Chapter 3
Diode Circuits

Rectifier

Rectifier Circuits

- A DC power supply is required to bias all electronic circuits.
- A diode rectifier forms the first stage of a DC power supply.

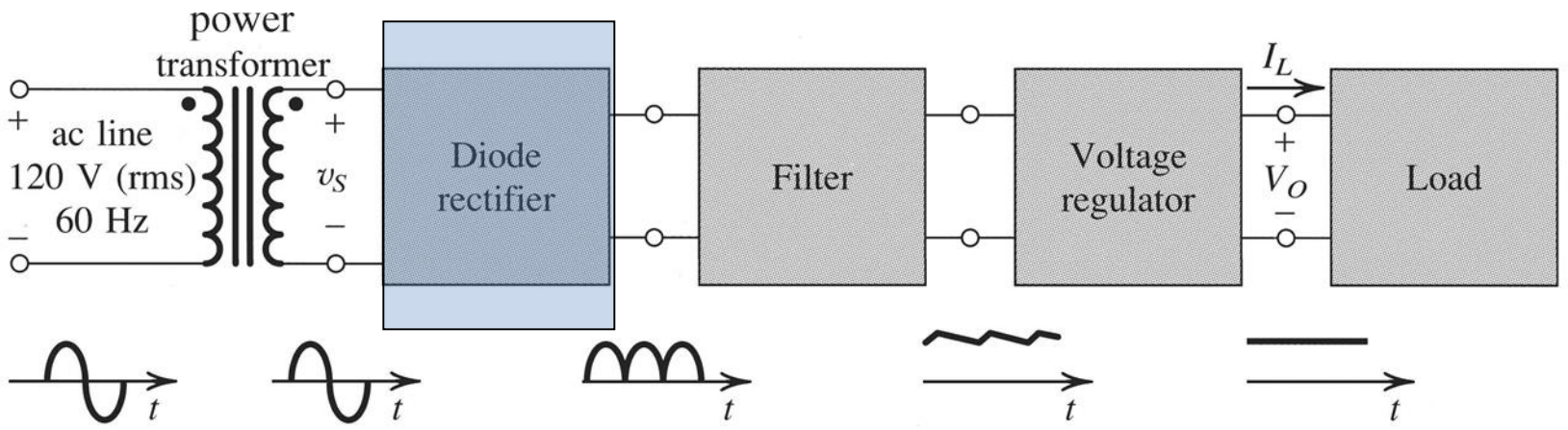


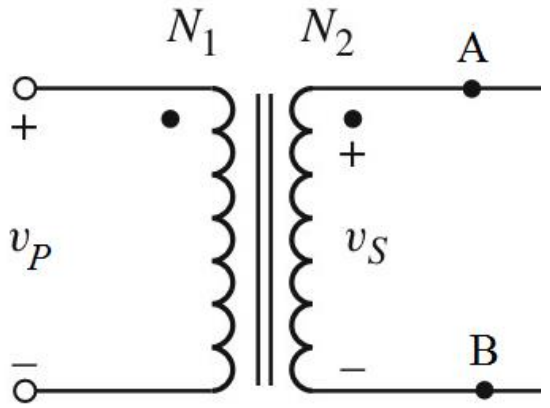
Diagram of an Electronic Power Supply

- Rectification is the process of converting an alternating (ac) voltage into one that is limited to one polarity.
- Rectification is classified as **half-wave** or **full-wave** rectifier.

Rectifier Parameters

Relationship between the number of turns of a step-down transformer and the input/output voltages - transformer ratio

$$\frac{v_P}{v_S} = \frac{N_1}{N_2}$$



The **peak inverse voltage (PIV)** of the diode is the peak value of the voltage that a diode can withstand when it is reversed biased

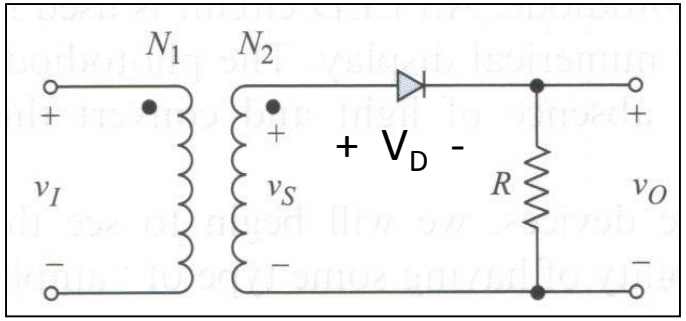
Duty Cycle: The **fraction of the wave cycle** over which the diode is conducting.

Half Wave Rectifier

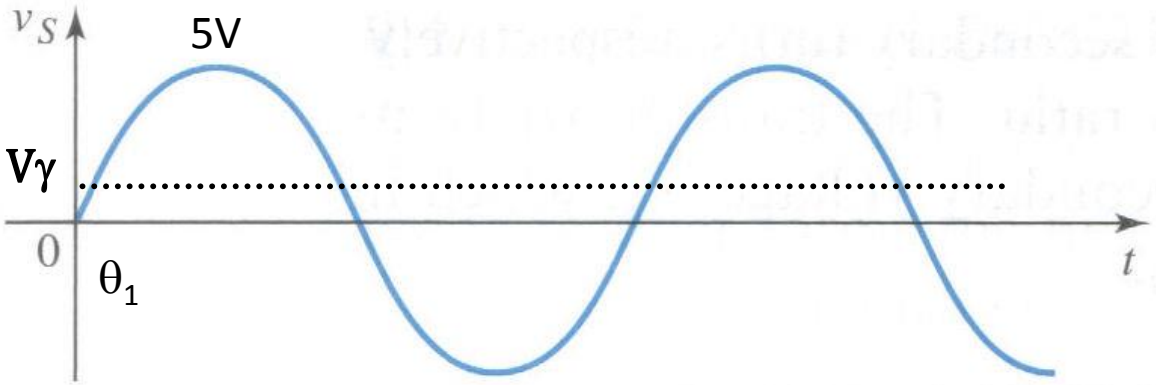
• $\mathcal{V}_s < \mathbf{V\gamma}$, diode off, open circuit, no current flow, **Vo = 0V**

