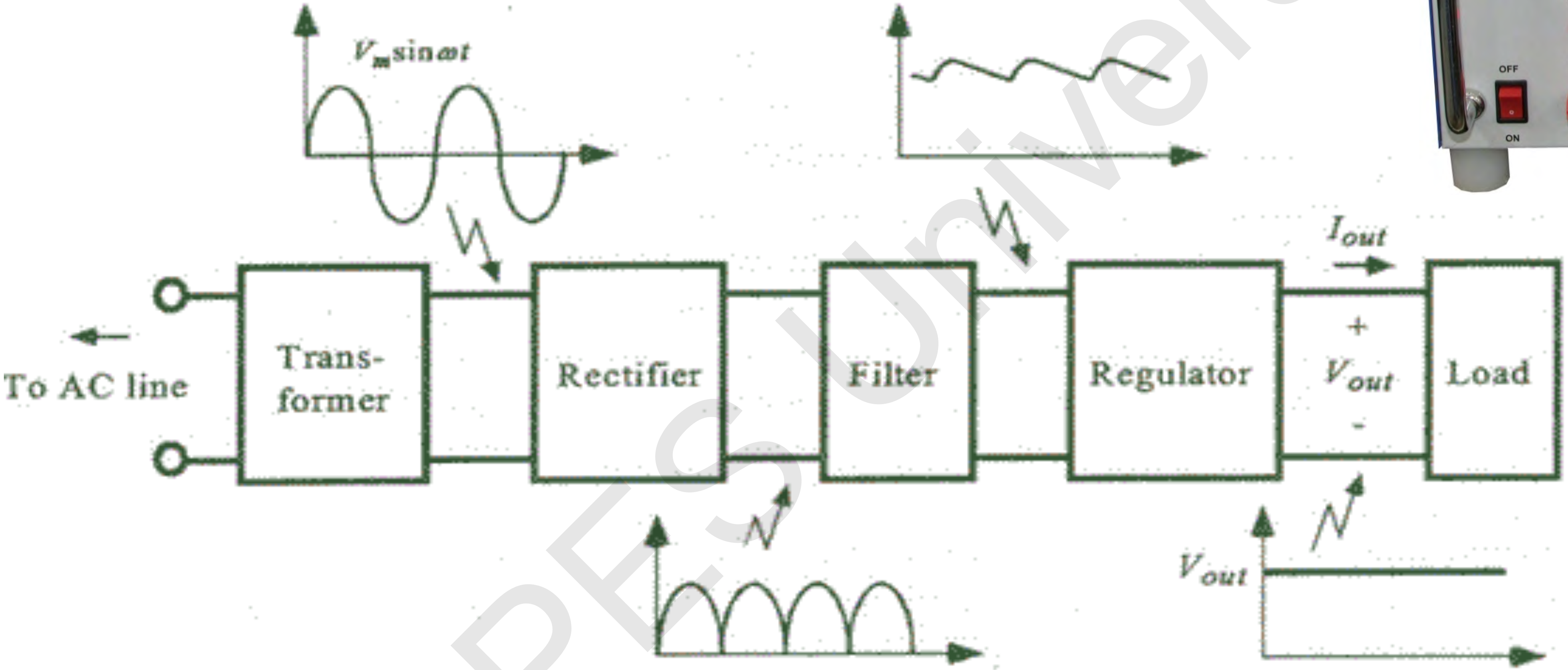
UNIT – 2

Unit Outcome

At the end of this unit, student will be able to

- Prepare a DC power supply
- implement different rectifier circuits, filter circuits.
- Understand different types of Zener diode voltage regulators and illustrate its working

Block Diagram of Regulated Power Supply



Regulated Power Supply contd.

Regulated power supply converts an alternating current signal to a constant signal
It consists of

- **Transformer** : The output sinusoid voltage is either step-up or step-down from the input sinusoid voltage value
- **Rectifier** : Converts an alternating current into a direct one by allowing a current to flow through it in one direction only.
- **Filter** : Removes the AC ripples from the DC signal obtained from the rectifier
- **Regulator** : Converts DC voltage into a lower constant voltage

