2. Rectifier:

A rectifier is an electrical circuit used to convert AC voltage into DC voltage. They are two types of rectifiers:

2.1 Half-Wave Rectifier (HWR):

Figure (2.1) shows Half-wave rectifier.

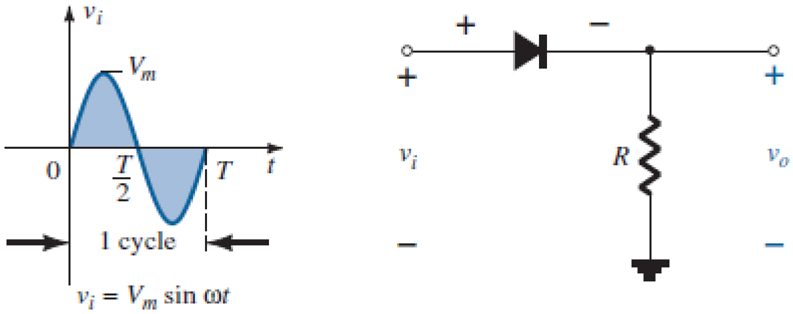


Figure (2.1): Half-wave rectifier.

The process of half-wave rectification is illustrated below:

- When sinusoidal input (V_{in}) goes positive, diode is Forward Biased (F.B), thus conducts current. The output voltage keeps the shape of the input voltage.

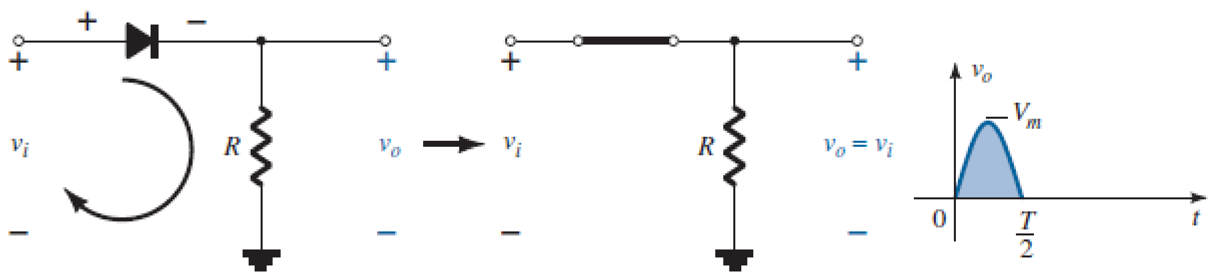


Figure (2.2): Conduction region (0 ➔ T/2).

- When (V_{in}) becomes negative (second half of cycle), diode is reverse biased (RB). There is no current the voltage across resistor RL is 0V.

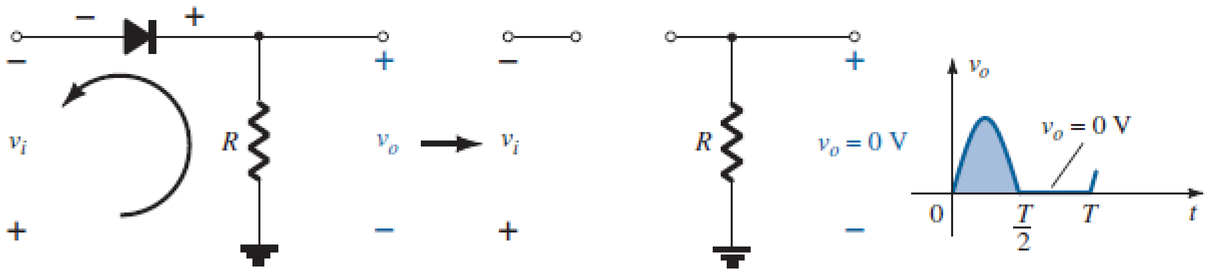


Figure (2.3): Nonconduction region (T/2 ➔ T).

- Net result is a pulsating dc voltage with same frequency as input.