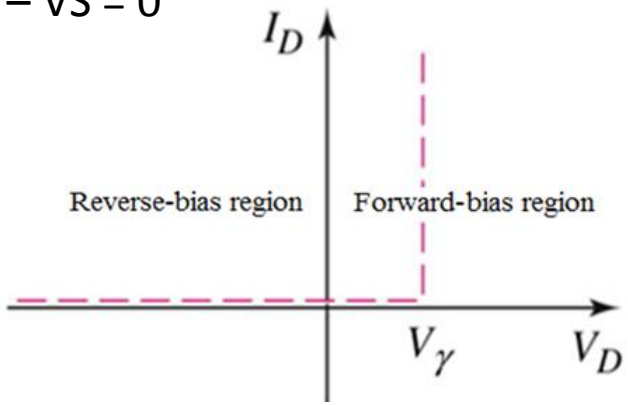
• $\mathcal{V}_s \geq \mathbf{V\gamma}$, diode conducts, current flows,

$\mathcal{V}_o = \mathcal{V}_s - V_D$



VD + VO – VS = 0

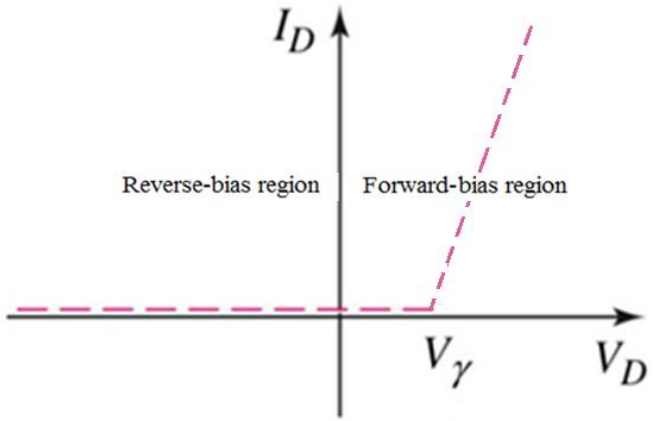




Equation of V_0 and current when diode is conducting

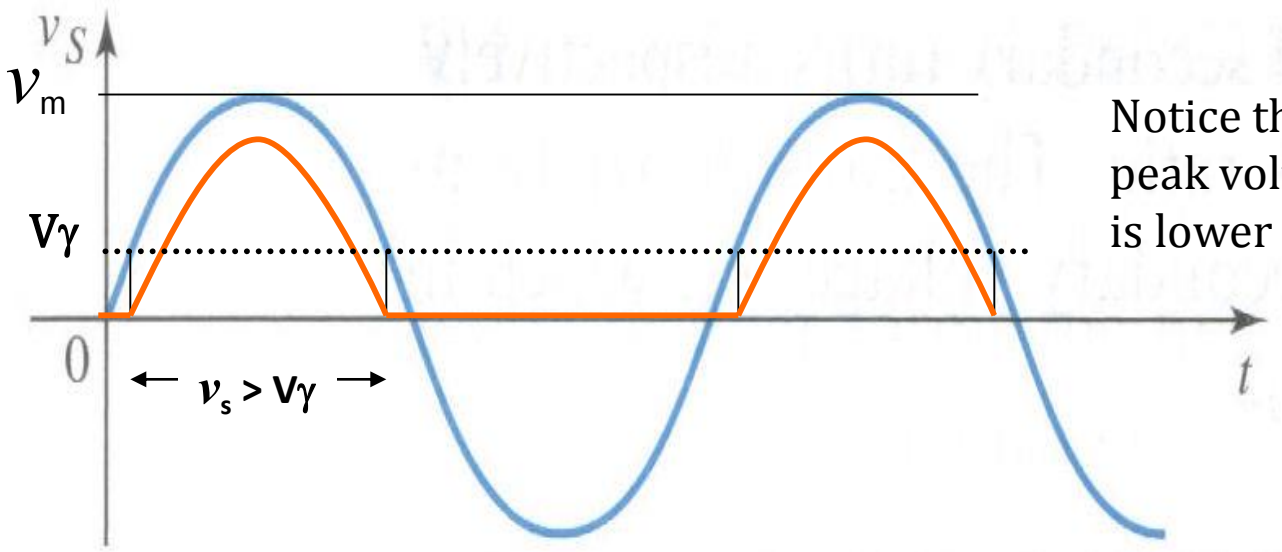
$$v_O = i_D R = v_S - V_D$$

$$i_D = \frac{v_S - V_D}{R}$$



- v_s < Vγ, diode off, **open circuit**, no current flow, v_o = 0V
- v_s > Vγ, diode conducts, current flows and $v_o = v_s - V_D$

Consider a sine wave where $v_s = v_m \sin \omega t$ and v_m is the peak value



Notice that the peak voltage of Vo is lower

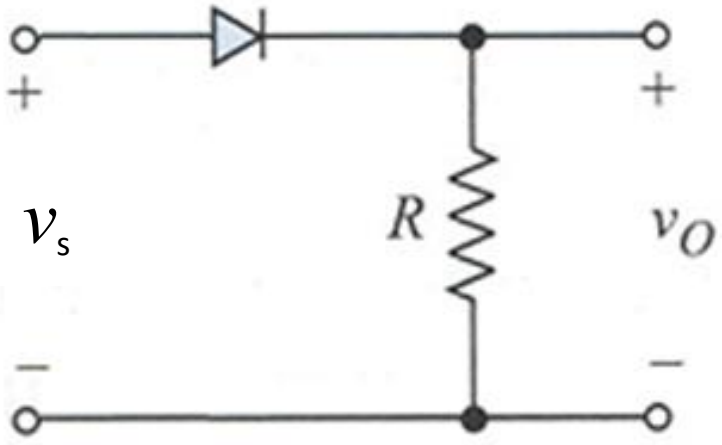
Example

Consider the rectifier circuit in the figure below. Let R = 1 kΩ, and the diode has the properties of $V_\gamma = 0.6$ V and $r_f = 20\ \Omega$.

