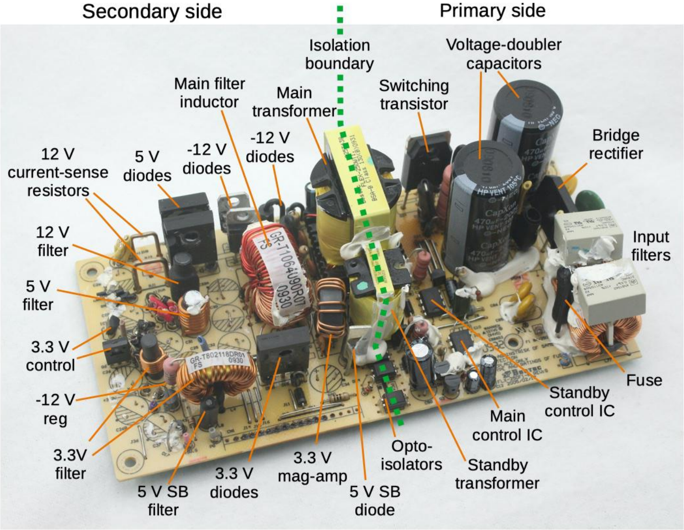

Rectifier Circuits

Kizito NKURIKIYEYEZU, Ph.D.

Rectifier Circuits

- The most important applications of diodes is in the design of rectifier circuits
- Rectifiers converts alternating current (AC) to DC current[1]

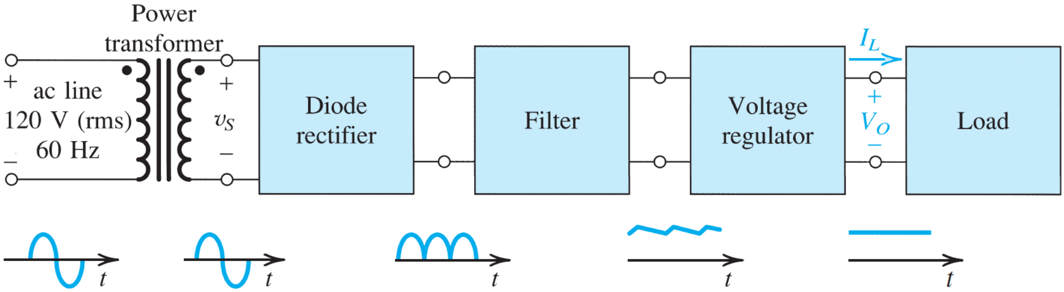

FIG 1. Block diagram of a dc power supply

The power supply is fed from the 120-V (rms) 60-Hz ac line, and it delivers a dc voltage V_o (usua in the range of 4 V to 20 V) to an electronic circuit represented by the load block. The dc voltage is required to be as constant as possible in spite of variations in the ac line voltage and in the current drawn by the load.

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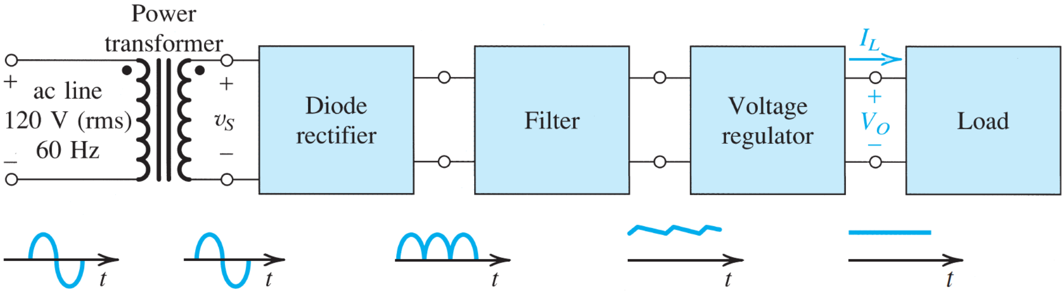

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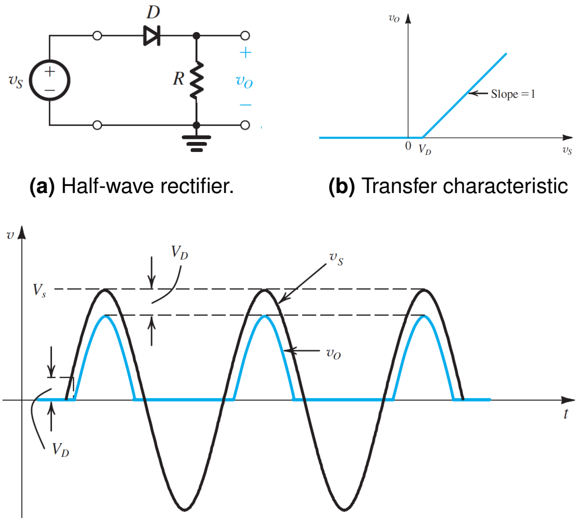
Half-wave rectifier