Rectifiers

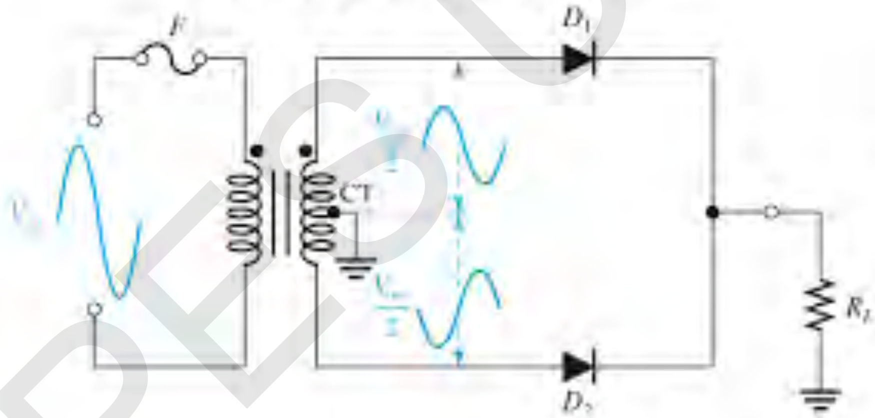
Rectifier

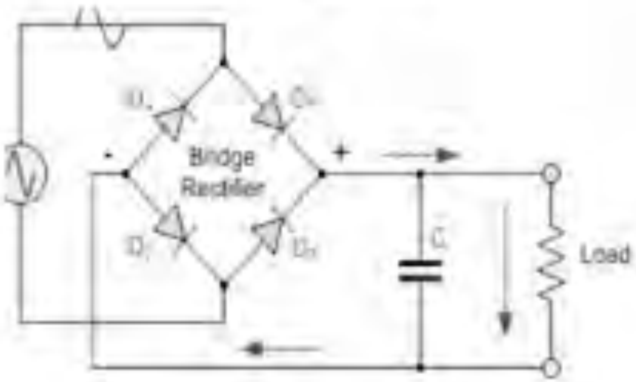
Half wave rectifier

Full wave rectifier

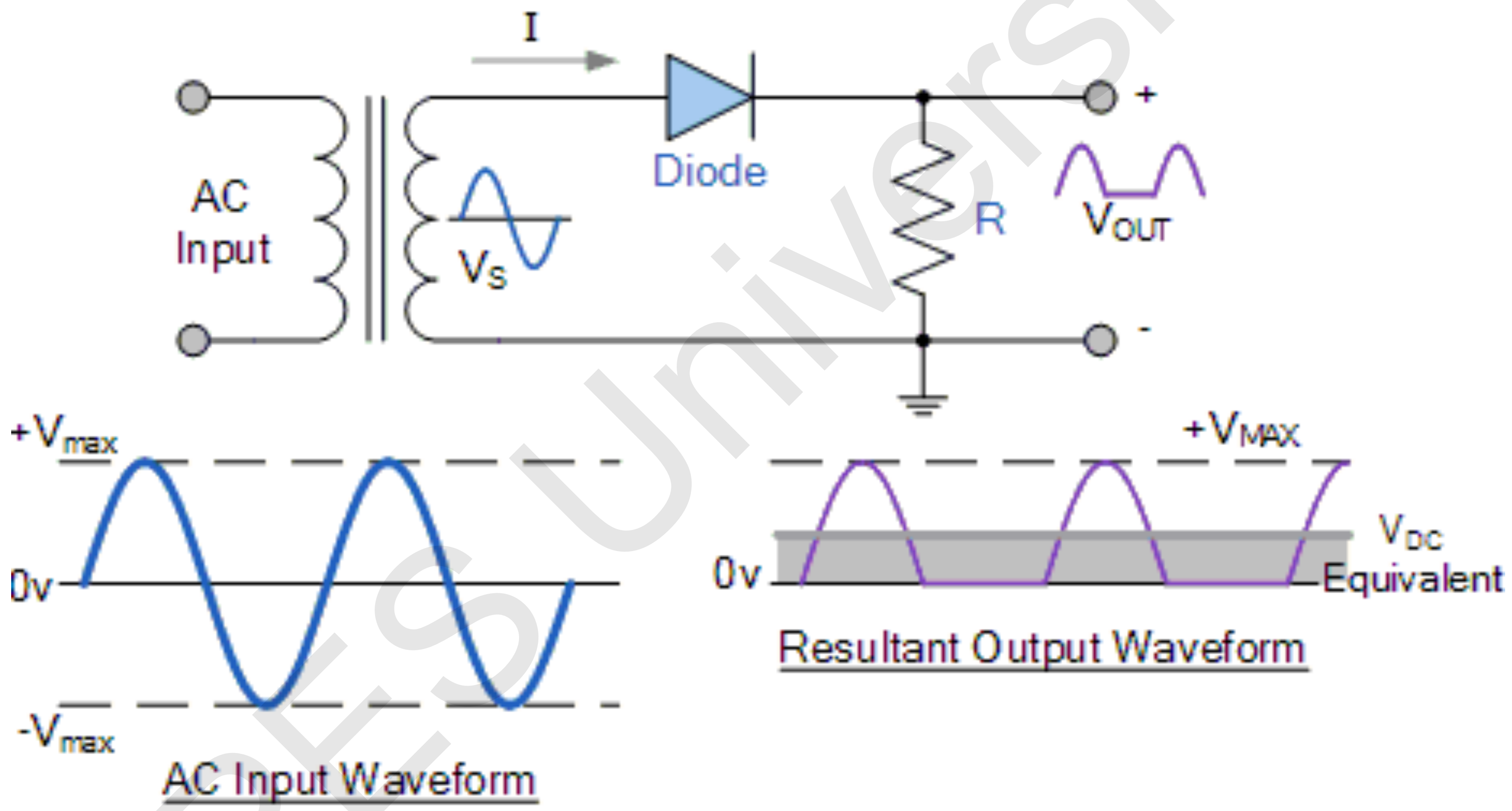
Center Tapped Full Wave Rectifier

Bridge Rectifier

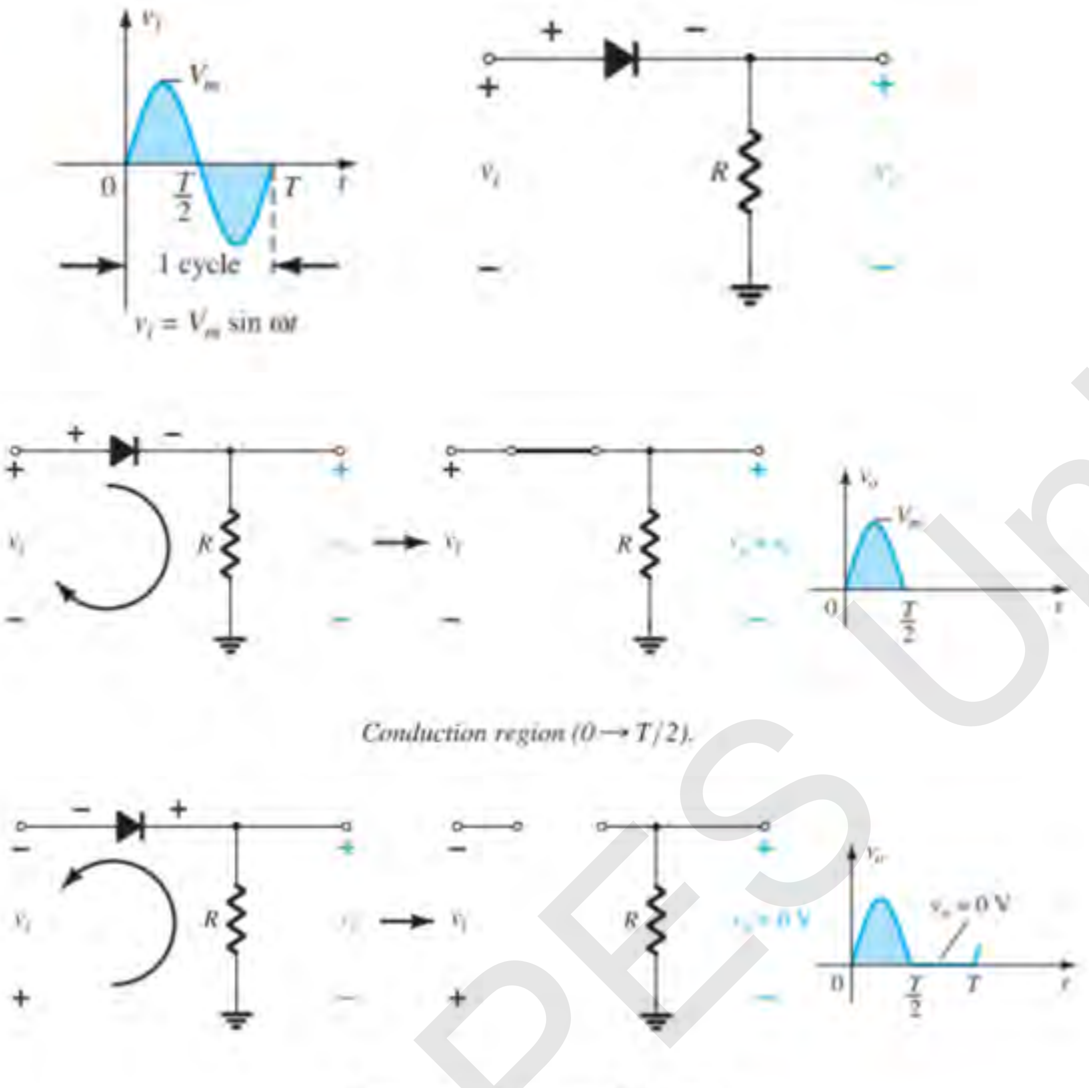




Half Wave Rectifier

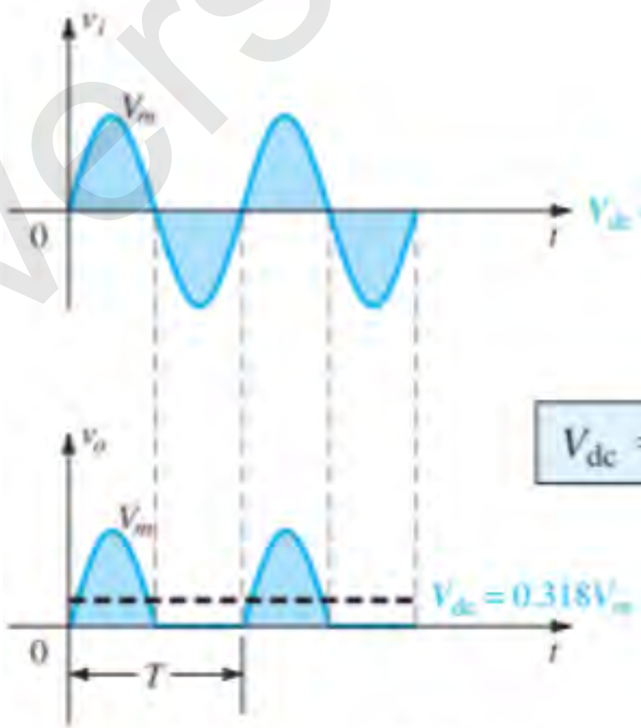


Half Wave Rectifier contd.



Conduction region $(0 \rightarrow T/2)$.

Nonconduction region $(T/2 \rightarrow T)$.



$$\boxed{V_{dc} = 0.318\ V_m} \quad \text{half-wave}$$

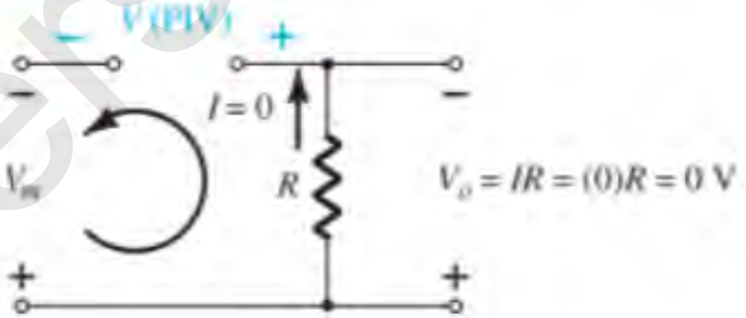
Half-wave rectified signal.

Half Wave Rectifier contd.