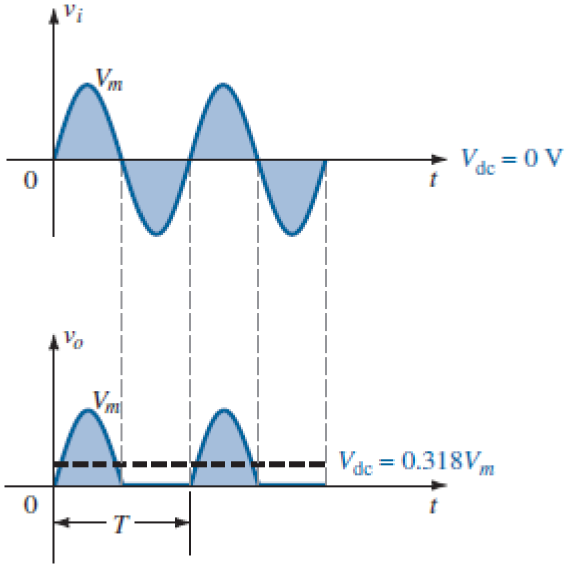


Figure (2.4): Half-wave rectified signal.

Average value (DC value) of HWR signal is:

$$V_{dc} = \frac{V_m}{\pi} = 0.318\, V_m$$

Where

V_m**:** The peak output voltage.

The root mean square value (RMS value) of HWR signal is:

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

For non-ideal diode (Silicon diode) the peak output voltage decreases by 0.7 V as:

$$V_{m(out)} = V_m - 0.7$$

For non-ideal diode (Germanium diode) the peak output voltage decreases by 0.3 V as:

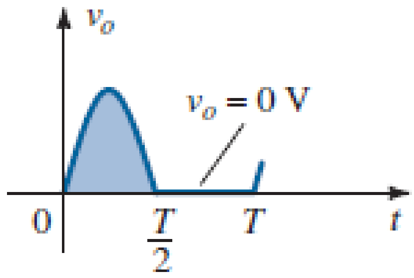
$$V_{m(out)} = V_m - 0.3$$

Example 1: Prove for HWR:

1. $V_{dc} = \frac{V_m}{\pi} = 0.318\, V_m$
2. $V_{rms} = \frac{V_m}{2}$

Solution:

1. $\boldsymbol{V_{dc}} = \frac{1}{T}\int_0^T V_m \sin\omega t \, dt$ where $T = 2\pi$ & $\omega = \frac{2\pi}{T} = 1$



$$\boldsymbol{V_{dc}} = \frac{1}{2\pi}\left(\int_0^{\pi} V_m \sin t \, dt + \int_{\pi}^{2\pi} 0 \, dt\right)$$

$$\boldsymbol{V_{dc}} = \frac{V_m}{2\pi}\int_0^{\pi} \sin t \, dt = \frac{V_m}{2\pi}\left(-\cos t|_0^{\pi}\right)$$

$$\boldsymbol{V_{dc}} = \frac{-V_m}{2\pi}(\cos\pi - \cos 0) = \frac{-V_m}{2\pi}(-2)$$

$$\therefore \boldsymbol{V_{dc} = \frac{V_m}{\pi} = 0.318\, V_m}$$

2. $\boldsymbol{V_{rms}} = \sqrt{\frac{1}{T}\int_0^T (V_m \sin\omega t)^2 \, dt}$ where $T = 2\pi$ & $\omega = \frac{2\pi}{T} = 1$

$$\boldsymbol{V_{rms}} = \sqrt{\frac{1}{2\pi}\left(\int_0^{\pi} (V_m \sin t)^2 \, dt + \int_{\pi}^{2\pi} (0)^2 \, dt\right)}$$

$$\boldsymbol{V_{rms}} = \sqrt{\frac{{V_m}^2}{2\pi}\int_0^{\pi} \sin^2 t \, dt}$$ where $\sin^2 t = \frac{1}{2}(1 - \cos 2t)$

$$\boldsymbol{V_{rms}} = \sqrt{\frac{{V_m}^2}{2\pi}\frac{1}{2}\int_0^{\pi} (1 - \cos 2t) \, dt} = \sqrt{\frac{{V_m}^2}{4\pi}\, t - \frac{\sin 2t}{2}\Big|_0^{\pi}}$$

