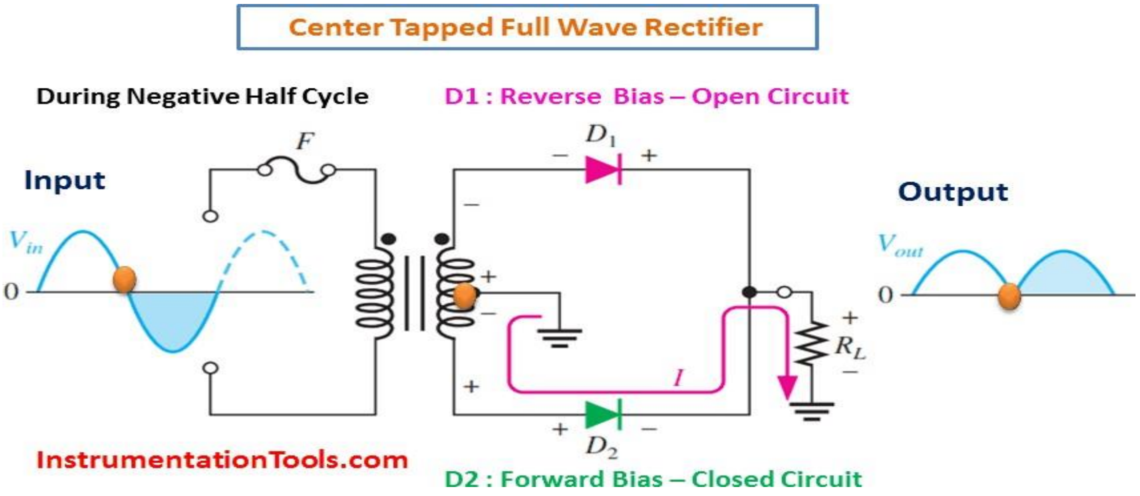
Figure - 1

For a positive half-cycle of the input voltage, the polarities of the secondary voltages are as shown in Figure (a). This condition forward-biases diode D1 and reverse-biases diode D2. The current path is through D1 and the load resistor RL, as indicated.

For a negative half-cycle of the input voltage, the voltage polarities on the secondary are as shown in Figure (b). This condition reverse-biases D1 and forward-biases D2. The current path is through D2 and RL, as indicated. Because the output current during both the positive and negative portions of the input cycle is in the same direction through the load, the output voltage developed across the load resistor is a full-wave rectified dc voltage, as shown.

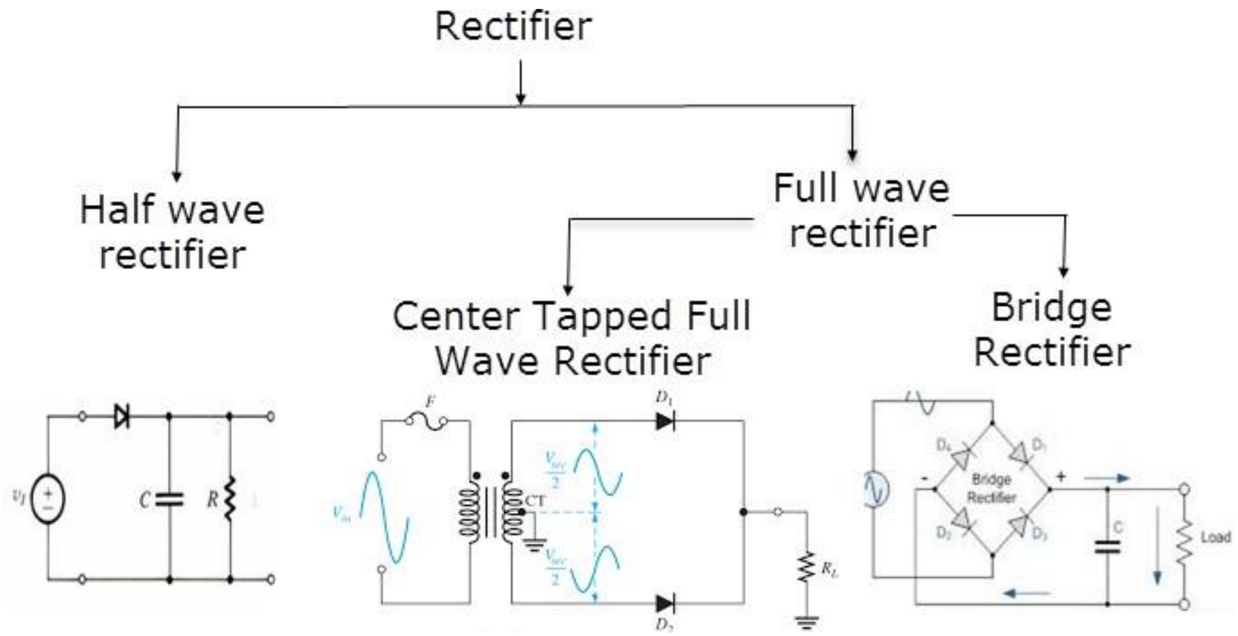


(A)

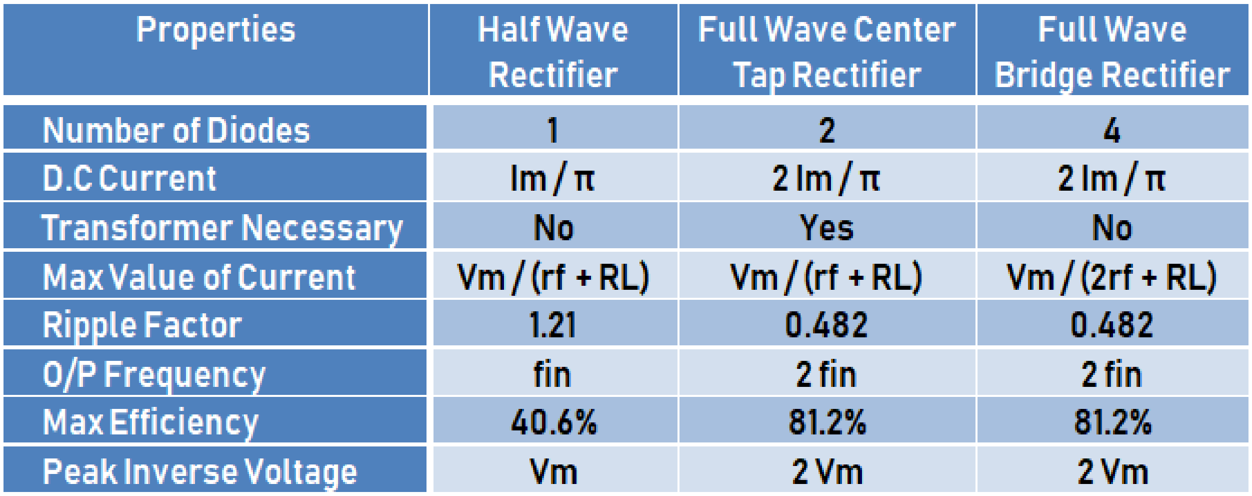


(B)

(b) During negative half-cycles, D2 is forward-biased and D1 is reverse-biased.

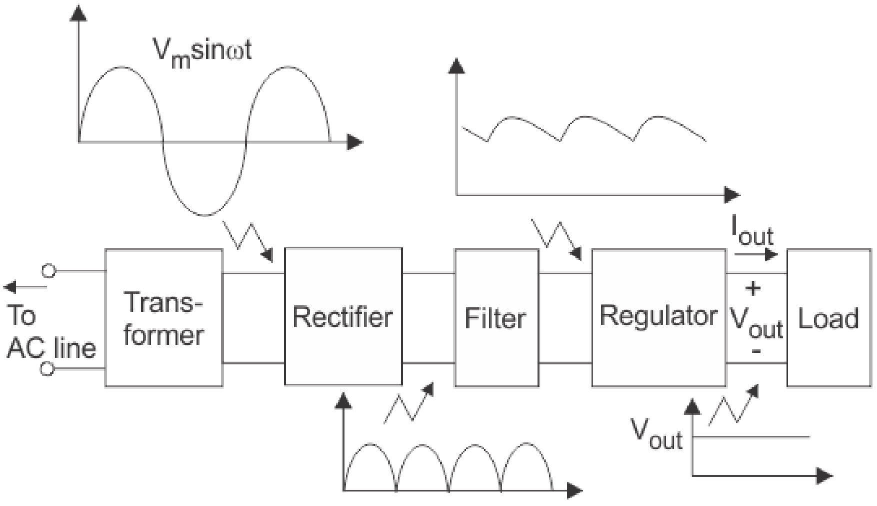


Comparison of Rectifiers



Properties	Half Wave Rectifier	Full Wave Center Tap Rectifier	Full Wave Bridge Rectifier
Number of Diodes	1	2	4
D.C Current	Im / π	2 Im / π	2 Im / π
Transformer Necessary	No	Yes	No
Max Value of Current	Vm / (rf + RL)	Vm / (rf + RL)	Vm / (2rf + RL)
Ripple Factor	1.21	0.482	0.482
O/P Frequency	fin	2 fin	2 fin
Max Efficiency	40.6%	81.2%	81.2%
Peak Inverse Voltage	Vm	2 Vm	2 Vm

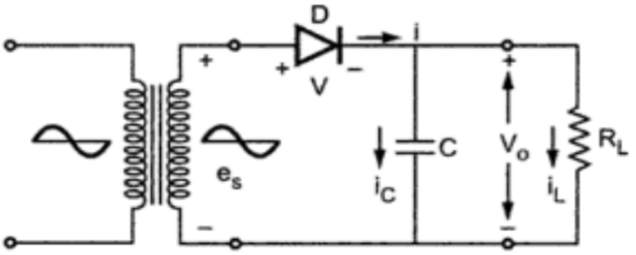
REGULATED POWER SUPPLY (PART 2)

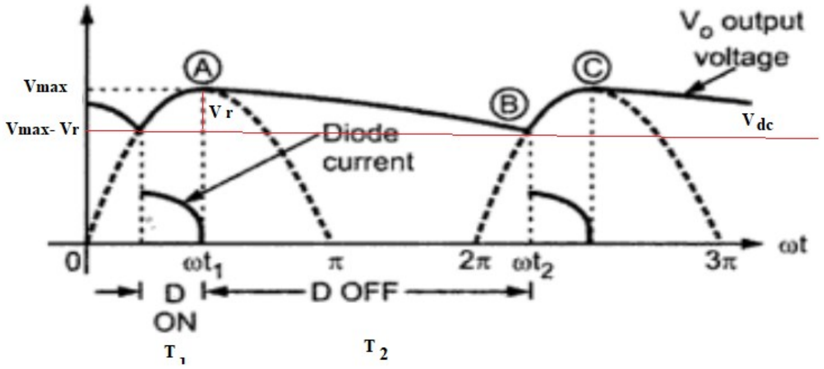


Components of typical linear power supply

DC FILTRATION (CAPACITOR FILTER)

The rectified voltage from the rectifier is a pulsating DC voltage having very high ripple content. But this is not we want, we want a pure ripple free DC waveform. Hence a filter is used. Different types of filters are used such as capacitor filter, LC filter, Choke input filter, π type filter. The figure below shows a capacitor filter connected along the output of the **half-wave rectifier** and the resultant output waveform.





During the time interval T_1 the diode is conducting and the capacitor C is getting charged.

While in the time interval T_2 , the diode is reverse biased and the capacitor discharges through the load resistance R_L .

$T = T_1 + T_2$, $T_2 \gg T_1$,
From Figure above $T_2 \approx 0.8\,T$

At T_2 (discharging of C), the charge lost $Q = C\,V_{r(p.p)}$

The current through C is

$$i = \frac{dQ}{dt}$$

$$\int dQ = \int i\,dt$$

$$Q = \int_0^{T_2} i\,dt = I_{dc}\,T_2$$

$$C\,V_r = I_{dc}\,T_2$$

$$V_r = \frac{I_{dc}\,T_2}{C} = \frac{I_{dc}}{1.25\,C\,F} \boxed{= \frac{V_{dc}}{1.25\,R_l\,C\,F}}$$

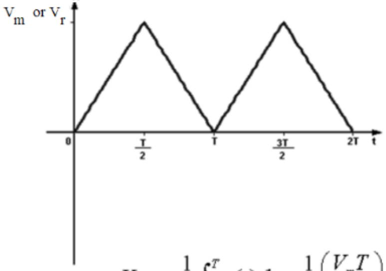
$$V_{dc} = V_{max} - V_{r\,(p)} \qquad V_{r\,(p)} = \frac{V_{r\,(p.p)}}{2}$$

$$V_{dc} = V_{max} - \frac{\frac{V_{dc}}{1.25\,R_l\,C\,F}}{2} = V_{max} - \frac{V_{dc}}{2.5\,R_l\,C\,F}$$

$$\boxed{V_{dc} = \frac{V_{max}}{1 + \frac{1}{2.5\,R_l\,C\,F}}}$$

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

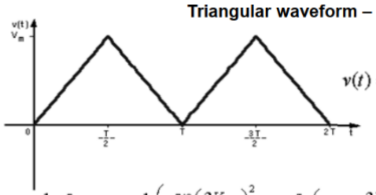
Triangular waveform – DC component



$$V_{DC} = \frac{1}{T}\int_0^T v(t)dt = \frac{1}{T}\left(\frac{V_m T}{2}\right)$$

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

Triangular waveform – RMS value



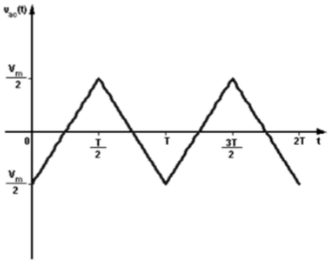
$$v(t) = \begin{cases} \frac{2V_m}{T}t, & 0 \le t < T/2 \\ 2V_m - \frac{2V_m}{T}t, & T/2 \le t < T \end{cases}$$

$$V_{rms}^2 = \frac{1}{T}\int_0^T v^2(t)dt = \frac{1}{T}\left(\int_0^{T/2}\left(\frac{2V_m}{T}t\right)^2 dt + \int_{T/2}^{T}\left(2V_m - \frac{2V_m}{T}t\right)^2 dt\right)$$
$$= \frac{1}{T}\left(\frac{4V_m^2}{T^2}\int_0^{T/2} t^2 dt + 4V_m^2\int_{T/2}^{T}\left(1-\frac{1}{T}t\right)^2 dt\right) = \frac{4V_m^2}{T^3}\int_0^{T/2} t^2 dt + \frac{4V_m^2}{T}\int_{T/2}^{T}\left(1-\frac{2}{T}t+\frac{1}{T^2}t^2\right)dt$$
$$= \frac{4V_m^2}{T^3}\left[\frac{t^3}{3}\right]_0^{T/2} + \frac{4V_m^2}{T}\left[t-\frac{t^2}{T}+\frac{t^3}{3T^2}\right]_{T/2}^{T}$$
$$= \frac{4V_m^2}{T^3}\frac{T^3}{24} + \frac{4V_m^2}{T}\left[\frac{T}{2}-\frac{3T^2}{4T}+\frac{7T^3}{24T^2}\right]$$
$$= \frac{V_m^2}{6} + 4V_m^2\left[\frac{1}{2}-\frac{3}{4}+\frac{7}{24}\right] = \frac{V_m^2}{3}$$

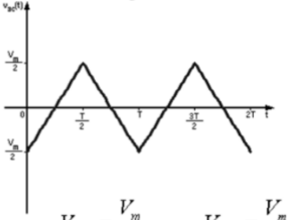
$$\boxed{V_{rms} = \frac{V_m}{\sqrt{3}}}$$

Triangular waveform – AC component

$$\boxed{v_{ac}(t) = v(t) - V_{DC} = v(t) - V_m/2}$$



AC Triangular Waveform – RMS value



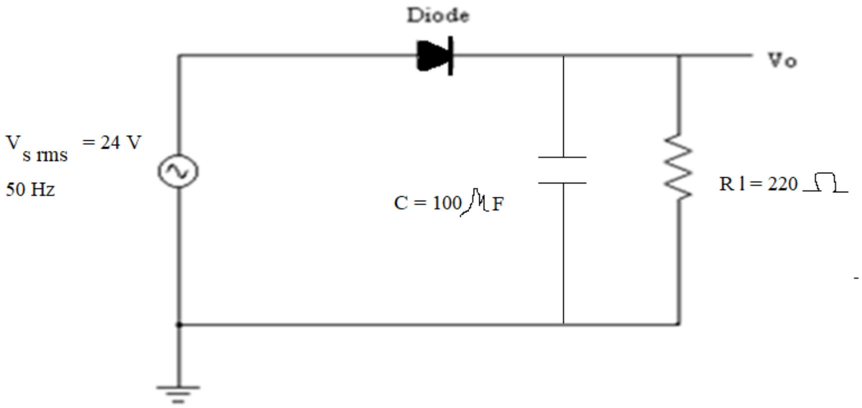
$$V_{rms} = \frac{V_m}{\sqrt{3}} \qquad V_{DC} = \frac{V_m}{2}$$

$$(V_{ac})_{rms}^2 = V_{rms}^2 - V_{DC}^2$$
$$= \frac{V_m^2}{3} - \frac{V_m^2}{4}$$
$$= \frac{V_m^2}{12}$$

$$\boxed{(V_{ac})_{rms} = \frac{V_m}{2\sqrt{3}}}$$

$$\text{Ripple factor } (r) = \frac{V_{rms}}{V_{dc}} = \frac{\frac{V_{r(p.p)}}{2\sqrt{3}}}{V_{dc}} = \frac{\frac{\frac{V_{dc}}{1.25\,R_l\,C\,F}}{2\sqrt{3}}}{V_{dc}} = \boxed{\frac{1}{2.5\sqrt{3}\,R_l\,C\,F}}$$

