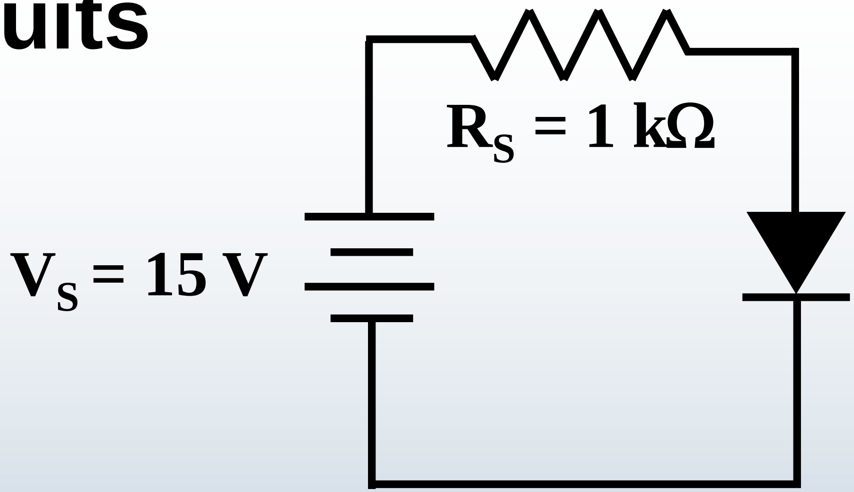
EEE 111
Diode Applications

Topic 2 (Chapter 2)

Solving Diode Circuits



A circuit like this can be solved in several ways:

1. Use the first approximation or ideal equivalent circuit

$$V_D = V_{FB} = V_{ON} = 0V; I_D = I_{RB} = I_{OFF} = 0A$$

2. Use the second approximation or simplified equivalent circuit or constant voltage drop model

$$V_D = V_{FB} = V_{ON} = 0.7V(Si)/0.3V(Ge)/1.2V(GaAs)$$

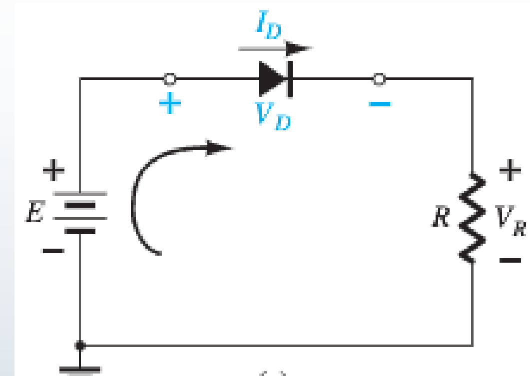
$$I_D = I_{RB} = I_{OFF} = 0A$$

3. Use the diode's characteristic curve (load line analysis)

2.2 Load-Line Analysis

$$+E - V_D - V_R = 0$$

$$\boxed{E = V_D + I_D R}$$

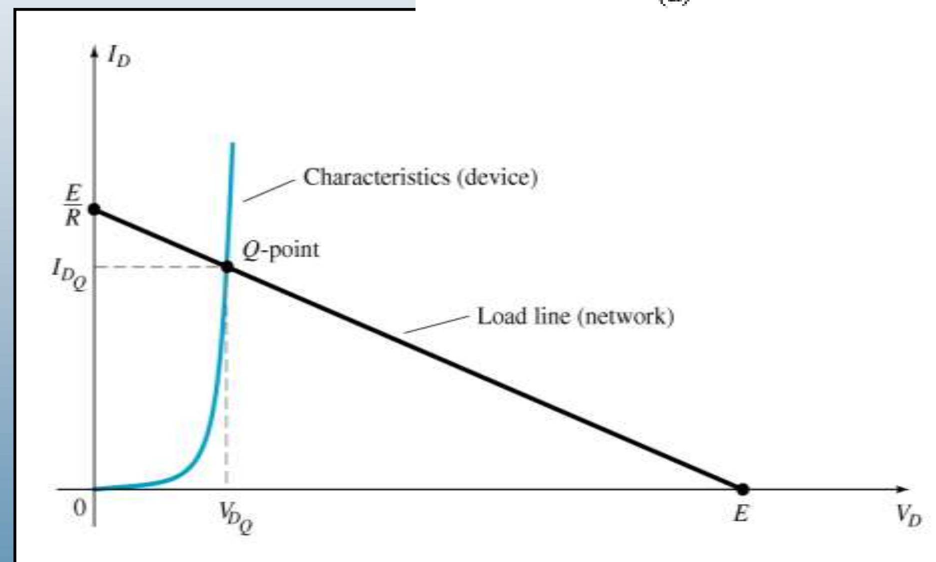


(a)

$$V_D = 0V \rightarrow I_D = \frac{E}{R} = I_{MAX}$$

$$I_D = 0A \rightarrow V_D = E = V_{MAX}$$

The load line plots all possible combinations of diode current (I_D) and voltage (V_D) for a given circuit. The maximum I_D equals E/R, and the maximum V_D equals E.