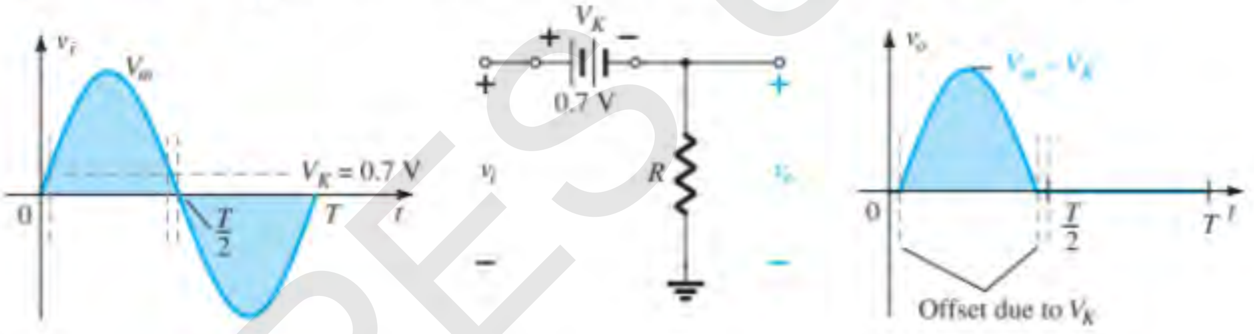
$$V_{rms} = \frac{V_{peak}}{2}$$

$$V_{dc} = \frac{V_{peak}}{\pi}$$

$\boxed{\text{PIV rating} \geq V_m}$ half-wave rectifier

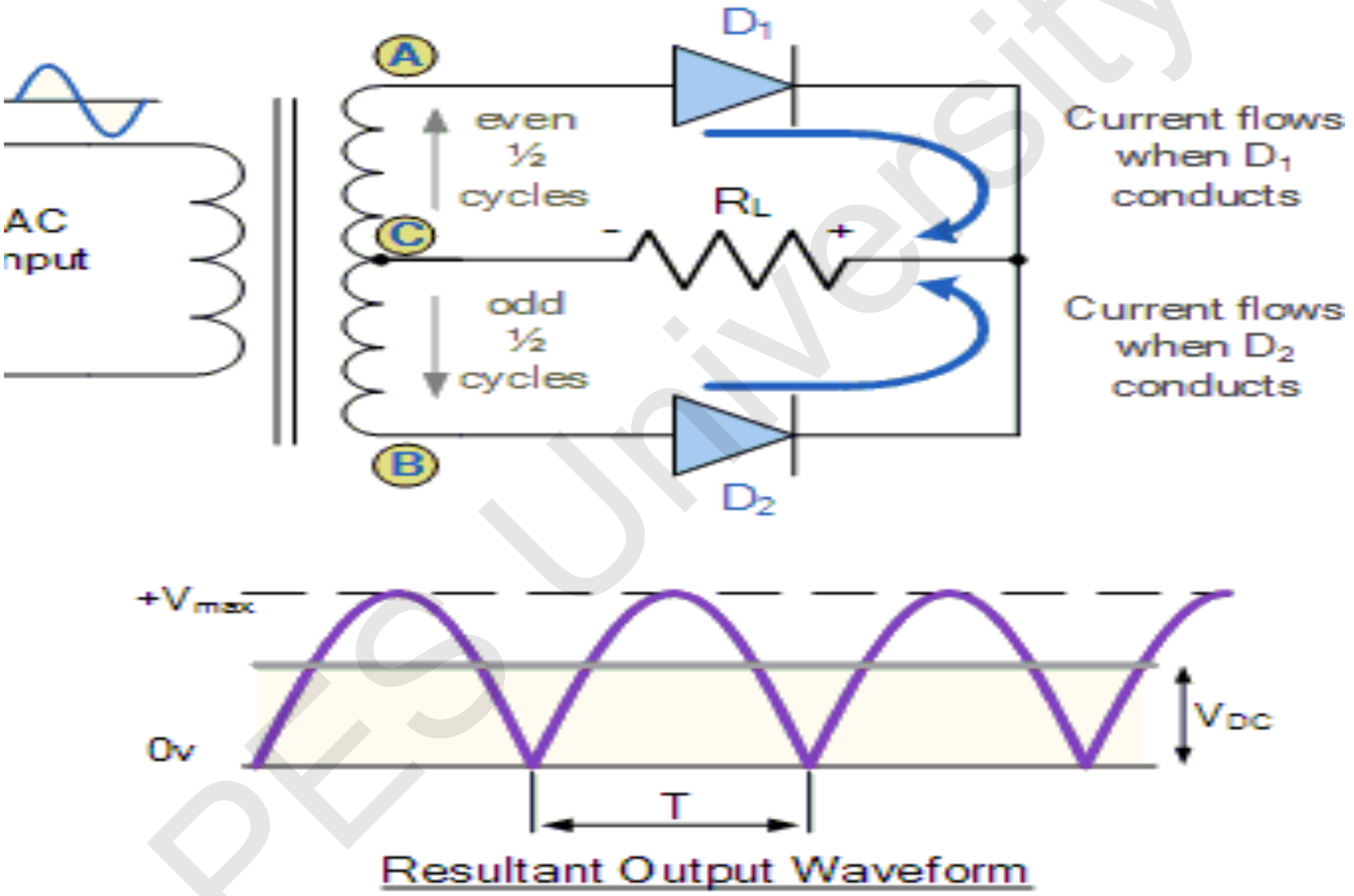


- Effect of V_K on half-wave rectified signal.

