Rectifiers

Semiconductor Devices and Circuits

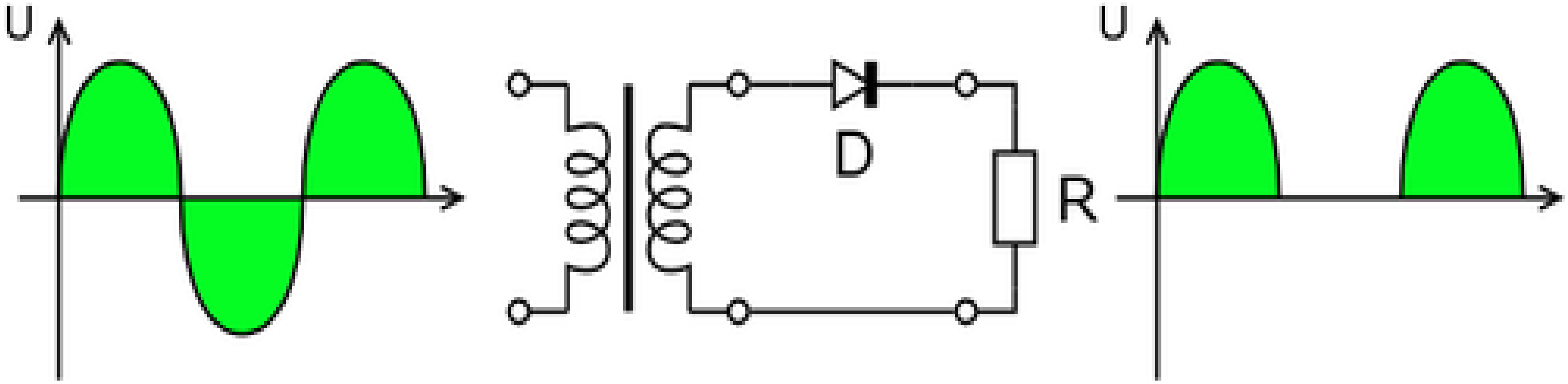
(ECE 181302)