Ex1: For the half-wave rectifier circuit below, determine $V_{r\,(p.p)}$, V_{dc} and ripple factor (r)



Ans:

$$v_{s\,rms} = \frac{V_{s\,max}}{\sqrt{2}}$$

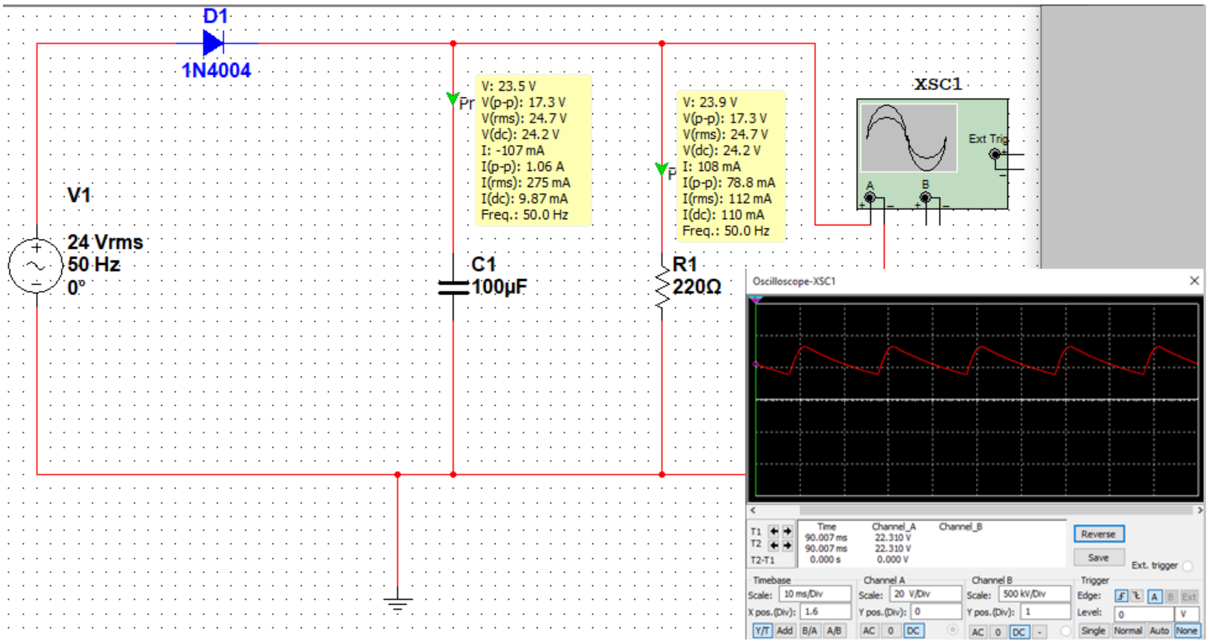
$$V_{s\,max} = 24 \times \sqrt{2} = 33.94\ V$$

$$V_{dc} = \frac{V_{max}}{1 + \frac{1}{2.5\ R_l\ C\ F}} = \frac{33.94}{1 + \frac{1}{2.5 \times 220 \times 100 \times 10^{-6} \times 50}} = 24.96\ V$$

$$V_r = \frac{V_{dc}}{1.25\ R_l\ C\ F} = \frac{24.96}{1.25 \times 50 \times 220 \times 100 \times 10^{-6}} = 18.1$$

$$r = \frac{1}{2.5\sqrt{3}\ R_l\ C\ F} = \frac{1}{2.5\sqrt{3} \times 220 \times 100 \times 10^{-6} \times 50} = 0.21$$

The Answer with MULTISIM



```
V: 23.5 V
V(p-p): 17.3 V
V(rms): 24.7 V
V(dc): 24.2 V
I: -107 mA
I(p-p): 1.06 A
I(rms): 275 mA
I(dc): 9.87 mA
Freq.: 50.0 Hz
```

```
V: 23.9 V
V(p-p): 17.3 V
V(rms): 24.7 V
V(dc): 24.2 V
I: 108 mA
I(p-p): 78.8 mA
I(rms): 112 mA
I(dc): 110 mA
Freq.: 50.0 Hz
```

```
        Time        Channel_A    Channel_B
T1      90.007 ms   22.310 V
T2      90.007 ms   22.310 V
T2-T1   0.000 s     0.000 V
```

Timebase
Scale: 10 ms/Div
X pos.(Div): 1.6

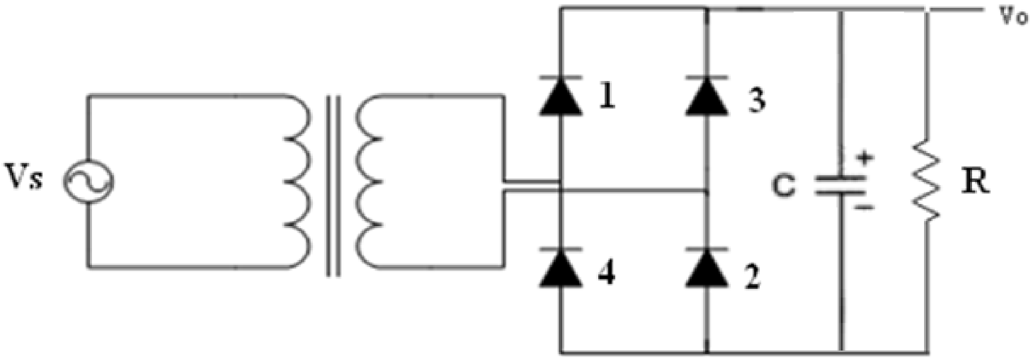
Channel A
Scale: 20 V/Div
Y pos.(Div): 0

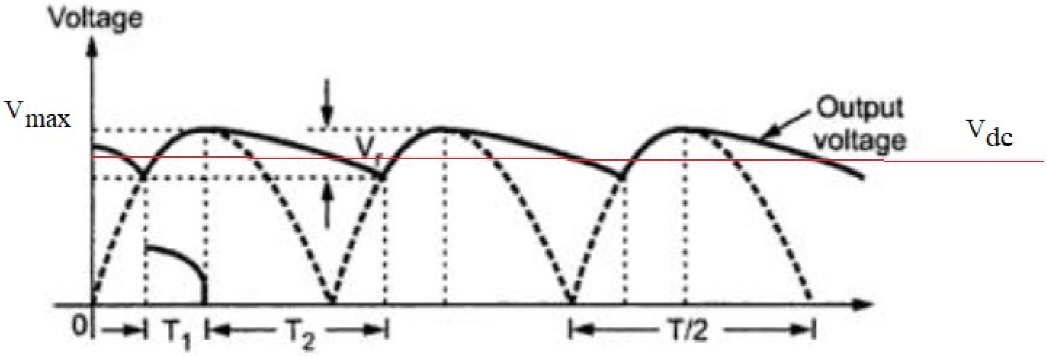
Channel B
Scale: 500 kV/Div
Y pos.(Div): 1

Trigger
Edge: A
Level: 0 V

Ex2 (H.W): For the half-wave rectifier circuit above, change C to 200 µF and load resistor R to 500 Ω and determine V_{dc} , $V_{r\,(p.p)}$, $V_{r\,(p)}$ and ripple factor (r).

The figure below shows a capacitor filter connected along the output of the **full-wave rectifier** and the resultant output waveform.

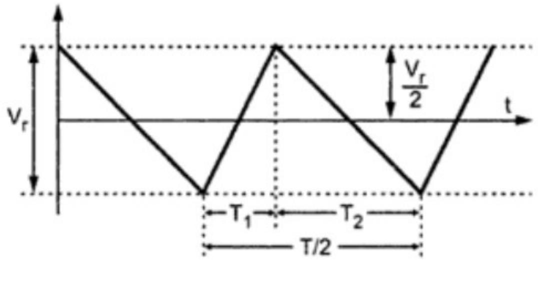




During the time interval T_1 the diode is conducting and the capacitor C is getting charged.

While in the time interval T_2 , the diode is reverse biased and the capacitor discharges through the load resistance R_L .

Let V_r be the peak to peak value of ripple voltage, which is assumed to be triangular as shown in the Fig.



It can be shown mathematically that the r.m.s. value of such a triangular waveform is

$$V_{rms} = \frac{V_r}{2\sqrt{3}}$$

$T/2 = T_1 + T_2$, $T_2 \gg T_1$,
From the output waveform of the full wave rectifier $T_2 \approx T/2 =$

At T_2 (discharging of C), the charge lost $Q = C\, V_{r(p.p)}$

The current through C is

$$i = \frac{dQ}{dt}$$

$$\int dQ = \int i\, dt$$

$$Q = \int_0^{T_2} i\, dt = I_{dc}\, T_2$$

$$C\, V_r = I_{dc}\, T_2$$

$$V_r = \frac{I_{dc}\, T_2}{C} = \frac{I_{dc} T}{2C} \boxed{= \frac{V_{dc}}{2\, R_l\, C\, F}}$$

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

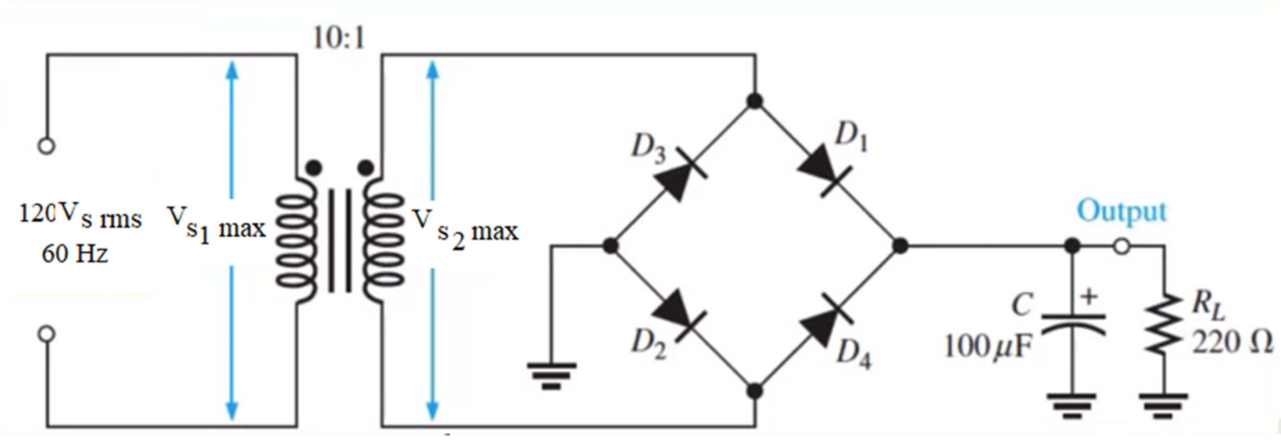
$$V_{dc} = V_{max} - \frac{V_{dc}}{2\, R_l\, C\, F}/2$$

$$\boxed{V_{dc} = \frac{V_{max}}{1 + \frac{1}{4\, R_l\, C\, F}}}$$

$$\because V_{rms} = \frac{V_{r(p.p)}}{2\sqrt{3}}$$

$$\text{Ripple factor } (r) = \frac{V_{rms}}{V_{dc}} = \frac{\frac{V_{r(p.p)}}{2\sqrt{3}}}{V_{dc}} = \frac{\frac{\frac{V_{dc}}{2\, R_l\, C\, F}}{2\sqrt{3}}}{V_{dc}} \boxed{= \frac{1}{4\sqrt{3}\, R_l\, C\, F}}$$

Ex3: For the full-wave rectifier circuit below, determine $V_{r\,(p.p)}$, V_{dc} and ripple factor (r)



Ans:

$$V_{s1\,max} = 120 \times \sqrt{2} = 169.71\,V$$

$$\therefore\ \frac{V_{s1\,max}}{V_{s2\,max}} = \frac{n_1}{n_2}$$

$$\frac{169.71}{V_{s2\,max}} = \frac{10}{1}$$

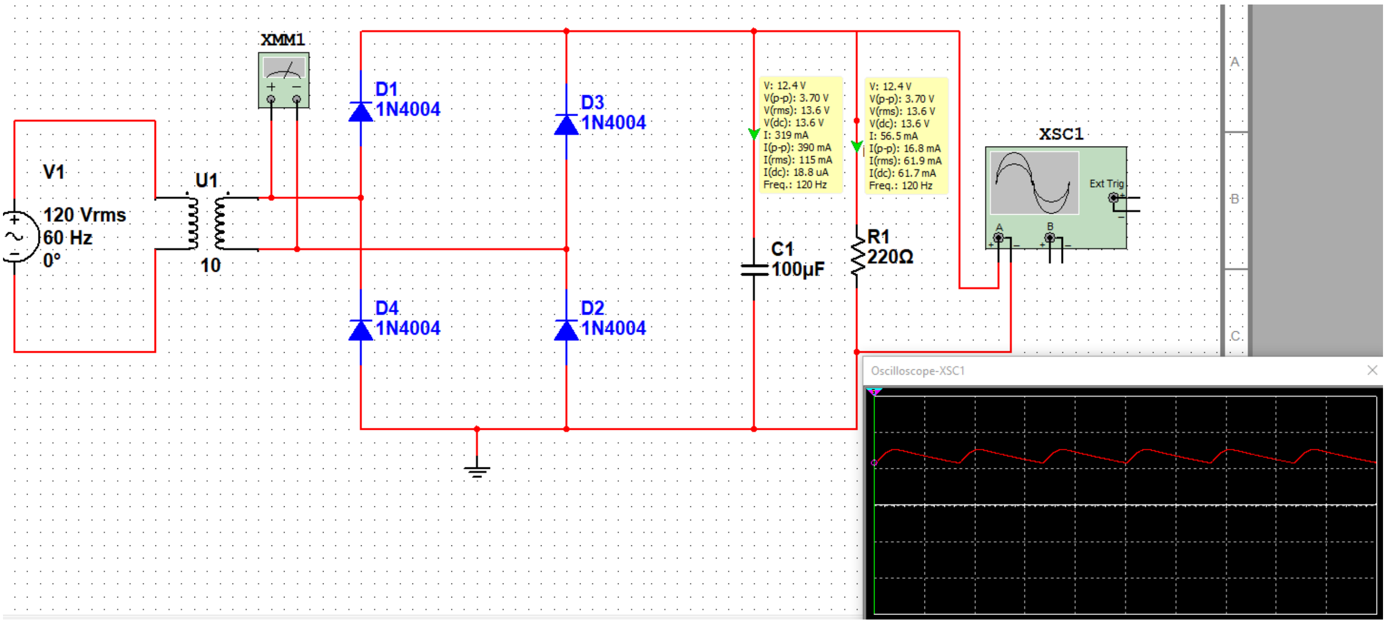
$$V_{s2\,max} = 16.97\,V$$

$$V_{dc} = \frac{V_{max}}{1 + \frac{1}{4\,R_l\,C\,F}} = \frac{V_{s2\,max}}{1 + \frac{1}{4\,R_l\,C\,F}} = \frac{16.97}{1 + \frac{1}{4 \times 220 \times 100 \times 10^{-6} \times 60}} = 14.2V$$

$$V_r = \frac{V_{dc}}{2\,R_l\,C\,F} = \frac{V_{dc}}{2\,R_l\,C\,F} = \frac{14.2}{2 \times 220 \times 100 \times 10^{-6} \times 60} = 5.3$$

$$r = \frac{1}{4\sqrt{3}\,R_l\,C\,F} = \frac{1}{4\sqrt{3} \times 220 \times 100 \times 60} = 0.109$$

The Answer with MULTISIM



```
V: 12.4 V
V(p-p): 3.70 V
V(rms): 13.6 V
V(dc): 13.6 V
I: 319 mA
I(p-p): 390 mA
I(rms): 115 mA
I(dc): 18.8 uA
Freq.: 120 Hz
```

```
V: 12.4 V
V(p-p): 3.70 V
V(rms): 13.6 V
V(dc): 13.6 V
I: 56.5 mA
I(p-p): 16.8 mA
I(rms): 61.9 mA
I(dc): 61.7 mA
Freq.: 120 Hz
```

Ex. 4 : *A 100 µF capacitor, when used as filtering element, has 12 V, d.c. across it with terminal load resistance of 2 k Ω. If the rectifier is full-wave and supply frequency is 5 Hz, what is the percentage of ripple in the output ? Draw the neat circuit diagram.*

Sol. : The circuit diagram is shown in the Fig.