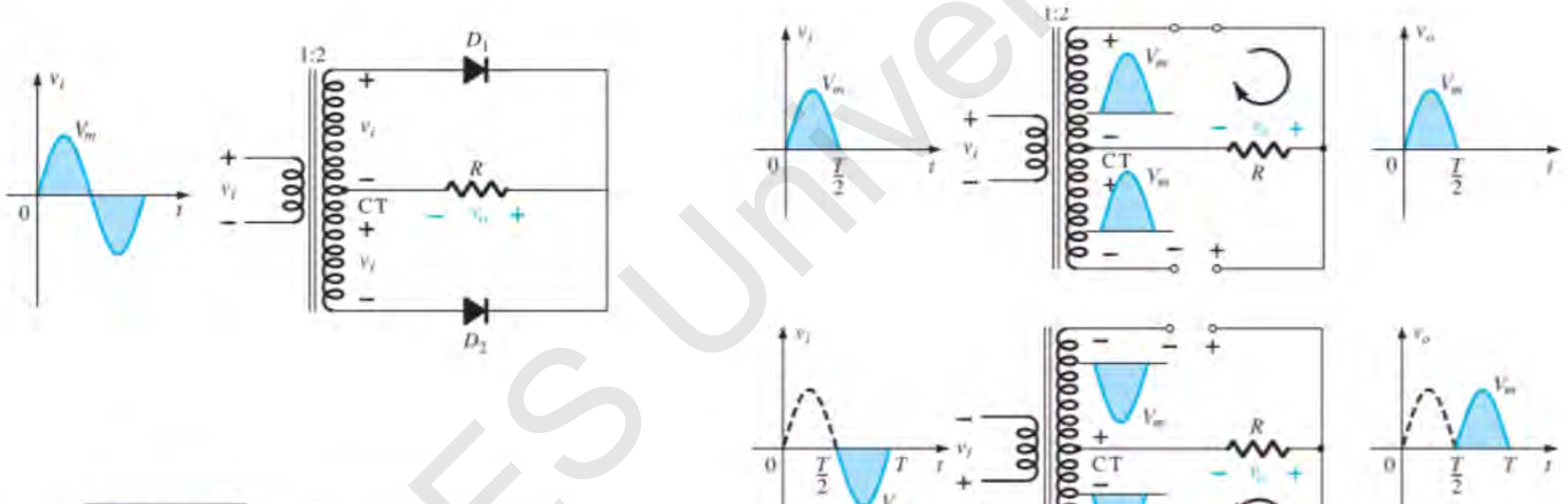


$$\boxed{V_{dc} \cong 0.318(V_m - V_K)}$$

Center Tapped Full Wave Rectifier



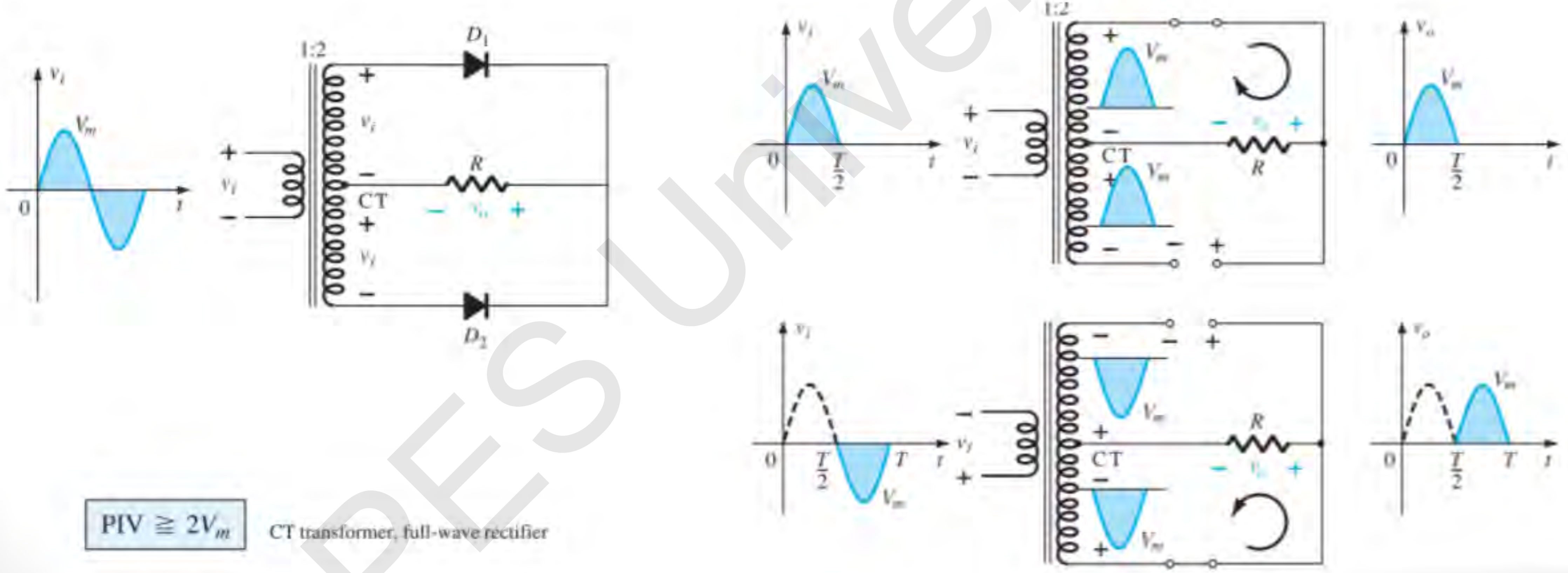
Center Tapped Full Wave Rectifier contd.



PIV $\geqq 2V_m$

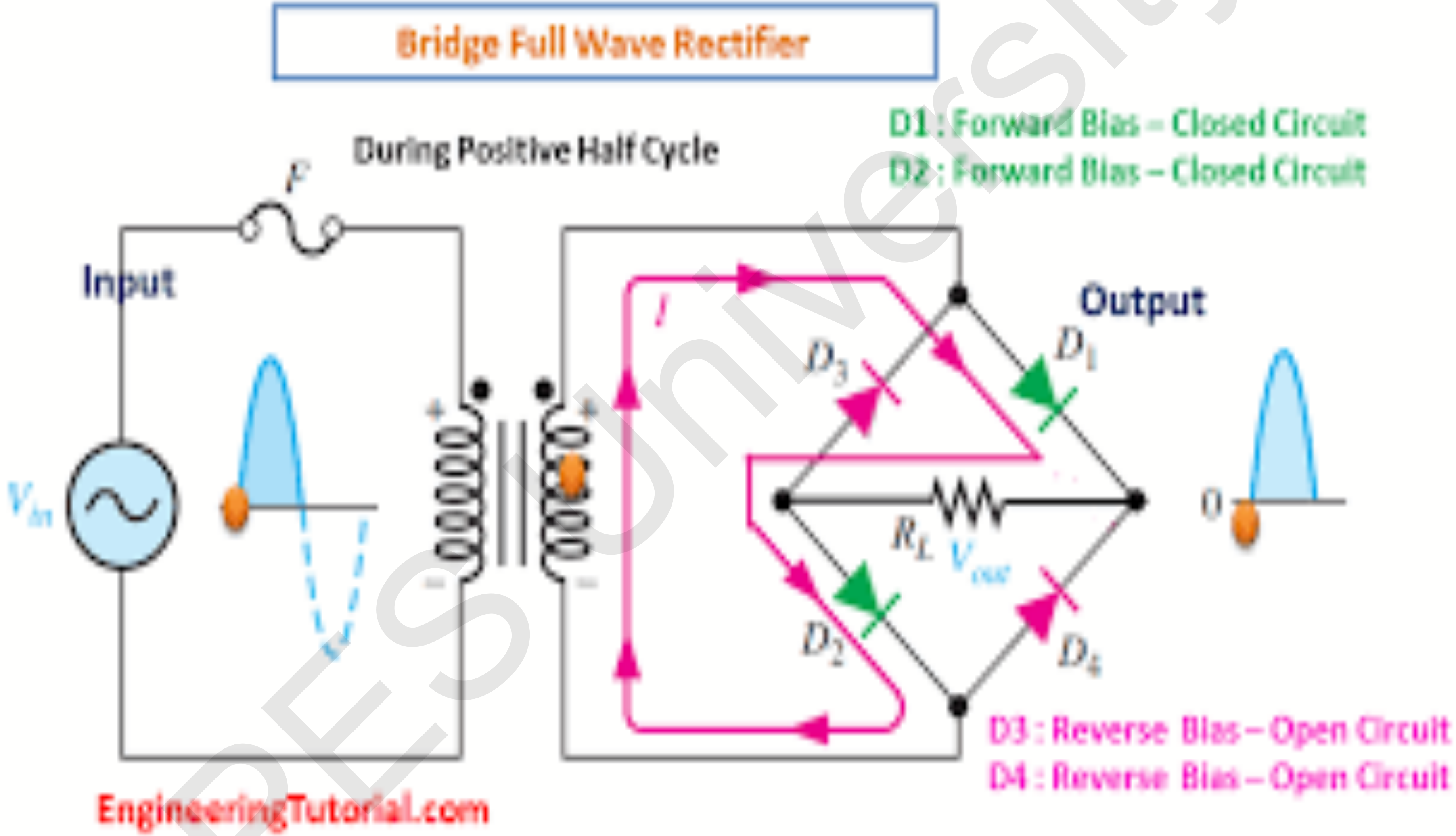
CT transformer, full-wave rectifier

Center Tapped Full Wave Rectifier contd.