Assume $v_s = 10 \sin \omega t$ (V)

i. Determine the **peak value** of the diode current

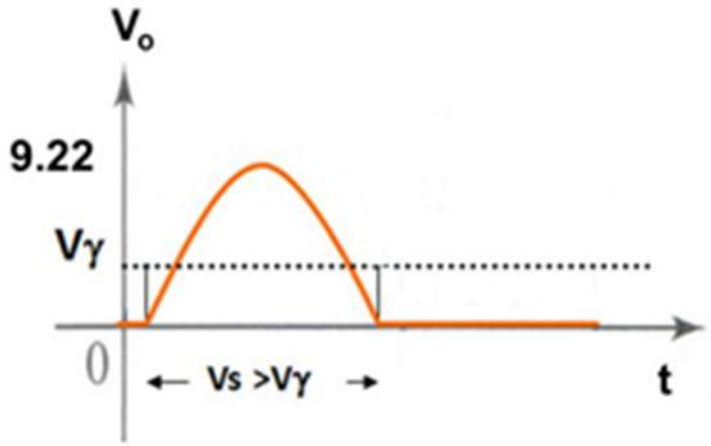
ii. Sketch v_0 versus time, t. Label the peak value of v_0.



SOLUTION

$0.6 + I_D r_f + I_D R - 10 = 0$

$I_D = (10 - 0.6) / 1020 = 9.22$ mA



- Peak Inverse Voltage – Half Wave
- Duty cycle – Half Wave

- **Peak Inverse Voltage** is also known as **Maximum Reverse Biased Voltage**
- The objective is to know whether the diode can withstand a certain voltage when it is reversed and to avoid damaging the diode – each diode has PIV rating.

$$V_{RMS} = \frac{1}{\sqrt{2}} \times V_{pk}$$

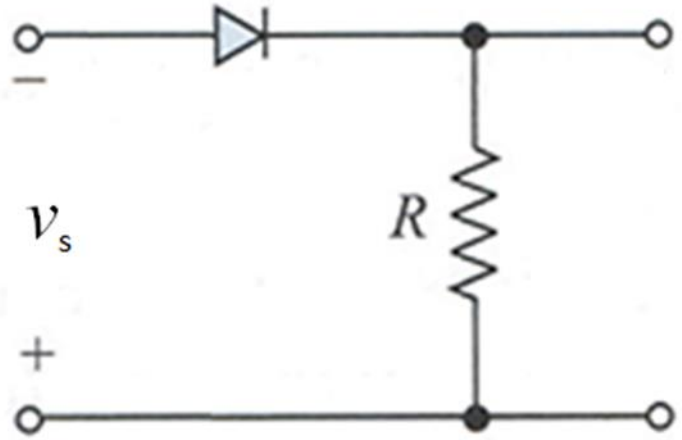
Maximum Ratings and Electrical Characteristics @T_A = 25°C unless otherwise specified

Single phase, half wave, 60Hz, resistive or inductive load.
For capacitive load, derate current by 20%.

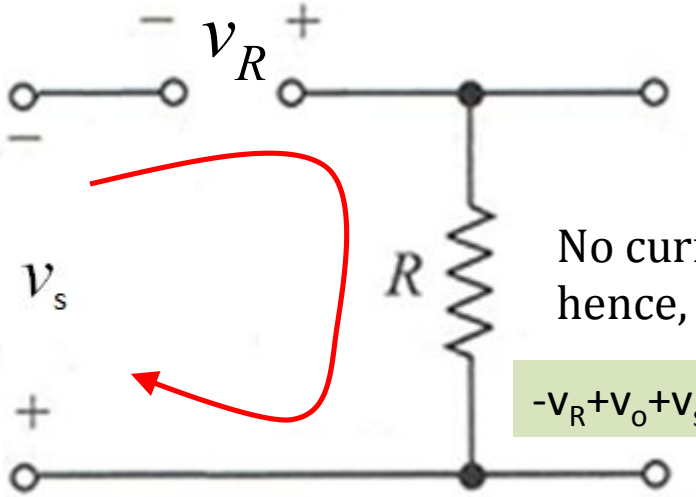
Characteristic	Symbol	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	V
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	V
Average Rectified Output Current (Note 1) @ T_A = 75°C	I_O	1.0							A
Non-Repetitive Peak Forward Surge Current 8.3ms single half sine-wave superimposed on rated load	I_{FSM}	30							A
Forward Voltage @ I_F = 1.0A	V_{FM}	1.0							V
Peak Reverse Current @T_A = 25°C at Rated DC Blocking Voltage @ T_A = 100°C	I_{RM}	5.0 50							μA
Typical Junction Capacitance (Note 2)	C_j	15				8			pF
Typical Thermal Resistance Junction to Ambient	$R_{\theta JA}$	100							K/W
Maximum DC Blocking Voltage Temperature	T_A	+150							°C
Operating and Storage Temperature Range	T_J, T_{STG}	-65 to +150							°C

Notes:
1. Leads maintained at ambient temperature at a distance of 9.5mm from the case.
2. Measured at 1.0 MHz and applied reverse voltage of 4.0V DC.
3. EU Directive 2002/95/EC (RoHS). All applicable RoHS exemptions applied, see EU Directive 2002/95/EC Annex Notes.

