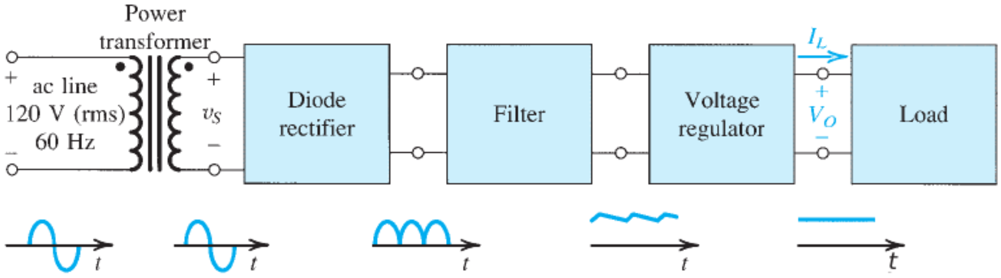
Lecture 3a

EE-215 Electronic Devices and Circuits

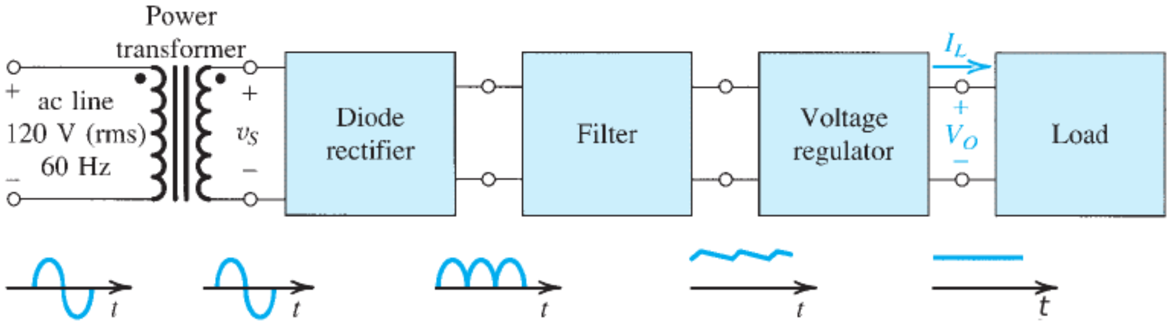
Asst Prof Muhammad Anis Chaudhary

Rectifier Circuits

- An important application of diodes is in the design of rectifier circuits
    - A diode rectifier forms an essential building block of a dc power supply

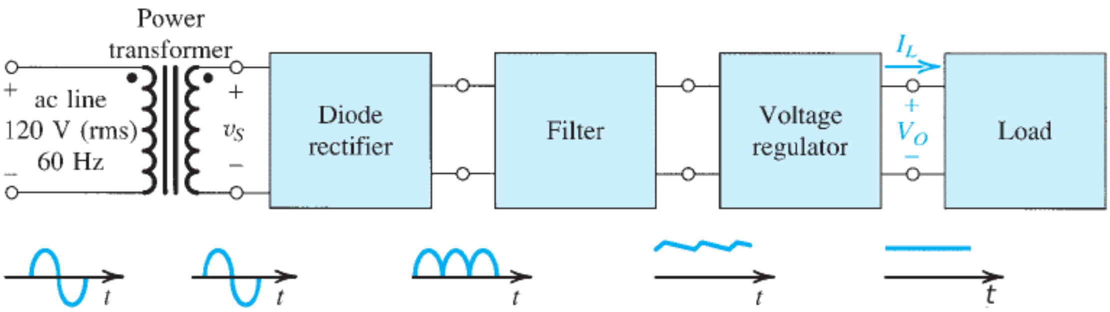


    - **Figure 4.20** Block diagram of a dc power supply.
    - A dc power supply produce a dc voltage,
        - which is required to power essentially every electronic device,
        - including personal computers, televisions and stereo systems
    - Also battery chargers for portable electronic devices such as cellphones, laptop computers etc. contain rectifiers.
- The dc power supply is fed from ac line typically (230V rms 50Hz) or (120V rms 60Hz)
    - and it delivers a dc voltage V_O to an electronic circuit represented here by the load block.
    - The building blocks of a dc power supply are
        - power transformer
        - diode rectifier
        - filtering stage
        - voltage regulator