- A half-wave rectifier utilizes alternate half-cycles of the input sinusoid
- If we use the constant voltage drop diode model in Fig. 2:

$$v_O = \begin{cases} 0, & \text{if } v_S < V_D \\ v_S - V_D & \text{otherwise} \end{cases} \quad (1)$$



(a) Half-wave rectifier. **(b)** Transfer characteristic

(c) Input and output waveforms

FIG 2. Characteristics of a half-wave rectifier

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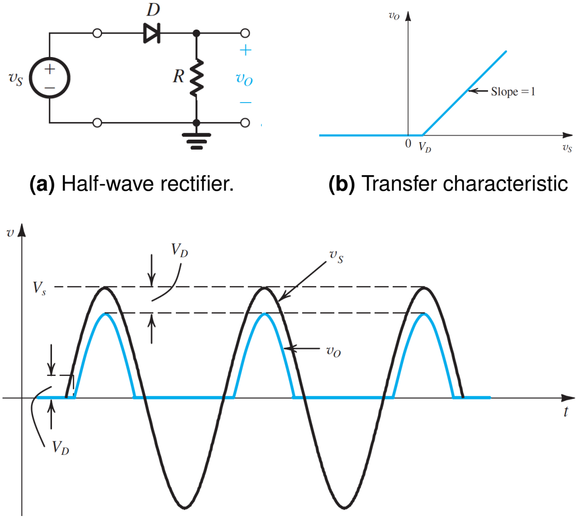

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Half-wave rectifier

In selecting diodes for rectifier design, two important parameters must be specified

- current-handling capability—what is maximum forward current diode is expected to conduct?
- peak inverse voltage (PIV)—what is maximum reverse voltage it is expected to block without breakdown?
  - When $v_s < 0$, the diode will be cut off and v_o will be zero and PIV is equal to the peak of v_s (Equation (2))

$$PIV = V_s \tag{2}$$

  - It is usually prudent, however, to select a diode that has a reverse breakdown voltage at least 50% greater than the expected PIV.
- **Note:**
  - It is possible to use the diode exponential model in describing rectifier operation; however, this requires too much work
  - The rectifier does not work well for small input voltage (e.g., $v_s < 100mV$). In this case, a precision rectifier (circuit with diode and op-amps) should be used.

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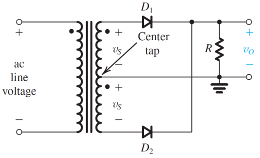
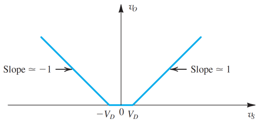
Full-wave rectifier

Full-wave rectifier

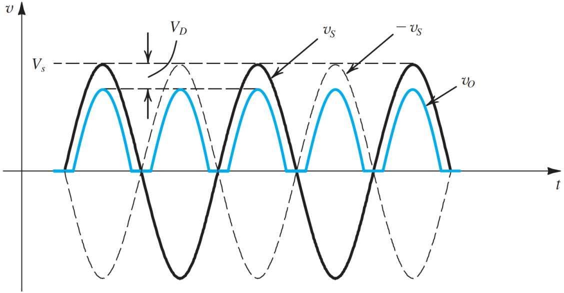
- The full-wave rectifier utilizes both halves of the input sinusoid.
- The center-tapping of the transformer, allowing “reversal” of certain currents



(a) Full-wave rectifier circuit



(b) Transfer characteristic



(c) Input and output waveforms

FIG 3. Full-wave rectifier utilizing a transformer with a center-tapped secondary winding

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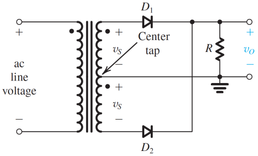

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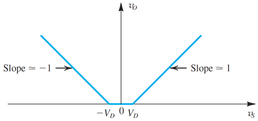

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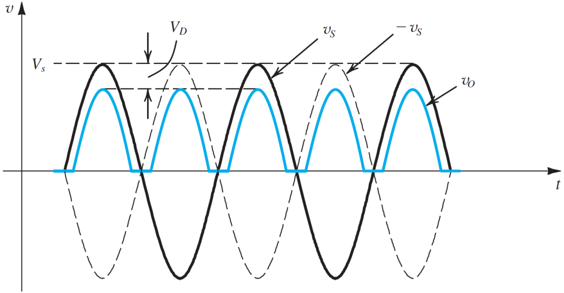