The point where the load line and the characteristic curve intersect is the Q-point, which identifies I_D and V_D for a particular diode in a given circuit.

Load-Line Analysis

- The solution found by load-line analysis is similar to that obtained by a simultaneous solution of

$$I_D = \frac{E}{R} - \frac{V_D}{R}$$

$$I_D = I_s(e^{V_D/nV_T} - 1)$$

(assuming this theoretical diode curve is very close to the actual curve.)

- The mathematics involved would require the use of nonlinear techniques that are beyond the needs and scope of this course.

EXAMPLE 2.1

- For the series diode configuration of Fig. 2.3a, employing the diode characteristics of Fig. 2.3b, determine:

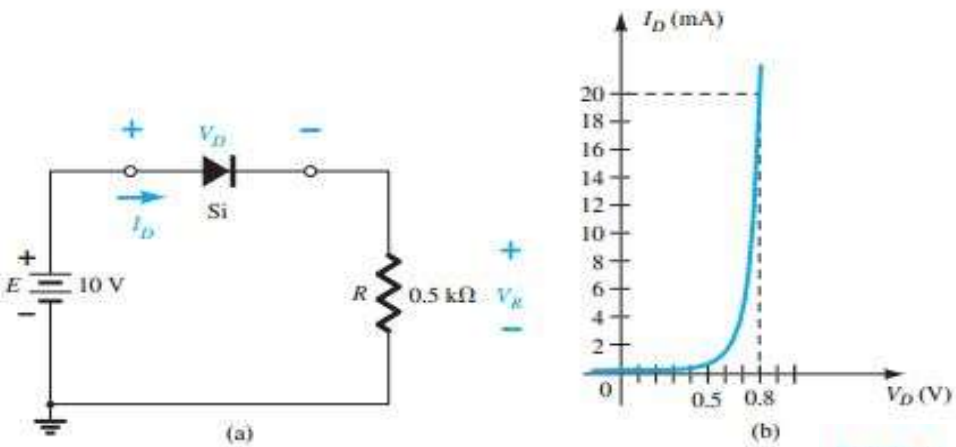


FIG. 2.3
(a) Circuit; (b) characteristics.

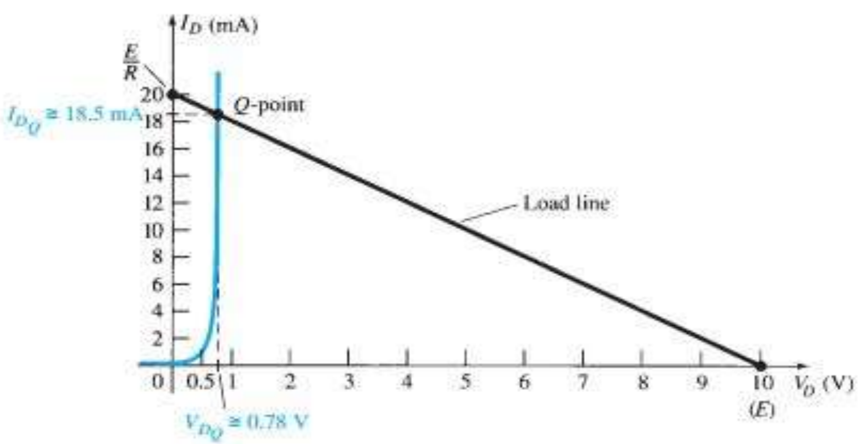


FIG. 2.4
Solution to Example 2.1.

Solution:

a. Eq. (2.2): $I_D = \dfrac{E}{R}\Big|_{V_D=0\,V} = \dfrac{10\,V}{0.5\,k\Omega} = 20\,mA$

Eq. (2.3): $V_D = E|_{I_D=0\,A} = 10\,V$

The resulting load line appears in Fig. 2.4. The intersection between the load line and the characteristic curve defines the *Q*-point as

$$V_{D_Q} \cong \mathbf{0.78\,V}$$
$$I_{D_Q} \cong \mathbf{18.5\,mA}$$

The level of V_D is certainly an estimate, and the accuracy of I_D is limited by the chosen scale. A higher degree of accuracy would require a plot that would be much larger and perhaps unwieldy.