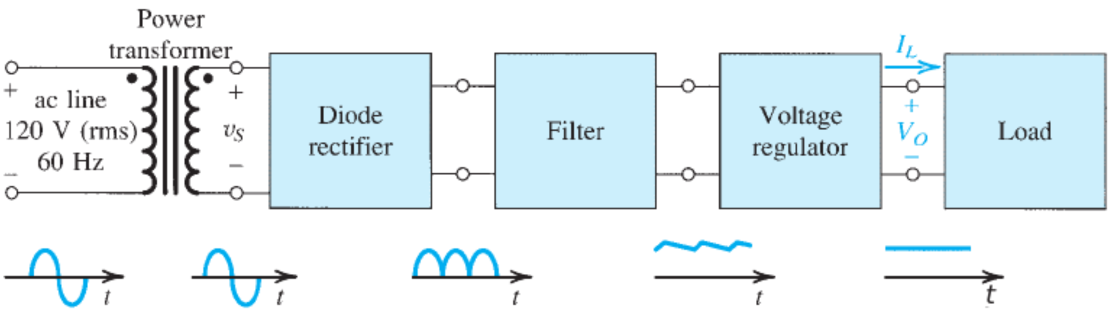


- **Figure 4.20** Block diagram of a dc power supply.
- The first block of a dc power supply is the power transformer
    - it is used to step down (or step up) the line ac voltage (of 120V or 230V rms)
    - to the desired ac voltage required to yield the particular dc voltage output of the supply
    - for example, a secondary voltage of 8V rms may be required for a dc output of 5V,

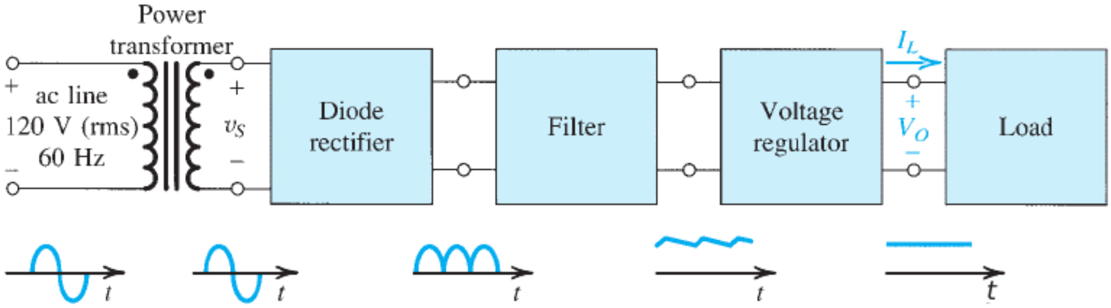
  - which can be achieved by using a transformer with turn ratio of 15:1 (if line voltage is 120V rms)
  - The power transformer also provide
    - electrical isolation between the electronic equipment and the ac line.
    - this isolation reduces the risk of electric shock to the equipment user.



- **Figure 4.20** Block diagram of a dc power supply.
  - The diode rectifier then
    - convert the ac voltage v_S to a unipolar output voltage
  - this waveform has a non-zero average component,
    - but it is pulsating
    - and can not be readily used as a dc source for electronic circuits.

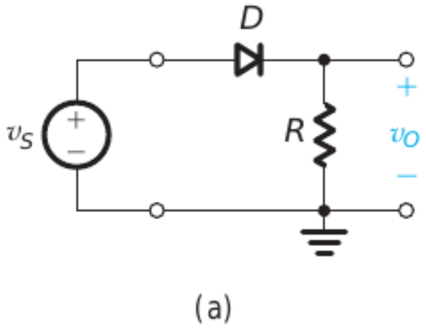


- **Figure 4.20** Block diagram of a dc power supply.
  - Thus a filter block is required
    - to minimize the variations in the
    - magnitude of the rectifier output.
  - A single capacitor can be used as an output filter.
  - The output of the filter block is thus much more constant
    - than without the filter, but it still has a
    - time-dependent component called ripple.



- Figure 4.20 Block diagram of a dc power supply.
    - This time-dependent component, “ripple ” is minimized by using a voltage regulator.
    - The voltage regulator not only minimize the ripple component but also provide load regulation ($\frac{\Delta v_O}{\Delta I_L}$)

The Half-Wave Rectifier

- utilizes alternate half-cycles of the input sinusoid
    - 

    - using the constant-voltage-drop model for the diode
    - $= \Rightarrow v_O = \begin{cases} 0 & , v_S < V_D \\ v_S - V_D & , v_S \geq V_D \end{cases}.$
    - where V_D is the constant voltage drop across the conducting diode, typically around 0.7V