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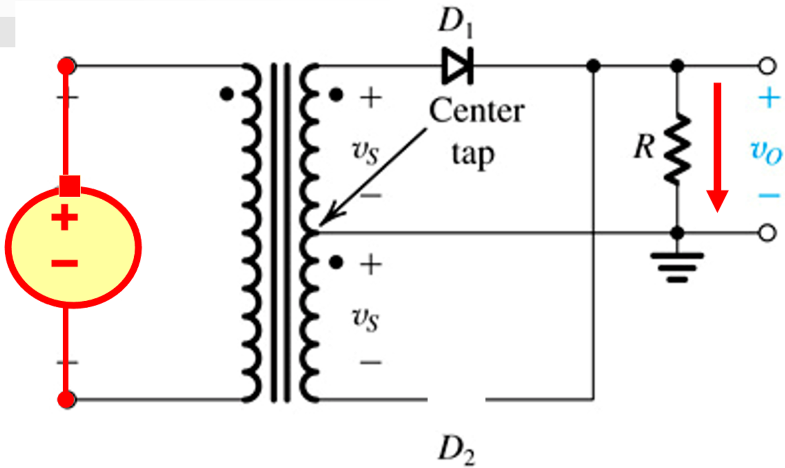
FIG 3. Full-wave rectifier utilizing a transformer with a center-tapped secondary winding

Working principle

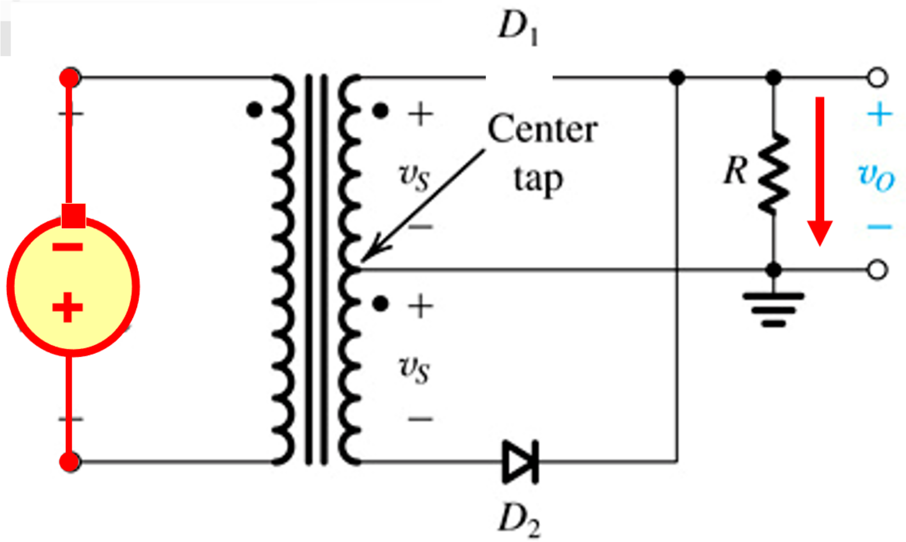
When $v_s > 0$, $D1$ conducts while $D2$ will be reverse biased. The current through D_1 will flow through R and back to the center tap of the secondary.



[1] https://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/rectifier/fullwaverectifier.html

Working principle

When $v_s < 0$, the situation reverses: D_2 conducts while D_1 blocks



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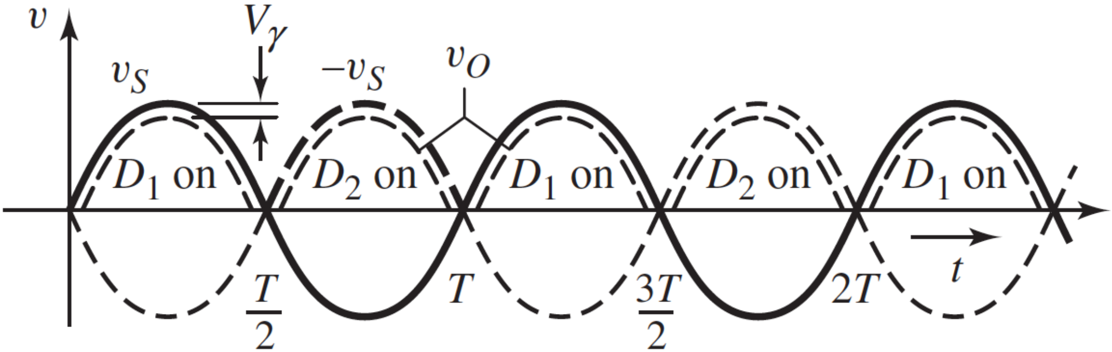


FIG 4. Full-wave rectifier working principle
When $v_s > V_D$, D_1 is on and D_2 is off. The output voltage is then $v_o = v_s - V_D$. When $v_s < V_D$, then for $v_s < -V_D$ or $-v_s > V_D$, D_1 is off and D_2 is on. The output voltage is $v_o = -v_s - v_D$[1]

[1] Adapted from Neamen, D. (2009). Microelectronics Circuit Analysis and Design (4th ed.)