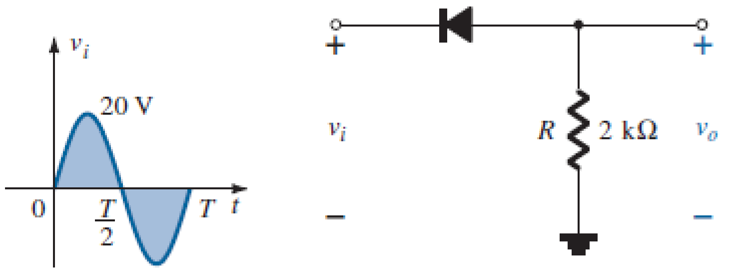
$$\boldsymbol{V_{rms}} = \sqrt{\frac{{V_m}^2}{4\pi}\left[(\pi - 0) - \frac{1}{2}(\sin 2\pi - \sin 0)\right]} = \sqrt{\frac{{V_m}^2}{4\pi}(\pi)}$$

$$\therefore \boldsymbol{V_{rms} = \frac{V_m}{2}}$$

Example 2: **For Half-wave rectifier:**

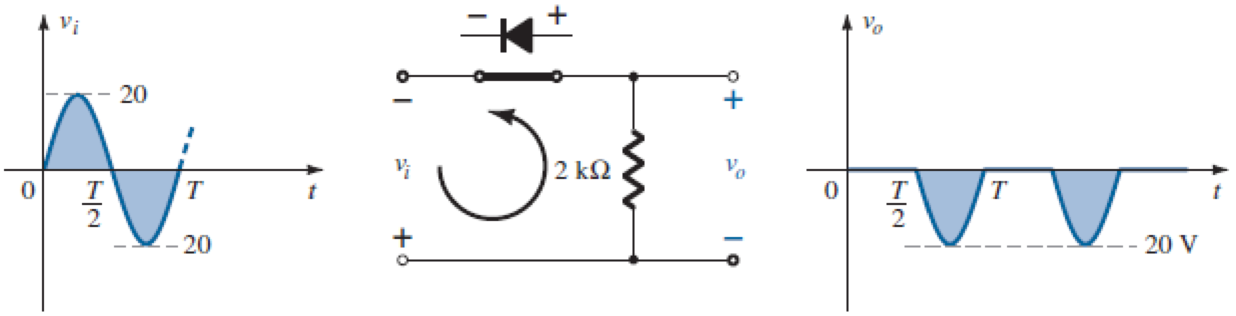
A. Sketch the output and Determine the DC level of the output for the network of Figure below.

B. Repeat part (A), if the ideal diode is replaced by a Silicon diode.



Solution:

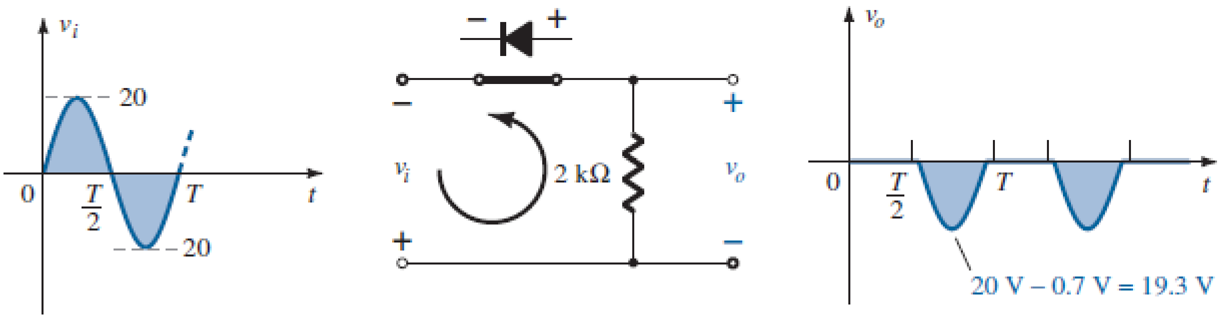
A. In this situation the diode will conduct during the negative part of the input and V_o will appear as shown in Figure below.