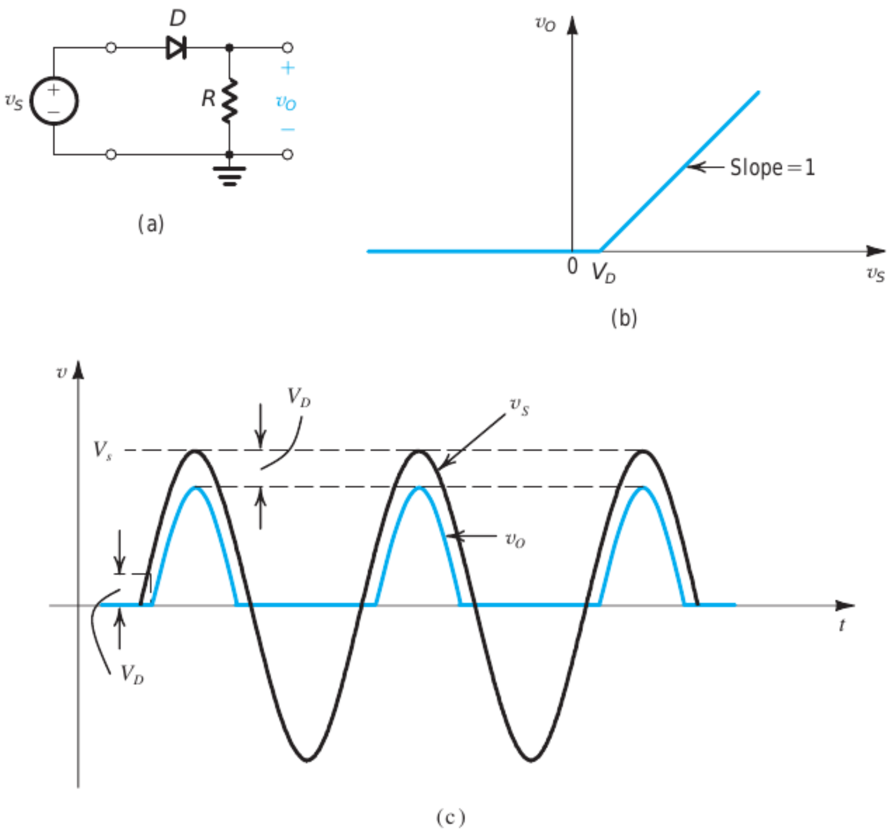
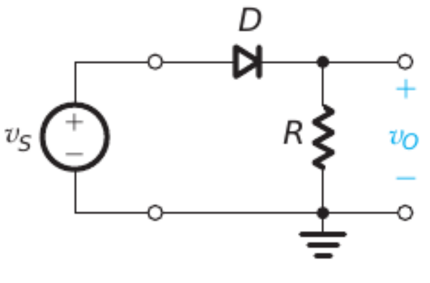
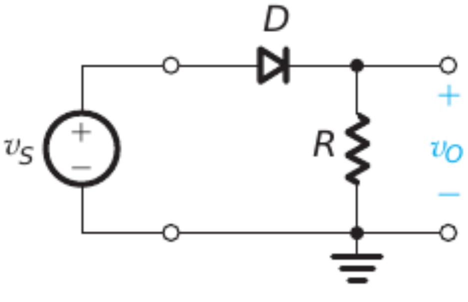


Figure 4.21 **(a)** Half-wave rectifier. **(b)** Transfer characteristic of the rectifier circuit. **(c)** Input and output waveforms.

- While selecting diodes for rectifier applications, two important parameters must be specified
    1. The current handling capability of the diode
        - which is the largest current the diode is expected to conduct
    2. The peak inverse voltage (PIV) that the diode must be able to withstand without breakdown
        - which is the largest reverse voltage that appears across the diode



- (a)



- (a)

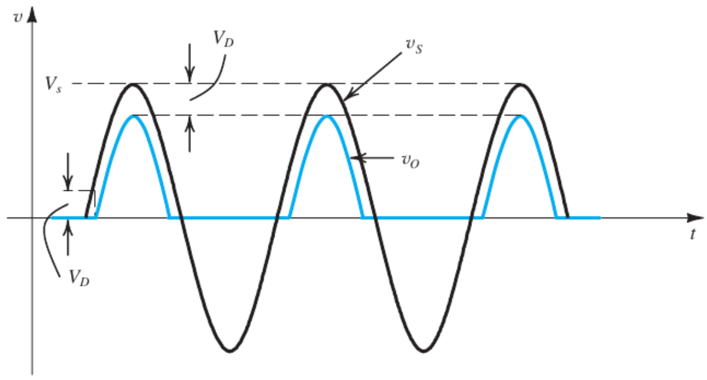
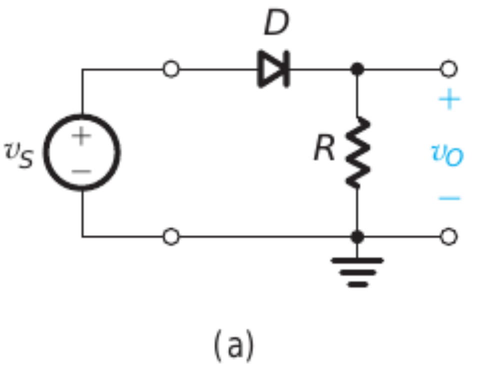


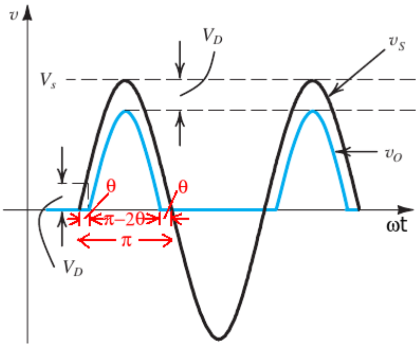
Figure 4.21 **(c)** Input and output waveforms. (c)