Peak inverse voltage

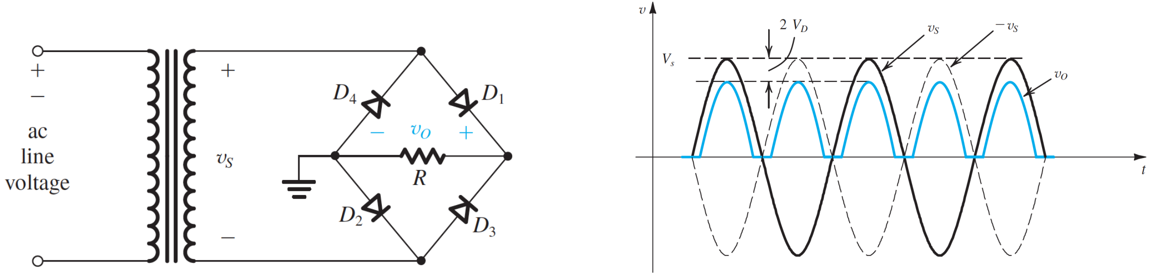
- The direction of current flowing across load never changes (both halves of AC wave are rectified). The full-wave rectifier produces a more “energetic” waveform than half-wave
- During the positive half-cycle:
  - diode D_1 is conducting, and D_2 is cut off. The voltage at the cathode of D_2 is v_o, and that at its anode is $-v_s$.
  - The reverse voltage across D_2 is $v_o + v_s$, and reaches the maximum when v_o is at its peak value of $V_p = V_s - V_D$
  - The peak inverse voltage is approximately twice that for the case of the half-wave rectifier as shown in Equation (3)

$$PIV = 2V_s - V_D \tag{3}$$

Bridge rectifier

Bridge rectifier

- Provides electrical isolation between the input ac powerline and the rectifier output, but does not require a center-tapped secondary winding.
- Uses four diodes, compared to only two in the previous circuit.
- Its Peak inverse voltage $VIP = V_s - 2V_D - V_D = V_s - V_D$ and is about half the value for the full-wave rectifier with a center-tapped transformer.



(a) Bridge rectifier circuit **(b)** input and output waveforms

FIG 5. A bridge rectifier

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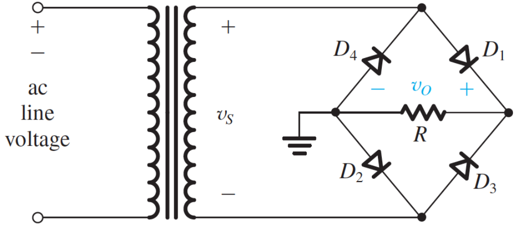

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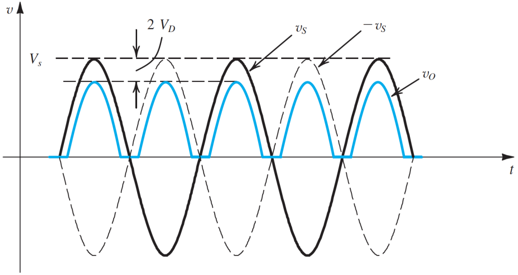

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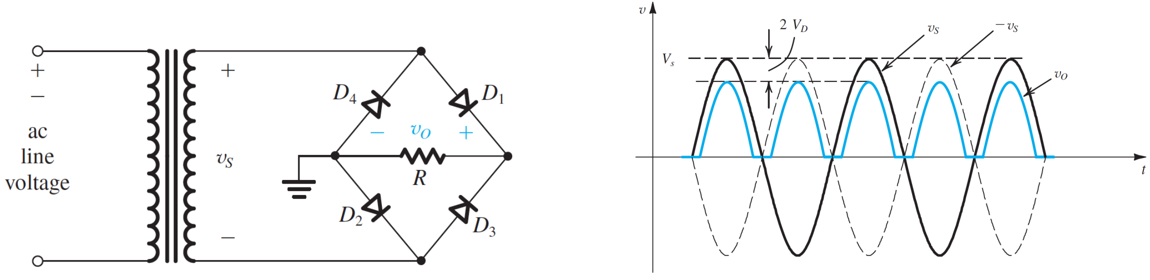

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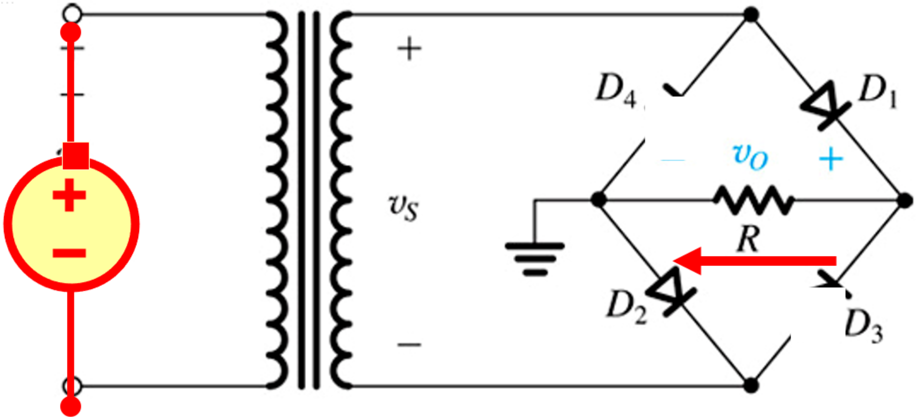
Working principles

- When the instantaneous source voltage $v_s > 0$, D_1 and D_2 conduct while D_3 and D_4 block
- In this case, the current passes from the source, then to D_1, then to D_2 and return back to the source.