We know that the diode is reversed biased during negative cycle



Diode is off, open circuit



No current flow, hence, $V_o = 0$ V

$-v_R+v_o+v_s = 0$

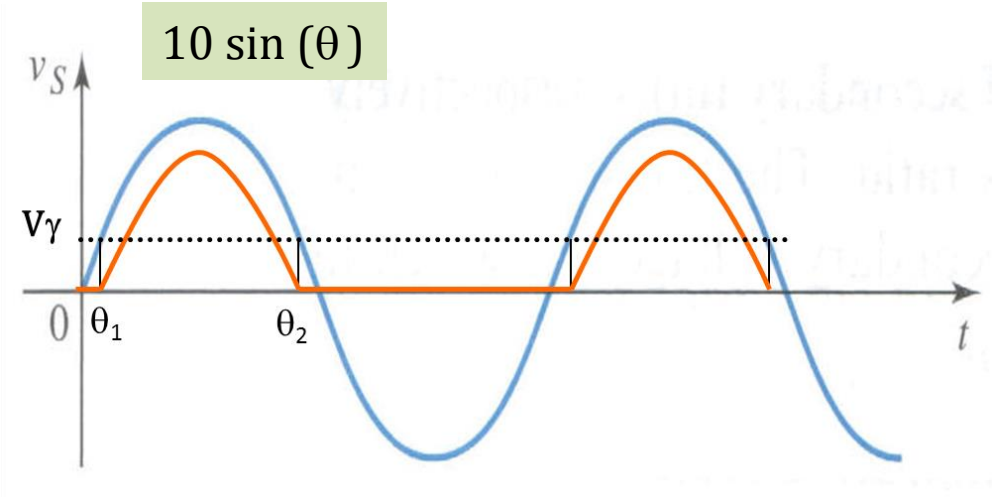
Using KVL

$-v_R + 0 + v_s \text{ peak} = 0$

$v_R = v_s \text{ peak}$

Hence, for the example just now, the PIV for the diode is 10 V

- **Duty cycle** is the fraction of the wave cycle over which the diode is conducting with respect to the full wave of the cycle



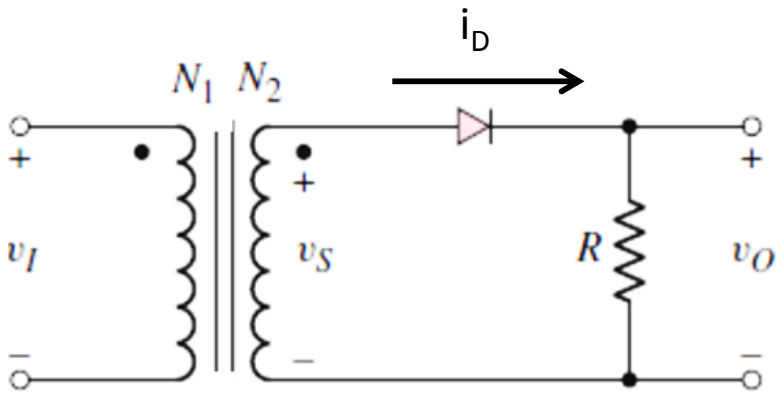
Hence for this example:

$0.6 = 10 \sin(\theta_1)$

$\theta_1 = \sin^{-1}(0.6/10) = 3.44°$

At second quadrant for sine wave: 176.56° $\theta_2 = 180° - \theta_1$

$$\text{Duty cycle} = \left(\frac{\theta_2 - \theta_1}{2\pi}\right) X\ 100\% = 48\%$$



A half-wave rectifier circuit is connected to a 2 kΩ load as shown in the figure. Assume that the input of the transformer is connected to a 120 V(rms), 60 Hz power supply, the turns ratio of the step-down transformer is 10:1, the diode cut-in voltage Vγ = 0.7 V

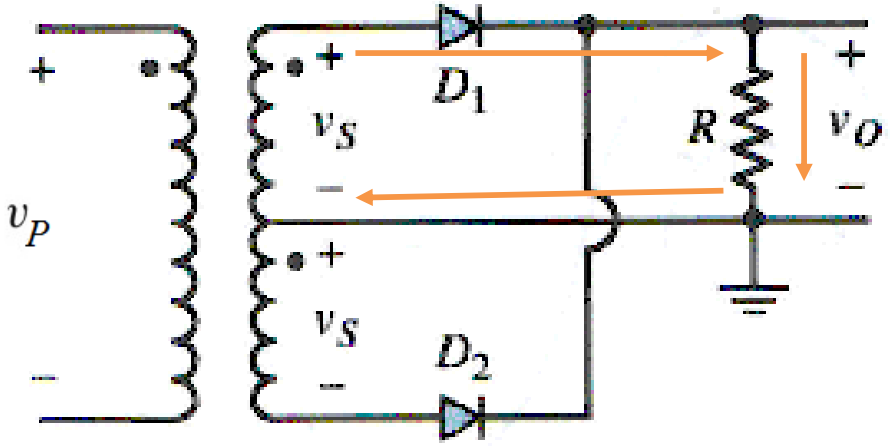
i. Calculate the peak output voltage, v_o
ii. Determine the peak diode current, i_D
iii. Determine the fraction of conduction angle of a cycle when diode is conducting.