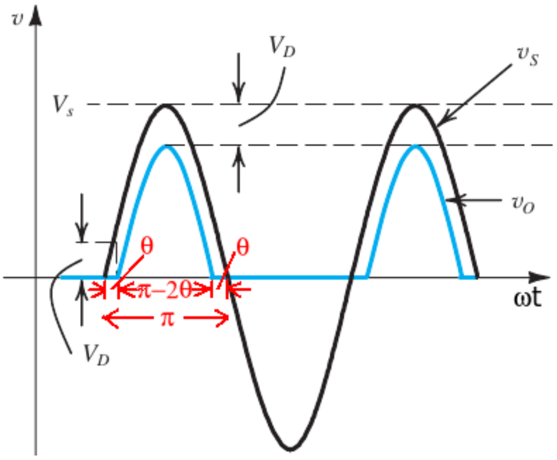
- Note that when v_S is -ve,
  - the diode will be cutoff
  - and v_O will be zero
- $= \Rightarrow$ PIV equals the peak of v_S
- i.e. $PIV = V_S$

Exercise 4.19

- For the half-wave rectifier circuit in Fig 4.21(a), show the following: (a) For the half-cycles during which the diode conducts, conduction begins at an angle $\theta = \sin^{-1}(V_D/V_S)$ and terminates at $(\pi - \theta)$, for a total conduction angle of $(\pi - 2\theta)$. (b) The average value (dc component) of v_O is $V_O \approx (1/pi)V_S - V_D/2$. (c) The peak diode current is $(V_S - V_D)/R$.
- Find numerical values for these quatities for the case of 12V (rms) sinusoidal input, $V_D = 0.7V$, and $R = 10\Omega$. Also give the value of PIV.
- 

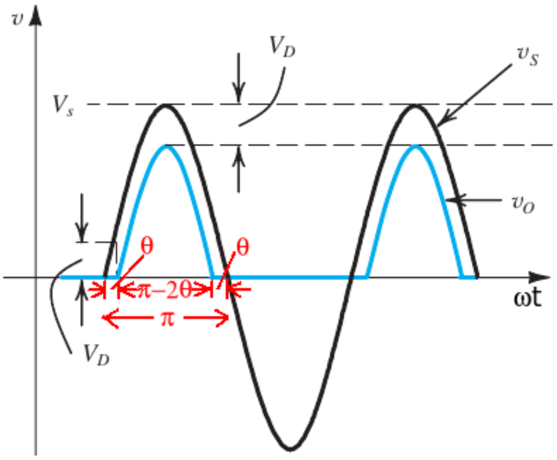
Exercise 4.19a

- For the half-wave rectifier circuit in Fig 4.21(a), show the following: (a) For the half-cycles during which the diode conducts, conduction begins at an angle $\theta = \sin^{-1}(V_D/V_S)$ and terminates at $(\pi - \theta)$, for a total conduction angle of $(\pi - 2\theta)$.
  - 

  - diode will conduct when $v_S \geq V_D$
  - when $\omega t = \theta = \Rightarrow v_S = V_D$
    - $v_S = V_S \sin\theta = V_D = \Rightarrow \theta = \sin^{-1}\left(\frac{V_D}{V_S}\right)$
- diode will conduct when $v_S \geq V_D$
  - when $\omega t = \theta = \Rightarrow v_S = V_D$
    - $v_S = V_S \sin\theta = V_D = \Rightarrow \theta = \sin^{-1}\left(\frac{V_D}{V_S}\right)$
    - 

  - from the figure diode conducts for angle of $\pi - 2\theta$
  - for $V_D = 0.7V$, $V_S = 12\sqrt{2} = 16.97V$
    - $\theta = \sin^{-1}\left(\frac{V_D}{V_S}\right) = \sin^{-1}\left(\frac{0.7}{16.97}\right) = 0.041rad = 2.364^o$
    - $= \Rightarrow$conduction angle = $\pi - 2\theta = 180^o - 2(2.364)^o = 175.272^o$

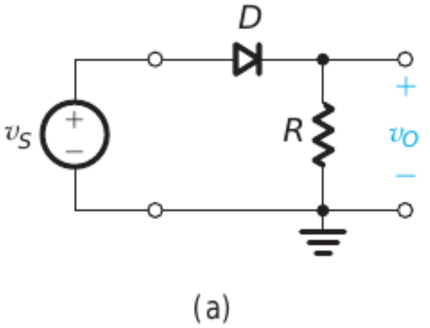
Exercise 4.19b

- For the half-wave rectifier circuit in Fig 4.21(a), show the following: (b) The average value (dc component) of v_O is $V_O \approx (1/pi)V_S - V_D/2$.
  - $v_{O,ave} = v_{O,average} = ?$
    - $v_{O,ave} = \frac{1}{T}\int_0^T v_O(t)dt = \frac{1}{2\pi}\int_0^{2\pi} v_O(\omega t)d(\omega t)$
    - from fig $v_O\left(\omega t\right) = \begin{cases} 0 & ,0 \leq \omega t \leq \theta \\ v_S - V_D & ,\theta \leq \omega t \leq \pi - \theta \\ 0 & ,\pi - \theta \leq \omega t \leq 2\pi \end{cases}$.
    - $v_S = V_S \sin(\omega t)$
    - 