Working principles

- When instantaneous source voltage is negative D_1 and D_2 block while D_3 and D_4 conduct
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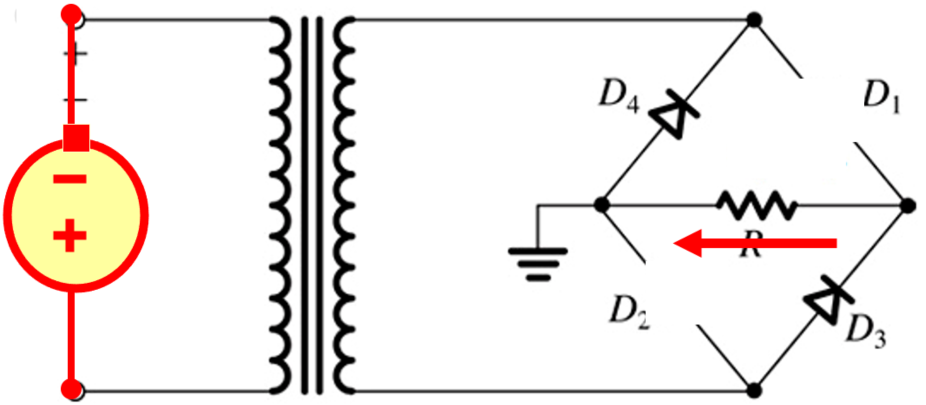
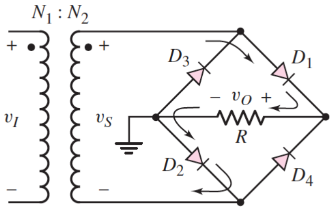
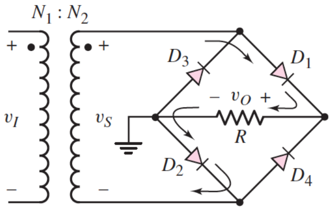




(a) Current direction for a positive input cycle



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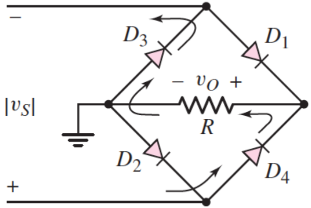

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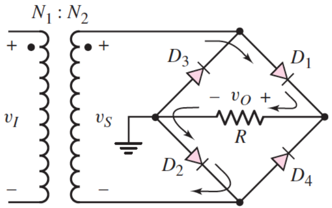

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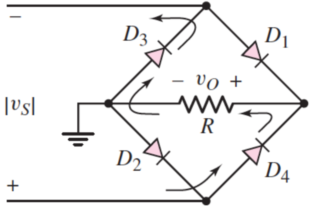

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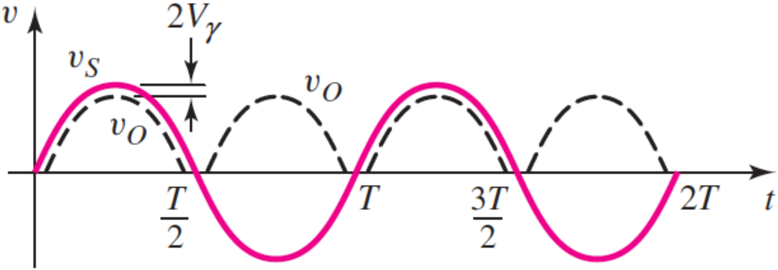
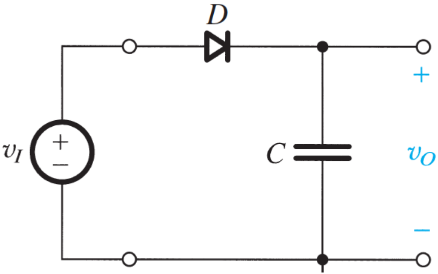


(c) Input and output waveforms

FIG 6. A full-wave bridge rectifier

The Peak Rectifier

- Pulsating nature of rectifier output makes unreliable dc supply.
- As such, a filter capacitor is employed to remove ripple.