For the full period, the DC level is:

$$V_{dc} = -\frac{V_m}{\pi} = -0.318\, V_m = -0.318 \times 20v = -6.36v$$

B. Using a silicon diode, the output has the appearance of Figure below:



$$V_{dc} = -\frac{V_m - 0.7v}{\pi} = -0.318\,(V_m - 0.7v) = -0.318 \times (20v - 0.7v) = -6.14v$$

2.2 Full-Wave Rectifier (FWR):

The Full-Wave Rectifiers are the most commonly used ones for dc power supplies. The FWR exactly the same as the half-wave, but allows unidirectional current through the load during the entire sinusoidal cycle (as opposed to only half the cycle in the halfwave) as shown in **Figure (2.5)**. The frequency of the output is twice that of the input. There are two main types of full wave rectifiers:

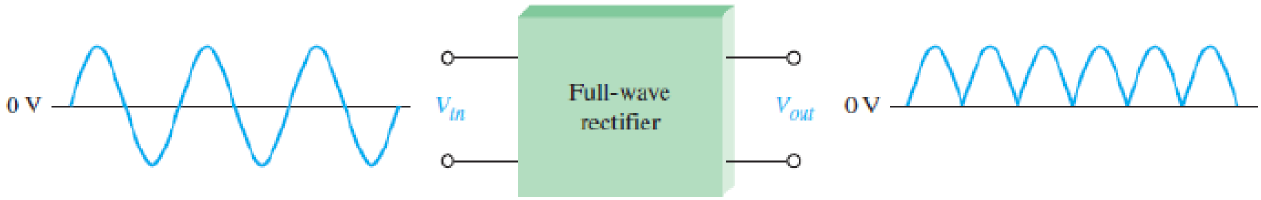


Figure (2.5): The FWR Output Waveform.

2.2.1 Center-Tapped (CT) Transformer FWR:

Two diodes connected to the secondary of a center-tapped transformer as shown in **Figure (2.6)**.

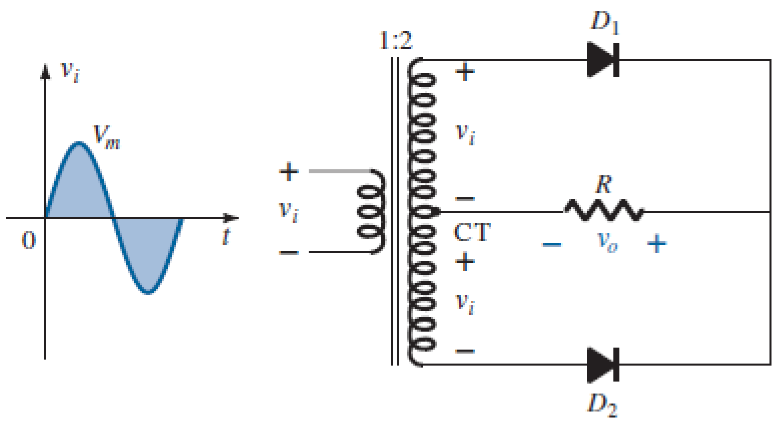
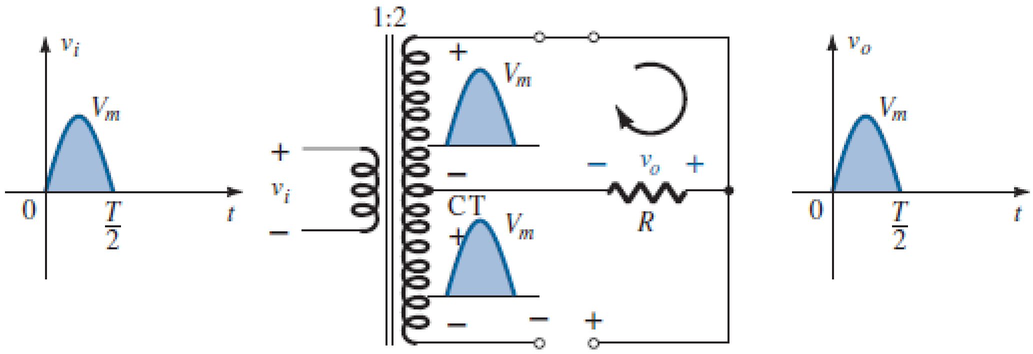