- $= \Rightarrow v_{O,ave} = \frac{1}{2\pi}\int_0^{2\pi} v_O(\omega t) d(\omega t) = \frac{1}{2\pi}\int_\theta^{\pi-\theta}\left\{V_S \sin(\omega t) - V_D\right\} d(\omega t)$

- $v_{O,ave} = \frac{1}{2\pi}\int_\theta^{\pi-\theta}\left\{V_S \sin(\omega t) - V_D\right\} d(\omega t)$
  - $v_{O,ave} = \frac{1}{2\pi}\left[\int_\theta^{\pi-\theta} V_S \sin(\omega t) d(\omega t) - \int_\theta^{\pi-\theta} V_D d(\omega t)\right]$
  - $v_{O,ave} = \frac{1}{2\pi}\left[V_S[-\cos(\omega t)]_\theta^{\pi-\theta} - V_D\left(\pi - \theta - \theta\right)\right]$
  - $v_{O,ave} = \frac{1}{2\pi}\left[V_S[-\cos(\pi-\theta) + \cos\theta] - V_D(\pi - 2\theta)\right]$
  - for $\theta \to 0 = \Rightarrow \pi - 2\theta \approx \pi$, $cos(\theta) \approx 1$ and $cos(\pi - \theta) \approx cos(\pi) = -1$
    - $v_{O,ave} = \frac{1}{2\pi}\left[V_S[-(-1)+1] - V_D(\pi)\right] = \frac{1}{2\pi}\left[2V_S - V_D(\pi)\right]$
    - $v_{O,ave} = \frac{V_S}{\pi} - \frac{V_D}{2}$
  - for $V_S = 16.97V$ and $V_D = 0.7V$
    - $= \Rightarrow v_{O,ave} = \frac{V_S}{\pi} - \frac{V_D}{2} = \frac{16.97}{\pi} - \frac{0.7}{2} = 5.0517V$

Exercise 4.19c

- For the half-wave rectifier circuit in Fig 4.21(a), show the following: (c) The peak diode current is $(V_S - V_D)/R$.
  - Also give the value of PIV.
  - 

  - peak diode current occurs when the diode is conducting
    - and the load is getting the peak current
    - i.e. when v_O is at maximum
  - peak output voltage is $V_S - V_D$

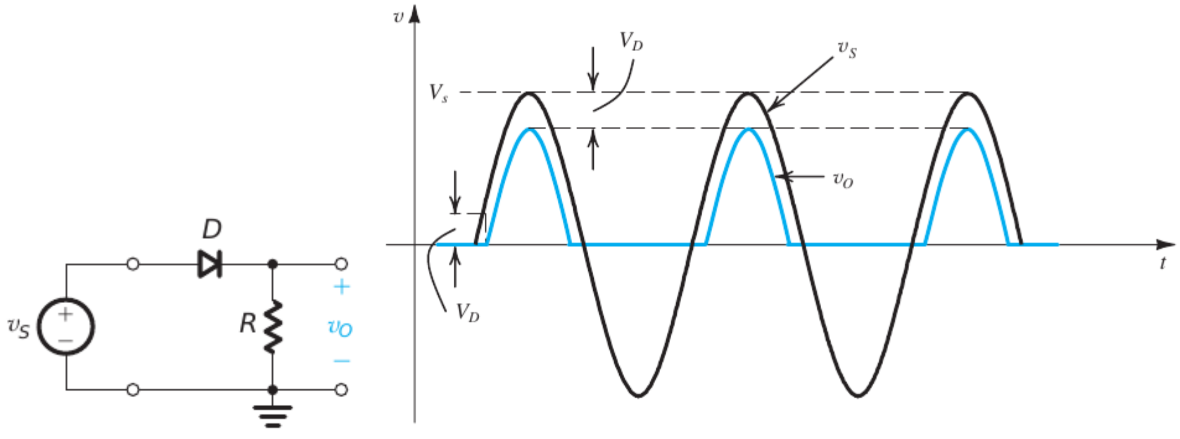
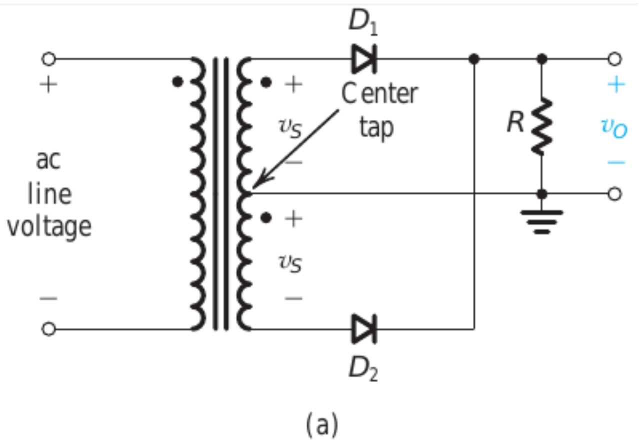
- 