b. $V_R = E - V_D = 10\,V - 0.78\,V = \mathbf{9.22\,V}$

2.3 Series Diode Configurations

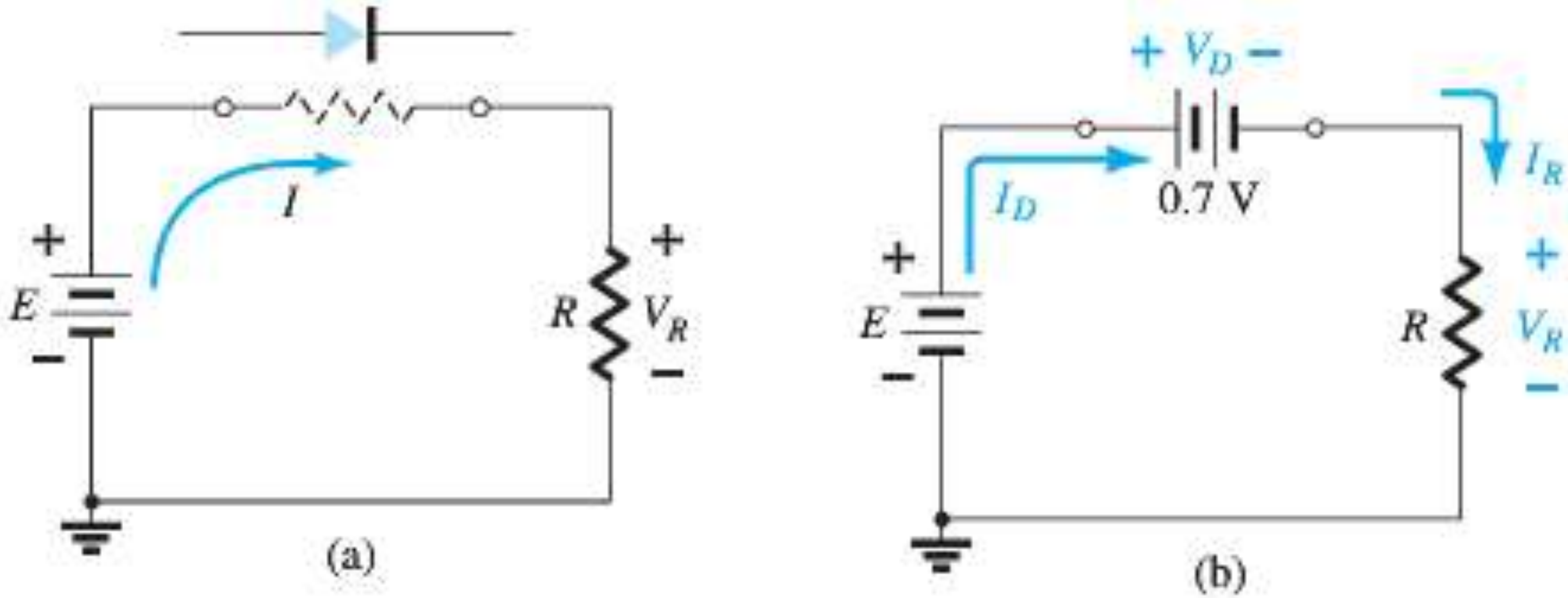


FIG. 2.9
(a) Determining the state of the diode of Fig. 2.8; (b) substituting the equivalent model for the "on" diode of Fig. 2.9a.

$$\boxed{V_D = V_K}$$

$$\boxed{V_R = E - V_K}$$

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

Reversing the diode

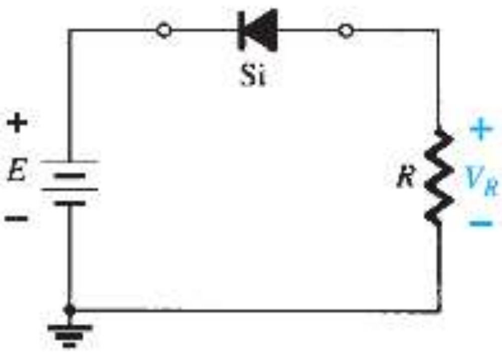


FIG. 2.10
Reversing the diode of Fig. 2.8.

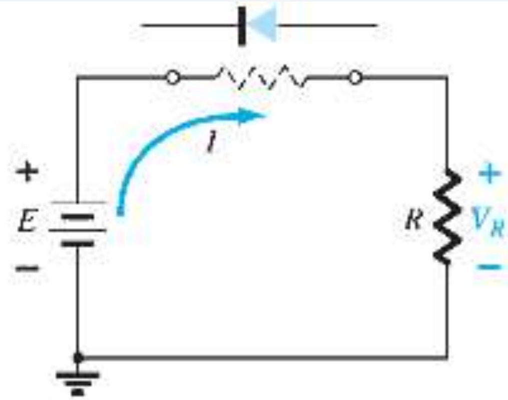


FIG. 2.11
Determining the state of the diode of Fig. 2.10.