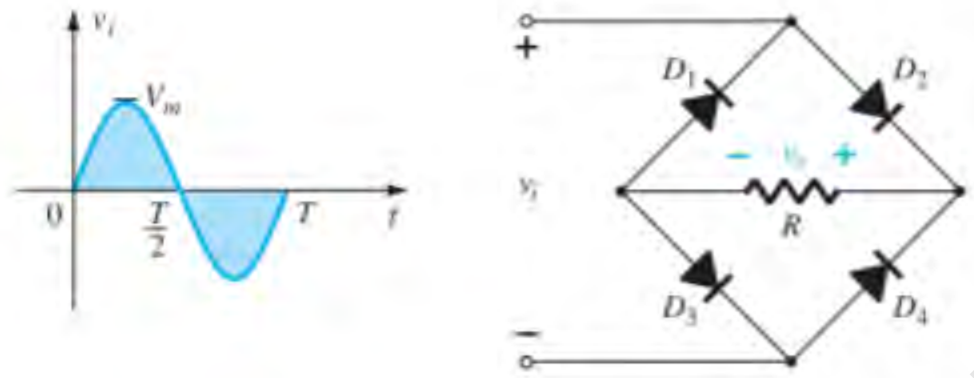
CT transformer, full-wave rectifier

Bridge-Full Wave Rectifier

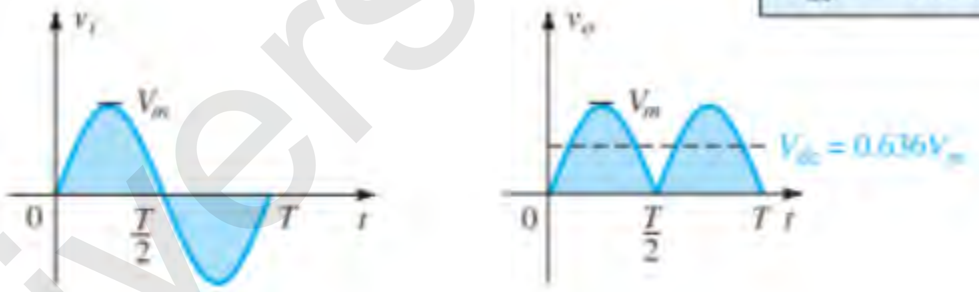


Bridge Full wave rectifier equations

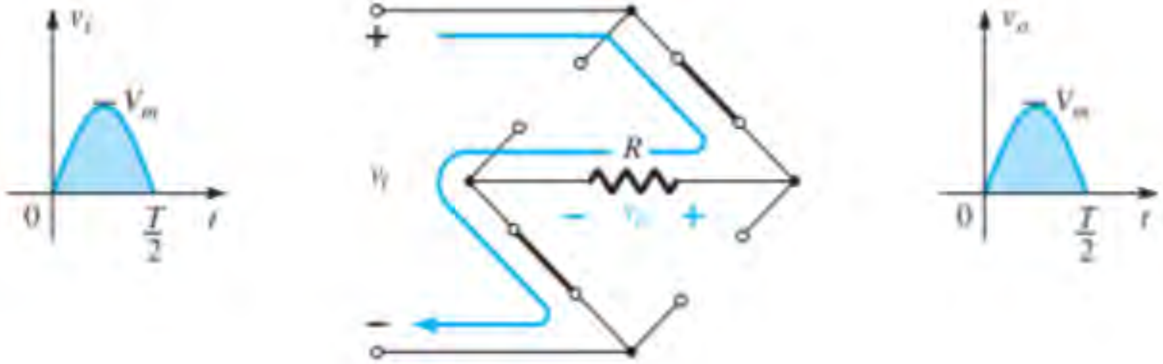
$$\boxed{V_{dc} = 0.636\, V_m} \quad \text{full-wave}$$



Full-wave bridge rectifier.

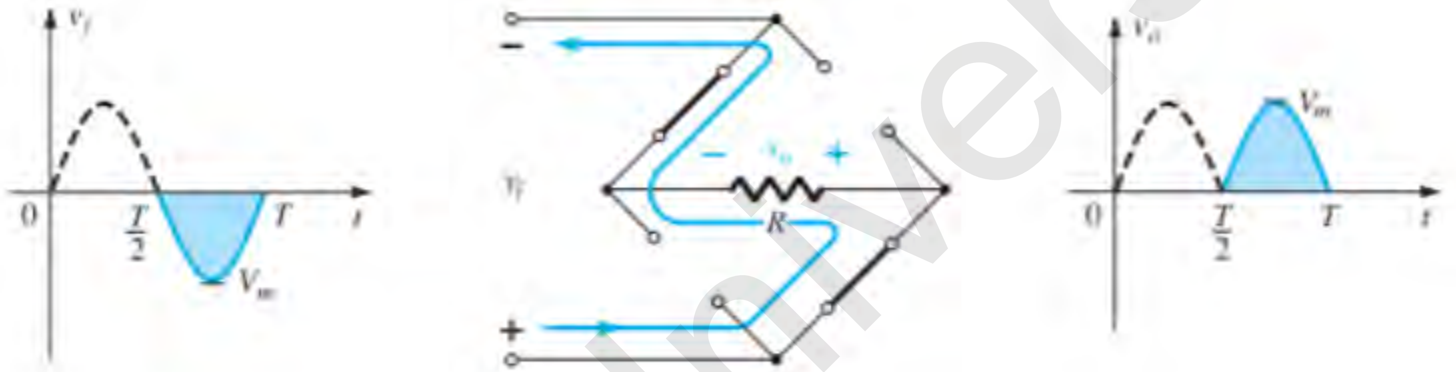


Input and output waveforms for a full-wave rectifier.

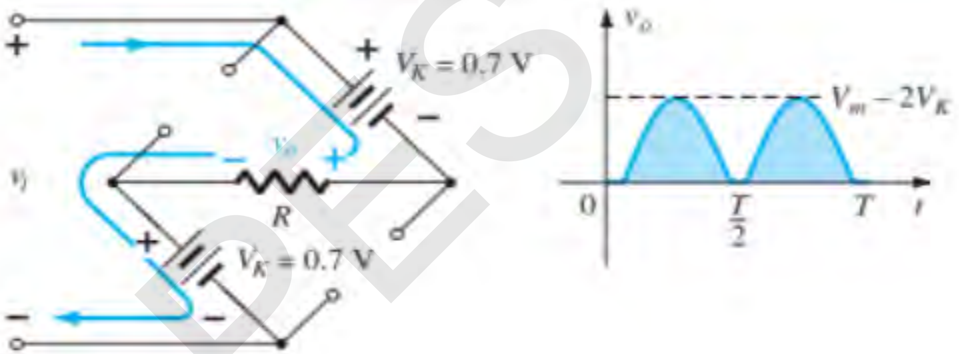


Conduction path for the positive region of v_i.

Bridge Full wave rectifier equations contd.



Conduction path for the negative region of v_i.



$$\boxed{V_{dc} \cong 0.636(V_m - 2V_K)}$$

$$\boxed{\text{PIV} \geq V_m}$$ full-wave bridge rectifier

PES UNIVERSITY

Ripple factor

$$\text{Ripple Factor}, \gamma = \frac{\text{RMS value of AC component present in Rectifier Output}}{\text{Average Value of Rectifier Output}}$$

$$\gamma = \frac{I'_{rms}}{I_{dc}} = \frac{V'_{rms}}{V_{dc}}$$

where I'_{rms} and V'_{rms} are the rms value of alternating component of load current and voltage respectively.

Ripple factor contd.

$$I'_{rms} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

where I'_{rms} = rms value of AC Component

$$r = \frac{I'_{rms}}{I_{dc}} = \sqrt{\frac{(I_{rms}^2 - I_{dc}^2)}{I_{dc}}}$$

$$= \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

$\boxed{r = 1.21}$ **For HWR**

$\boxed{r = 0.48}$ **For FWR**

Peak Inverse Voltage (PIV)

•PIV rating of a diode is the maximum reverse bias Voltage that a diode can sustain without going into reverse breakdown.

For half wave rectifier : PIV = Vm

For full wave rectifier : PIV = 2Vm

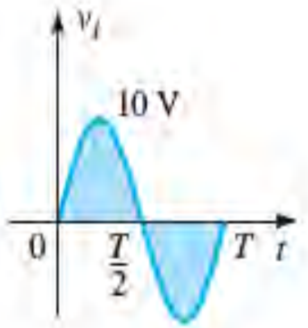
For bridge rectifier : PIV = Vm

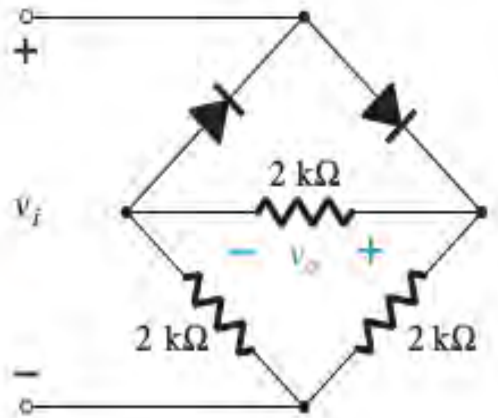
Comparison Table for HWR & FWR

Measure	HWR Ideal	HWR Practical	CT-Ideal	CT-Practical	Bridge- Ideal	Bridge-Practical
I_{dc}	$\frac{I_m}{\pi}$	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
V_{dc}	$\frac{V_m}{\pi}$	$\frac{V_m - V_k}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2(V_m - V_k)}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2(V_m - 2V_k)}{\pi}$
I_{rms}	$\frac{I_m}{2}$	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
V_{rms}	$\frac{V_m}{2}$	$\frac{V_m - V_k}{2}$	$\frac{V_m}{\sqrt{2}}$	$\frac{V_m - V_k}{\sqrt{2}}$	$\frac{V_m}{\sqrt{2}}$	$\frac{V_m - 2V_k}{\sqrt{2}}$
PIV	V_m	V_m	$2V_m$	$2V_m - V_k$	V_m	$V_m - V_k$

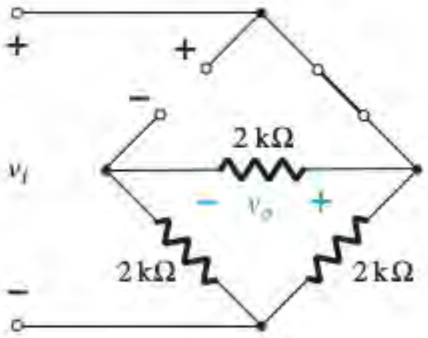
Solved example

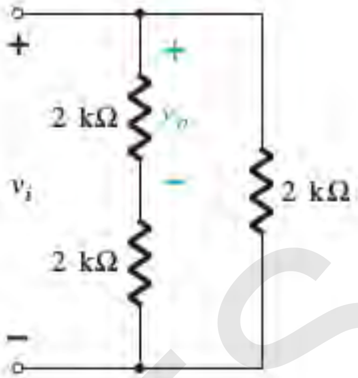
Determine the output waveform for the network and calculate the output dc level and the required PIV of each diode.