  Figure 4.21 **(c)** Input and output waveforms.
  - peak output voltage is $V_S - V_D$
  - $= \Rightarrow$ peak output current =peak diode current

$=\frac{V_S - V_D}{R} = \frac{16.97-0.7}{100} = 162.7mA$

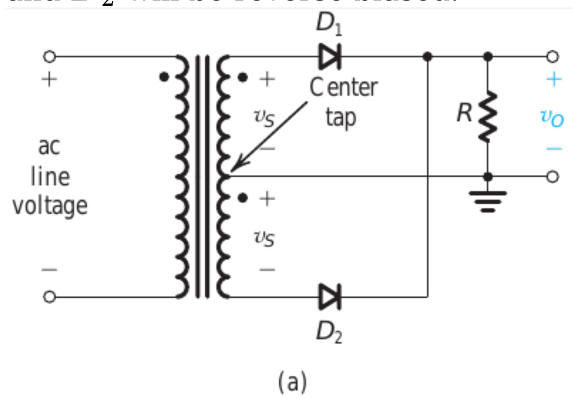
- $PIV = V_S = 16.97V$

The Full-Wave Rectifier using a Center-tapped Transformer

- utilizes both halves of the input sinusoid
  - to provide unipolar output, it inverts the negative halves of the input sine wave
  - One way to implement such a full wave rectifier is to
    - utilize a transformer with center-tapped secondary winding
  - 

- the transformer secondary winding is center-tapped to provide two equal voltages v_S

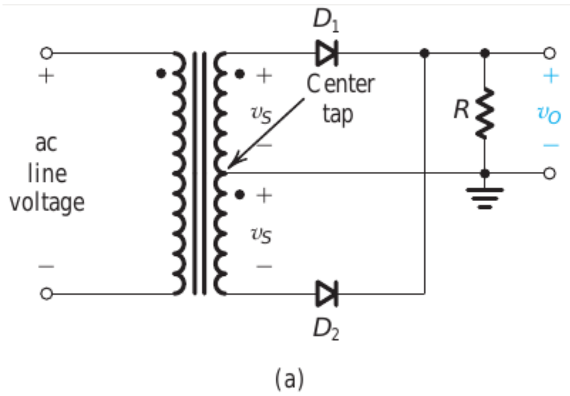
when the input line voltage is +ve

- both the voltages labeled v_S will be positive
  - $= \Rightarrow D_1$ will conduct
    - and D_2 will be reverse biased.
    - 

  - the current through D_1 will flow through R and then back to the center tap
  - thus the circuit behaves as a half-wave rectifier
    - and the diode D_1 conduct during the +ve half cycle of line voltage

when the input line voltage is -ve

- both the voltages labeled v_S will be negative
  - $= \Rightarrow D_1$ will be reverse biased.
    - D_2 will conduct (forward biased

- 

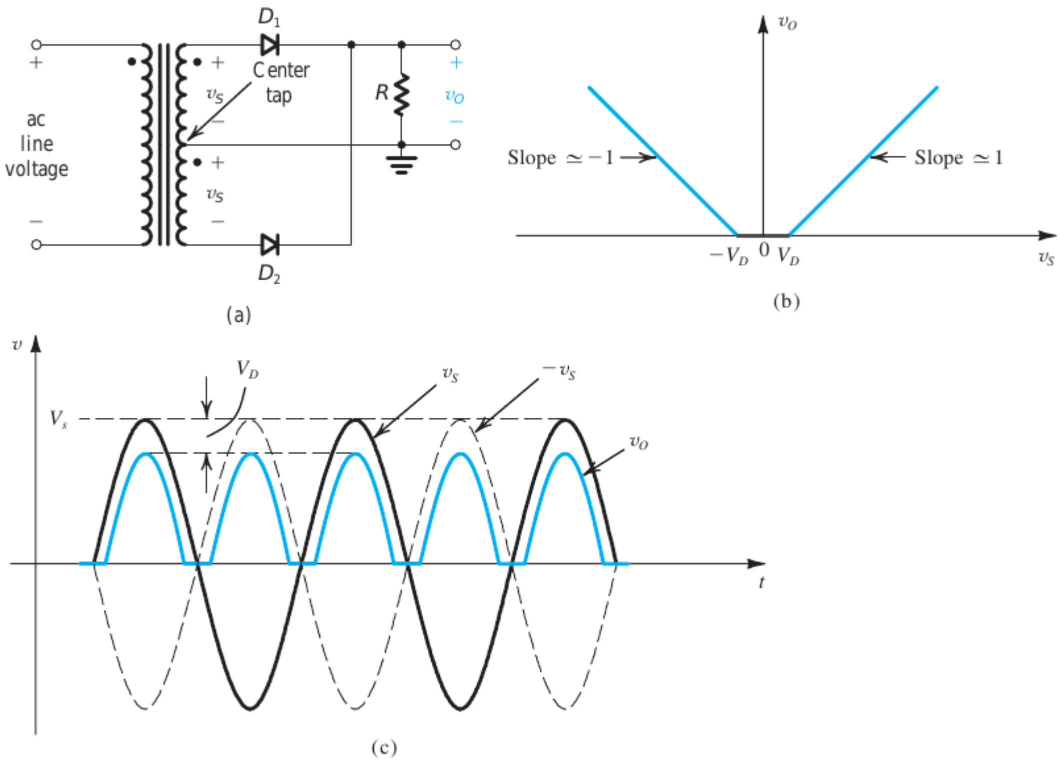
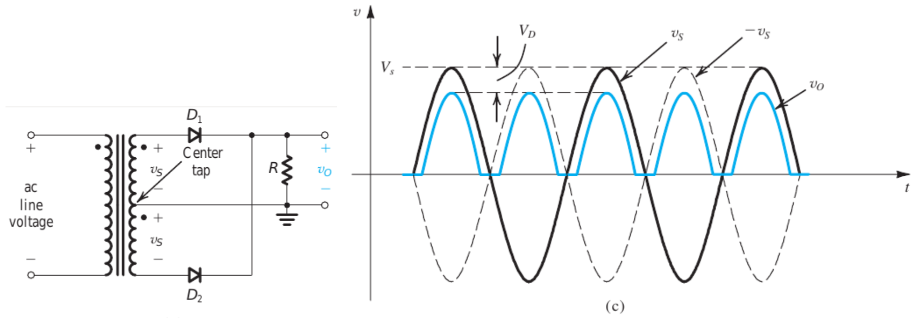
  - the current conducted through D_2 will flow through R and then back to the center tap
  - Thus the circuit is again acting as a half wave rectifier
    - during the negative-cycle with D_2 forward-biased
- Note that the current through R always flows in the same direction
  - $= \Rightarrow v_O$ will be unipolar
    - Using the constant voltage drop model for the diodes,
      - the transfer characteristic of this rectifier is
- 