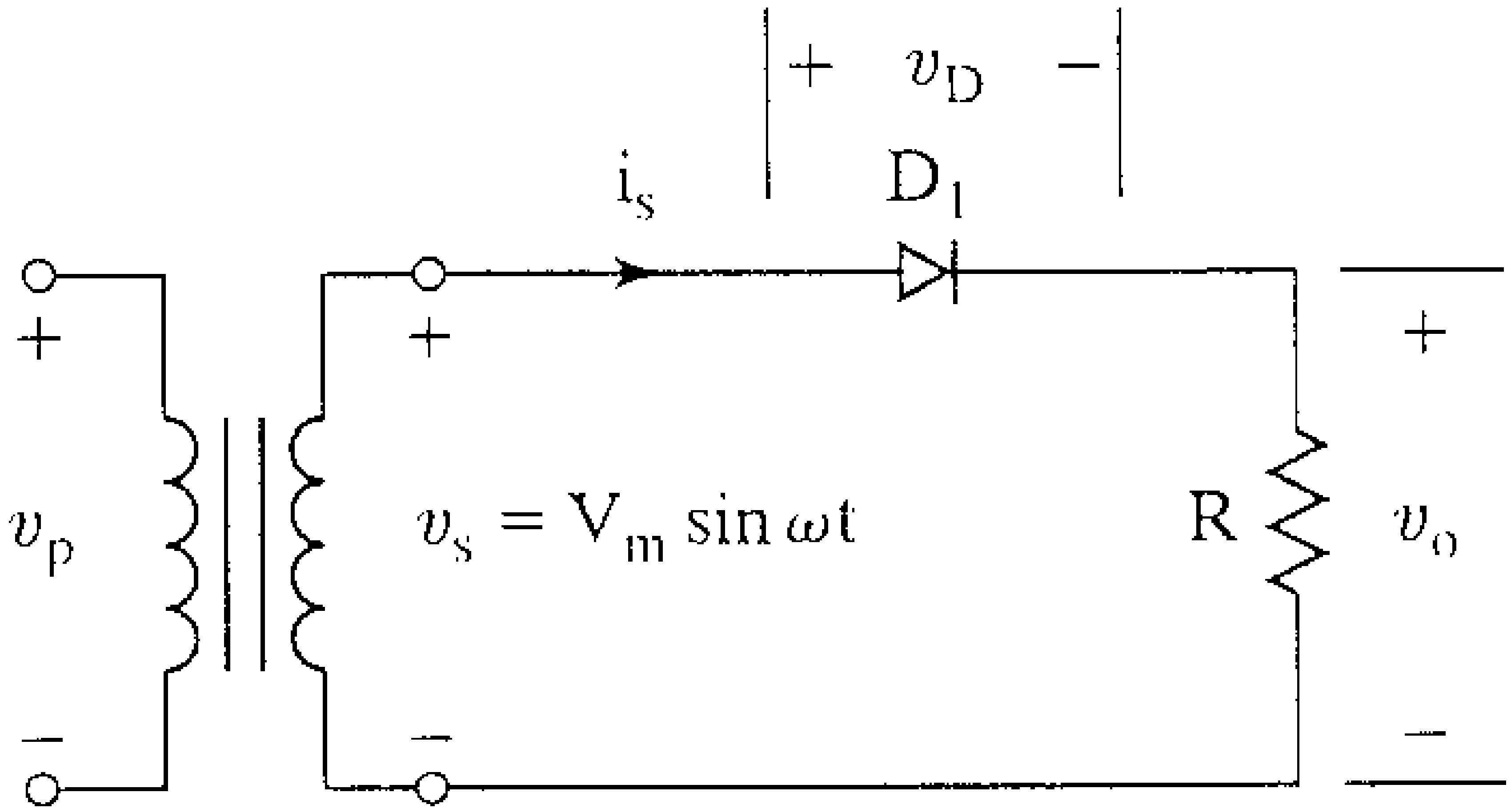
9th November 2021

Types of Rectifiers

- Half-wave Rectifier
- Full-wave Rectifier
- Bridge Rectifier

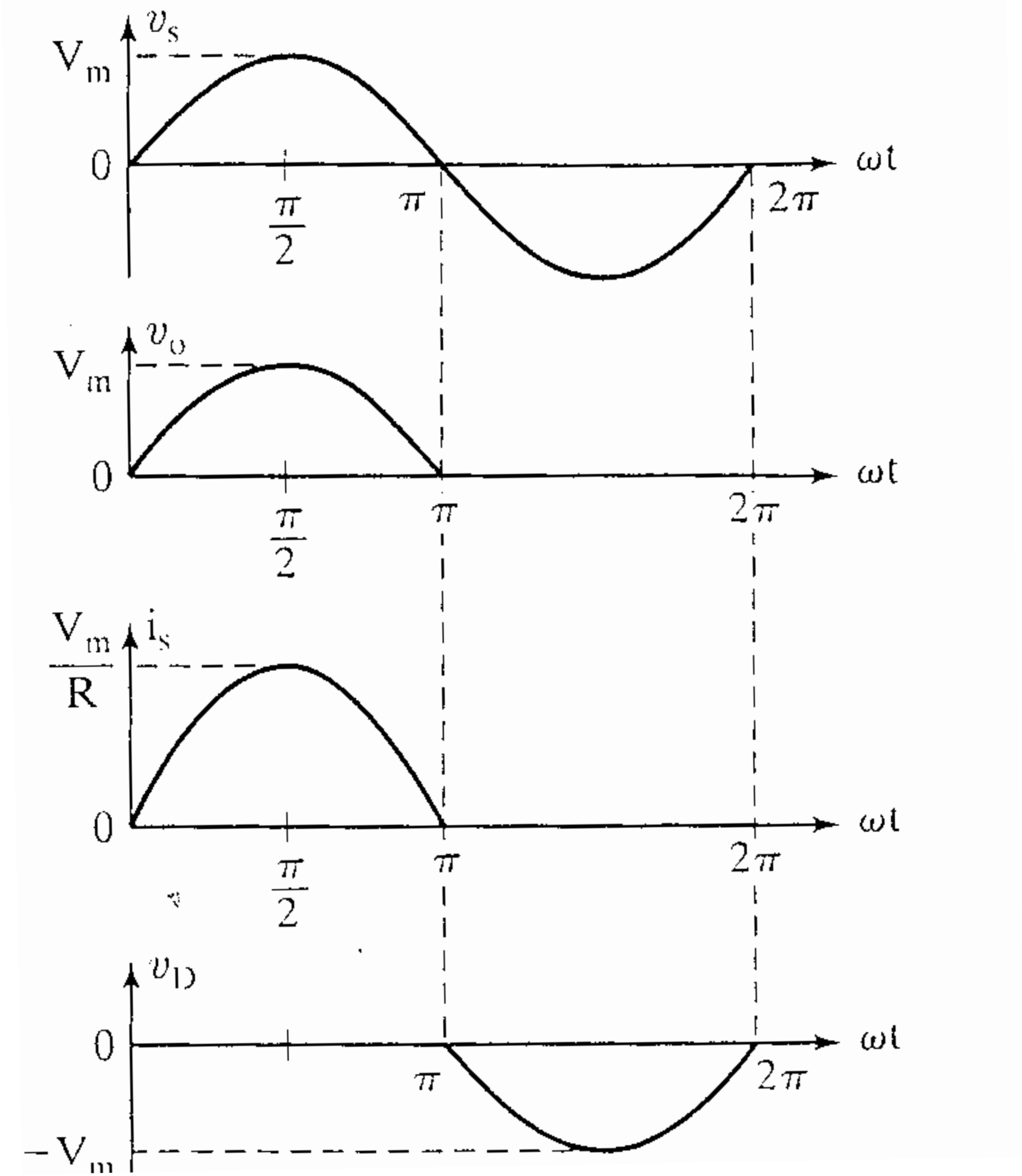
Half-Wave Rectifier





+ v_D −
i_s
D_1
+
+
+
v_p
$v_s = V_m \sin \omega t$
R
v_o
−
−
−

Waveforms



v_s
V_m
0
ωt
$\frac{\pi}{2}$
π
2π
v_o
V_m
0
ωt
$\frac{\pi}{2}$
π
2π
$\frac{V_m}{R}$
i_s
0
ωt
$\frac{\pi}{2}$
π
2π
v_D
0
ωt
π
2π
$-V_m$

Working of a Half-wave Rectifier

- The ac voltage across the secondary winding changes polarities after every half cycle of the input wave.
- During the positive half-cycles of the input ac voltage the diode is forward biased and therefore conducts current.
- Input voltage during the positive half-cycles is directly applied to the load resistance R_L, making its upper-end positive w.r.t. its lower end. The waveforms of the output current and output voltage are of the same shape as that of the input ac voltage.
- During the negative half cycles of the input ac voltage the diode is reverse biased and so does not conduct.
- Thus during the negative half cycles the current and the voltage across the load remains zero.
- No power is delivered to the load during the negative half cycle.
- The output is only a pulsating dc wave.
- How do we make the output wave smooth and useful in a DC power supply?