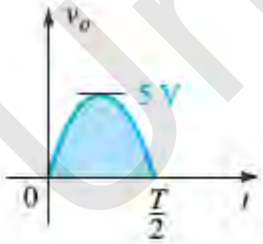




Solution:

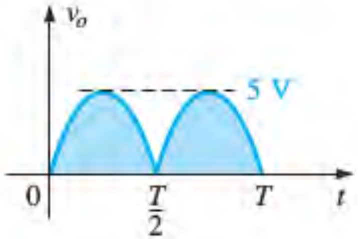




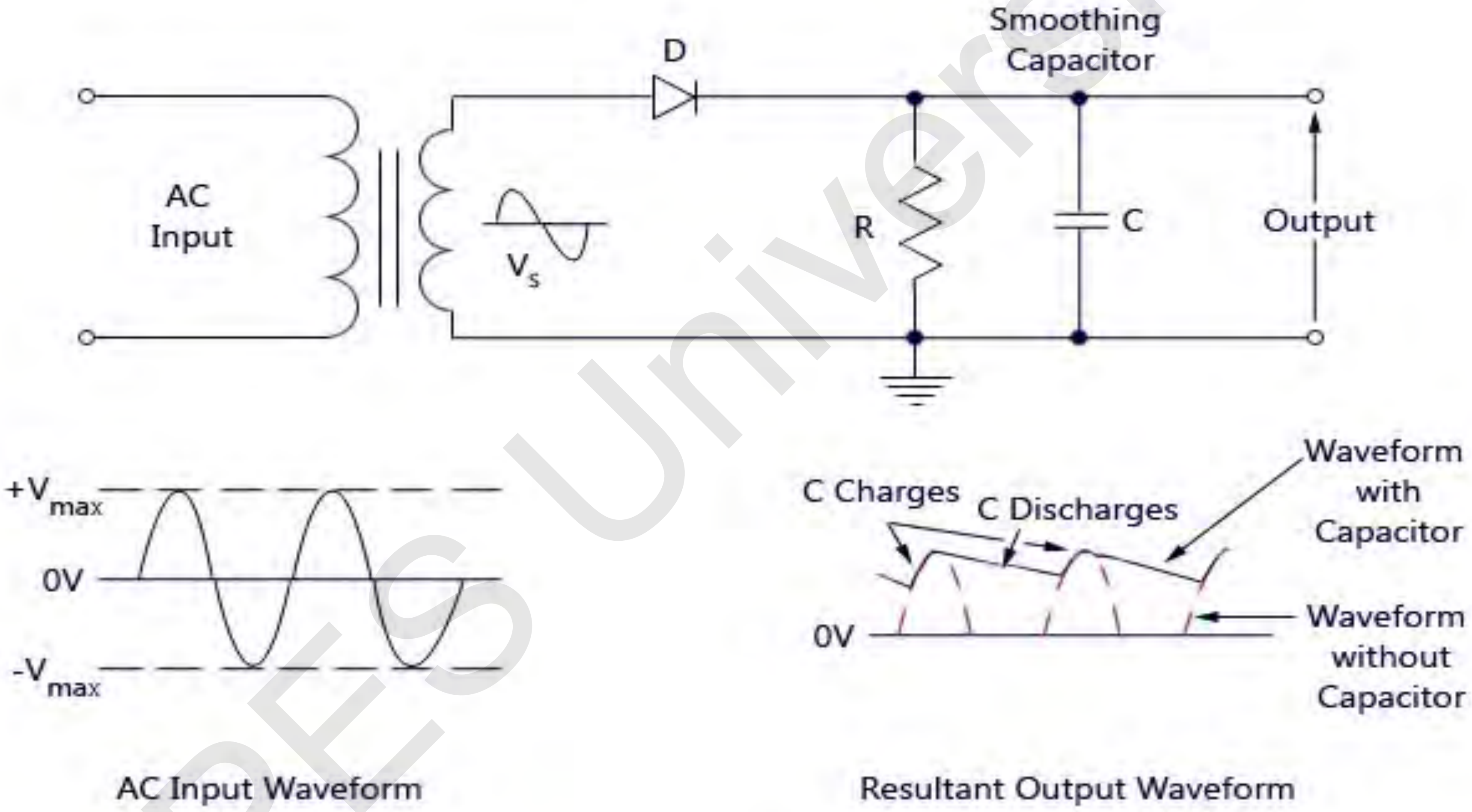


V o max = 12 V i max = 12 (10 V) = 5 V

$$V_{dc} = 0.636(5\text{ V}) = 3.18\text{ V}$$



HWR with capacitor filter



Ripple factor for HWR with capacitor filter

We know that $T_1 + T_2 = T/2$ complete time period of the rectifier and we have assumed the time period $T_2 \approx T$.

Replacing this in the above equations, we have

$$C(V_r)_{p-p} = I_{dc}T_2$$
$$(V_r)_{p-p} = \frac{I_{dc}T_2}{C} = \frac{I_{dc}T}{C} = \frac{I_{dc}}{fC} = \frac{V_{dc}}{fCR_L}$$

We can write $(V_r)_{p-p}$ as

$$\boxed{(V_r)_{p-p} = \frac{V_{dc}}{fCR_L}}$$

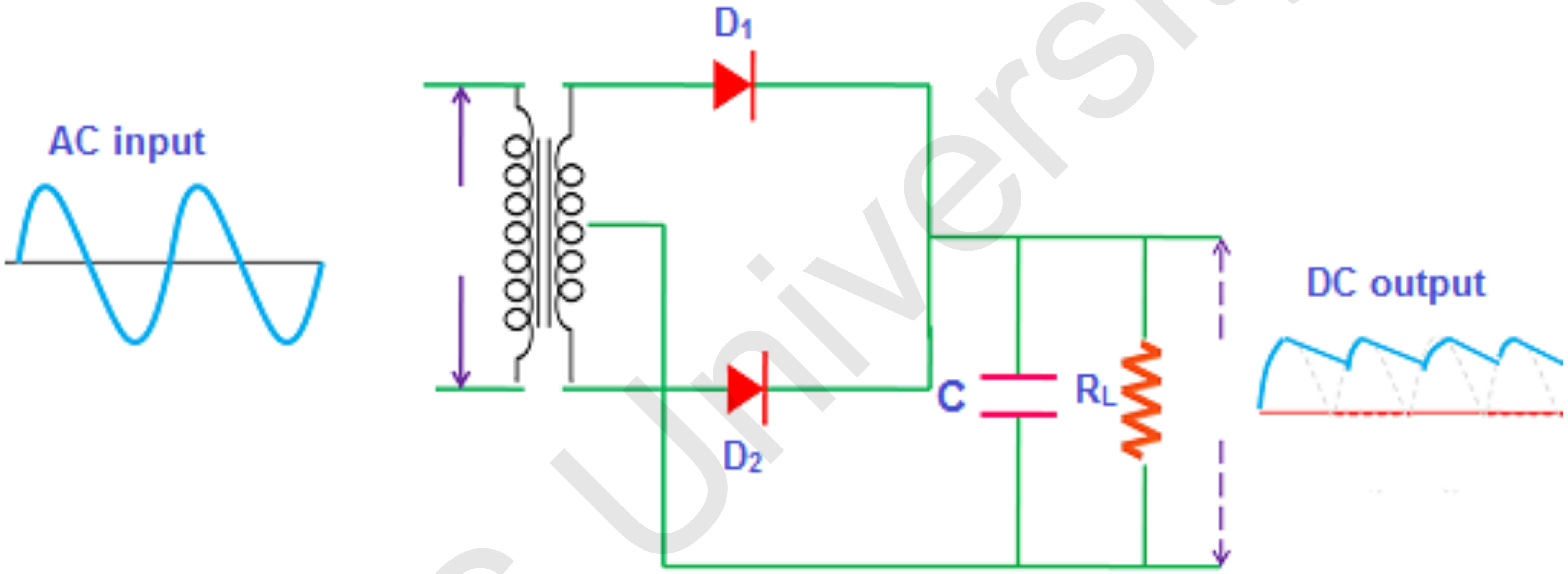
Using equation 19 and 23 we can write

$$(V_r)_{rms} = \frac{(V_r)_{p-p}}{2\sqrt{3}} = \frac{V_{dc}}{fCR_L 2\sqrt{3}}$$

Now, we will use the definition of ripple factor and write

$$\boxed{r = \frac{(V_r)_{rms}}{V_{dc}} = \frac{1}{2\sqrt{3}fCR_L}}$$

FWR with capacitor filter



Full wave rectifier with capacitor filter

Ripple factor for FWR with capacitor filter

The charge that the capacitor loses during T_2 can be given by

$$Q = C(V_r)_{p-p}$$

In the interval T2 we can write that the charge due to the current is given by

$$Q = \int_0^{T_2} id(t)$$

And the average value over 1 cycle is I_{dc} and that is given by

$$\frac{1}{T_2}\int_0^{T_2} id(t) = I_{dc}$$

$$\int_0^{T_2} id(t) = I_{dc}T_2$$

Using equation of the charge the capacitor loses and the above equation we can write