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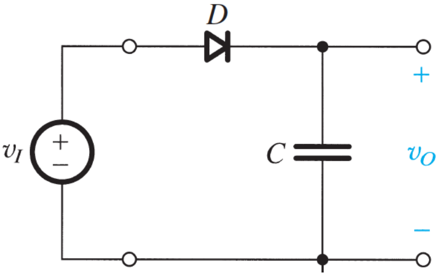

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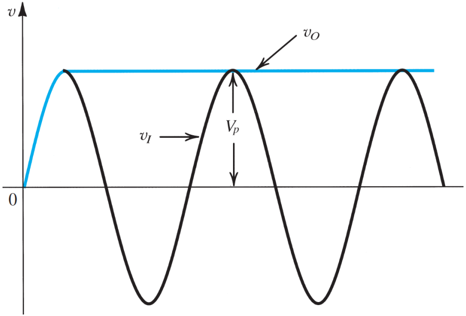

(b) Input and output assuming an ideal diode

FIG 7. A simple circuit used to illustrate the effect of a filter capacitor.
Note that the circuit provides a dc voltage equal to the peak of the input sine wave. The circuit is therefore known as *a peak rectifier or a peak detector*

The Peak Rectifier

The peak rectifiers works in three steps:

- Step1: The source voltage is positive, diode is ON—then capacitor charges.
- Step 2: The source voltage is reverse, diode is OFF—then capacitor cannot discharge
- Step 3: The source voltage is positive, diode is ON—then capacitor charges—thus, the capacitor maintains the existing voltage.
- This example is, of course, unrealistic because for any practical application, the converter would supply a load—which in turn provides a path for capacitor discharging.

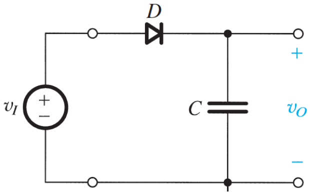

FIG 8. this is figure 1

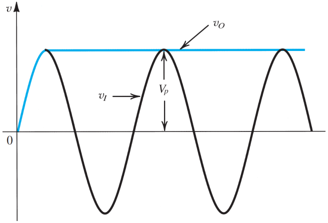

FIG 9. this is figure 2

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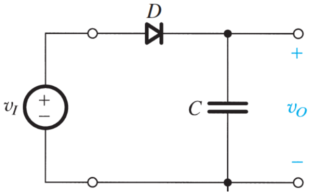

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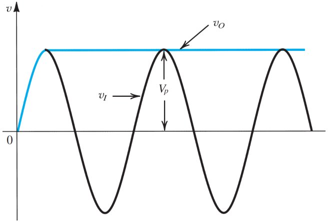

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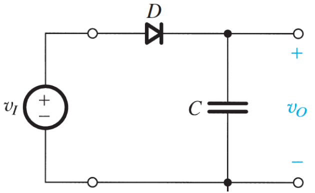

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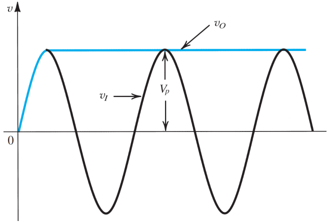

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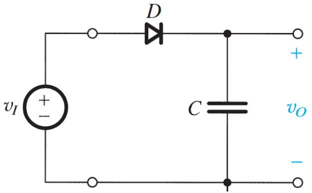

FIG 8. this is figure 1

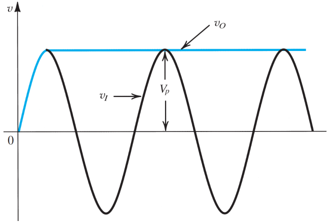

FIG 9. this is figure 2

Peak Rectifier with a load

- Practical situation where a load resistance R is connected across the capacitor C
- In this case, one must consider the discharging of capacitor across load.
- When diode is forward biased and conducting.

$$v_O(t) = v_I(t) - v_D \tag{4}$$

- When diode is reversed biased.

$$v_O(t) = V_{peak} e^{-\frac{t}{RC}} \tag{5}$$

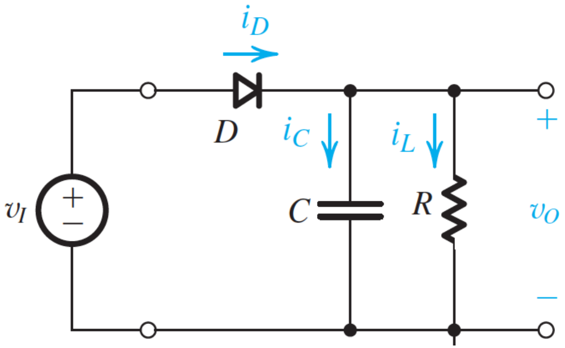

FIG 10. Rectifier with a filter capacitor and a load

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- Practical situation where a load resistance R is connected across the capacitor C
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- When diode is forward biased and conducting.