Performance Parameters

- Average value of the output voltage, V_{dc}
- Average value of the output current, I_{dc}
- Output dc power, P_{dc}
  - $P_{dc} = V_{dc}I_{dc}$
- rms value of the output voltage, V_{rms}
- Output ac power, P_{ac}
  - $P_{ac} = V_{rms}I_{rms}$

Performance Parameters (continued)

- Efficiency, η
  - $\eta = P_{dc}/P_{ac}$
- Effective (rms) value of the ac component of the output voltage, V_{ac}
  - $V_{ac} = \sqrt{V_{rms}^2 - V_{dc}^2}$
- Form factor, FF
  - $FF = V_{rms}/V_{dc}$
- Ripple factor, RF
  - $RF = V_{ac}/V_{dc}$

- Efficiency: η
  - Ratio of DC output power to the AC input power.
  - Signifies, how efficiently the rectifier circuit converts AC power into DC power.

- Ripple Factor:
  - Ratio of RMS value of AC component to the DC component in the output.
  - Or ratio of the effective AC component of the load voltage versus the DC voltage.
  - Describes the quality of the rectification.
  - It represents the smoothness of the voltage waveform at the output of the rectifier.
  - Our goal is to obtain a voltage and a current in the load as steady as possible.

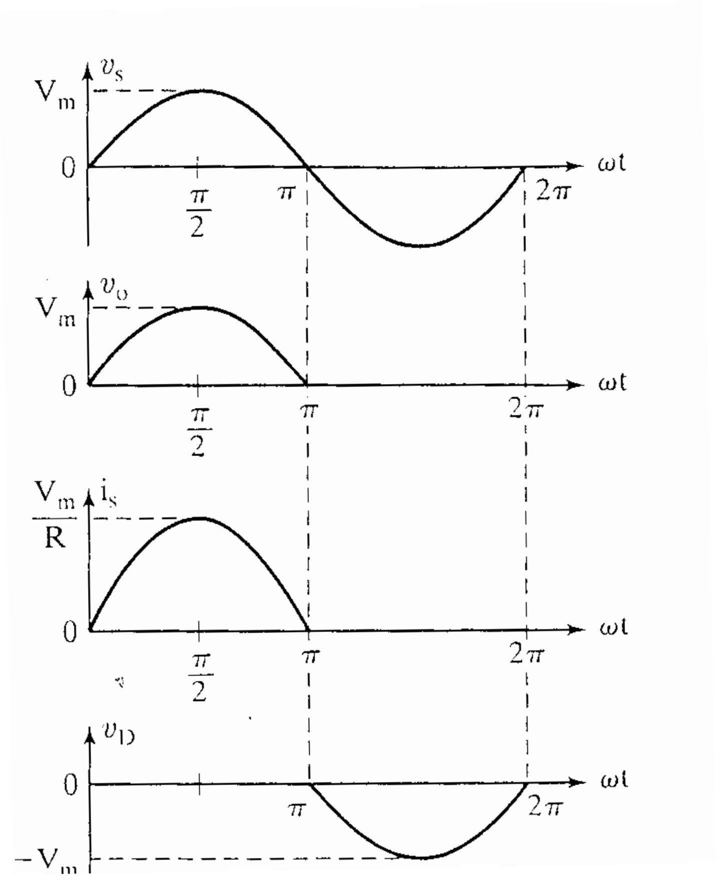
DC Voltage, V_{dc}

- Average value/DC value/mean value = $\dfrac{Area\ over\ one\ period}{Total\ time\ period}$