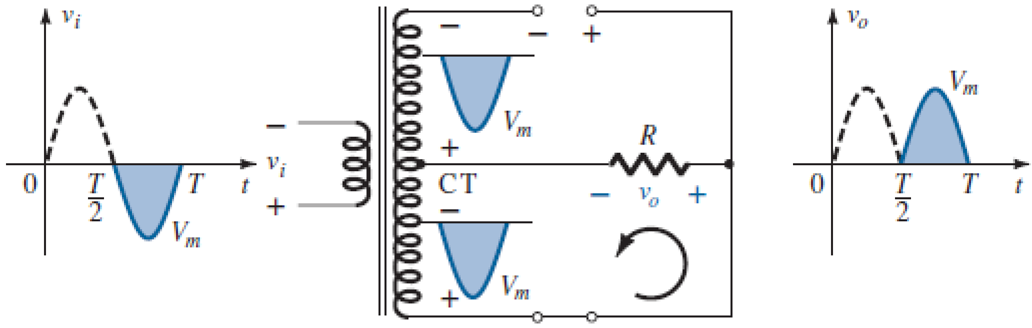
Figure (2.6): Center-tapped transformer full-wave rectifier.

Half of V_{in} shows up between the center tap and each secondary V_m. At any point in time, only one of the diodes is forward biased. This allows for continuous conduction through load.

Positive Cycle
D1 : F.B
D2 : R.B



Negative Cycle
D1 : R.B
D2 : F.B



Average value (DC value) of FWR center-tap signal is:

$$V_{dc} = \frac{2\,V_m}{\pi} = 0.636\,V_m$$

The root mean square value (RMS value) of HWR signal is:

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

For non-ideal diode (Silicon diode) the peak output voltage decreases by 0.7 V as:

$$V_{m(out)} = V_m - 0.7$$

For non-ideal diode (Germanium diode) the peak output voltage decreases by 0.3 V as:

$$V_{m(out)} = V_m - 0.3$$

2.2.2 Bridge Full-Wave Rectifier:

Four diodes connected to transform as shown in **Figure (2.7)**. Every two diode work together in one cycle of signal.

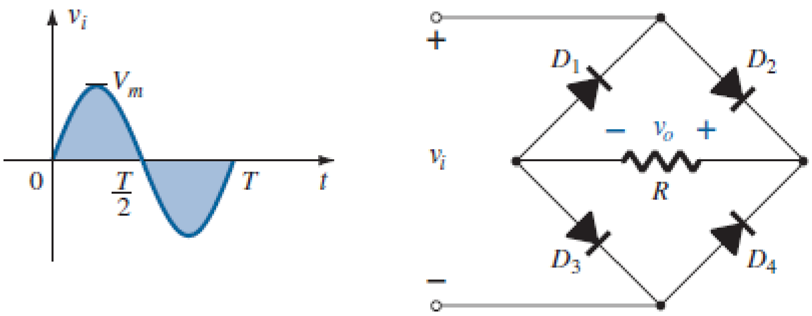
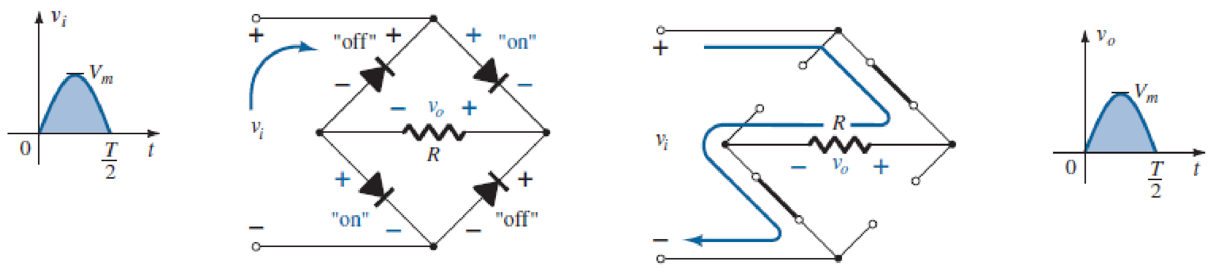
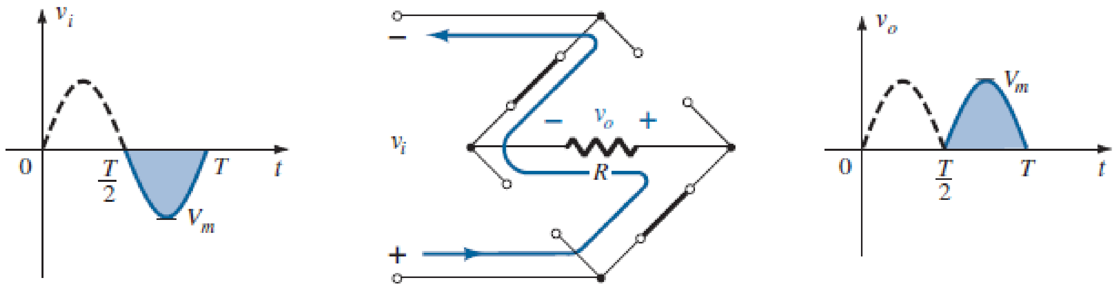