Figure 4.22 Full-wave rectifier utilizing a transformer with a center-tapped secondary winding: **(a)** circuit; **(b)** transfer characteristic assuming a constant-voltage-drop model for the diodes; **(c)** input and output waveforms.

PIV (Peak Inverse Voltage)

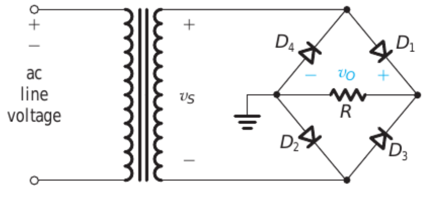
- during the +ve half cycle of line voltage,
  - D_1 is conducting and D_2 is reverse-biased (cut-off)

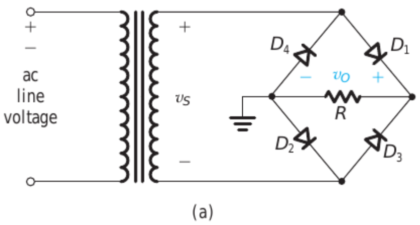
- 

  (a) (c) Figure 4.22 (c) input and output waveforms.

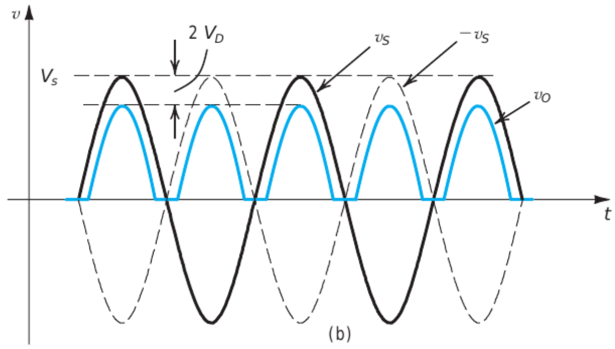
- PIV is the maximum reverse voltage across the diode D_2
  - the voltage at the cathode of D_2 is $v_O = v_S - V_D$ and $v_{O,max} = V_S - V_D$
    - the voltage at the anode of D_2 is $-v_S$ and when v_O is maximum $= \Rightarrow -v_S$ is at $-V_S$
    - $= \Rightarrow PIV$ =maximum reverse voltage across D_2
      - PIV =max voltage at cathode - max voltage at anode
      - PIV =$(V_S - V_D)$−$(-V_S)$= $2V_S - V_D$