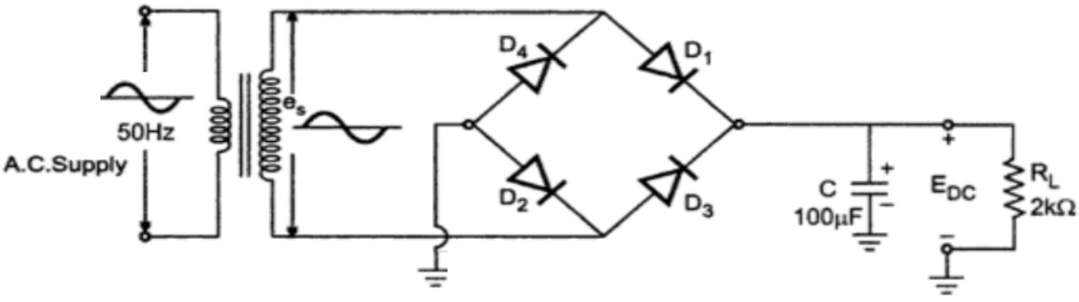


Fig. 3.28

Given : $R_L = 2\text{k}\,\Omega$, $C = 100\,\mu\text{F}$, $E_{DC} = 12$ V, Supply frequency = 50 Hz

$$\text{Ripple factor} = \frac{1}{4\sqrt{3}\,f\,C\,R_L} = \frac{1}{4\sqrt{3}\,[50][100\times10^{-6}][2\times10^{3}]}$$

$$= \frac{1}{4\sqrt{3}\,(50)\,(2\times10^{-1})} = 0.01443$$

∴ % of ripple in the output = 0.01443 × 100 = 1.443 %

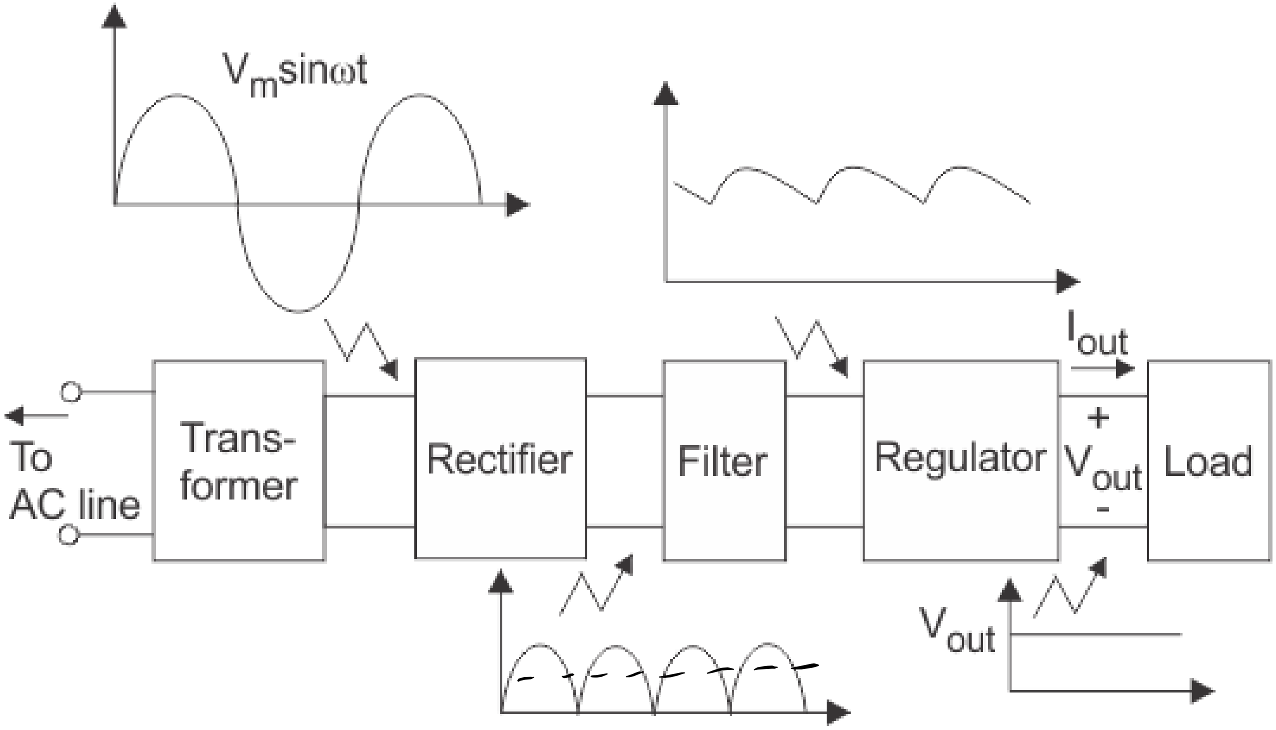
Ex5 (H.W): For the full-wave rectifier circuit above, repeat the question with C= 200 μF and load resistor R = 1K Ω, and determine V_{dc} , $V_{r\ (p.p)}$, $V_{r\ (p)}$ and ripple factor (r).

Ex6 (H.W): A full-wave bridge rectifier supplies a load with 50 V dc, 100mA using 100 μF of filtering capacitor. Assume ideal diodes and $V_s=V_{smax}$ sin314 t, determine $V_{r(p.p)}$, $V_{s\ max}$ **and** $V_{s\ rms}$.

Regulated Power Supply (Part 3)

The basic building blocks of a regulated DC power supply are as follows:

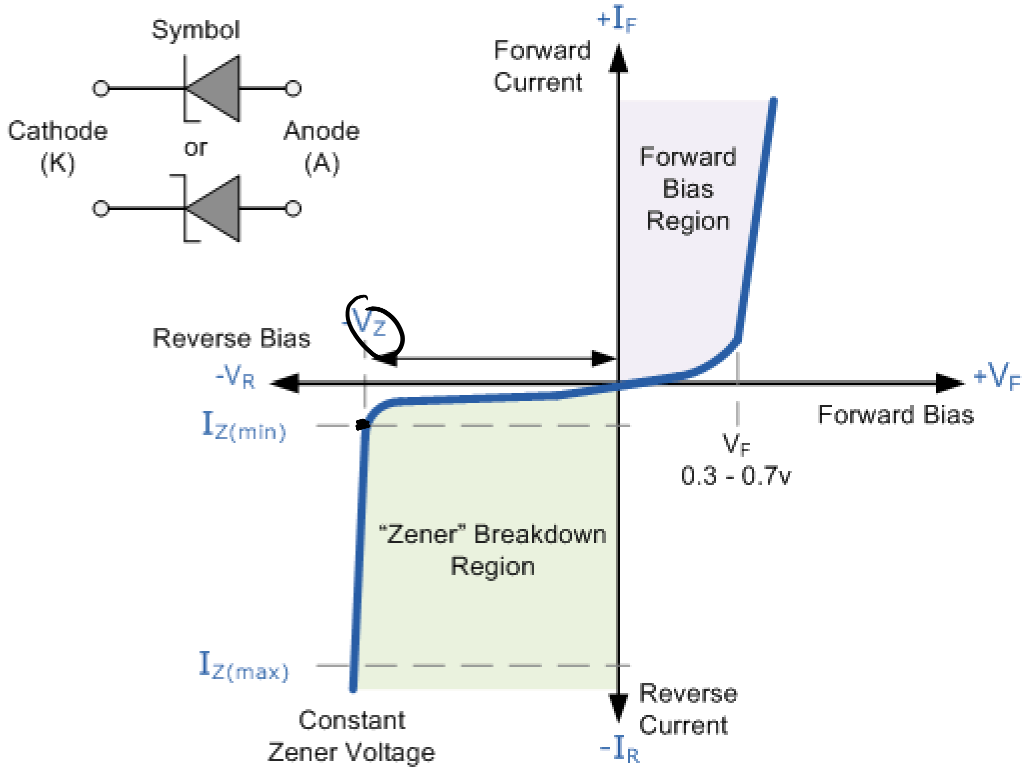
1. A step-down transformer
2. A rectifier
3. A DC filter
4. **A regulator**



Components of typical linear power supply

Zener Diode Regulator

A **Zener diode** is a special type of diode designed to reliably allow current to flow "backwards" when a certain set reverse voltage, known as the Zener voltage, is reached.

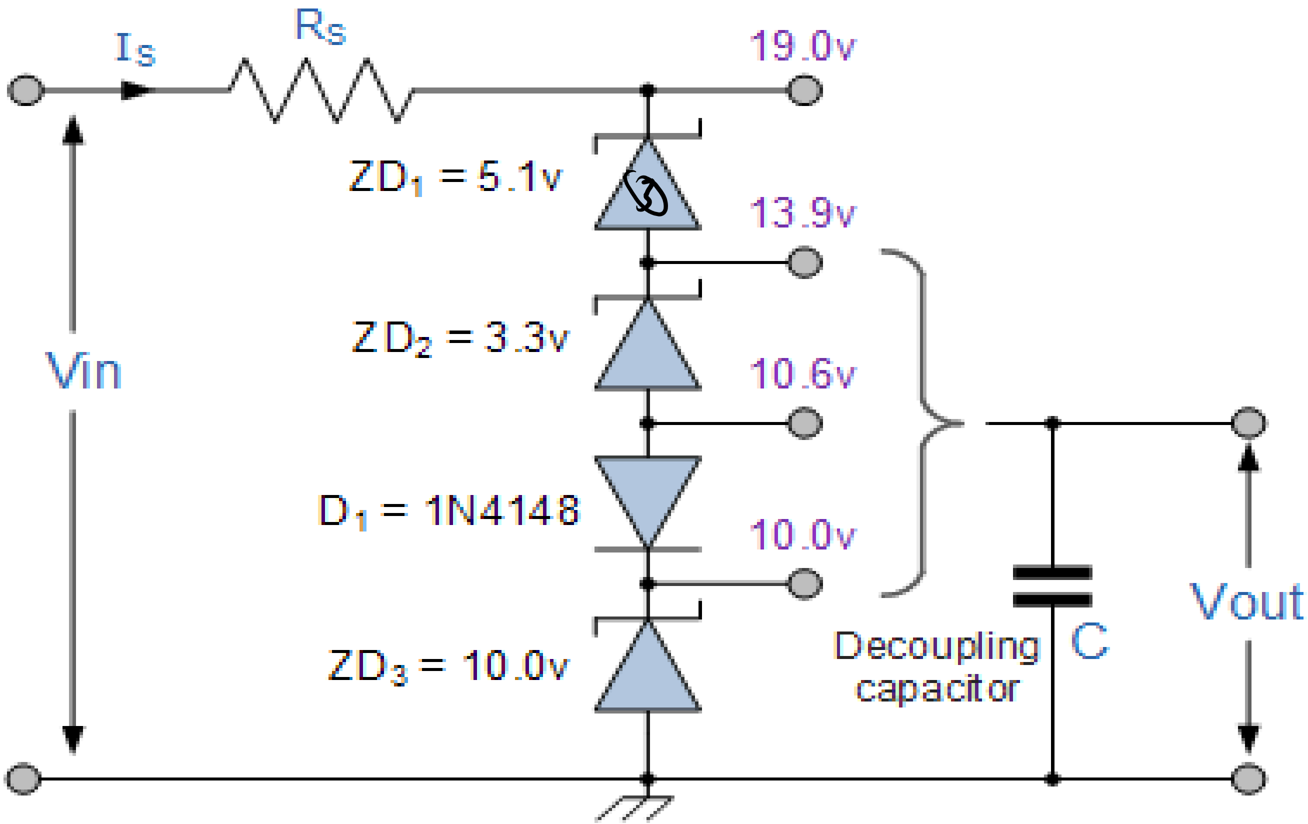


The values of the individual Zener diodes can be chosen to suit the application while the silicon diode will always drop about 0.6 – 0.7V in the forward bias condition. The supply voltage, Vin must of course be higher than the largest output reference voltage and in our example above this is 19v.

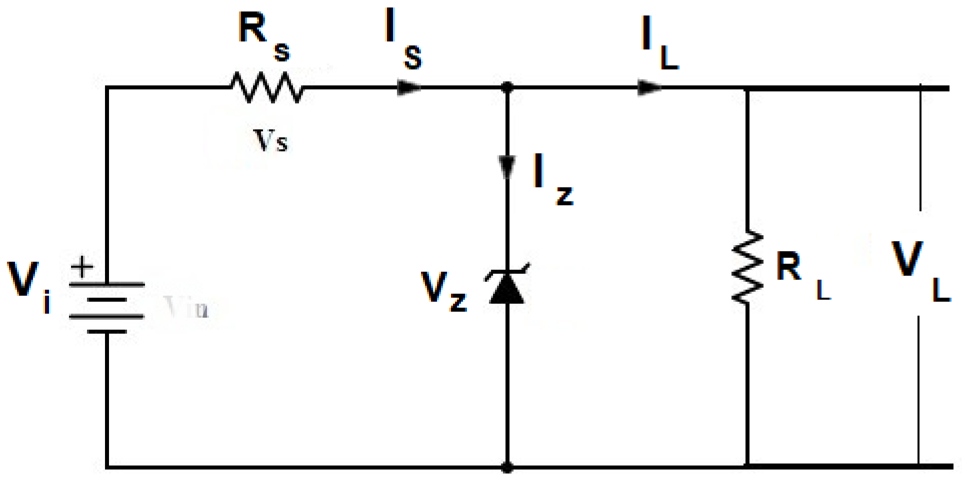
A typical **Zener diode** for general electronic circuits is the 500mW, *BZX55* series or the larger 1.3W, *BZX85* series were the Zener voltage is given as, for example, *C7V5* for a 7.5V diode giving a diode reference number of *BZX55C7V5*.

As well as producing a single stabilized voltage output, zener diodes can also be connected together in series along with normal silicon signal diodes to produce a variety of different reference voltage output values as shown below.

Zener Diodes Connected in Series



Stage 1: Fixed V_i and Fixed R_L



When $\boldsymbol{V_z > V_L}$ Zener is off

$$V_L = \frac{R_L}{R_L + R_s} V_i$$

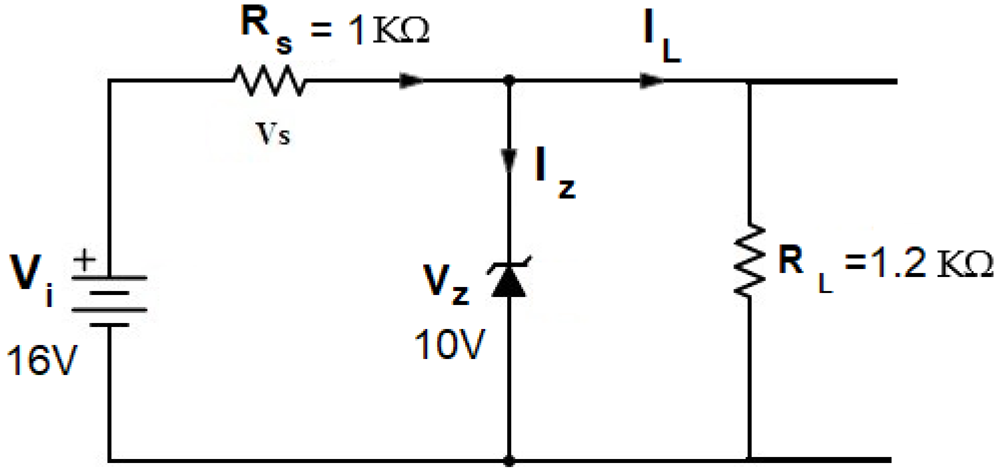
$$I_L = \frac{V_L}{R_L}$$

$$V_i - V_s - V_L = 0$$

$$I_s = \frac{V_s}{R_s}$$

$$I_z = 0$$

Ex1: For the Zener circuit below, determine V_L, I_L, V_s, I_s and I_z



Ans:

$$V_L = \frac{R_L}{R_L + R_s} V_i = \frac{1.2}{1.2 + 1} \times 16 = 8.72\ V$$

$$\because \boldsymbol{V_z\ (10\ V) > V_L\ (8.72\ V)} \quad \therefore \textbf{ Zener is off}$$