$$V_{dc} = \frac{1}{T}\int_0^T v_L(t)dt$$

$$V_{dc} = \frac{1}{T}\int_0^{\frac{T}{2}} V_m \sin \omega t dt$$

$$V_{dc} = -\frac{V_m}{\omega T}(\cos \frac{\omega T}{2} - 1)$$

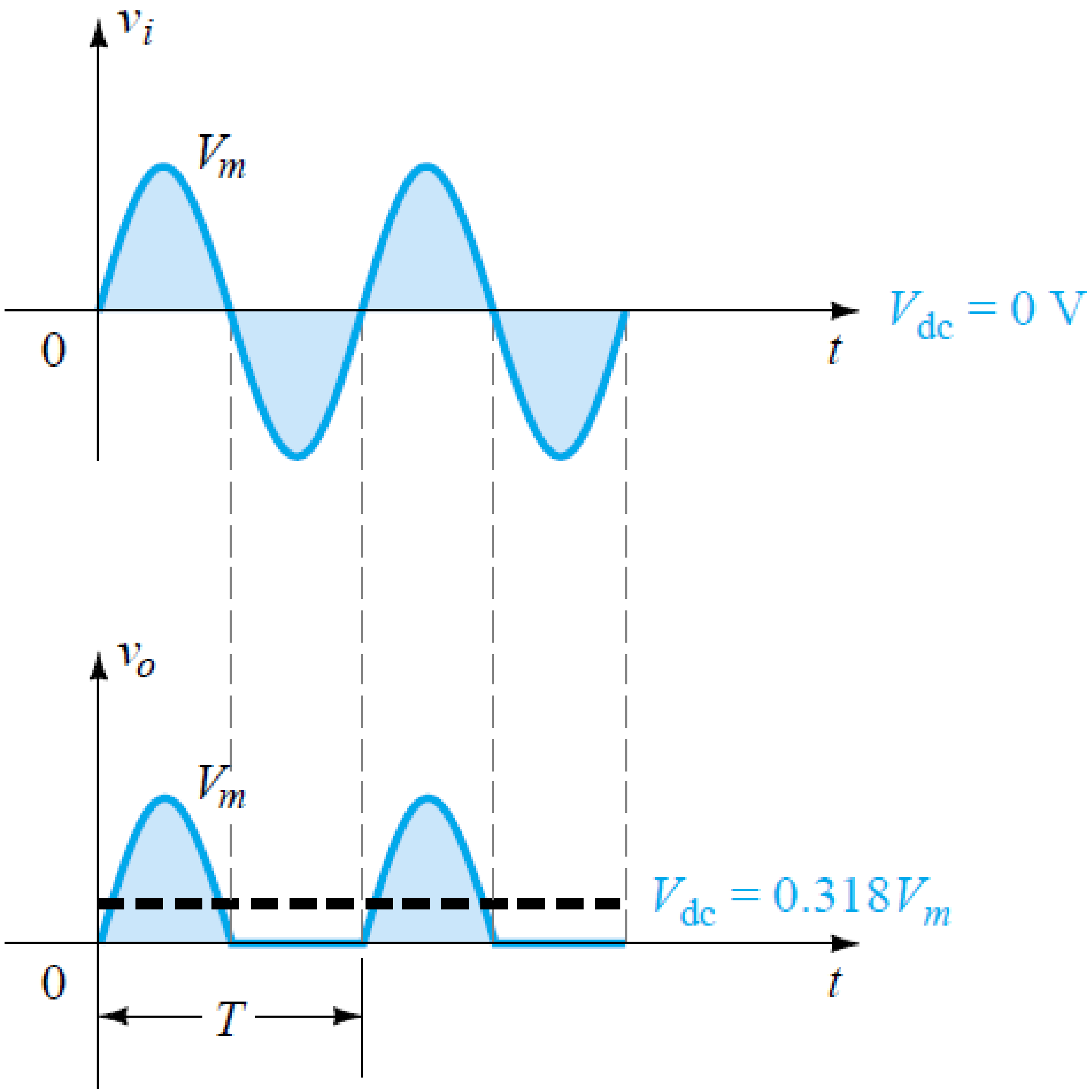


$$f = \frac{1}{T}$$

$$\omega = 2\pi f$$

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

$$I_{dc} = \frac{V_{dc}}{R} = \frac{0.318V_m}{R}$$



v_i
V_m
0
t
$V_{dc} = 0$ V
v_o
V_m
$V_{dc} = 0.318V_m$
0
t
T

RMS Voltage

- RMS Voltage (root mean square voltage) is the effective value of a varying voltage or current.
- It is the equivalent steady DC (constant) value which gives the same effect as AC.
- For example, a lamp connected to a 10V RMS AC supply will shine with the same brightness when connected to a steady 10V DC supply.
- A method of denoting an AC voltage/ current (sine waveform) by an equivalent voltage which represents the DC voltage/current.
- The root mean square value of a quantity is the square root of the mean value of the squared values of the quantity taken over an interval.