$$\begin{aligned} C(V_r)_{p-p} &= I_{dc}T_2 \\ (V_r)_{p-p} &= \frac{I_{dc}T_2}{C} \\ &= \frac{I_{dc}T}{2C} \\ &= \frac{I_{dc}}{2fC} \\ &= \frac{V_{dc}}{2fCR_L} \end{aligned}$$

Thus we can write $(V_r)_{p-p}$ as

$$\boxed{(V_r)_{p-p} = \frac{V_{dc}}{2fCR_L}}$$

Using equation 19 and 20 we can write

$$(V_r)_{rms} = \frac{(V_r)_{p-p}}{2\sqrt{3}} = \frac{V_{dc}}{2fCR_L 2\sqrt{3}}$$

Now, we will use the definition of ripple factor and write

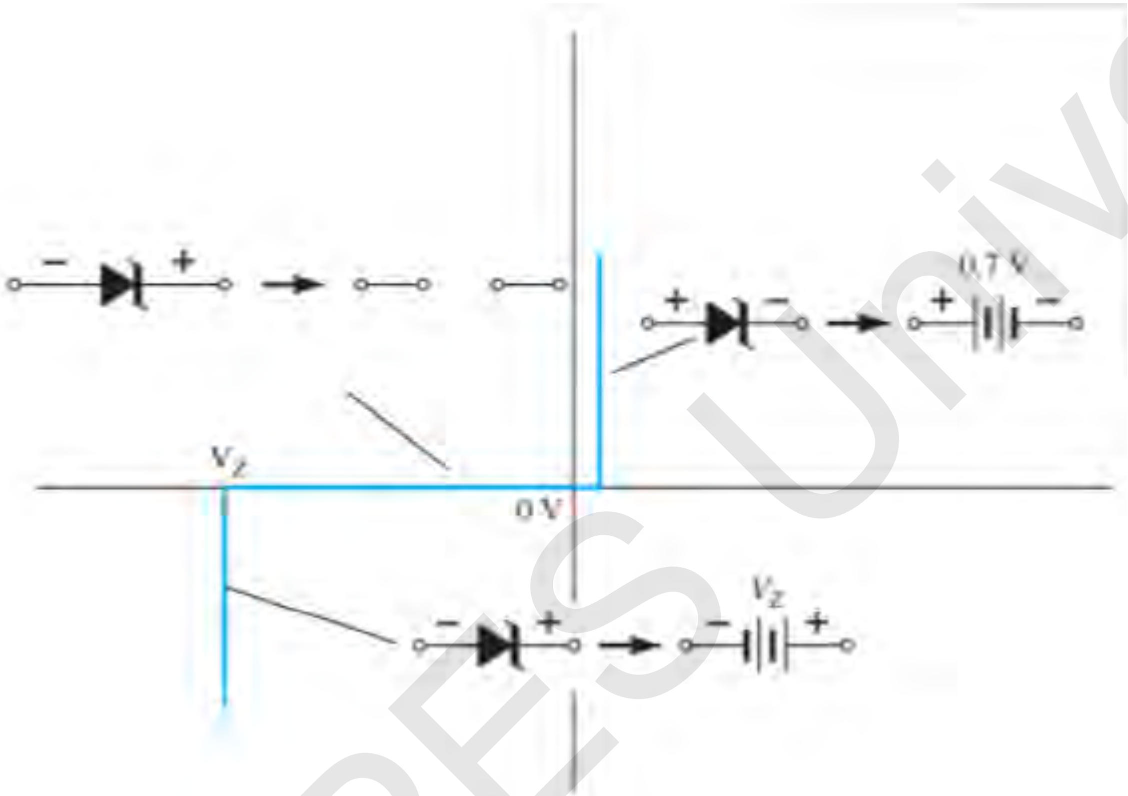
$$\boxed{r = \frac{(V_r)_{rms}}{V_{dc}} = \frac{1}{4\sqrt{3}fCR_L}}$$

DC voltage can be computed by the formula

$$\boxed{V_d = V_m - \frac{(V_r)_{p-p}}{2}}$$

Zener diode

Zener Diode characteristics is as shown in the figure :



Zener Diode as Voltage Regulator

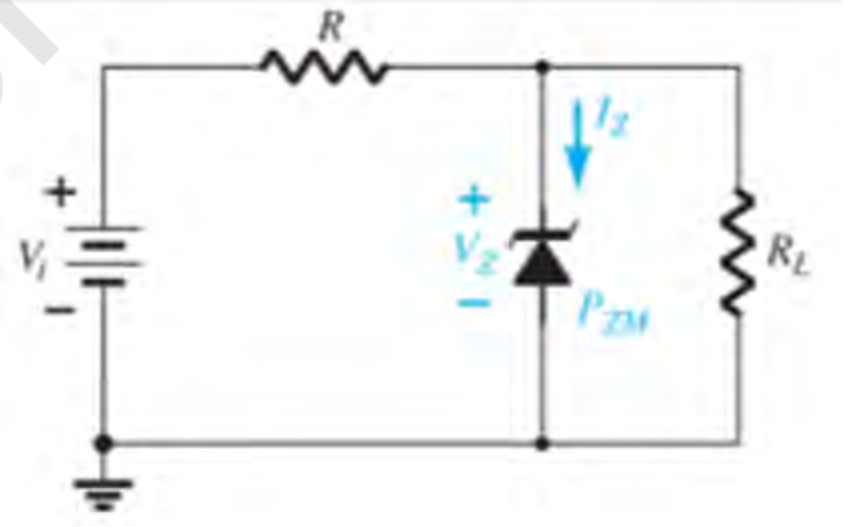
Four type of regulators :

1.Fixed Vi and fixed R

2.Fixed Vi and Variable R

3.Variable Vi and Fixed R

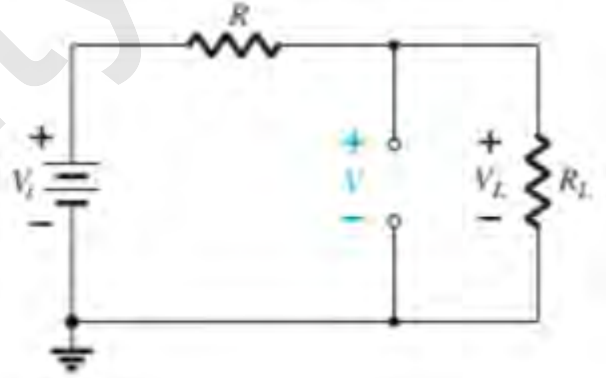
4.Variable Vi and Variable R



Fixed Vi and fixed R Voltage Regulator

1. Determine the state of the Zener diode by removing it from the network and calculating the voltage across the resulting open circuit.

$$\boxed{V = V_L = \frac{R_L V_i}{R + R_L}}$$



Determining the state of the Zener diode.