The Bridge Rectifier

- A full wave rectifier can also be implemented using 4 diodes
  - 

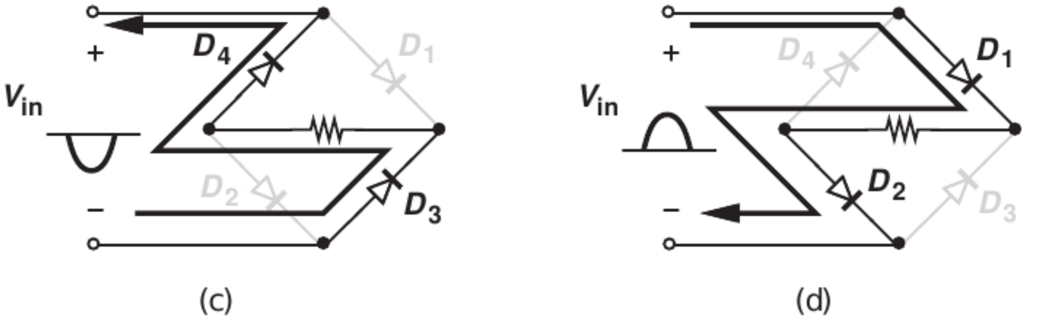
    (a)
    Figure 4.23 The bridge rectifier: (a) circuit;
  - this bridge rectifier doesnot require a center-tapped transformer
  - this rectifier however requires four diodes
    - instead of 2 incase of a full wave rectifier.
  - this is not much a disadvantage, as diodes are inexpensive and a diode bridge can be purchased in a single package
  - the operation of the bridge rectifier can be explained as follows
- 

  (a)
  Figure 4.23 The bridge rectifier: (a) circuit; (b) input and output waveforms.

  (b)
- During the positive half-cycle of the input-line voltage
  - v_s is positive $= \Rightarrow$ diodes D_1 and D_2 are forward-biased
    - D_3 and D_4 are reverse-biased
    - so the current flows through D_1, resistor R and D_2.
  - Note that there are two diodes in series in the conduction path.
  - $= \Rightarrow v_O$ will be lower than v_S by two diode drops
    - $v_O = v_S - 2V_D$

- During the negative half-cycle of the input-line voltage
  - v_S is negative and $-v_S$ is positive
    - $= \Rightarrow$ diodes D_3 and D_4 are forward-biased
    - while D_1 and $D_2$are reverse-biased
    - so the current flows through D_3, resistor R and D_4.
- Note that during both half cycles,
  - current flows through R in the same direction



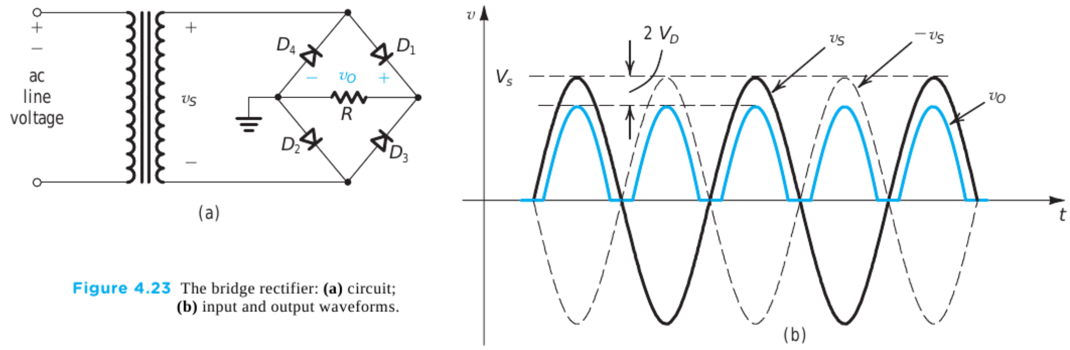
  - (c) current path for negative input, (d) current path for positive input.
  - $= \Rightarrow v_O$ will always be positive
- v_O is unipolar
  - 

Figure 4.23 The bridge rectifier: (a) circuit; (b) input and output waveforms.

PIV (Peak Inverse Voltage)

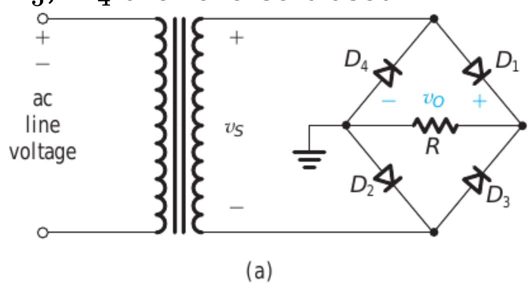
- During the +ve half cycle of line voltage
  - D_1, D_2 are conducting
  - D_3, D_4 are reverse biased
  - 

Figure 4.23 The bridge rectifier: (a) circuit;
  - for Diode D_3 , KVL along the loop formed by D_3 , R and D_2
    - $= \Rightarrow V_{D2,on} + v_O = v_{D3,off}$
    - $= \Rightarrow V_D + v_O = v_{D3,off} \because V_{D2,on} = V_D$
  - $v_{D3,off} = V_D + v_O$
  - the maximum value of $v_{D3,off}$ ocurrs when v_O is at its peak value of $V_S - 2V_D$
    - $= \Rightarrow PIV$ for D_3 = V_D +($V_S - 2V_D$)= $V_S - V_D$
  - Note that PIV for other diodes will be the same as for D_3

- PIV for bridge rectifier $= V_S - V_D$
    - PIV for full wave rectifier with center-tapped transformer $= 2V_S - V_D$
    - $= \Rightarrow$ {PIV for bridge rectifier} $\approx$ half of {PIV for full wave rectifier with center-tapped transformer}