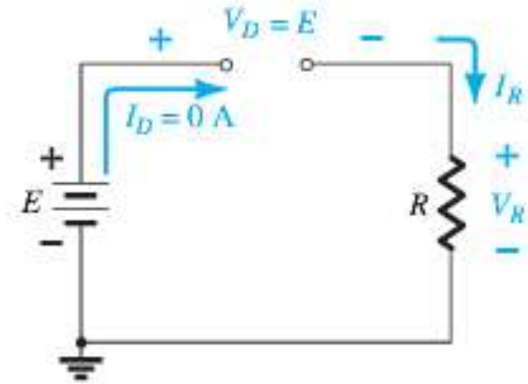


FIG. 2.12
Substituting the equivalent model for the "off" diode of Fig. 2.10.

$$V_R = I_R R = I_D R = (0\,\text{A})R = \mathbf{0\,V}$$

EXAMPLE 2.4 For the series diode configuration of Fig. 2.13, determine V_D, V_R, and I_D.

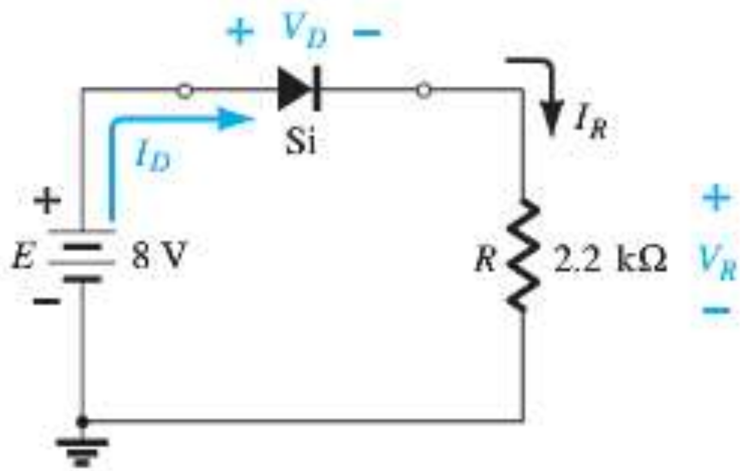


FIG. 2.13
Circuit for Example 2.4.

Solution: Since the applied voltage establishes a current in the clockwise direction to match the arrow of the symbol and the diode is in the "on" state,

$$V_D = \mathbf{0.7\ V}$$

$$V_R = E - V_D = 8\ \text{V} - 0.7\ \text{V} = \mathbf{7.3\ V}$$

$$I_D = I_R = \frac{V_R}{R} = \frac{7.3\ \text{V}}{2.2\ \text{k}\Omega} \cong \mathbf{3.32\ mA}$$

EXAMPLE 2.5 Repeat Example 2.4 with the diode reversed.

Solution: Removing the diode, we find that the direction of I is opposite to the arrow in the diode symbol and the diode equivalent is the open circuit no matter which model is employed. The result is the network of Fig. 2.14, where $I_D = \mathbf{0\ A}$ due to the open circuit. Since $V_R = I_R R$, we have $V_R = (0)R = \mathbf{0\ V}$. Applying Kirchhoff's voltage law around the closed loop yields

$$E - V_D - V_R = 0$$

and

$$V_D = E - V_R = E - 0 = E = 8\ \text{V}$$

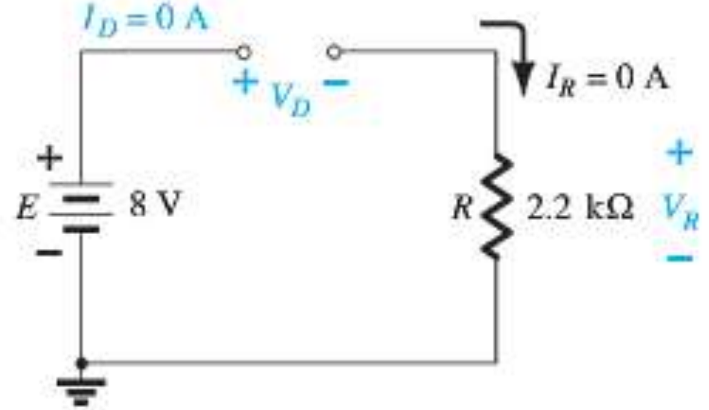


FIG. 2.14
Determining the unknown quantities for Example 2.5.