2. Substitute the appropriate equivalent circuit and solve for the desired unknowns.

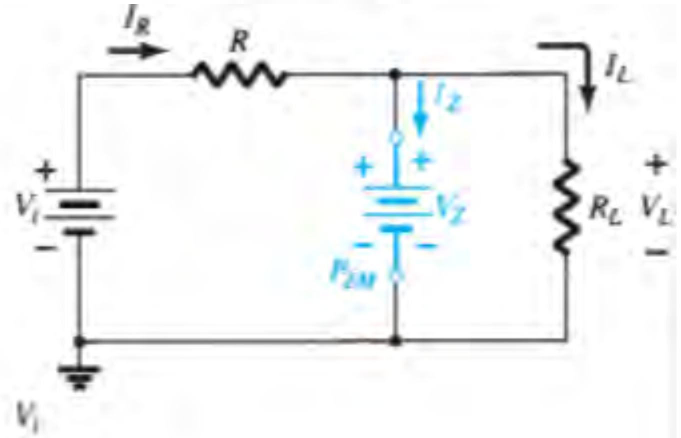
$$\boxed{V_L = V_Z}$$

$$I_R = I_Z + I_L$$

$$\boxed{I_Z = I_R - I_L}$$

$$I_L = \frac{V_L}{R_L} \qquad I_R = \frac{V_R}{R} = \frac{V_i - V_L}{R}$$

$$\boxed{P_Z = V_Z I_Z}$$



Substituting the Zener equivalent for the "on" situation.

Fixed Vi and Variable RL Voltage Regulator

$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$\boxed{R_{L_{\min}} = \frac{R V_Z}{V_i - V_Z}}$$

$$\boxed{I_{L_{\max}} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L_{\min}}}}$$

$$\boxed{V_R = V_i - V_Z}$$

$$\boxed{I_R = \frac{V_R}{R}}$$

$$\boxed{I_Z = I_R - I_L}$$

$$\boxed{I_{L_{\min}} = I_R - I_{ZM}}$$

$$\boxed{R_{L_{\max}} = \frac{V_Z}{I_{L_{\min}}}}$$

Solved example

Find the range of load resistance and the maximum power rating for the circuit?

$$R_{L_{min}} = \frac{RV_Z}{V_i - V_Z} = \frac{(1\ k\Omega)(10\ V)}{50\ V - 10\ V} = \frac{10\ k\Omega}{40} = \mathbf{250\ \Omega}$$

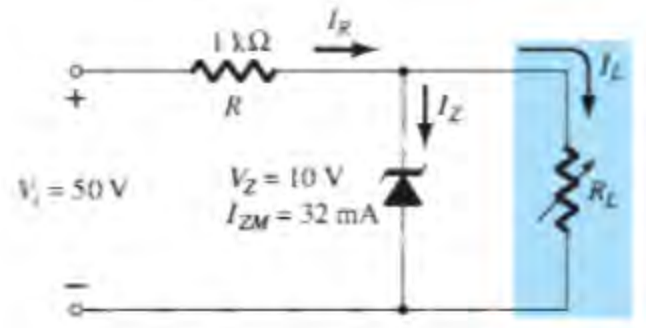
$$V_R = V_i - V_Z = 50\ V - 10\ V = \mathbf{40\ V}$$

$$I_R = \frac{V_R}{R} = \frac{40\ V}{1\ k\Omega} = \mathbf{40\ mA}$$

$$I_{L_{min}} = I_R - I_{ZM} = 40\ mA - 32\ mA = \mathbf{8\ mA}$$

$$R_{L_{max}} = \frac{V_Z}{I_{L_{min}}} = \frac{10\ V}{8\ mA} = \mathbf{1.25\ k\Omega}$$

$$P_{max} = V_Z I_{ZM} = (10\ V)(32\ mA) = \mathbf{320\ mW}$$



Variable Vi and Fixed RL Voltage Regulator

$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$\boxed{V_{i_{min}} = \frac{(R_L + R)V_Z}{R_L}}$$

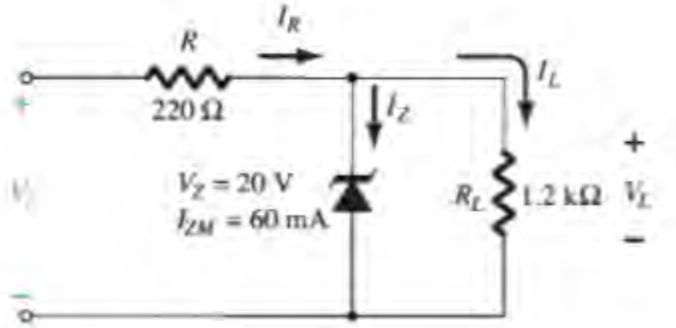
$$\boxed{I_{R_{max}} = I_{ZM} + I_L}$$

$$V_{i_{max}} = V_{R_{max}} + V_Z$$

$$\boxed{V_{i_{max}} = I_{R_{max}} R + V_Z}$$

Solved example

Determine the range of values of Vi that will maintain Zener diode in the "on" state?

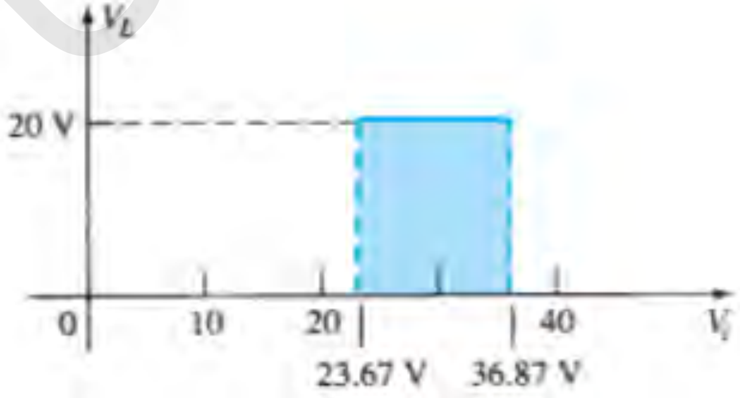


$$V_{i_{min}} = \frac{(R_L + R)V_Z}{R_L} = \frac{(1200\ \Omega + 220\ \Omega)(20\ \text{V})}{1200\ \Omega} = \mathbf{23.67\ V}$$

$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{20\ \text{V}}{1.2\ \text{k}\Omega} = 16.67\ \text{mA}$$

$$I_{R_{max}} = I_{ZM} + I_L = 60\ \text{mA} + 16.67\ \text{mA}$$
$$= 76.67\ \text{mA}$$

$$V_{i_{max}} = I_{R_{max}} R + V_Z$$
$$= (76.67\ \text{mA})(0.22\ \text{k}\Omega) + 20\ \text{V}$$
$$= 16.87\ \text{V} + 20\ \text{V}$$
$$= \mathbf{36.87\ V}$$



Variable V_i and Variable R_L Voltage Regulator

Vi= Small value (Vimin)

Rs= Large value(Rsmax)

RL = small value(Rlmin & ILmax)

$$R_{Smax} = \frac{V_{Imin} - V_Z}{I_{Zmin} + I_{Lmax}}$$

Vi= Large value (Vimax)

Rs= Small value(Rsmin)

RL = Large value(Rlmax & ILmin)

$$R_{Smin} = \frac{V_{Imax} - V_Z}{I_{Zmax} + I_{Lmin}}$$

Practical Applications

- Rectification – Battery chargers
- Protective Configurations
- Polarity Insurance
- Controlled Battery Powered Backup
- Polarity Detector
- AC Regulator & Square wave Generator.

Practice problem – 1

1. A Bridge rectifier with ideal diodes has an ac source of RMS value 220 V, 50Hz connected to the primary of transformer. If the load resistance is 200Ω, find the dc output volatge, dc output current and output frequency.

2. In a two diode FWR using Si diodes, the RMS voltage across each half of the transformer secondary is 100V. The load resistance is 975 Ω and each diode has a forward resistance of 25Ω Find (i) Average current (ii) Average output voltage (iii) PIV of diode.

Practice problem – 2

1. Design a zener regulator that maintains V_0 at 10V for input voltage variation of 20V±10% and load current variation of 30mA ±20%. Given I_{Zmin} =2mA and P_{Zmax} =0.5W

2. In a Zener diode regulator, the input DC is 10 V±20%. The output requirement is 5 V and 20 mA. Assume I_{Zmin} and I_{Zmax} as 5 mA and 80 mA , design the voltage regulator. Calculate the power rating of the Zener diode.

3. Design a voltage regulator that will maintain an output voltage of 20V across a 1 kΩ load with an input that vary between 30V and 50V.

4. Design a Zener diode regulator that maintains output voltage at 10V for an input voltage variation 20V±10% and a load current variation of 30mA±20% .Given Izmin=2mA and Pzmax=0.5W

Resources on rectifiers and filters

- https://www.slideshare.net/mumerlari/solved-problems-on-rectifiers