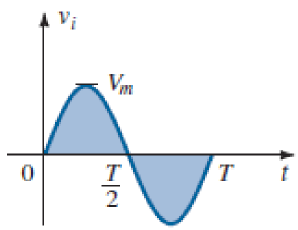
Figure (2.7): Full-wave bridge rectifier.

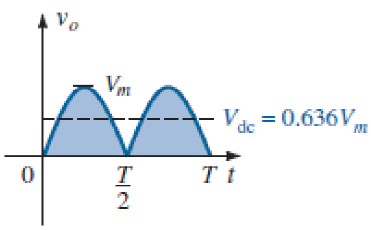
Positive Cycle
D2, D3 : F.B
D1, D4 : R.B



Negative Cycle
D2, D3 : R.B
D1, D4 : F.B







When the input cycle is positive, diodes D1 and D2 are forward biased. When the input cycle is negative, diodes D3 and D4 are the ones conducing. The output voltage becomes:

$$\boldsymbol{V_{m(out)} = V_m - 1.4}$$

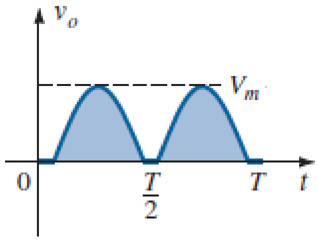
Example 3: Prove for FWR:

1. $\boldsymbol{V_{dc} = \frac{2\,V_m}{\pi} = 0.363\,V_m}$
2. $\boldsymbol{V_{rms} = \frac{V_m}{\sqrt{2}}}$

Solution:

1. $V_{dc} = \frac{1}{T}\int_0^T V_m\, sin\omega t\, dt \qquad where\ T = 2\pi\ \&\ \omega = \frac{2\pi}{T} = 1$

$$V_{dc} = \frac{1}{2\pi}\left(\int_0^{\pi} V_m\, sint\, dt + \int_{\pi}^{2\pi} V_m\, sint\, dt\right)$$



$$V_{dc} = \frac{2\,V_m}{2\pi}\int_0^{\pi} sint\, dt = \frac{2\,V_m}{2\pi}\left(-cost|_0^{\pi}\right)$$

$$V_{dc} = \frac{-2\,V_m}{2\pi}(\cos\pi - \cos 0) = \frac{-2\,V_m}{2\pi}(-2)$$

$$\therefore V_{dc} = \frac{2\,V_m}{\pi} = 0.363\,V_m$$

2. $V_{rms} = \sqrt{\frac{1}{T}\int_0^T (V_m\, sin\omega t)^2\, dt} \qquad where\ T = 2\pi\ \&\ \omega = \frac{2\pi}{T} = 1$

$$V_{rms} = \sqrt{\frac{1}{2\pi}\left(\int_0^{\pi} (V_m\, sint)^2\, dt + \int_{\pi}^{2\pi} (V_m\, sint\, dt)^2\, dt\right)}$$

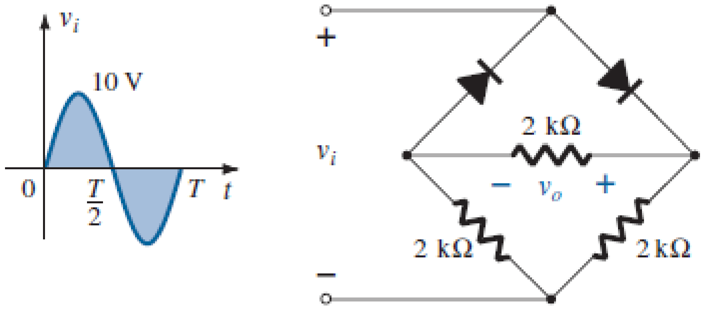
$$V_{rms} = \sqrt{\frac{2\,{V_m}^2}{2\pi}\int_0^{\pi} sin^2 t\, dt} \qquad where\ sin^2 t = \frac{1}{2}(1 - cos2t)$$