$$\text{RMS value} = \sqrt{\frac{1}{b-a}\int_a^b y^2 dt}$$

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V^2 \, dt}$$

$$\text{RMS value} = \sqrt{\frac{1}{b-a}\int_a^b y^2 dt}$$

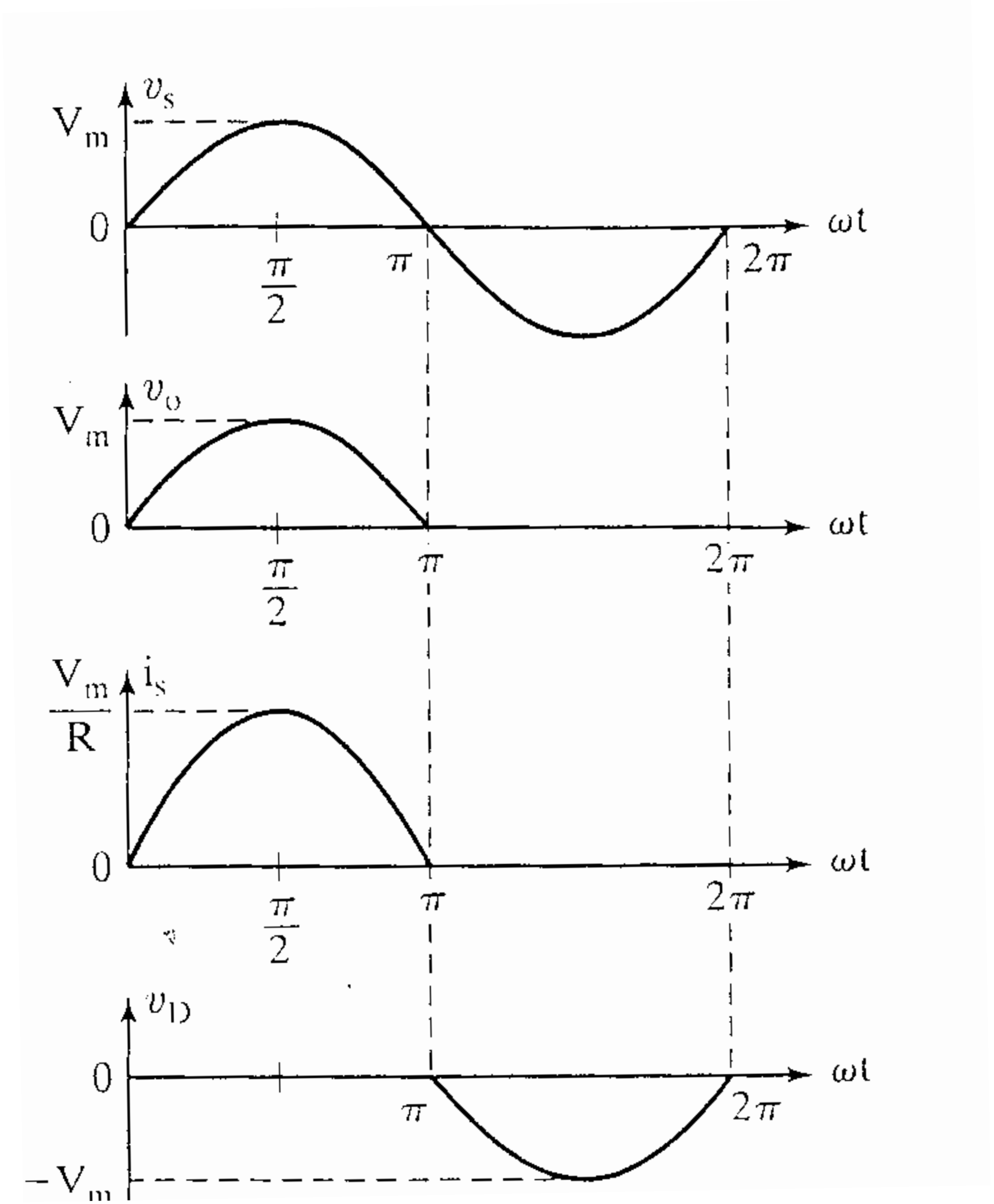
$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V^2\, dt}$$

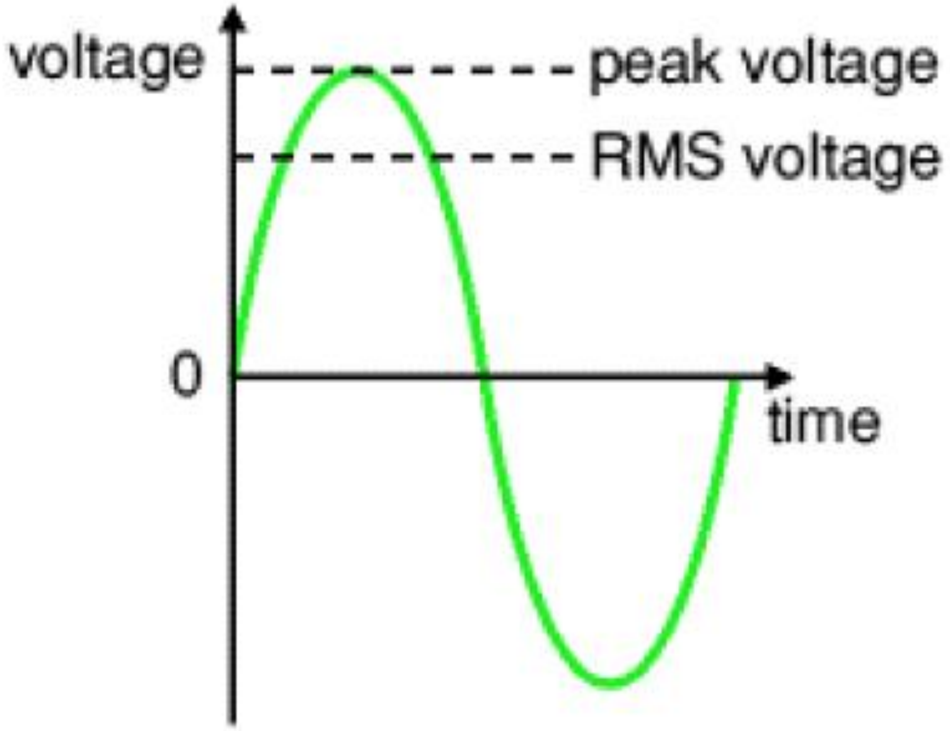
$$V_{rms} = \left[\frac{1}{T}\int_0^T v_L^2(t)dt\right]^{\frac{1}{2}}$$

$$V_{rms} = \left[\frac{1}{T}\int_0^{\frac{T}{2}} (V_m \sin \omega t)^2 dt\right]^{\frac{1}{2}}$$