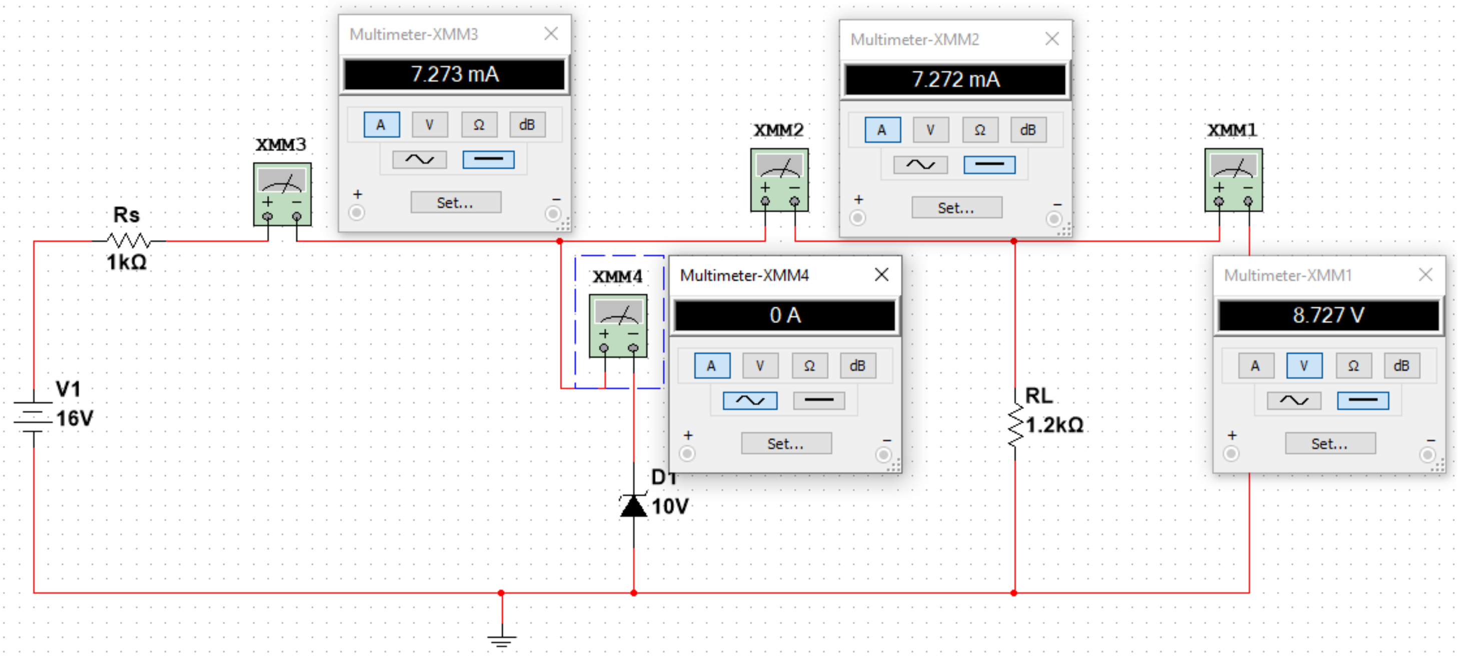
$$I_L = \frac{V_L}{R_L} = \frac{8.72}{1.2 \times 10^3} = 7.27\ mA$$

$$V_i - V_s - V_L = 0$$
$$16 - V_s - 8.72 = 0$$
$$V_s = 7.27\ V$$

$$I_s = \frac{V_s}{R_s} = \frac{7.27}{1K} = 7.27\ mA$$

$$I_z = 0$$

Answer with MULTISIM



Repeat Ex.1 with $\boldsymbol{R_L = 3\ K\Omega}$

Ans:

$$V_L = \frac{R_L}{R_L + R_s}\, V_i = \frac{3}{3+1} \times 16 = 12\ V$$

$\because \boldsymbol{V_z\ (10\ V) < V_L\ (12\ V)}$ $\therefore$ **Zener is on**

$$\therefore V_L = V_z = 10\ V$$

$$I_L = \frac{V_L}{R_L} = \frac{10}{3 \times 10^3} = 3.33\ mA$$

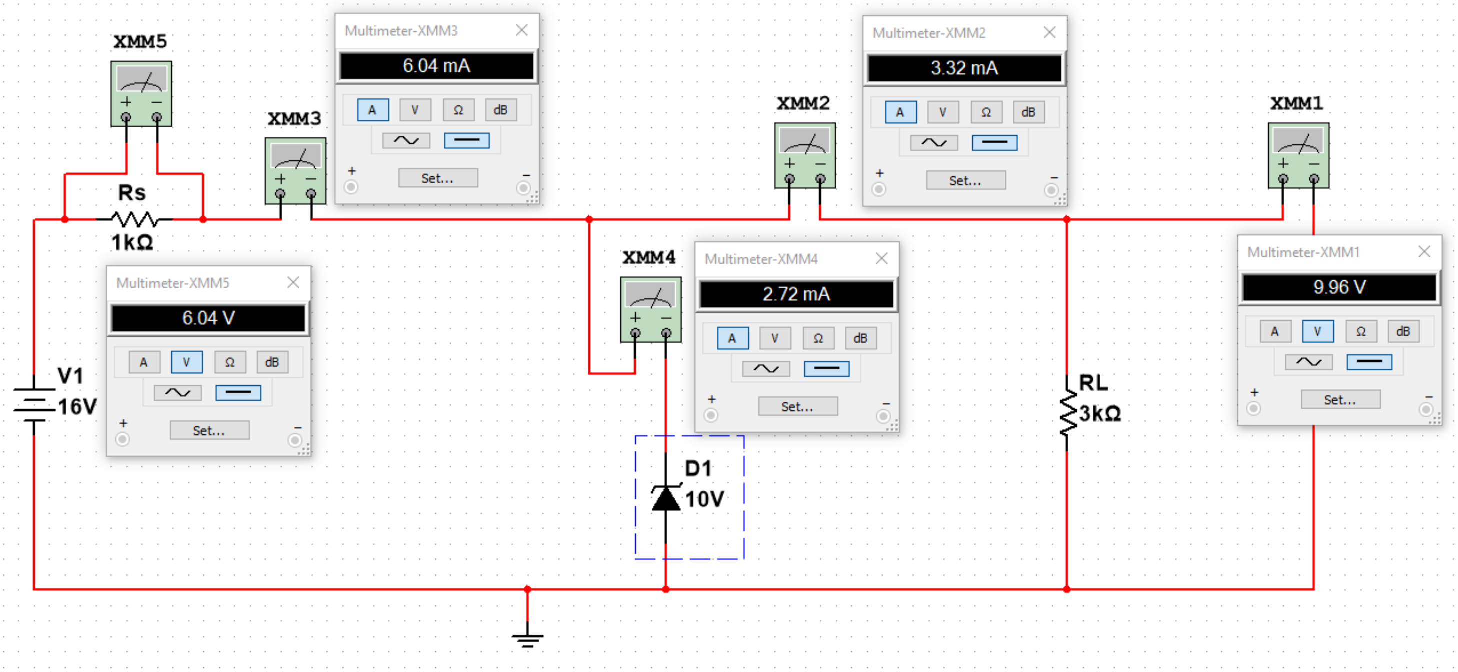
$$V_i - V_s - V_z = 0$$
$$16 - V_s - 10 = 0$$
$$V_s = 6\ V$$

$$I_s = \frac{V_s}{R_s} = \frac{6}{1K} = 6\ mA$$

$$I_s = I_z + I_L$$

$$\therefore I_z = I_s - I_L = 6 - 3.33 = 2.67\ mA$$

Answer with MULTISIM



Ex2: A 5.0V stabilized power supply is required to be produced from a 12V DC power supply input source. The maximum power rating Pz of the Zener diode is 2W. Using the Zener regulator circuit above calculate:

a). The maximum current flowing through the Zener diode.

$$\text{Maximum Current} = \frac{\text{Watts}}{\text{Voltage}} = \frac{2w}{5v} = 400mA$$

b). The minimum value of the series resistor, Rs

$$R_S = \frac{V_S - V_Z}{I_Z} = \frac{12 - 5}{400mA} = 17.5\Omega$$

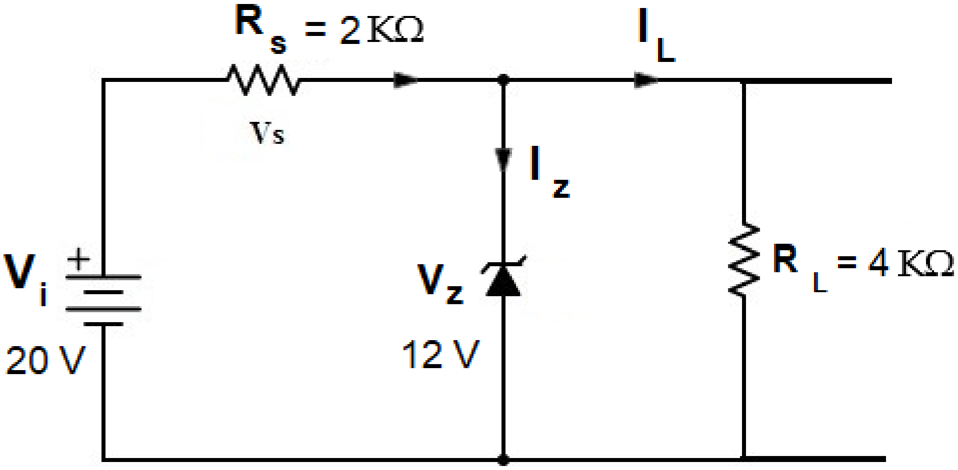
c). The load current IL if a load resistor of 1kΩ is connected across the Zener diode.

$$I_L = \frac{V_Z}{R_L} = \frac{5v}{1000\Omega} = 5mA$$

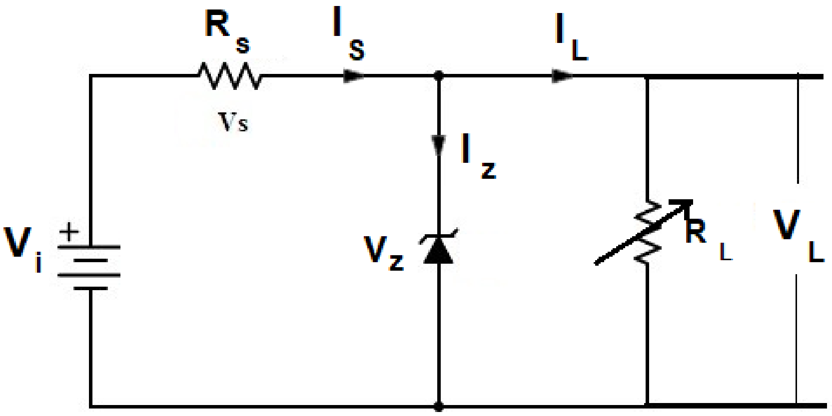
d). The Zener current Iz at full load.

$$I_Z = I_S - I_L = 400mA - 5mA = 395mA$$

Ex3 (H.W): For the Zener circuit below, determine V_L, I_L, V_S, I_s and I_z



Stage 2: Fixed V_i and Variable R_L



$$R_{Lmin} = \frac{V_z}{V_i - V_z} R_s$$

$$V_L = V_z$$

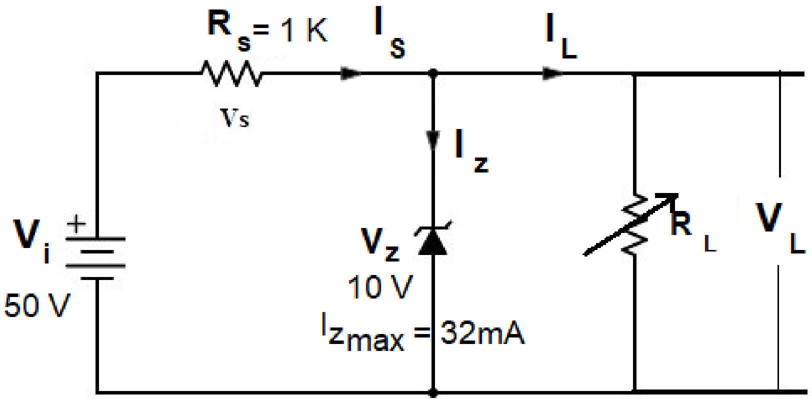
$$I_{Lmax} = \frac{V_z}{R_{Lmin}}$$

$$I_z = I_s - I_L$$

$$I_{Lmin} = I_s - I_{zmax}$$

$$I_{Lmin} = \frac{V_z}{R_{Lmax}}$$

Ex4: For the Zener circuit below, determine the range of R_L and I_L



Ans:

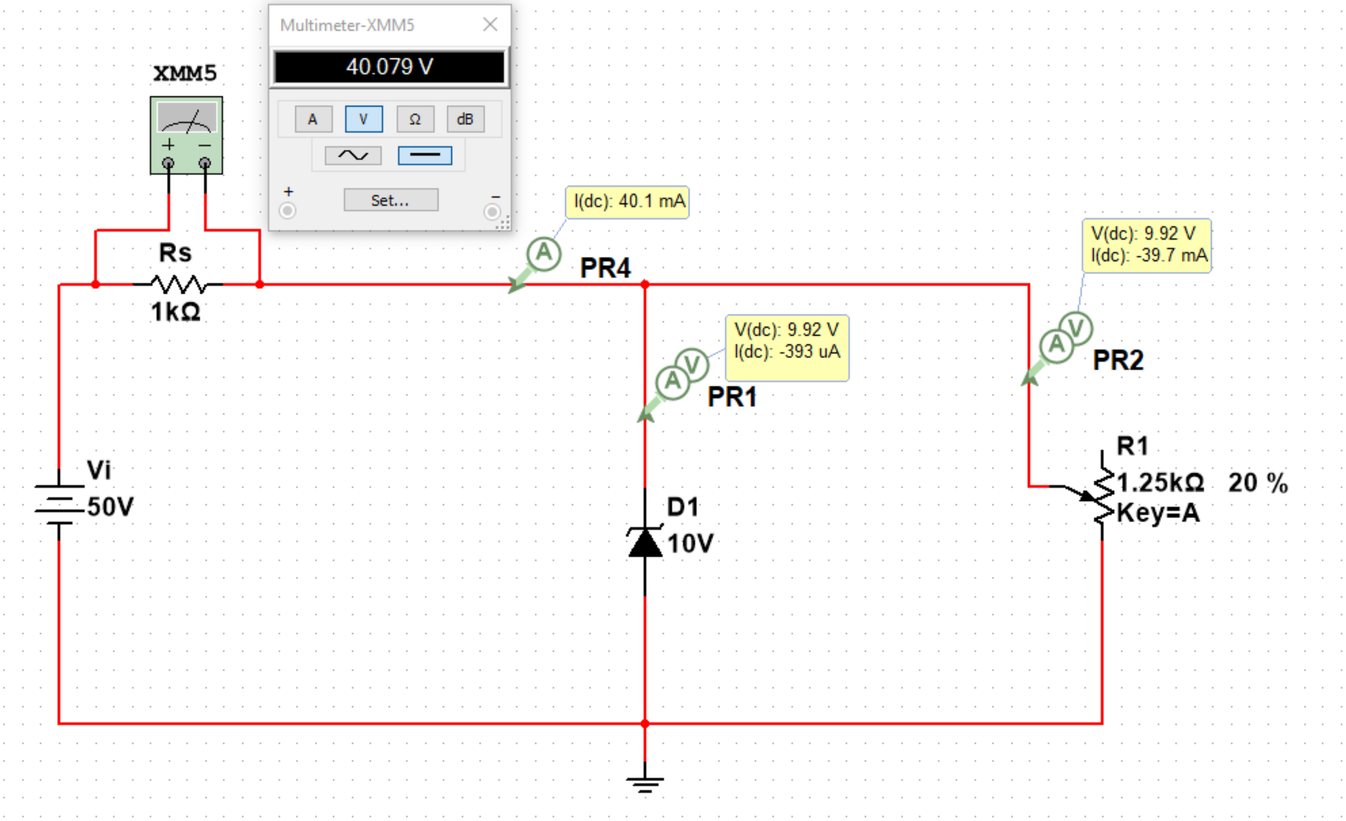
$$R_{Lmin} = \frac{V_z}{V_i - V_z} R_s = \frac{10}{50 - 10} \times 1000 = 0.25\ K\Omega$$

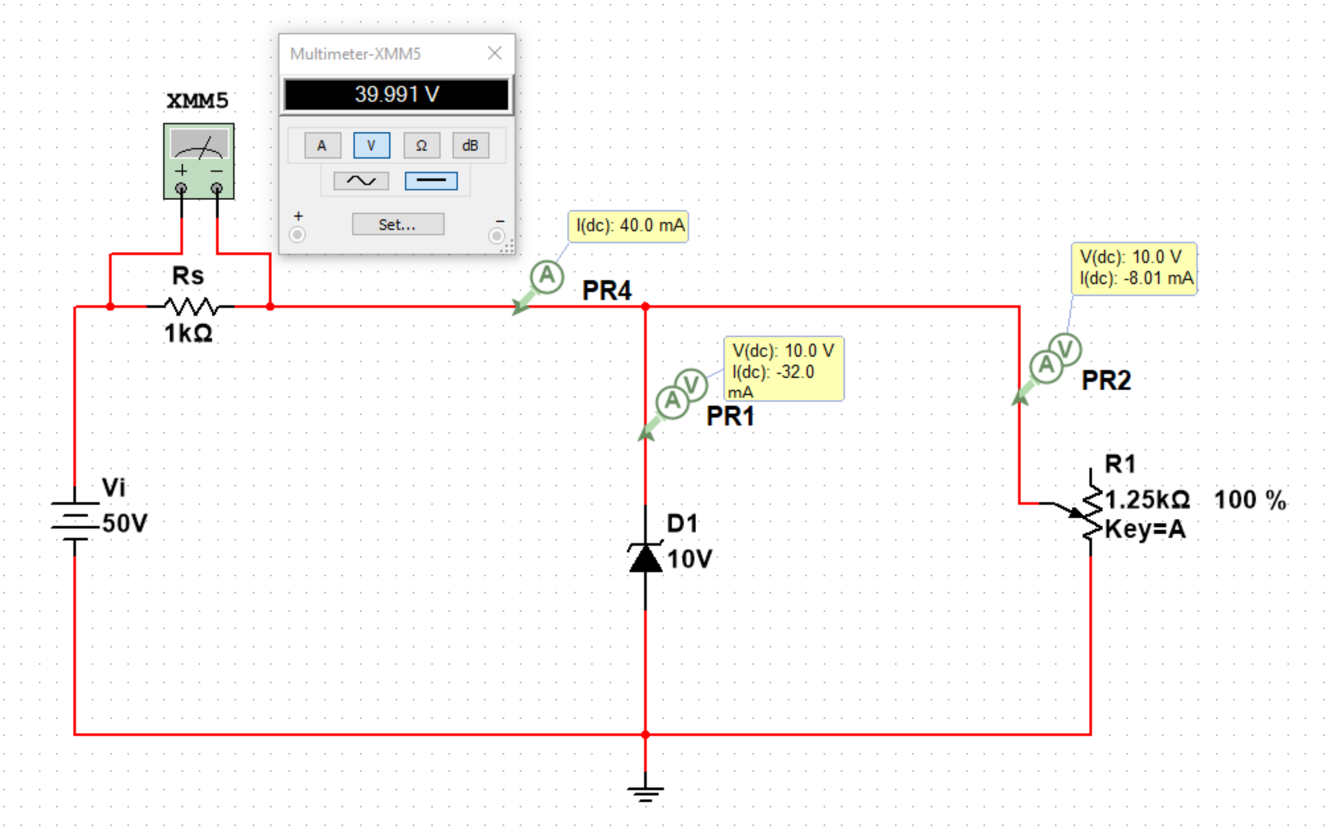
$$V_i - V_s - V_z = 0$$
$$50 - V_s - 10 = 0$$
$$V_s = 40\ V$$

$$I_s = \frac{V_s}{R_s} = \frac{40}{1K} = 40\ mA$$
$$I_{Lmin} = I_s - I_{zmax} = 40 - 32 = 8\ mA$$