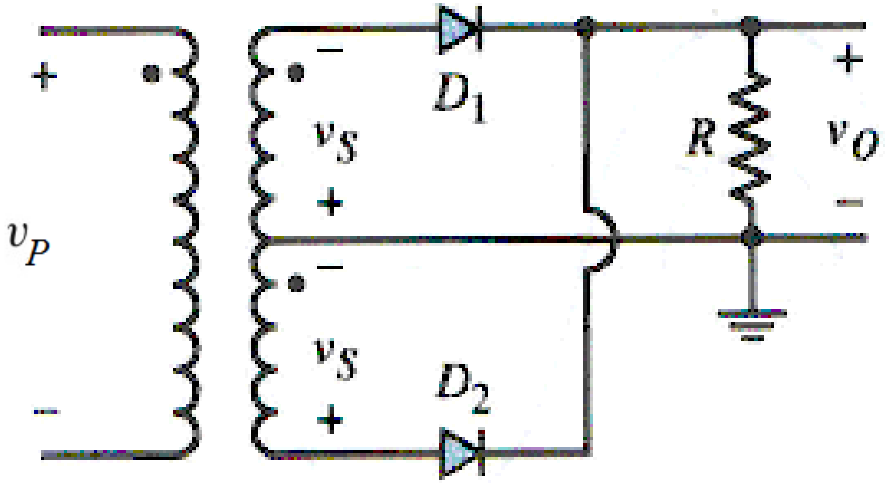
v_o = 16.27 V
i_D = 16.27 / 2 = 8.135 mA
Duty cycle = 48.69%

Full Wave Rectifier

- Center-Tapped
- Bridge

$$\frac{v_P}{v_S} = \frac{N_1}{N_2}$$



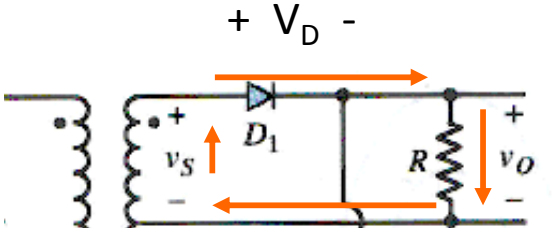


Full-Wave Rectification – circuit with center-tapped transformer

- *Positive cycle*, D2 off, D1 conducts;

$V_o - V_S + V_D = 0$

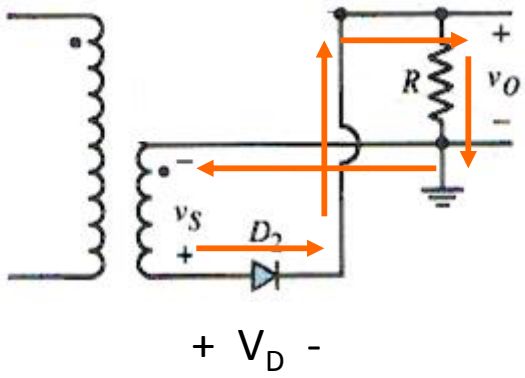
$\mathbf{V_o = V_s - V_D}$



- *Negative cycle*, D1 off, D2 conducts;

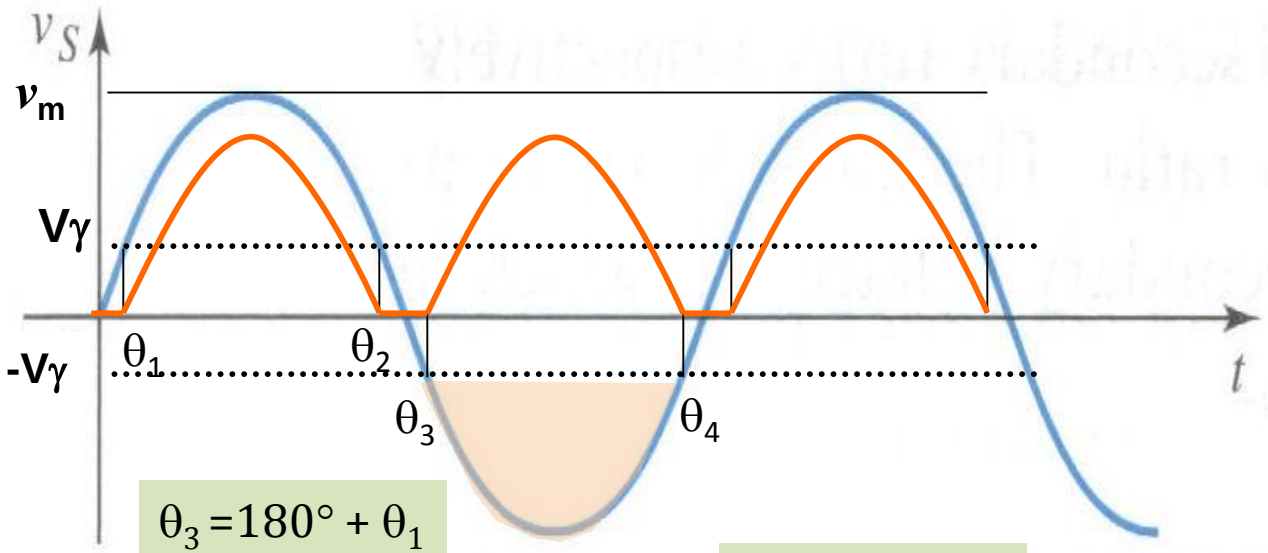
$V_o - V_S + V_D = 0$

$\mathbf{V_o = V_s - V_D}$



- Since a rectified output voltage occurs during both positive and negative cycles of the input signal, this circuit is called a **full-wave rectifier**.
- Also notice that the **polarity of the output voltage for both cycles is the same**

$$v_s = v_m \sin \omega t$$



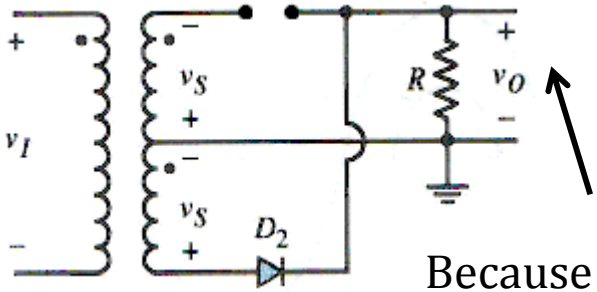
Notice again that the peak voltage of Vo is lower since $\mathbf{V_o = V_s - V_D}$