$$V_{rms} = \frac{V_m}{2} = 0.5V_m$$

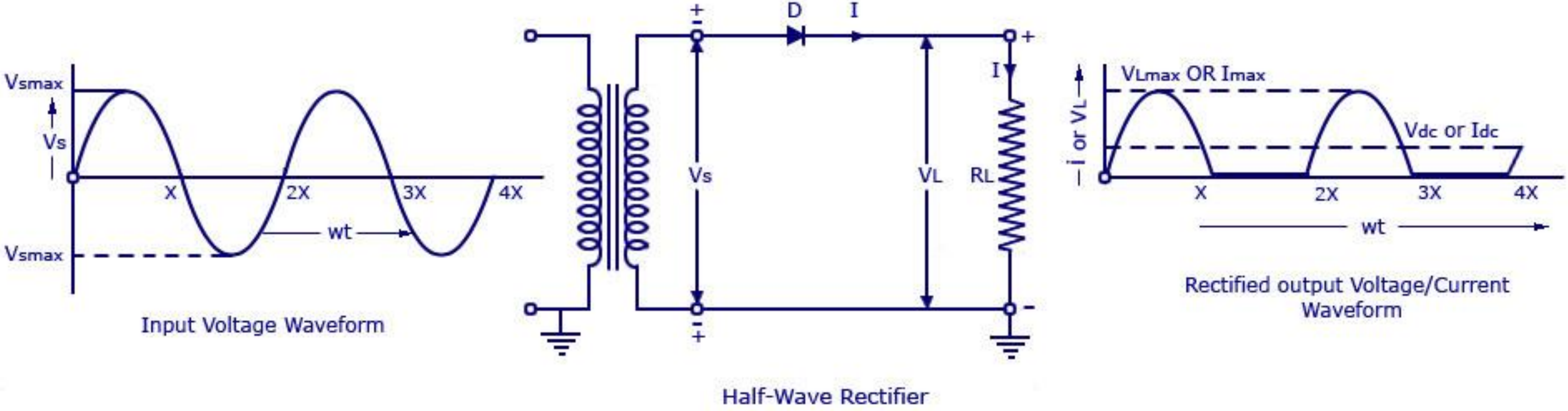
$$I_{rms} = \frac{V_{rms}}{R} = \frac{0.5V_m}{R}$$

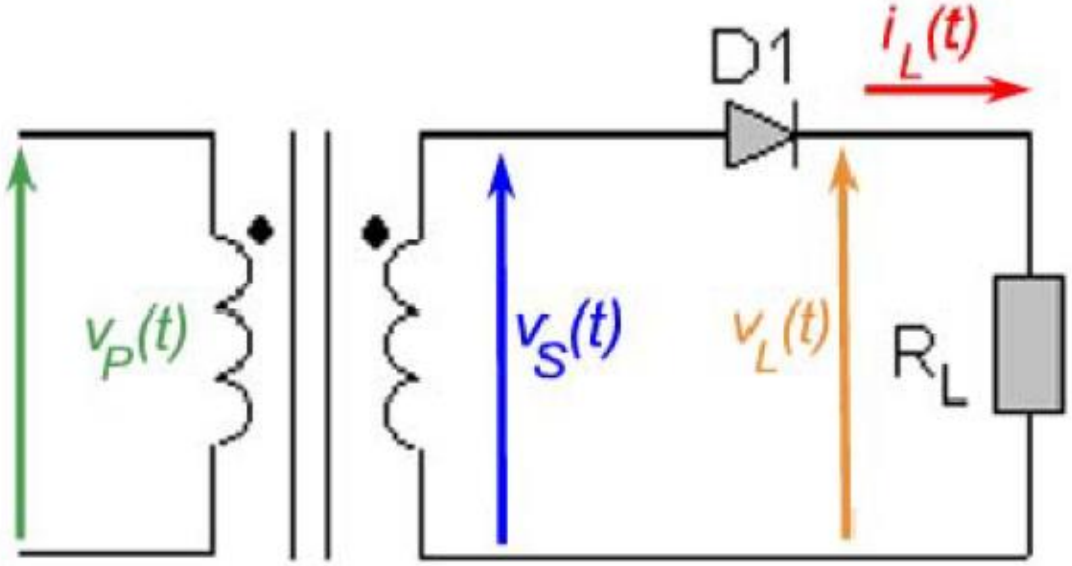




$$V_{RMS} = 0.7 \times V_{peak} \text{ or } V_{peak} = 1.4 \times V_{RMS}$$

Half-wave Rectifier





$$V_{\mathrm{DC}} = \frac{V_{\mathrm{S}}}{\pi}.$$

$$I_{\mathrm{DC}} = \frac{V_{\mathrm{DC}}}{R_{\mathrm{L}}} = \frac{V_{\mathrm{S}}}{\pi \cdot R_{\mathrm{L}}}$$

$$I_{rms} = \frac{V_{rms}}{R_{\mathrm{L}}} = \frac{V_{\mathrm{S}}}{2 \cdot R_{\mathrm{L}}}$$

Peak factor and Form Factor

- Peak factor= Ratio of peak value to RMS value = $\frac{Peak\ Value}{RMS\ Value}$ = $\frac{Vs}{Vs/2}$ = 2