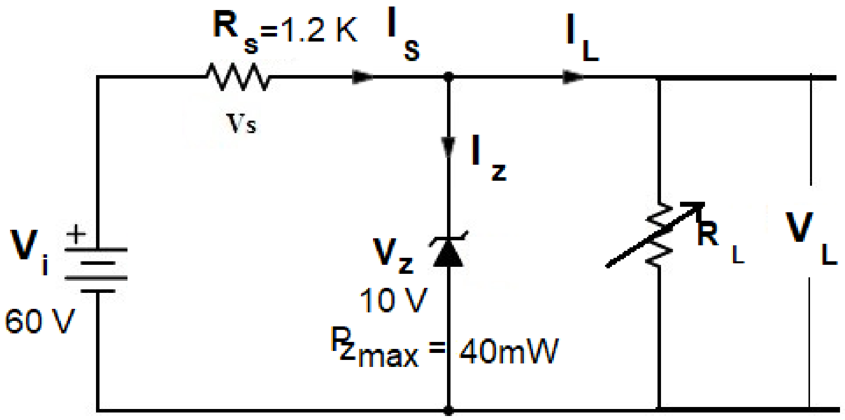
$$R_{Lmin} = \frac{V_z}{I_{Lmax}} = \frac{10}{8m} = 1.25\ K\Omega$$
$$I_{Lmax} = \frac{V_z}{R_{Lmin}} = \frac{10}{0.25K} = 40\ mA$$

Answer with MULTISIM

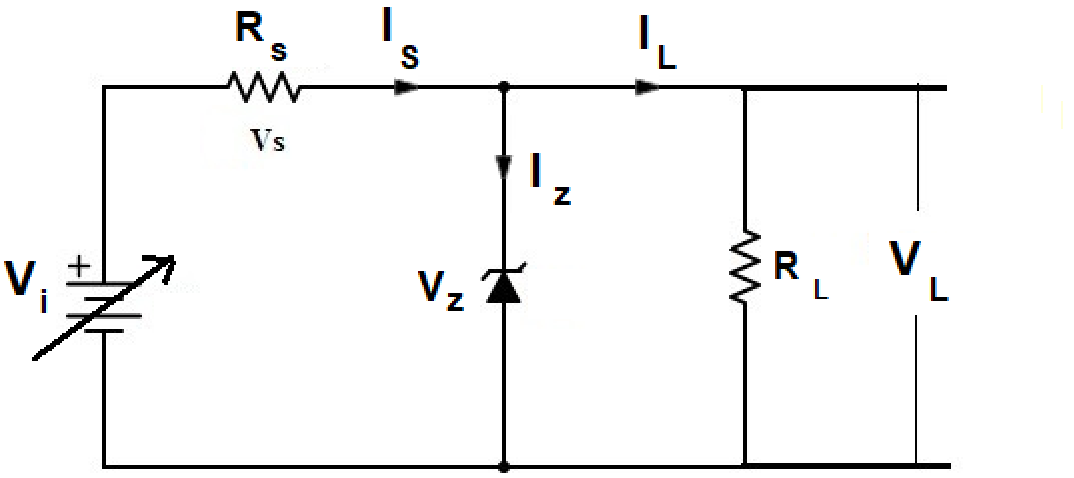




Ex5 (H.W): For the Zener circuit below, determine the range of R_L and I_L



Stage 3: Variable V_i and Fixed R_L



$$V_{i\,min} = \frac{R_L + R_s}{R_L} V_z$$

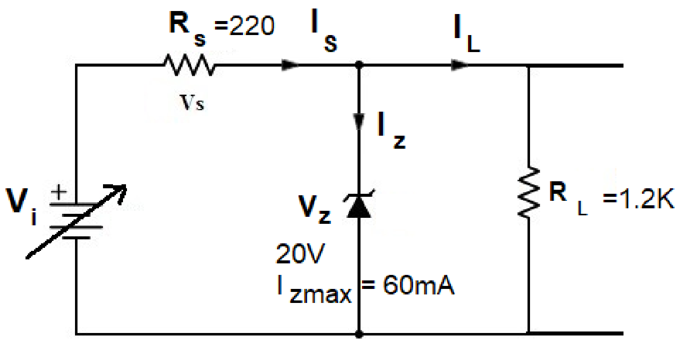
$$I_{S\,max} = I_{z\,max} + I_L$$

$$V_{i\,max} = I_{s\,max}.R_s + V_z$$

$$V_{s\,max} = I_{s\,max}\,R_s$$

$$V_{s\,min} = I_{s\,min}\,R_s$$

Ex6: For the Following circuit, determine the range of the input voltage and V_s



Answer:

$$V_{i\,min} = \frac{R_L + R_s}{R_L}\,V_z = \frac{1200 + 220}{1200} \times 20 = 23.67\ V$$

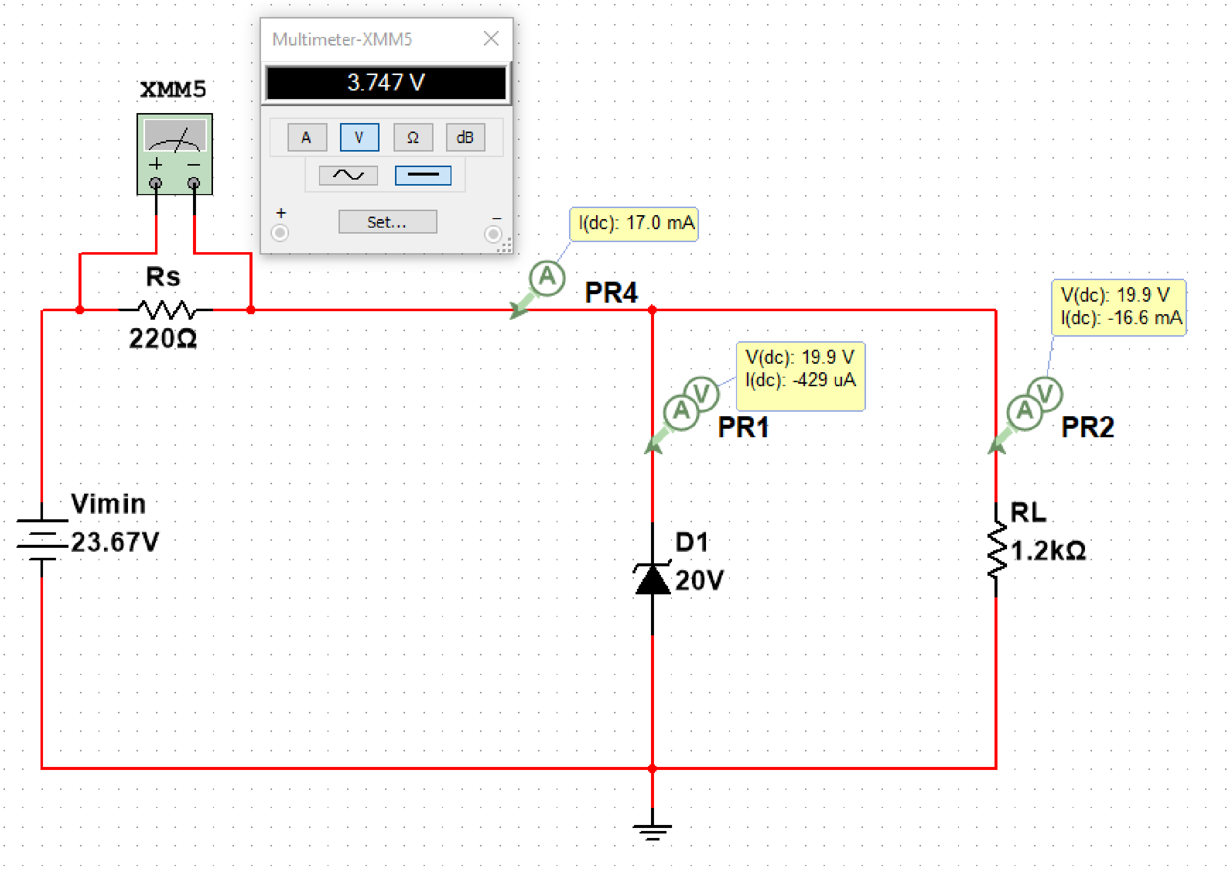
$$I_L = \frac{V_L}{R_L} = \frac{20}{1.2 \times 10^3} = 16.6\ mA$$

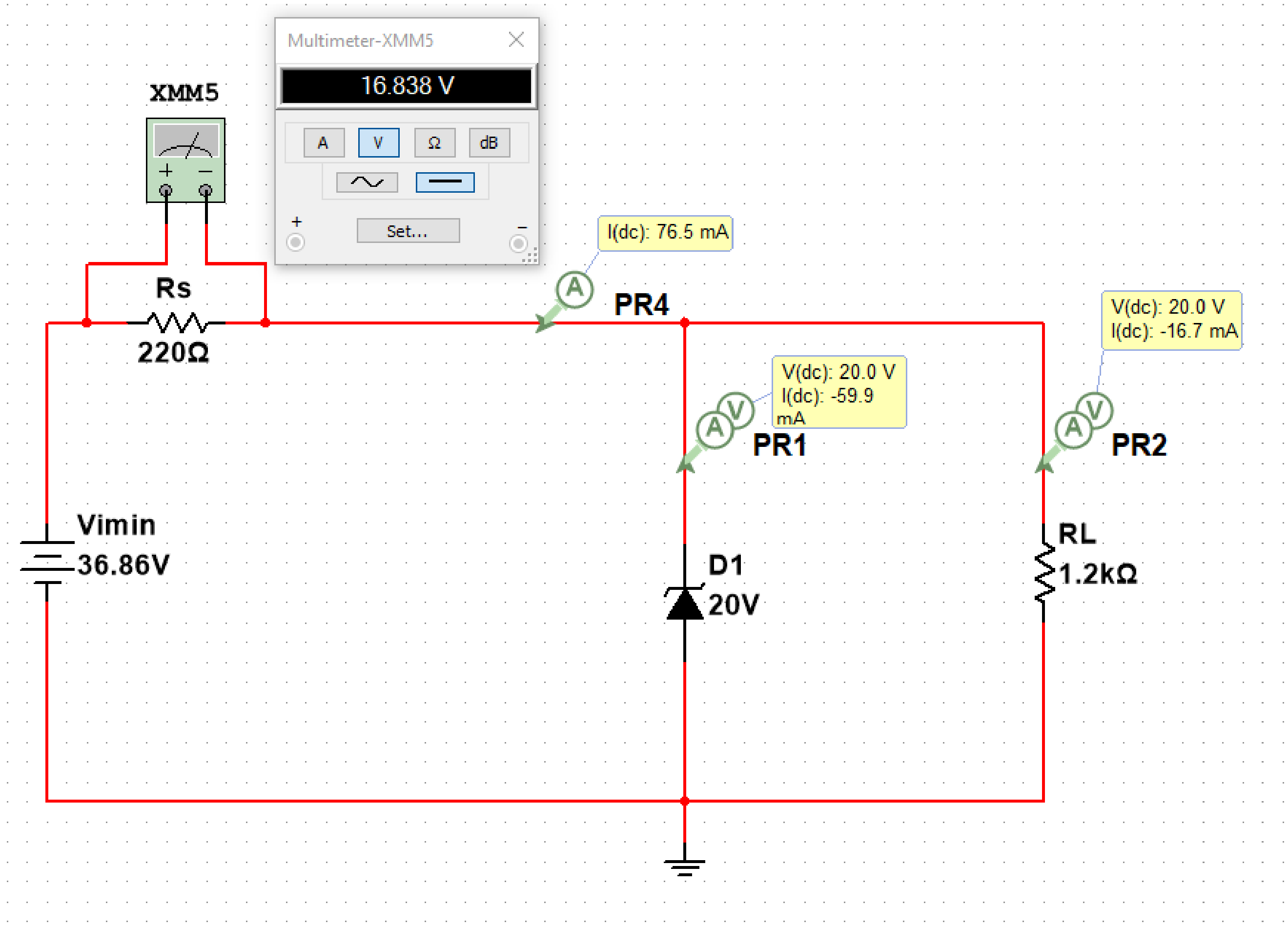
$$I_{S\,max} = I_{z\,max} + I_L = 60 + 16.6 = 76.6\ mA$$

$$V_{i\,max} = I_{s\,max}.\,R_s + V_z = 76.6m \times 220 + 20 = 36.86\ V$$

$$V_{s\,max} = I_{s\,max}\ R_s = 76.6 \times 220 = 16.852V$$

$$V_{s\,min} = I_{s\,min}\ R_s == 17.032 \times 220 = 3.747V$$

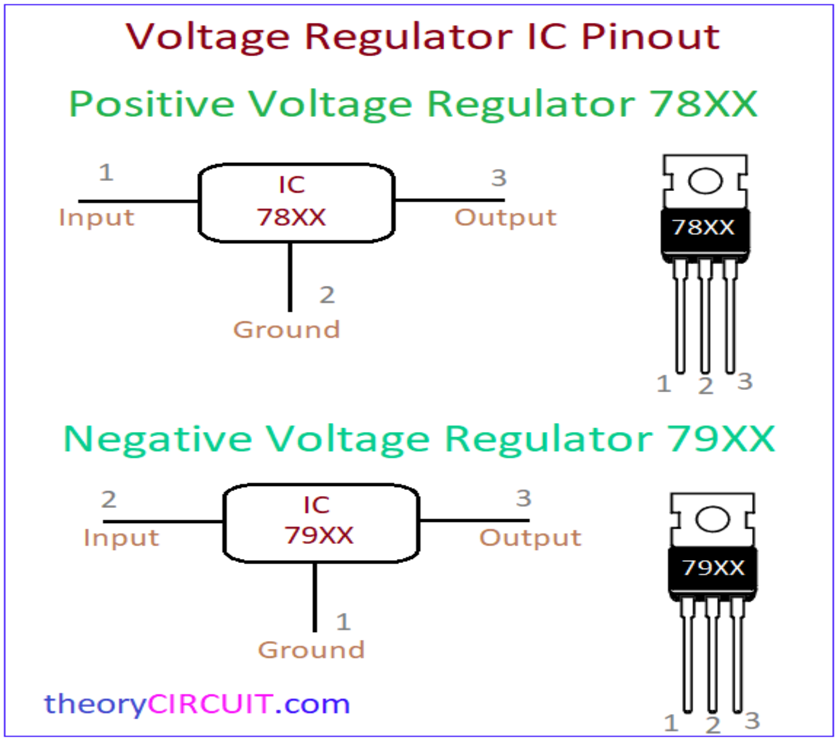




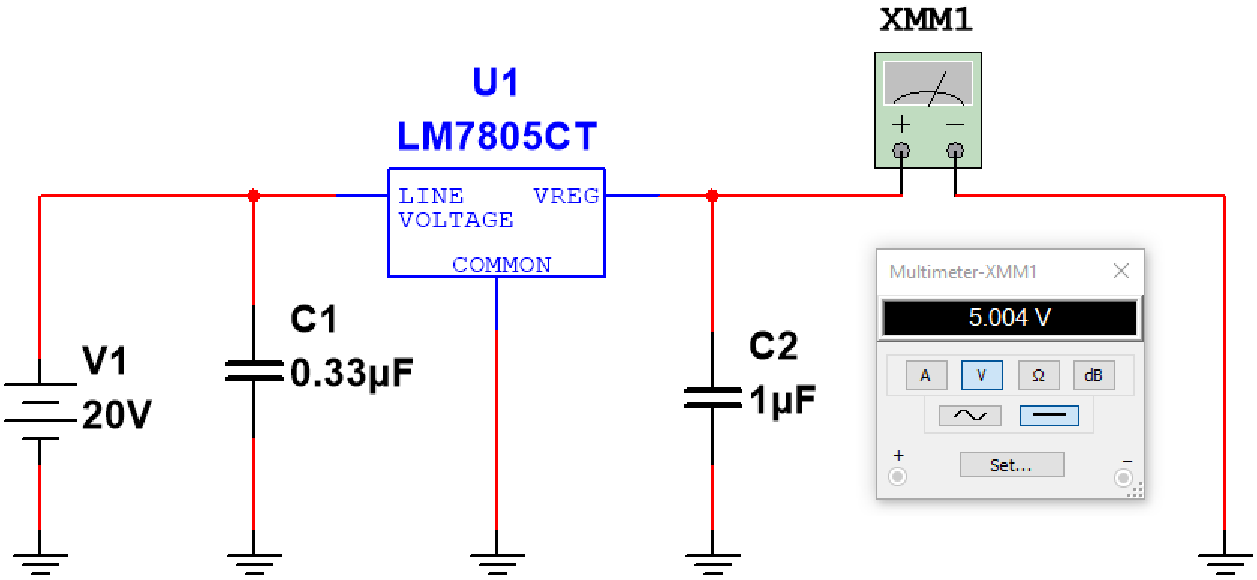
Ex7 (H.W): Repeat with $R_s = 330$ and $R_L = 2$ K and $V_z = 22$ V

IC Regulator

IC's like LM78XX and 79XX (such as the IC 7805) are used to obtained fixed values of voltages at the output.