- $\mathbf{V_s < V\gamma}$, diode off, **open circuit**, no current flow, $\mathbf{V_o = 0V}$

PIV FOR CENTER-TAPPED RECTIFIER

For center tapped, at each cycle, there will one diode off and one diode on and v_o will have a value

off



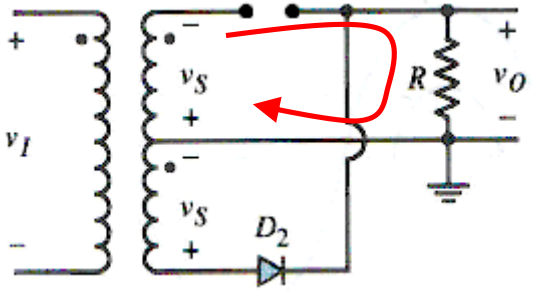
on

Because diode D_2 is on, there is current in R, and

$\mathbf{V_o = V_s - V_D}$

Diode is off, open circuit

$- v_R +$



Using KVL

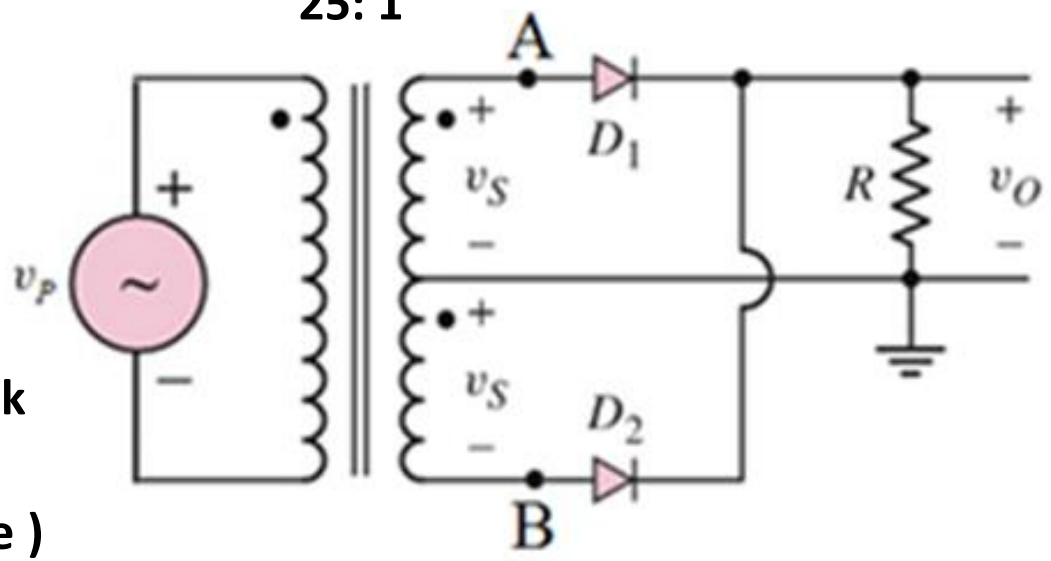
$-v_R + \mathbf{v_o} + v_s \text{ peak} = 0$

$-v_R + (v_s\text{peak} - V_D) + v_s \text{ peak} = 0$

$v_R = 2v_s\text{peak} - V_D$

- A full-wave center-tapped rectifier circuit is shown in the figure below. Assume that for each diode, the cut-in voltage, $V_\gamma = 0.6$ V and the diode forward resistance, r_f is 15Ω. The load resistor, R = 95 Ω. Determine:
  i. peak output voltage, v_o across the load, R
  ii. Sketch the output voltage, v_o and label its peak value.

25: 1



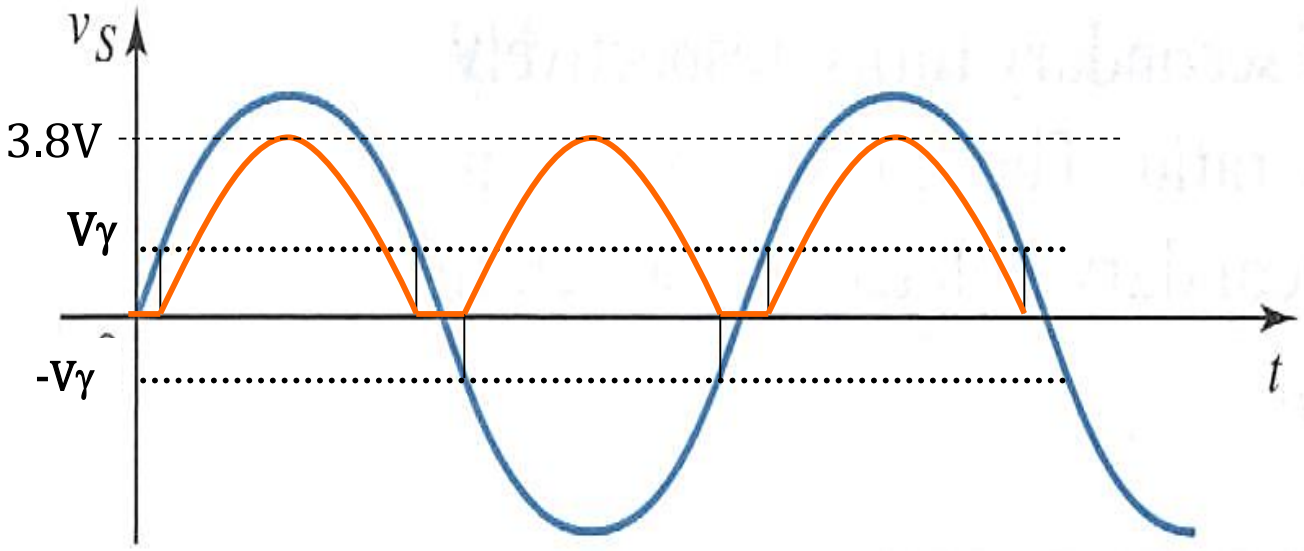
125 V (peak voltage)