- Form factor = $\frac{RMS\ Value}{Average\ Value}$ = $\frac{Vs/2}{Vs/\pi}$ = 1.57

$$FF = \frac{V_{rms}}{V_{dc}} = \frac{0.5V_m}{0.318V_m}$$

$$FF = 1.57 = 157\%$$

$$RF = \sqrt{FF^2 - 1}$$

$$RF = \sqrt{1.57^2 - 1} = 1.21 = 121\%$$

P_{dc}, P_{ac}, and η

$$P_{dc} = \frac{(0.318 V_m)^2}{R}$$

$$P_{ac} = \frac{(0.5 V_m)^2}{R}$$

$$\eta = \frac{(0.318 V_m)^2}{(0.5 V_m)^2} = 40.5\%$$

- P_D represents the losses in the rectifier
- R_D is the equivalent resistance of the rectifier.
- With no losses, that is $R_D = 0$

$$\eta = \frac{P_{\mathrm{DC}}}{P_{\mathrm{L}} + P_{\mathrm{D}}}$$

$$P_{\mathrm{DC}} = V_{\mathrm{DC}} \cdot I_{\mathrm{DC}}$$

$$P_{\mathrm{L}} = V_{rms} \cdot I_{rms}$$

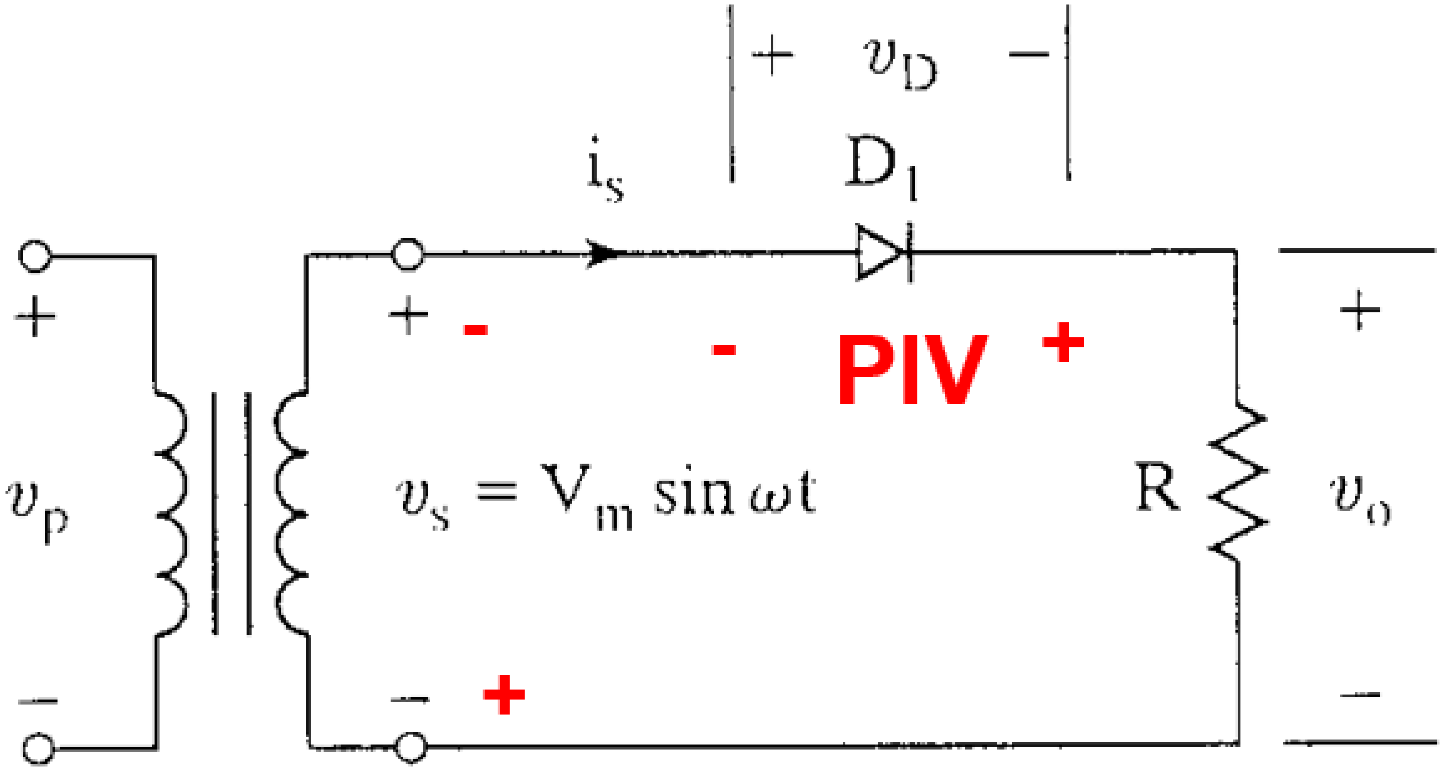
$$P_{\mathrm{D}} = R_{\mathrm{D}} \cdot I_{rms}^2$$

$$\eta = \frac{V_{\mathrm{DC}} \cdot I_{\mathrm{DC}}}{V_{rms} \cdot I_{rms} + R_{\mathrm{D}} \cdot I_{rms}^2} = \frac{V_{\mathrm{DC}}^2}{V_{rms}^2} \cdot \frac{1}{1 + \left(R_{\mathrm{D}}/R_{\mathrm{L}}\right)}.$$

$$\eta = \left(\frac{V_{\mathrm{DC}}}{V_{rms}}\right)^2 = \left(\frac{1}{FF}\right)^2.$$