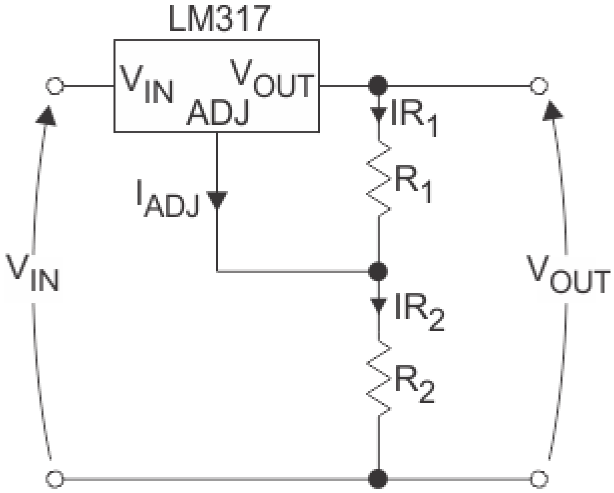


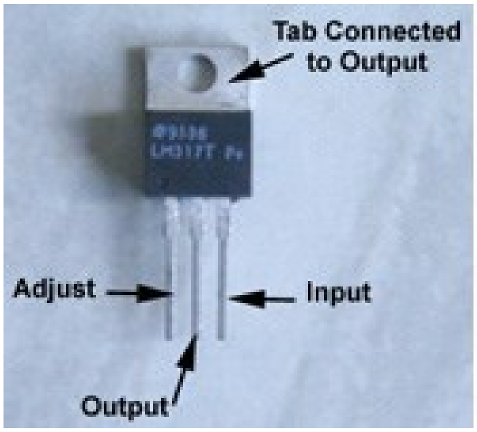
An example for LM7805 in Multisim

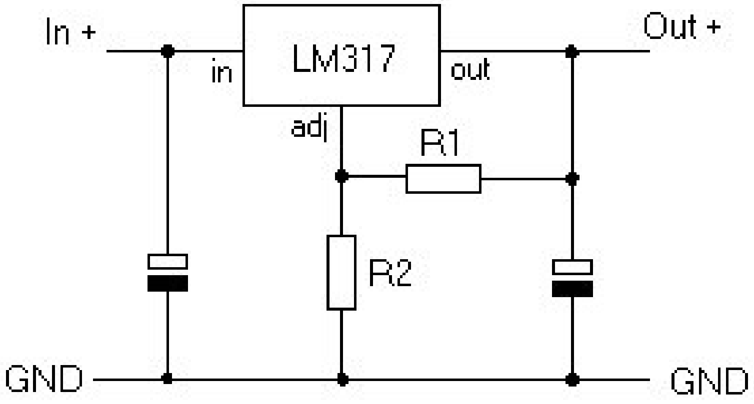


With IC's like LM 317 and 723, we can adjust the output voltage to a required constant value. The figure below shows the LM317 voltage regulator. The output voltage can be adjusted by adjusting the values of resistances R_1 and R_2. Usually, coupling capacitors of values about 0.01μF to 10μF need to be connected at the output and input to address input noise and output transients. Ideally, the output voltage is given by

$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right)$$





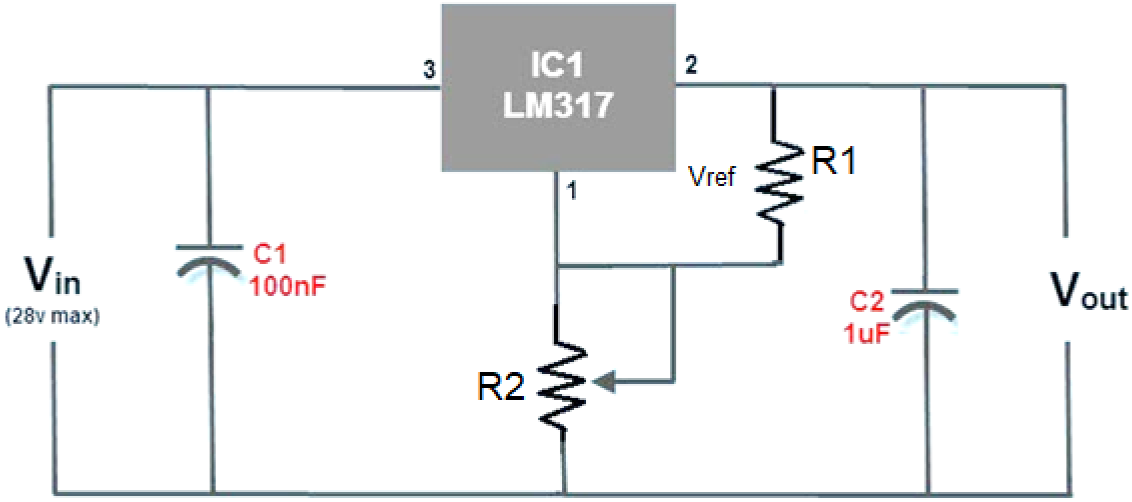


LM317 Voltage Regulator Circuit

The three terminals are input pin, output pin and adjustment pin. The LM317 circuit is shown in the below figure is a typical configuration of the LM317 voltage regulator circuit diagram including the decoupling capacitors. This

LM317 circuit is capable to provide variable DC power supply with output of 1A and can be adjusted up to 30V. The circuit consists of a low-side resistor and high-side resistor connected in series forming a resistive voltage divider which is a passive linear circuit used to produce an output voltage which is a fraction of its input voltage.

Decoupling capacitors are used for decoupling or to prevent undesired coupling of one part of an electrical circuit from another part. To avoid the effect of noise caused by some circuit elements over the remaining elements of the circuit, the decoupling capacitors in the circuit are used for addressing the input noise and output transients. A heat sink is used with the circuit to avoid the components getting overheated due to more power dissipation.



LM317 **Voltage Regulator Circuit**

C_1=C_{in} needed if regulator is located far from power supply filter.

C_2=C_{out} improves transient response.

Features of LM317 Voltage Regulator

There are some special features of LM317 regulator and a few are as follows:

- It is capable of providing excess current of 1.5A, hence it is conceptually considered as operational amplifier with an output voltage ranging from 1.2V to 37V.
- The LM317 voltage regulator circuit internally consists of thermal overload protection and short circuit current limiting constant with temperature.
- It is available in two packages as 3-Lead Transistor Package and surface mount D2PAK-3.
- Stocking of many fixed voltages can be eliminated.

Working of Voltage Regulator LM317 Circuit (Adjustable Voltage Regulator)

The LM317 regulator can provide excess output current and hence with this capacity, it is conceptually considered as an operational amplifier. The adjustment pin is the inverting input of the amplifier and to produce a stable reference voltage of 1.25V, an internal bandgap reference voltage is used to set the non-inverting input.

The output pin voltage can be continuously adjusted to a fixed amount using a resistive-voltage divider between the output and ground, which will configure the operational amplifier as a non-inverting amplifier.

A bandgap reference voltage is used to produce constant output voltage irrespective of the changes in supply power. It is also called as temperature independent reference voltage frequently used in integrated circuits.

The output voltage (ideally) of the LM317 voltage regulator circuit

$$V_{out} = V_{ref} * (1 + (R_2/R_1))$$

Where V_{ref} **is 1.25V,** an error term is added because some quiescent current flows from the adjustment pin of the device.

$$V_{out} = V_{ref} * (1+(R_2/R_1)) + I_{adj} R_2$$

For achieving more stable output, the LM317 voltage regulator circuit diagram is designed such that to make the quiescent current less than or equal to 100 micro Amp. Thus, in all practical cases the error can be ignored.

If we replace the low-side resistor of the divider from the LM317 voltage regulator circuit diagram with the load, then the resulting configuration of the LM317 regulator will regulate the current to a load. Hence, this LM317 circuit can be treated as LM317 Current Regulator Circuit.

The output current is the voltage drop of reference voltage across the resistance RH and is given as

Output current in ideal case is

$$I_{out} = V_{ref}/R_1$$

Considering the quiescent current, the output current is given as

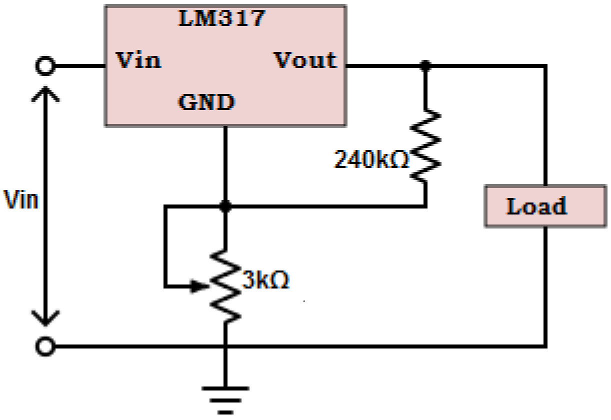
$$I_{out} = (V_{ref}/R_1) + I_{adj}$$

These linear voltage regulators LM317 and LM337 are frequently used in DC-DC converter applications. Linear regulators naturally draw much current as they supply. The power produced due to the multiplication of this current with the voltage difference between the input and output will be dissipated and wasted as heat.

Due to this, a heat is required to be considered for significant design and leads to inefficiency. If the voltage difference increases, then the power wasted will increase and sometimes this dissipated waste power will be more than the supplied power.

Even though this is insignificant, but as the linear voltage regulators with a few additional components is a simple way to obtain stable voltage, so, we must accept this trade-off. The switching voltage regulators are alternative for these linear regulators as these switching regulators are generally more efficient, but they require more number of components to design and thus need more space.

Ex 8: Calculate the output voltage for LM317 regulator. The current I_{ADJ} is very small in the order of 100µA. (Assume V_{REF}=1.25v)



Answer:

Explanation: The output voltage, V_{Out} =V_{REF}[1=(R_2/R_1)]+(I_{ADJ}×R_2)=1.25V_{in}× [1+(3kΩ/240Ω)] +(100µA×3kΩ)= 16.875 +0.3.
=> V_{Out}=17.17v.

Ex9: Drive the following questions

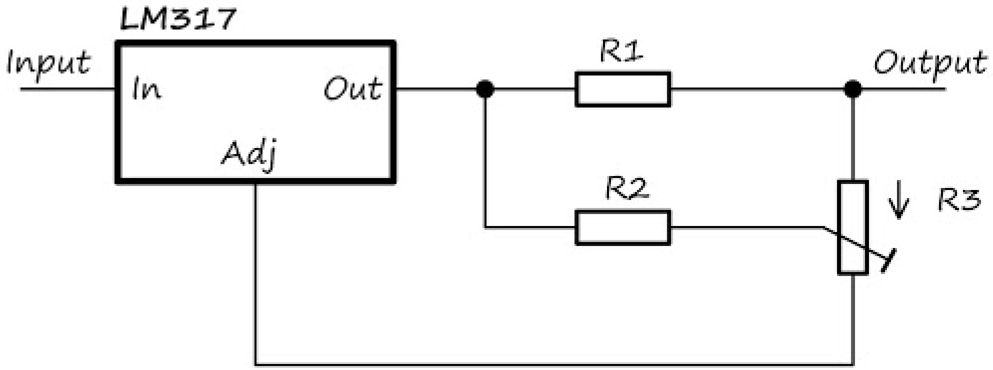
$$V_{out} = V_{ref}(1 + \frac{R_2}{R_1})$$

$$R_1 = R_2 \frac{1.25}{V_o - 1.25}$$

$$R_2 = R_1 \frac{V_o - 1.25}{1.25}$$

Adjustable Current Regulator

LM317 (adjustable current source)



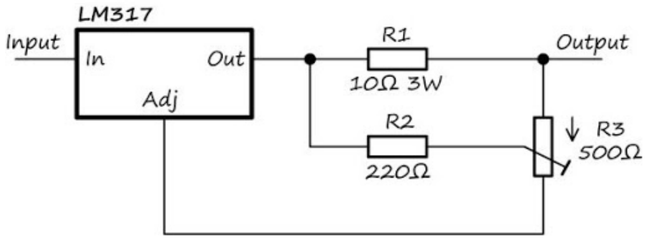
$\boldsymbol{V_{R1} = 1.25\,(1 + \frac{xR_3}{R_2})}$ **x= 0 to 1**

$$\boldsymbol{I_{R1} = \frac{V_{R1}}{R_1}}$$

$$\boldsymbol{I_{min} = \frac{1.25}{R_1}}$$

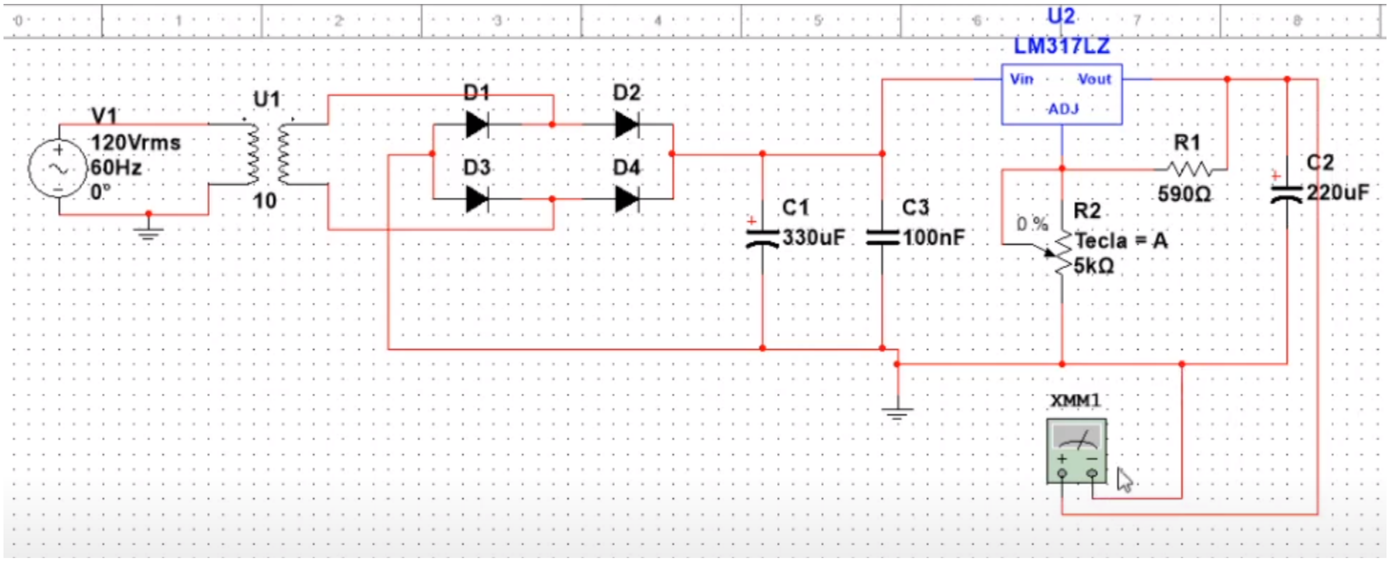
$$\boldsymbol{I_{max} = \frac{1.25}{R_1}\,(1 + \frac{R_3}{R_2})}$$

Ex10 (H.W): Determine I_{min} and I_{max} of the following circuit.



LM317 adjustable current source
approx. 125-400mA range

Full Regulated Power Supply Using Multisim



Clippers and Clampers

Clippers

Zener diode based clipping circuits limit the certain part of the input waveform that is applied across the input terminals. These Zener diode clippers are generally used for protecting the circuits and in shaping of the input waveforms. Consider a clipper circuit as shown in the figure. If we want to clip the waveform above 3.2 V, we will use a 3.2 V Zener diode.