$$V_{rms} = \sqrt{\frac{V_m{}^2}{\pi}\frac{1}{2}\int_0^{\pi}(1-cos2t)\ \ dt} = \sqrt{\frac{V_m{}^2}{2\pi}\ t - \frac{sin2t}{2}\Big|_0^{\pi}}$$

$$V_{rms} = \sqrt{\frac{V_m{}^2}{2\pi}\left[(\pi-0)-\frac{1}{2}(sin2\pi - sin0)\right]} = \sqrt{\frac{V_m{}^2}{2\pi}\ (\pi)}$$

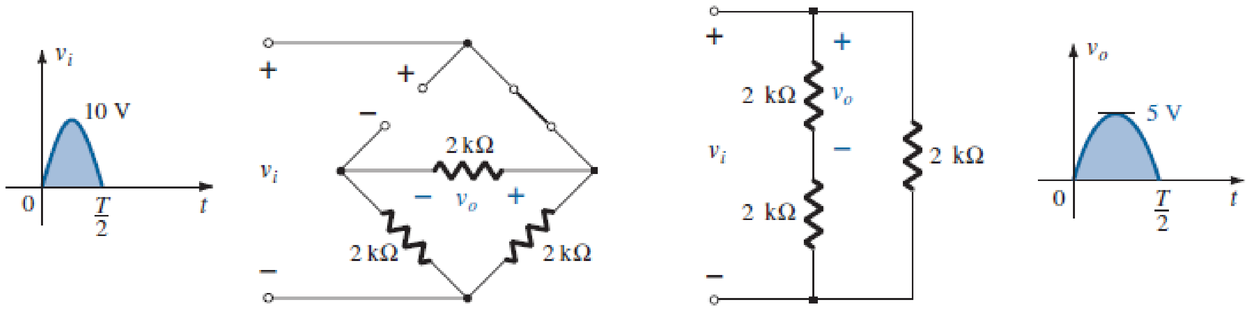
$$\therefore V_{rms} = \frac{V_m}{\sqrt{2}}$$

Example 4: For Full-wave rectifier in the network of Figure below: Determine the output waveform, and calculate the output DC level.



Solution:

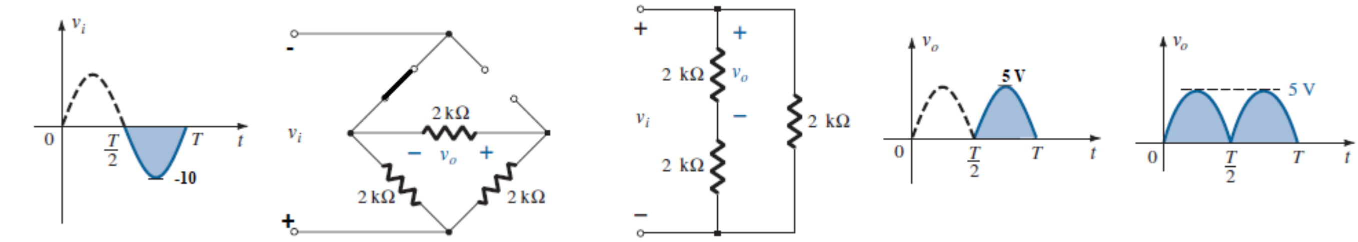
The network will appear as shown in Figure below for the positive region of the input voltage:



$$V_o = V_{in} \times \frac{2K}{2K+2K} = \frac{V_{in}}{2}$$

$$OR\ \ V_{o(max)} = \frac{V_{in(max)}}{2} = \frac{10\ v}{2} = 5\ v$$

For the negative part of the input voltage, the network will be appearing as shown in Figure below:



The effect of removing two diodes from the bridge configuration was therefore to reduce the available dc level to the following:

$$V_{dc} = \frac{2\,V_m}{\pi} = 0.363\,V_m = 0.636 \times 5v = 3.18\,v$$