EXAMPLE 2.6 For the series diode configuration of Fig. 2.16, determine V_D, V_R, and I_D.

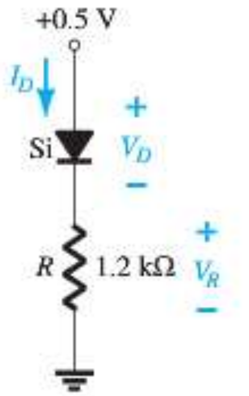


FIG. 2.16
Series diode circuit for Example 2.6.

Solution: Although the "pressure" establishes a current with the same direction as the arrow symbol, the level of applied voltage is insufficient to turn the silicon diode "on." The point of operation on the characteristics is shown in Fig. 2.17, establishing the open-circuit equivalent as the appropriate approximation, as shown in Fig. 2.18. The resulting voltage and current levels are therefore the following:

$$I_D = \mathbf{0\ A}$$

$$V_R = I_R R = I_D R = (0\,\text{A})\,1.2\,\text{k}\Omega = \mathbf{0\ V}$$

and

$$V_D = E = \mathbf{0.5\ V}$$

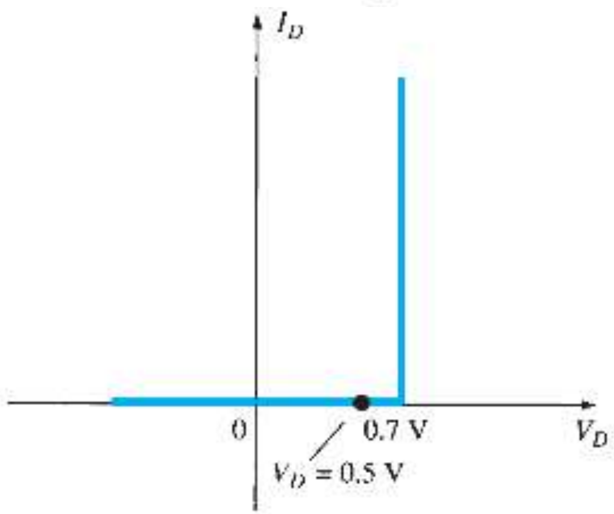


FIG. 2.17
Operating point with $E = 0.5$ V.

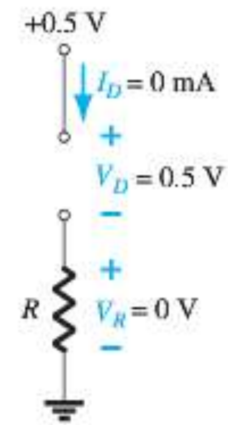


FIG. 2.18
Determining I_D, V_R, and V_D for the circuit of Fig. 2.16.

EXAMPLE 2.7 Determine V_o and I_D for the series circuit of Fig. 2.19.

Assume 1.8V forward voltage drop for the red LED.

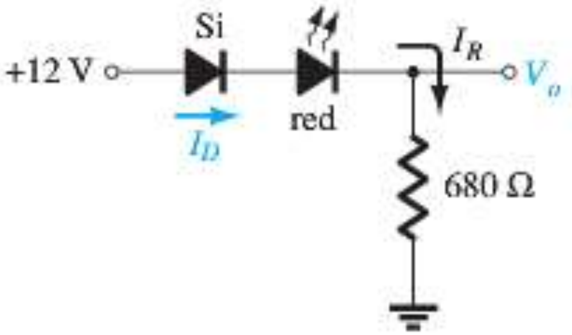


FIG. 2.19
Circuit for Example 2.7.

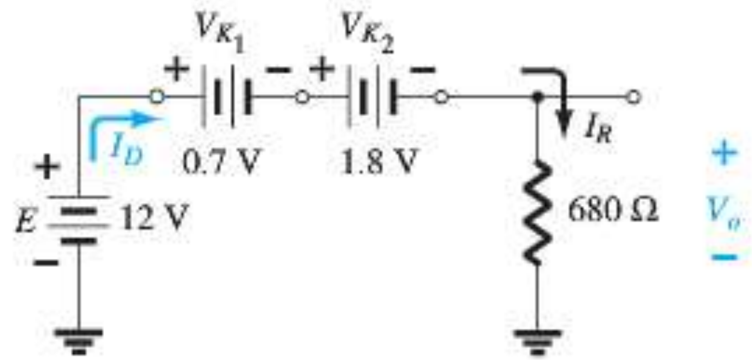


FIG. 2.20
Determining the unknown quantities for Example 2.7.