(sine wave)

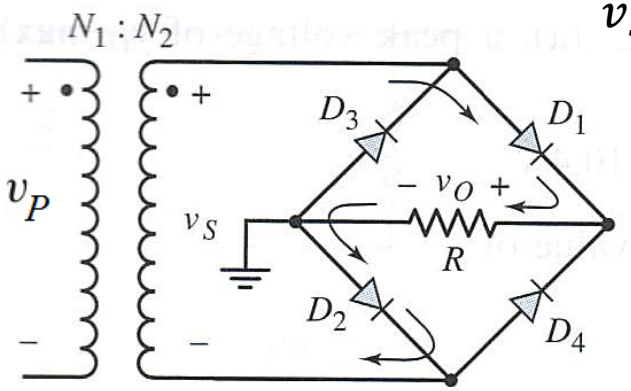
- **SOLUTION**

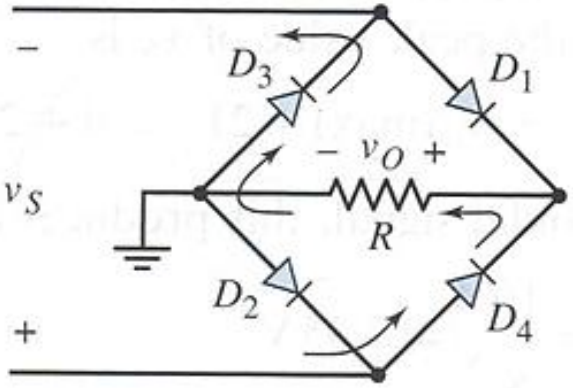
i. peak output voltage, V_o

ii.



$$\frac{v_P}{v_S} = \frac{N_1}{N_2}$$



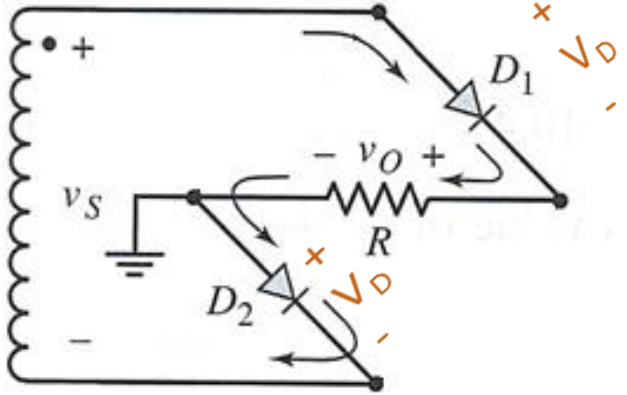


Full-Wave Rectification –Bridge Rectifier

- **Positive cycle**, D_1 and D_2 conducts, D_3 and D_4 off;