The output waveform can be clipped on the positive side by greater than 3.2 V and there maintains a constant output. The waveform on the negative side is clipped at 0.7 V and there after the Zener diode turns ON and acts as a silicon diode.

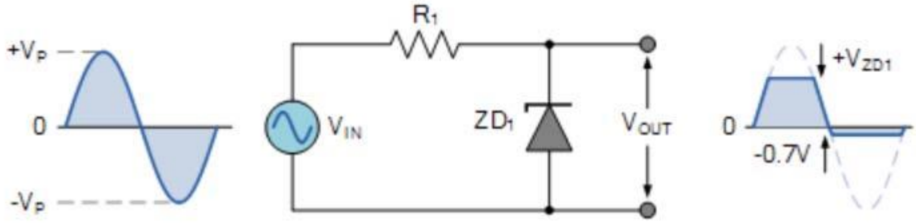
The diode and power supply as shown will prevent the output voltage from exceeding 0.7V. Zener diode clipping circuits are used to eliminate noise in amplitude and spikes in voltage, voltage regulation and to make fresh waveforms from an existing signal such as squaring off the peaks of a sinusoidal waveform to obtain a rectangular waveform.

As we know, the Zener diode is another type of diode that has been specially manufactured to operate in its reverse biased breakdown region and as such can be used for voltage regulation or Zener diode clipping applications. In the forward region, the Zener acts just like an ordinary silicon diode with a forward voltage drop of 0.7V (700mV) when conducting, the same as above.

However, in the reverse bias region, the voltage is blocked until the Zener diodes breakdown voltage is reached. At this point, the reverse current through the Zener increases sharply but the Zener voltage, VZ across the device remains constant even if the Zener current, IZ varies. Then we can put this Zener action to good effect by using them for clipping a waveform as shown.

Positive Zener Clipping Circuits

With



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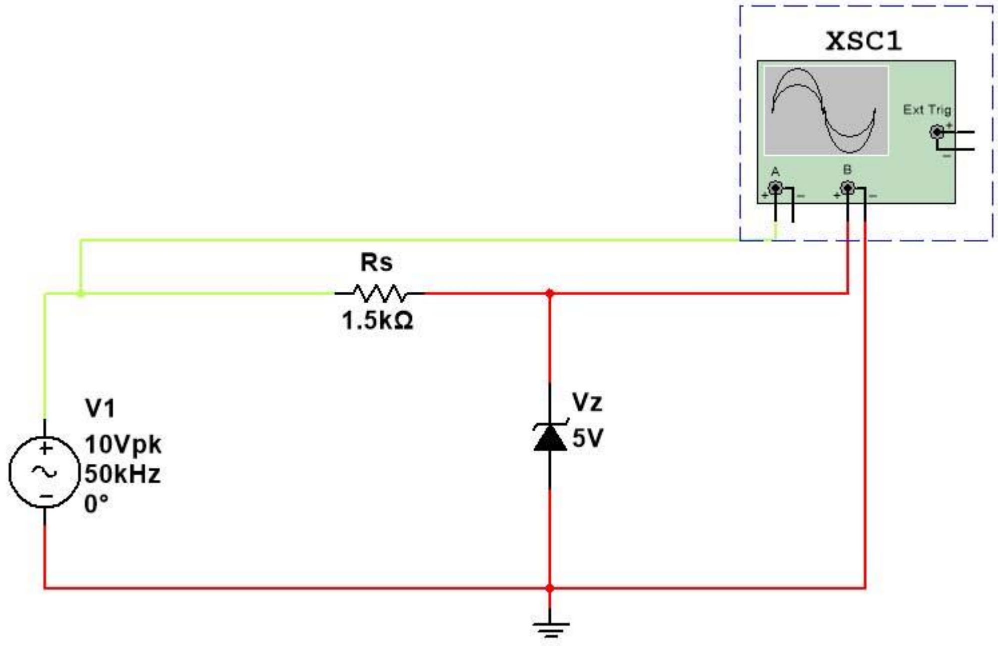
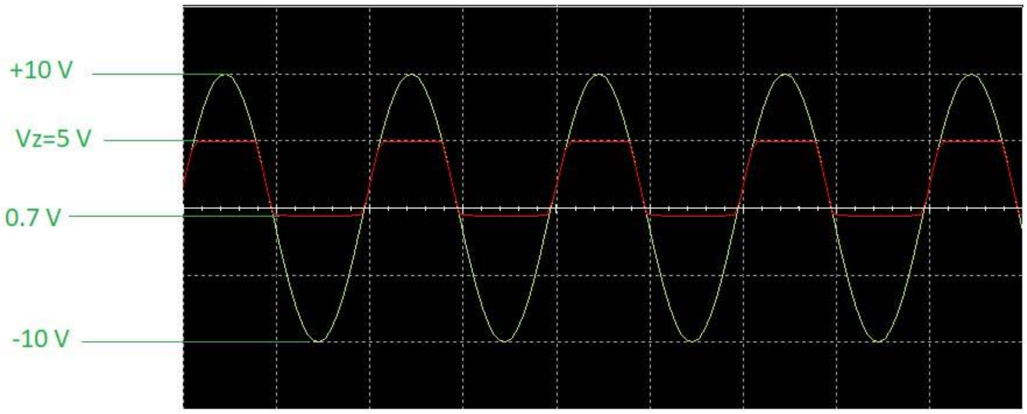
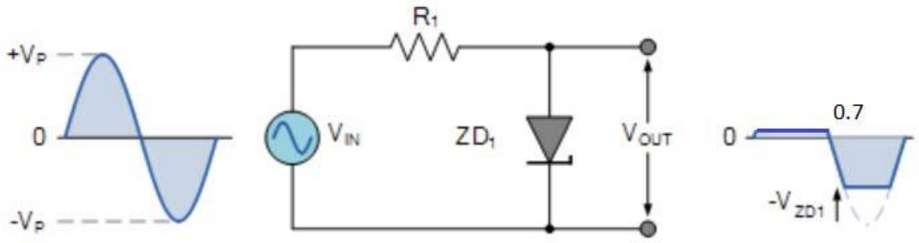




Negative Zener Clipping Circuits

With



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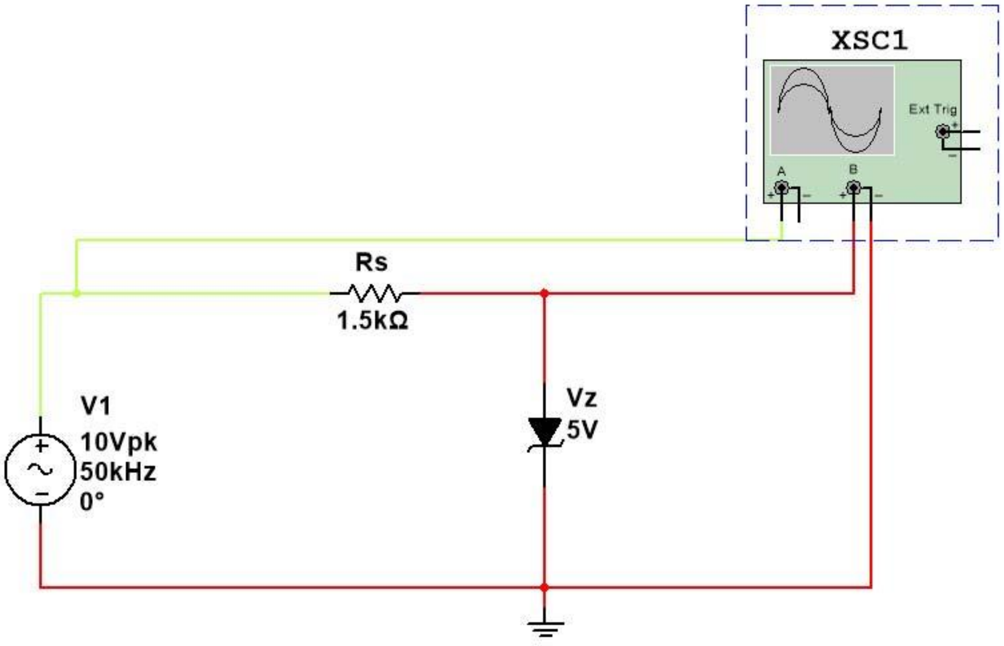
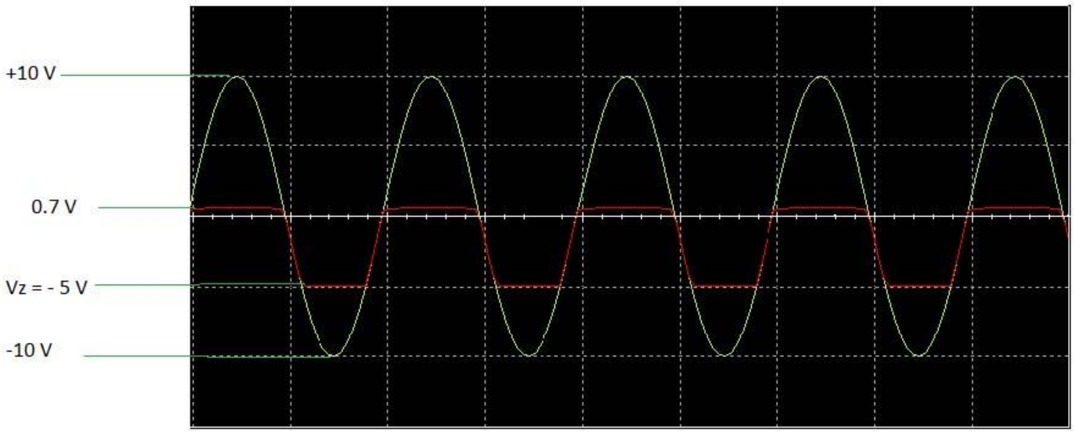
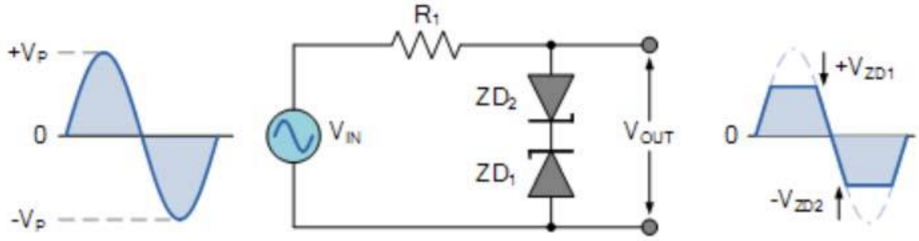


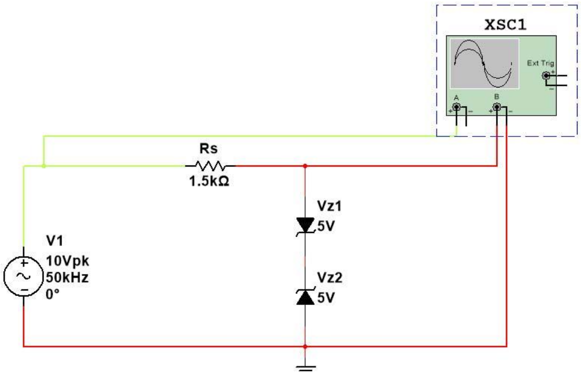


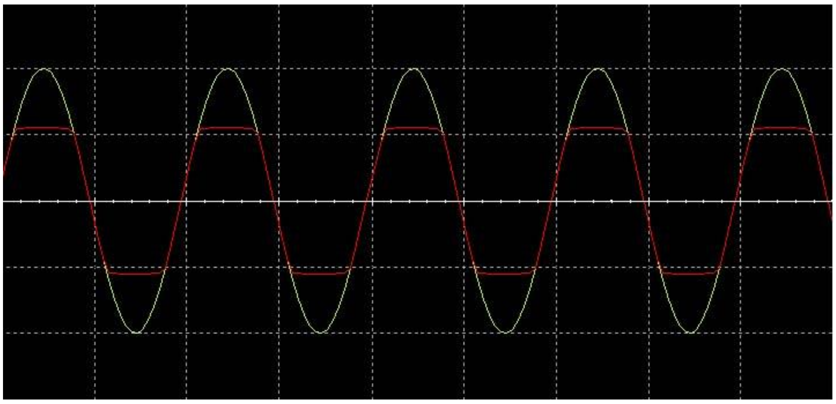
Full-wave Zener Diode Clipping



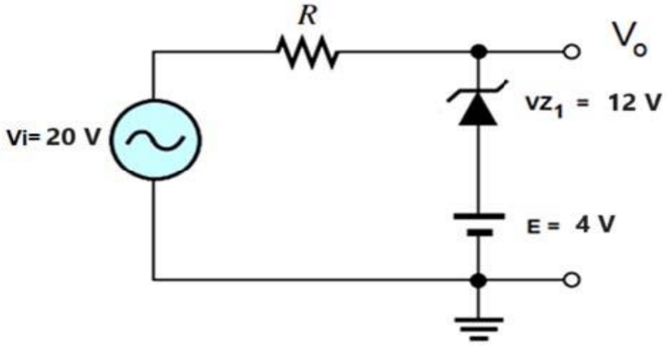
Connecting the Zener diodes in opposite direction, back-to-back fashion produces an AC regulator that can be used as a square wave generator. It is the most commonly used Zener diode connection for clipping the waveforms and protecting the electronic circuits from over voltage. Both the Zener diodes are usually connected across the input terminals of the power supply, at some point in the normal functioning, one of the Zener diodes in the circuit is OFF and the other Zener diode have no or very little affect.

With MULTISIM

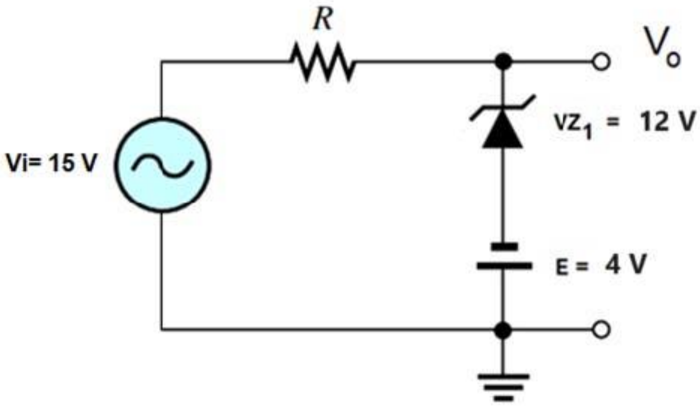




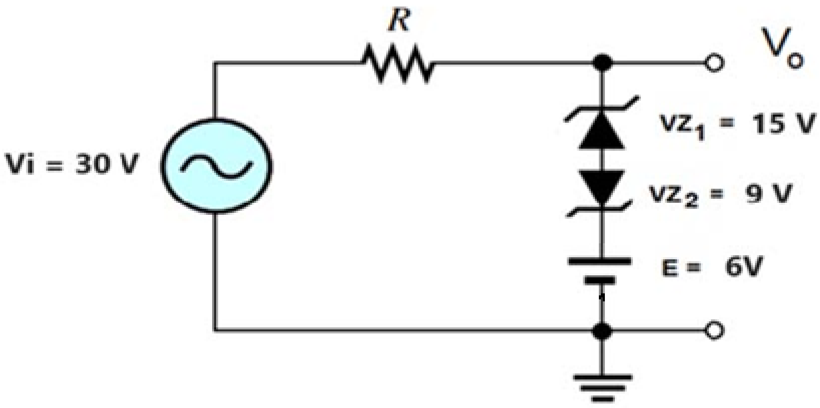
Ex (H.W): Draw V_o and V_{Rs}.



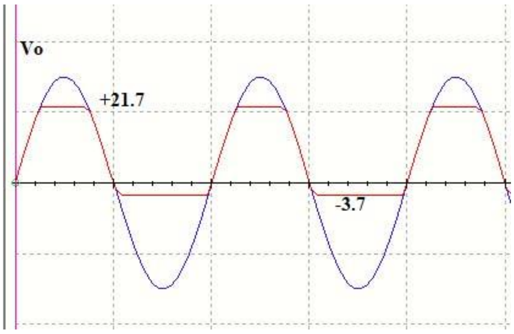
Ex (H.W): Draw V_o and V_{Rs}.

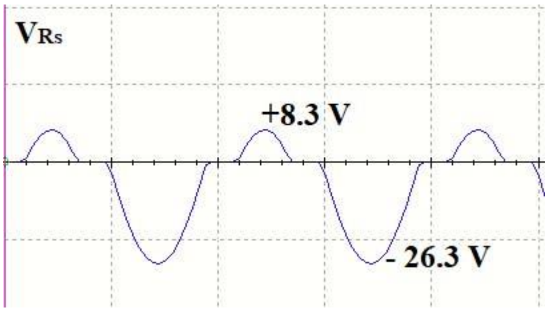


Ex: Draw V_o and V_{Rs}.