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- When diode is reversed biased.

$$v_O(t) = V_{peak} e^{-\frac{t}{RC}} \quad (5)$$

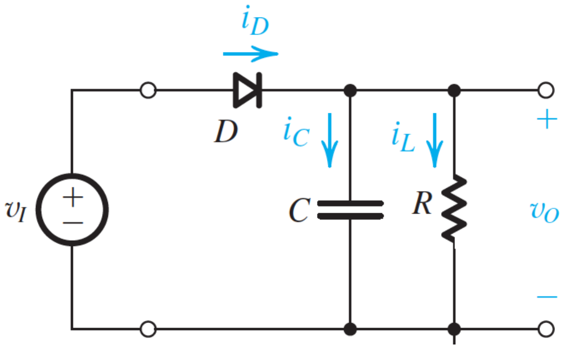

FIG 10. Rectifier with a filter capacitor and a load

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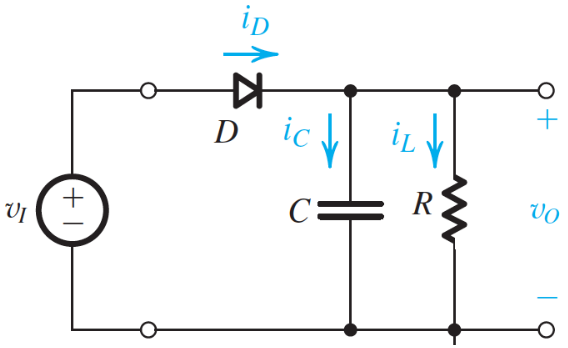

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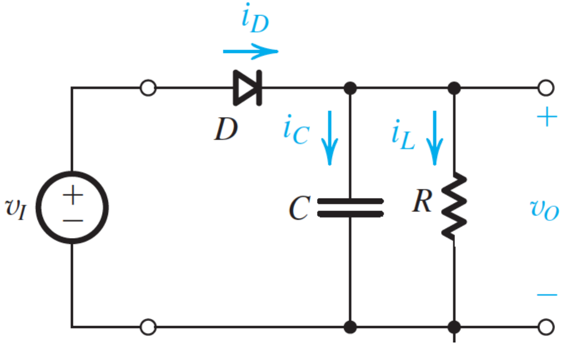

FIG 10. Rectifier with a filter capacitor and a load

Case 1: —when the diode is forward biased

- The load current i_L is given $i_L = v_o/R$
- The diode current is (Equation (6))

$$i_D = i_C + i_L = C\frac{dv_I}{dt} + i_L \quad (6)$$

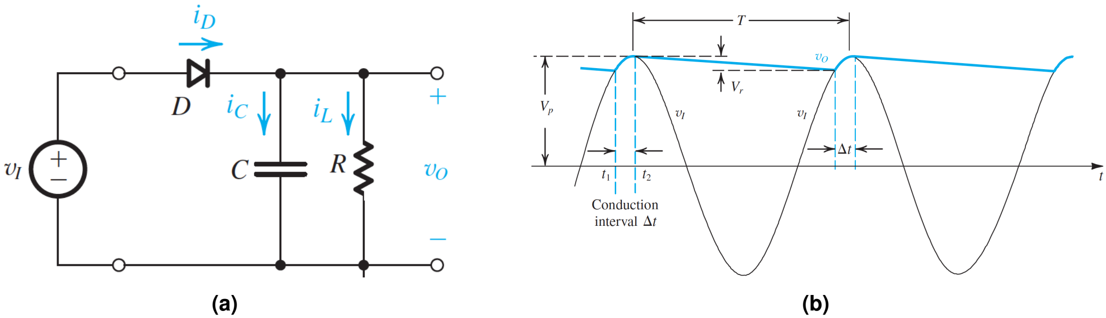

FIG 11. Peak rectifier with $v_I > 0$ for an ideal diode

Fig. 11b shows the steady-state input and output voltage under the assumption that $CR \gg T$

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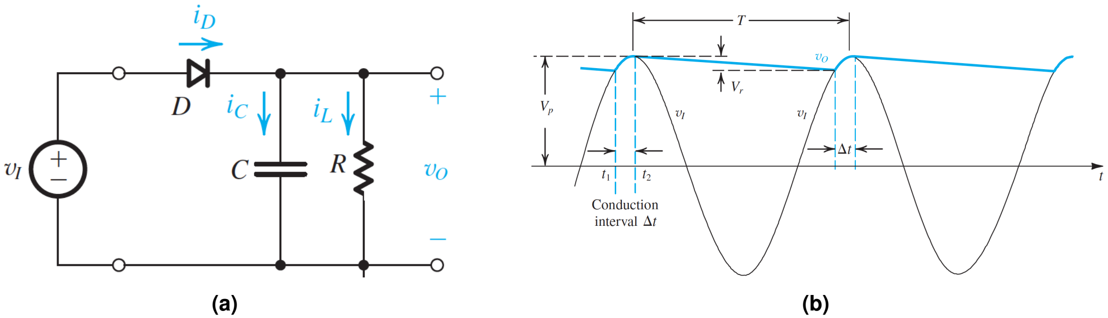
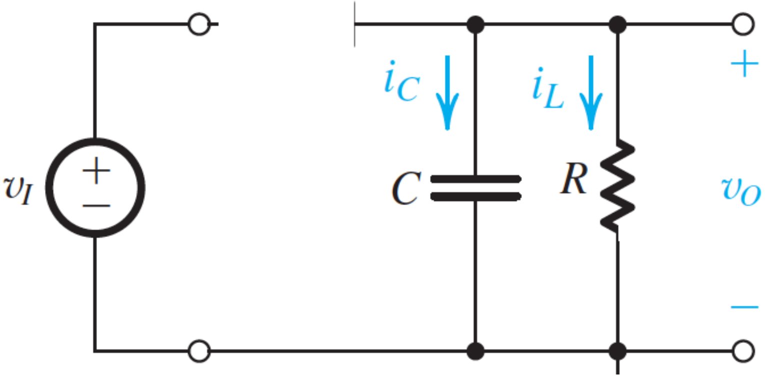