Peak Inverse Voltage (PIV)

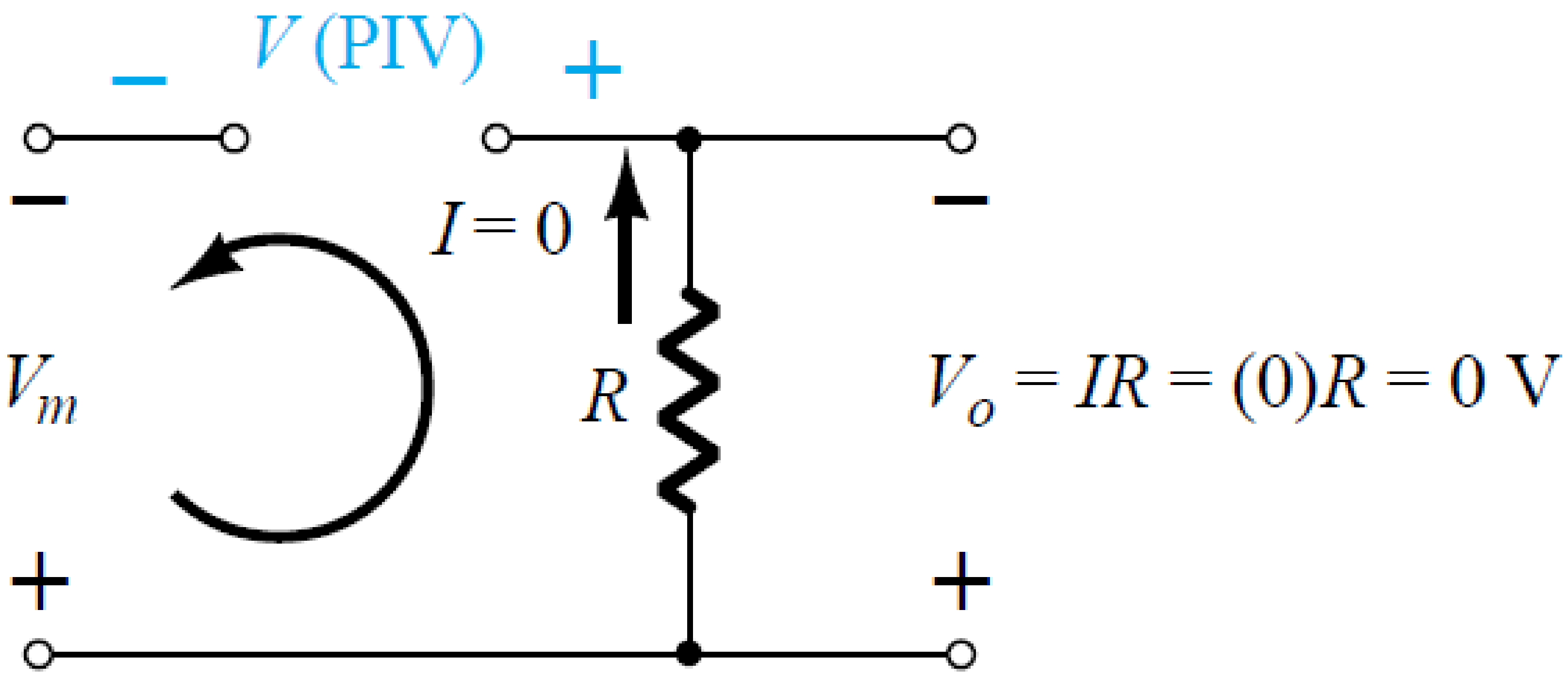
- PIV is the maximum (peak) voltage that appears across the diode when reverse biased. Here, PIV = V_m.



PIV

- The maximum voltage that the rectifying diode has to withstand, during the reversely biased period.
- When the diode is reverse biased, during the negative half cycle, there will be no current flow through the load resistor R_L.
- Hence, there will be no voltage drop through the load resistance R_L which causes the entire input voltage to appear across the diode.
- V_{SMAX}, the peak secondary voltage, appears across the diode.
- Peak Inverse Voltage (PIV) of half wave rectifier = V_{SMAX}

- Voltage rating must not be exceeded in the reverse-bias region or the diode will enter the Zener avalanche region.
- PIV rating of the diode must equal or exceed the peak value of the applied voltage.



$$\text{PIV rating} \geqq V_m$$

References:

- Microelectronic Circuits, 7th edition by Adel S. Sedra Kenneth C. Smith.
- G. Streetman, and S. K. Banerjee, “Solid State Electronic Devices,” 7th edition, Pearson,2014.
- D. Neamen, D. Biswas, "Semiconductor Physics and Devices," McGraw-Hill Education.
- Electronic Devices and Circuit Theory 11th Edition by Boylestad, Robert . L, Louis Nashelskyl.
- http://ecee.colorado.edu/~bart/book/book/contents.htm
- http://www.ecse.rpi.edu/~schubert/Course-ECSE-2210-Microelectronics-Technology-2010/