Solution: An attack similar to that applied in Example 2.4 will reveal that the resulting current has the same direction as the arrowheads of the symbols of both diodes, and the network of Fig. 2.20 results because $E = 12\text{ V} > (0.7\text{ V} + 1.8\text{ V [Table 1.8]}) = 2.5\text{ V}$. Note the redrawn supply of 12 V and the polarity of V_o across the 680-Ω resistor. The resulting voltage is

$$V_o = E - V_{K_1} - V_{K_2} = 12\text{ V} - 2.5\text{ V} = \mathbf{9.5\text{ V}}$$

and

$$I_D = I_R = \frac{V_R}{R} = \frac{V_o}{R} = \frac{9.5\text{ V}}{680\ \Omega} = \mathbf{13.97\text{ mA}}$$

EXAMPLE 2.8 Determine I_D, V_{D_2}, and V_o for the circuit of Fig. 2.21.

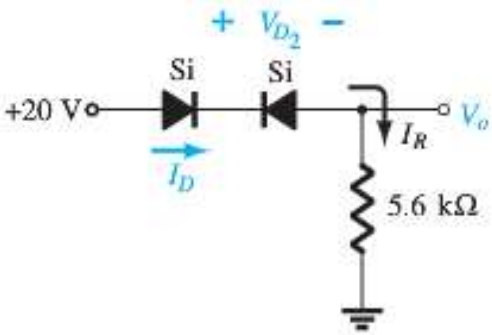


FIG. 2.21
Circuit for Example 2.8.

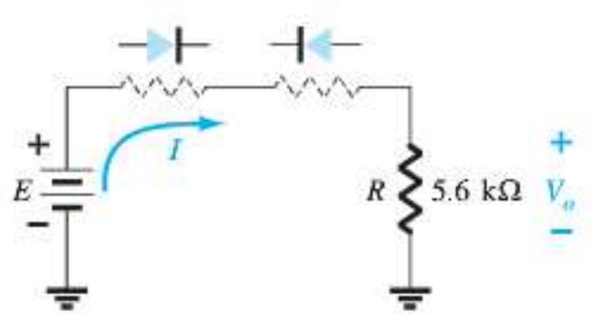


FIG. 2.22
Determining the state of the diodes of Fig. 2.21.

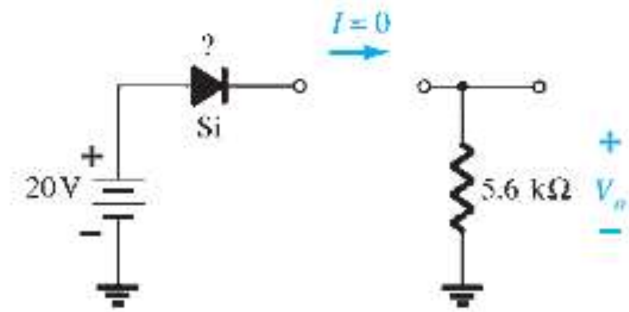


FIG. 2.23
Substituting the equivalent state for the open diode.

For an actual practical diode, when
$I_D = 0$ A, $V_D = 0$ V (and vice versa)

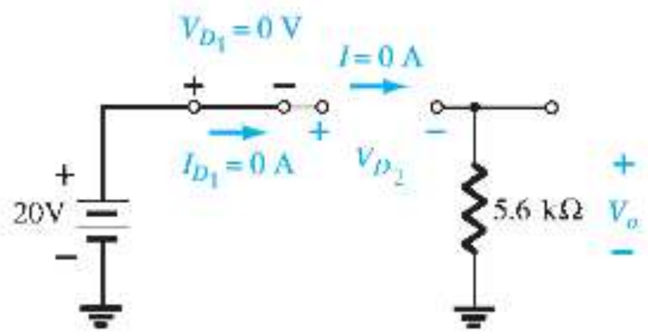


FIG. 2.24
Determining the unknown quantities for the circuit of Example 2.8.

$$V_o = I_R R = I_D R = (0\text{ A})R = \mathbf{0\ V}$$

and $$V_{D_2} = V_{\text{open circuit}} = E = \mathbf{20\ V}$$

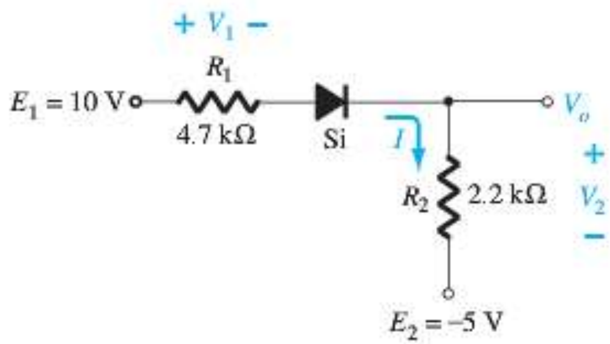
Applying Kirchhoff's voltage law in a clockwise direction gives

$$E - V_{D_1} - V_{D_2} - V_o = 0$$

and $$V_{D_2} = E - V_{D_1} - V_o = 20\text{ V} - 0 - 0$$
$$= \mathbf{20\ V}$$

with $$V_o = \mathbf{0\ V}$$

EXAMPLE 2.9 Determine I, V_1, V_2, and V_o for the series dc configuration of Fig. 2.25.