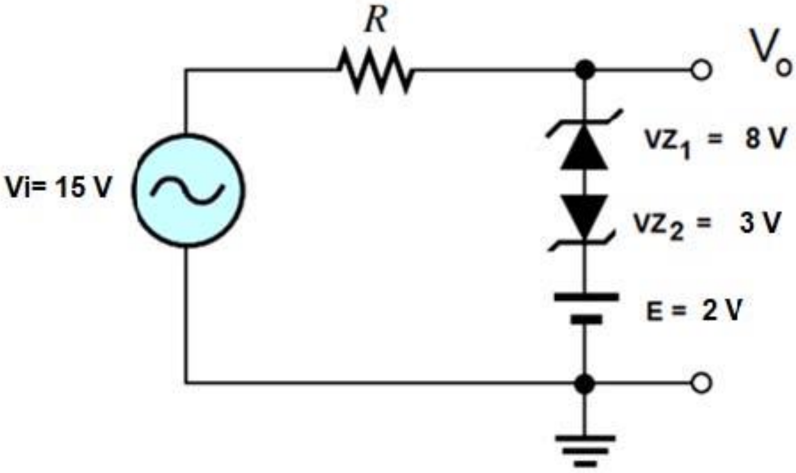


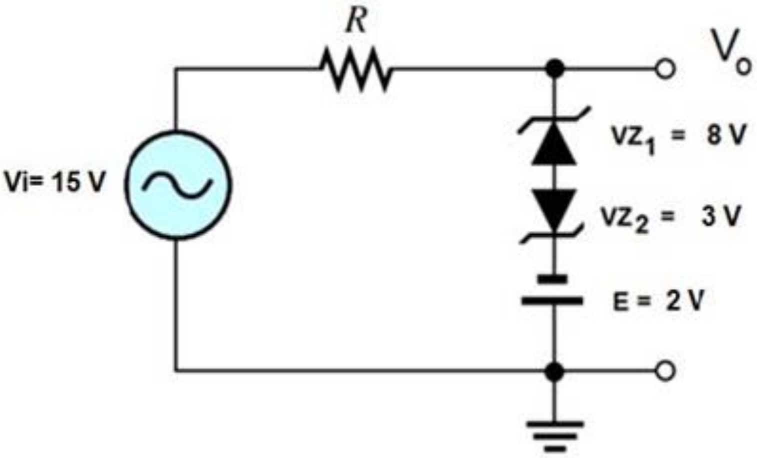
Ans:





Ex(H.W): Draw V_o and V_{Rs}.

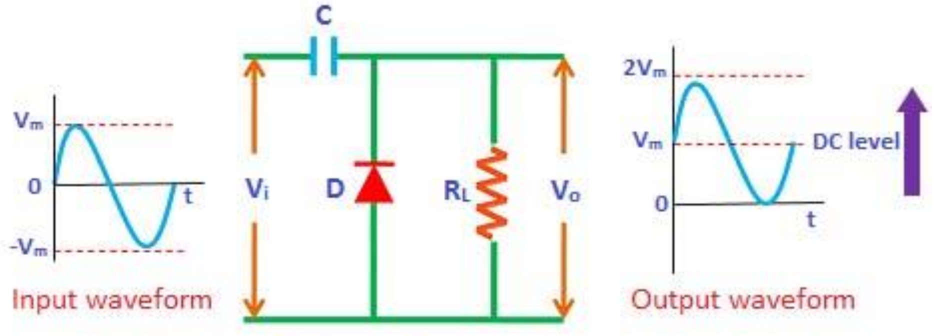




Clamper circuits

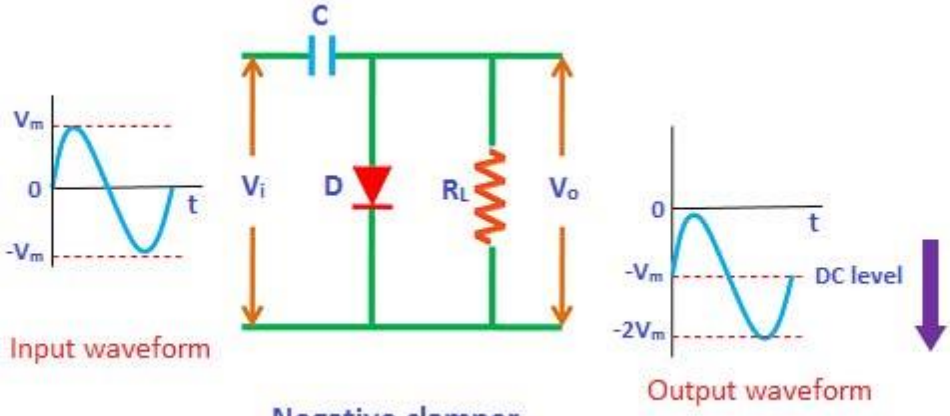
A clamper is an electronic circuit that changes the DC level of a signal to the desired level without changing the shape of the applied signal. In other words, the clamper circuit moves the whole signal up or down to set either the positive peak or negative peak of the signal at the desired level.

The dc component is simply added to the input signal or subtracted from the input signal. A clamper circuit adds the positive dc component to the input signal to push it to the positive side. Similarly, a clamper circuit adds the negative dc component to the input signal to push it to the negative side.



Positive clamper

If the circuit pushes the signal upwards then the circuit is said to be a positive clamper. When the signal is pushed upwards, the negative peak of the signal meets the zero level



Negative clamper

On the other hand, if the circuit pushes the signal downwards then the circuit is said to be a negative clamper. When the signal is pushed downwards, the positive peak of the signal meets the zero level.

The construction of the clamper circuit is almost similar to the clipper circuit. The only difference is the clamper circuit contains an extra element called capacitor. A capacitor is used to provide a dc offset (dc level) from the stored charge.

A typical clamper is made up of a capacitor, diode, and resistor. Some clampers contain an extra element called DC battery. The resistors and capacitors are used in the clamper circuit to maintain an altered DC level at the clamper output. The clamper is also referred to as a DC restorer, clamped capacitors, or AC signal level shifter.

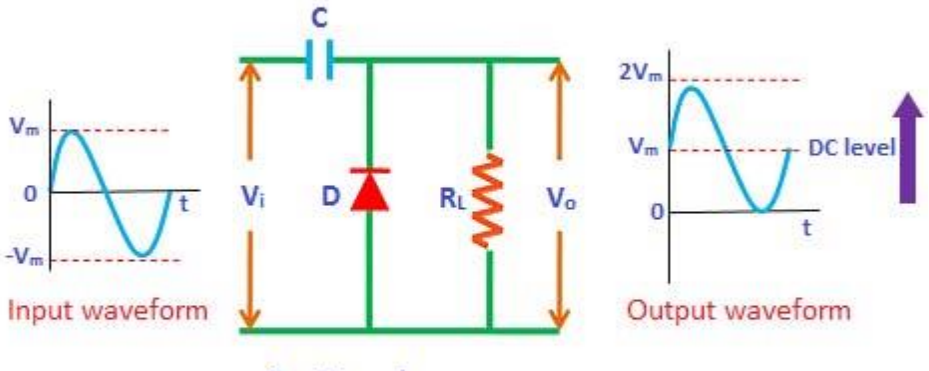
Types of clampers

Clamper circuits are of three types:

1. Positive clampers
2. Negative clampers
3. Biased clampers

1. Positive clamper

The positive clamper is made up of a voltage source Vi, capacitor C, diode D, and load resistor RL. In the below circuit diagram, the diode is connected in parallel with the output load. So the positive clamper passes the input signal to the output load when the diode is reverse biased and blocks the input signal when the diode is forward biased.



Positive clamper

During negative half cycle:

During the negative half cycle of the input AC signal, the diode is forward biased and hence no signal appears at the output. In forward biased condition, the diode allows electric current through it. This current will flows to the capacitor and charges it to the peak value of input voltage Vm. The capacitor charged in inverse polarity (positive) with the input voltage. As input current or voltage decreases after attaining its maximum value -Vm, the capacitor holds the charge until the diode remains forward biased.

During positive half cycle:

During the positive half cycle of the input AC signal, the diode is reverse biased and hence the signal appears at the output. In reverse biased condition, the diode does not allow electric current through it. So the input current directly flows towards the output.

When the positive half cycle begins, the diode is in the non-conducting state and the charge stored in the capacitor is discharged (released). Therefore, the voltage appeared at the output is equal to the sum of the voltage stored in the capacitor (Vm) and the input voltage (Vm) { I.e. Vo = Vm+ Vm = 2Vm} which have the same polarity with each other. As a result, the signal shifted upwards.

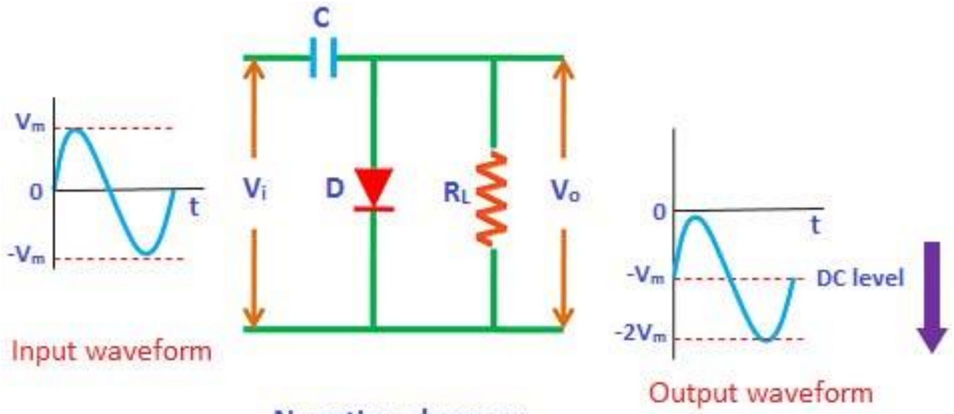
The peak to peak amplitude of the input signal is 2Vm,similarly the peak to peak amplitude of the output signal is also 2Vm. Therefore, the total swing of the output is same as the total swing of the input.

The basic difference between the clipper and clamper isthat the clipper removes the unwanted portion of the input signal whereas the clamper moves the input signal upwards or downwards.

2. Negative clamper

During positive half cycle:

During the positive half cycle of the input AC signal, the diode is forward biased and hence no signal appears at the output. In forward biased condition, the diode allows electric current through it. This current will flows to the capacitor and charges it to the peak value of input voltage in inverse polarity -Vm. As input current or voltage decreases after attaining its maximum value Vm, the capacitor holds the charge until the diode remains forward biased.



Negative clamper

During negative half cycle:

During the negative half cycle of the input AC signal, the diode is reverse biased and hence the signal appears at the output. In reverse biased condition, the diode does not allow electric current through it. So the input current directly flows towards the output.

When the negative half cycle begins, the diode is in the non-conducting state and the charge stored in the capacitor is discharged (released). Therefore, the voltage appeared at the output is equal to the sum of the voltage stored in the capacitor (-Vm) and the input voltage (-Vm) {I.e. Vo = -Vm- Vm = -2Vm} which have the same polarity with each other. As a result, the signal shifted downwards.

3. Biased clampers

Sometimes an additional shift of DC level is needed. In such cases, biased clampers are used. The working principle of the biased clampers is almost similar to the unbiased clampers. The only difference is an extra element called DC battery is introduced in biased clampers.

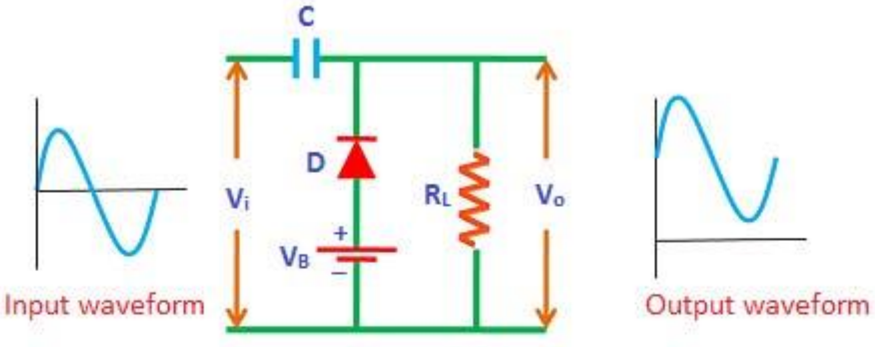
Positive clamper with positive bias

If positive biasing is applied to the clamper then it is said to be a positive clamper with positive bias. The positive clamper with positive bias is made up of an AC voltage source, capacitor, diode, resistor, and dc battery.

During positive half cycle:

During the positive half cycle, the battery voltage forward biases the diode when the input supply voltage is less than the battery voltage. This current or voltage will flows to the capacitor and charges it.

When the input supply voltage becomes greater than the battery voltage then the diode stops allowing electric current through it because the diode becomes reverse biased.



Positive clamper with positive bias

During negative half cycle:

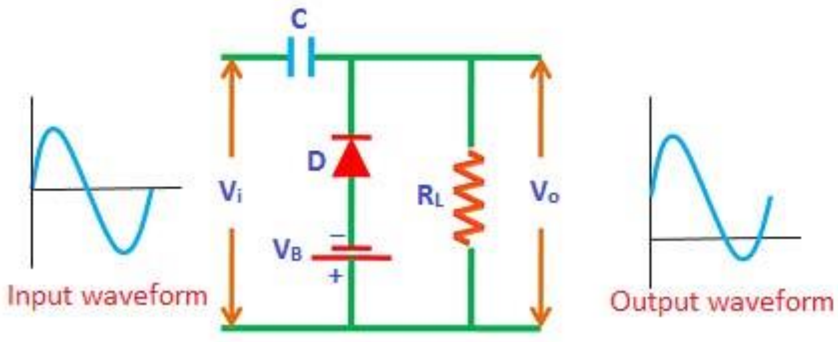
During the negative half cycle, the diode is forward biased by both input supply voltage and battery voltage .So the diode allows electric current. This current will flows to the capacitor and charges it.

Positive clamper with negative bias

During negative half cycle:

During the negative half cycle, the battery voltage reverse biases the diode when the input supply voltage is less than the battery voltage. As a result, the signal appears at the output.

When the input supply voltage becomes greater than the battery voltage, the diode is forward biased by the input supply voltage and hence allows electric current through it. This current will flows to the capacitor and charges it



Positive clamper with negative bias

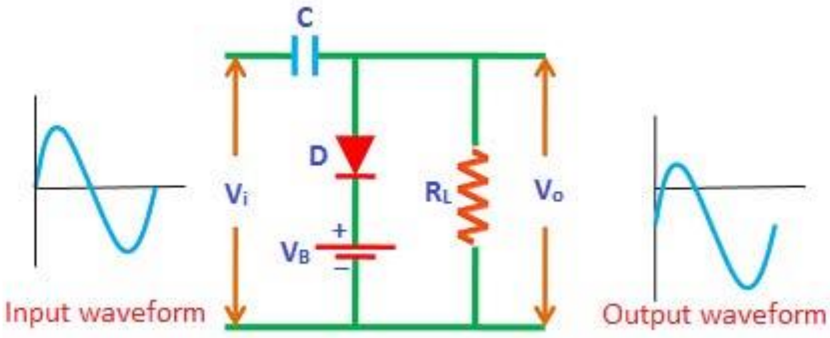
During positive half cycle:

During the positive half cycle, the diode is reverse biased by both input supply voltage and the battery voltage. As a result, the signal appears at the output. The signal appeared at the output is equal to the sum of the input voltage and capacitor voltage.

Negative clamper with positive bias

During positive half cycle:

During the positive half cycle, the battery voltage reverse biases the diode when the input supply voltage is less than the battery voltage. When the input supply voltage becomes greater than the battery voltage, the diode is forward biased by the input supply voltage and hence allows electric current through it. This current will flows to the capacitor and charges it



Negative clamper with positive bias

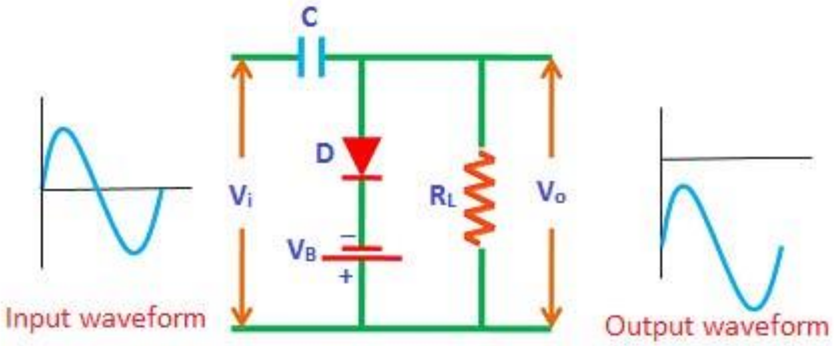
During negative half cycle:

During the negative half cycle, the diode is reverse biased by both input supply voltage and battery voltage .As a result, the signal appears at the output.

Negative clamper with negative bias

During positive half cycle:

During the positive half cycle, the diode is forward biased by both input supply voltage and battery voltage. As a result, current flows through the capacitor and charges it



Negative clamper with negative bias

During negative half cycle:

During the negative half cycle, the battery voltage forward biases the diode when the input supply voltage is less than the battery voltage. When the input supply voltage becomes greater than the battery voltage, the diode is reverse biased by the input supply voltage and hence signal appears at the output.