  $V_D + v_o + V_D - v_s = 0$

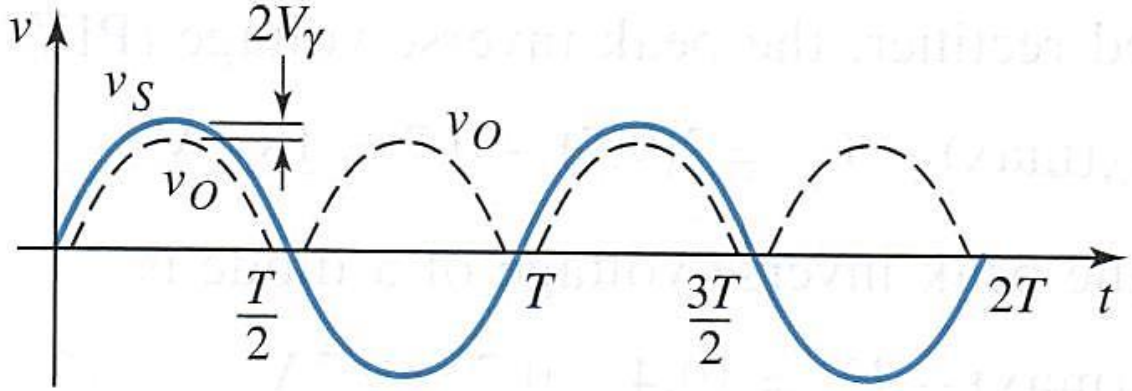
  $\mathbf{v_o = v_s - 2V_D}$

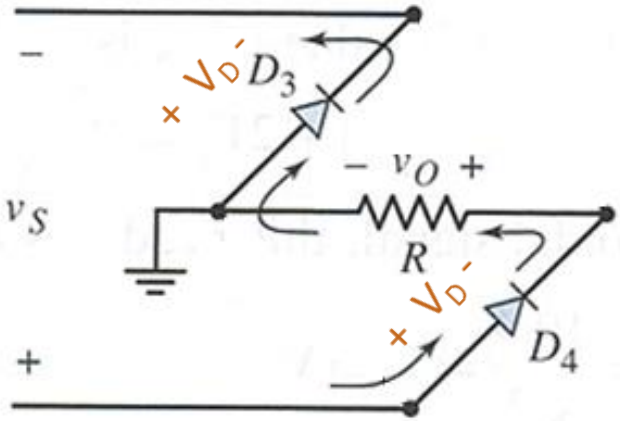


- **Negative cycle**, *D3* and *D4* conducts, *D1* and *D2* off

  $V_D + v_o + V_D - v_s = 0$

  $\mathbf{v_o = v_s - 2V_D}$

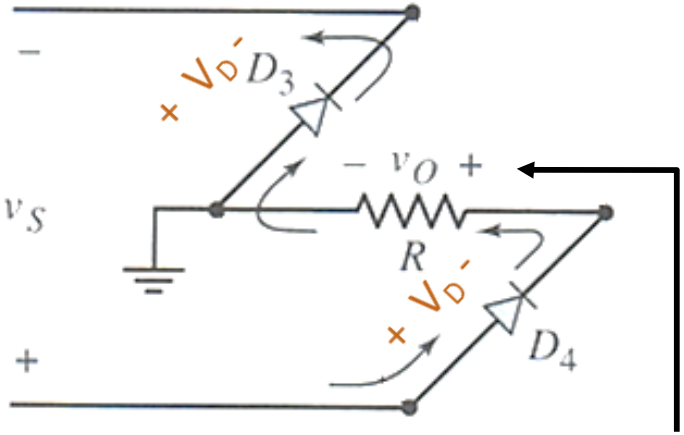




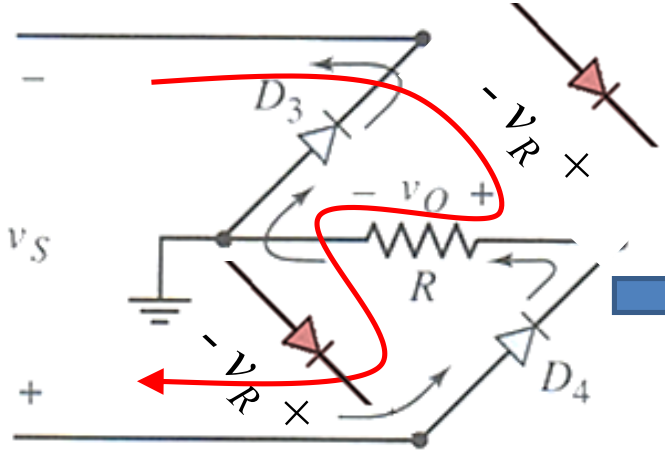
- Also notice that the **polarity of the output voltage for both cycles is the same**

PIV FOR BRIDGE RECTIFIER

For bridge rectifier, at each cycle, there will two diodes off and two diodes on and v_o will have a value



Because diode D_3 and D_4 is on, there is current in R, and $\mathbf{V_o = V_s - 2V_D}$



Using KVL

$-v_R + \mathbf{v_o} - v_R + v_s\,peak = 0$

$-2v_R + (v_s peak - 2V_D) + v_s\,peak = 0$

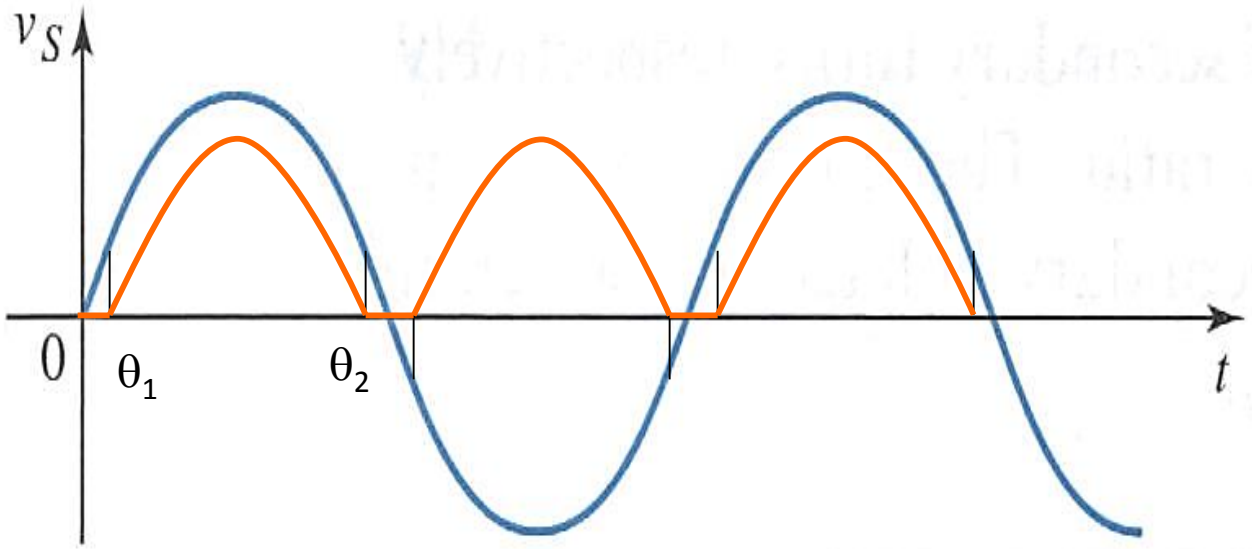
$2v_R = 2v_s peak - 2V_D$

$v_R = v_s peak - V_D$

Summary of PIV

Type of Rectifier	**PIV**
Half Wave	Peak value of the input secondary voltage, $v_{s\ (peak)}$
Full Wave : Center-Tapped	$2v_{s\ (peak)} - V_D$
Full Wave: Bridge	$v_{s\ (peak)} - V_D$

- DUTY CYCLE FOR FULL WAVE



$$Duty\ cycle = \left(\frac{\theta_2 - \theta_1}{2\pi}\right) X\ 100\%$$

Multiply by 2