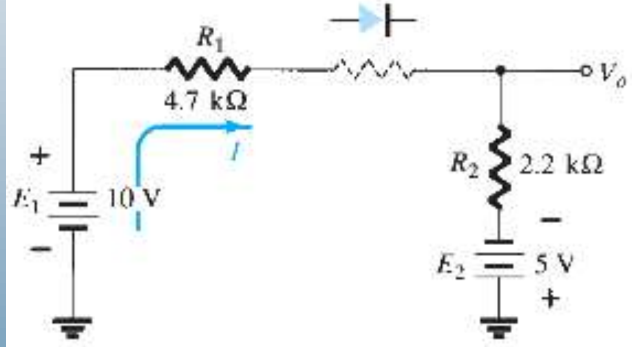


FIG. 2.26

Determining the state of the diode for the network of Fig. 2.25.

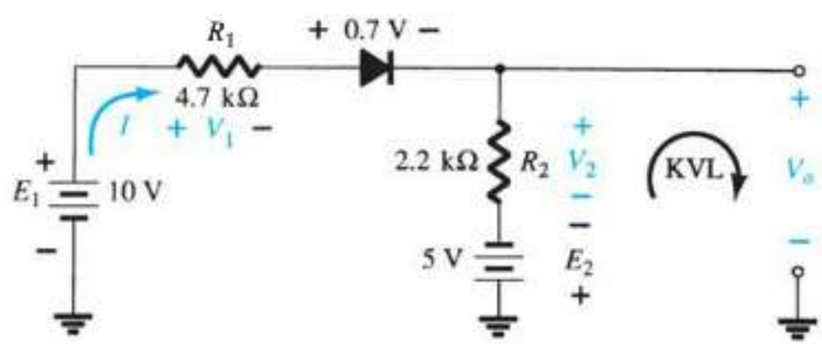


FIG. 2.27

Determining the unknown quantities for the network of Fig. 2.25. KVL, Kirchhoff voltage loop.

The resulting current through the circuit is

$$I = \frac{E_1 + E_2 - V_D}{R_1 + R_2} = \frac{10\text{ V} + 5\text{ V} - 0.7\text{ V}}{4.7\text{ k}\Omega + 2.2\text{ k}\Omega} = \frac{14.3\text{ V}}{6.9\text{ k}\Omega}$$