FIG 11. Peak rectifier with $v_I > 0$ for an ideal diode

Fig. 11b shows the steady-state input and output voltage under the assumption that $CR \gg T$

Case 2: —when the diode is reverse biased

- The diode current is $i_D = 0$
- The output voltage v_o is $v_o = Ri_L$
- The load current is $i_L = -i_C$



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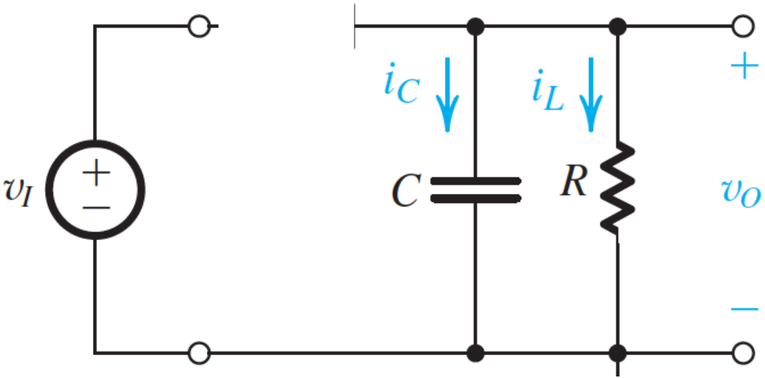

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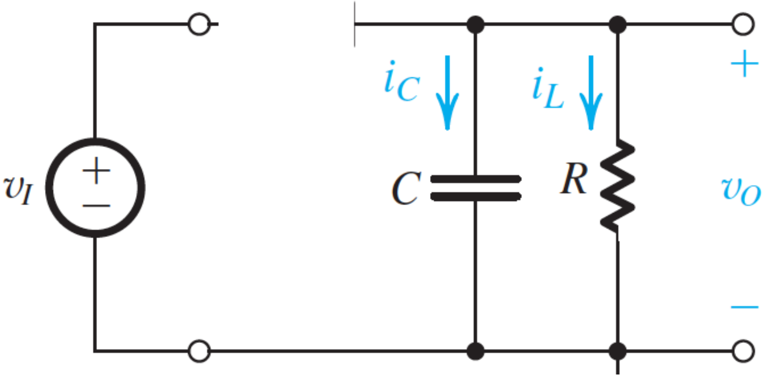

Full-wave peak rectifier.

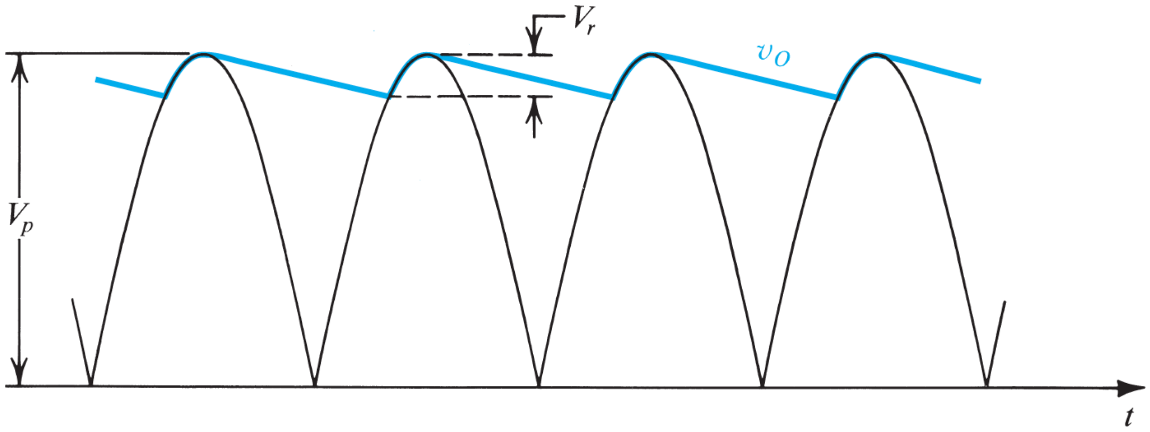

FIG 12. Waveforms in the full-wave peak rectifier.

The end