$$\cong \mathbf{2.07\text{ mA}}$$

$$V_1 = IR_1 = (2.07\text{ mA})(4.7\text{ k}\Omega) = \mathbf{9.73\text{ V}}$$

$$V_2 = IR_2 = (2.07\text{ mA})(2.2\text{ k}\Omega) = \mathbf{4.55\text{ V}}$$

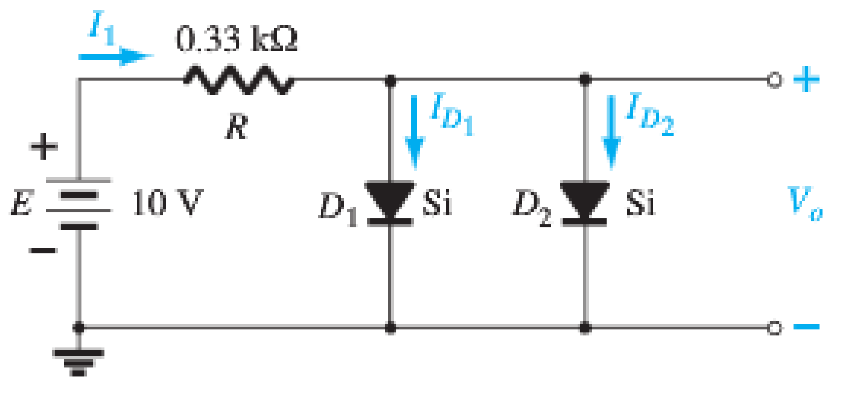
$$-E_2 + V_2 - V_o = 0$$

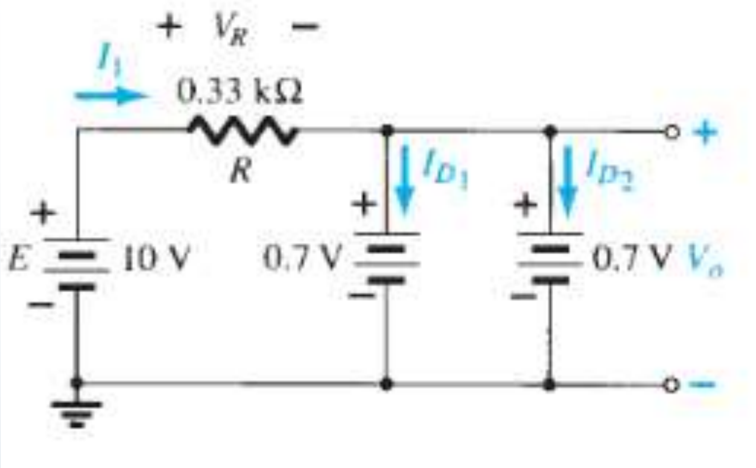
$$V_o = V_2 - E_2 = 4.55\text{ V} - 5\text{ V} = \mathbf{-0.45\text{ V}}$$

2.4 PARALLEL AND SERIES–PARALLEL CONFIGURATIONS

- The methods applied for series diode configurations can be extended to the analysis of parallel and series–parallel configurations.
- For each area of application, simply match the sequential series of steps applied to series diode configurations.

EXAMPLE 2.10 Determine V_o, I_1, I_{D_1}, and I_{D_2} for the parallel diode configuration of Fig. 2.28.





$$V_o = \mathbf{0.7\ V}$$

The current is

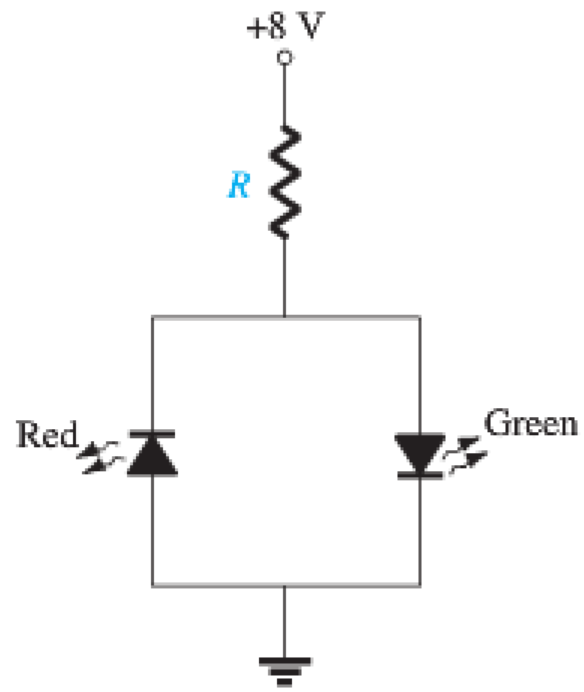
$$I_1 = \frac{V_R}{R} = \frac{E - V_D}{R} = \frac{10\text{ V} - 0.7\text{ V}}{0.33\text{ k}\Omega} = \mathbf{28.18\ mA}$$

Assuming diodes of similar characteristics, we have

$$I_{D_1} = I_{D_2} = \frac{I_1}{2} = \frac{28.18\text{ mA}}{2} = \mathbf{14.09\ mA}$$

EXAMPLE 2.11 In this example there are two LEDs that can be used as a polarity detector. Apply a positive source voltage and a green light results. Negative supplies result in a red light. Packages of such combinations are commercially available.

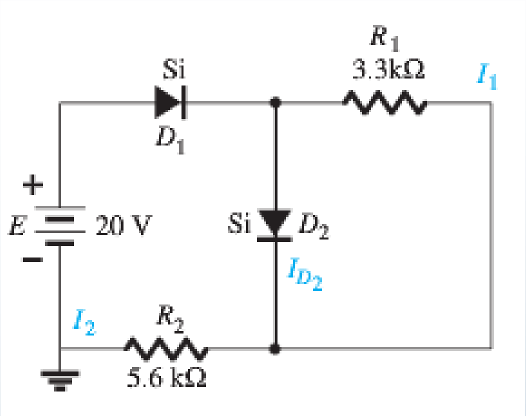
Find the resistor R to ensure a current of 20 mA through the "on" diode for the configuration of Fig. 2.30. Both diodes have a reverse breakdown voltage of 3 V and an average turn-on voltage of 2 V.

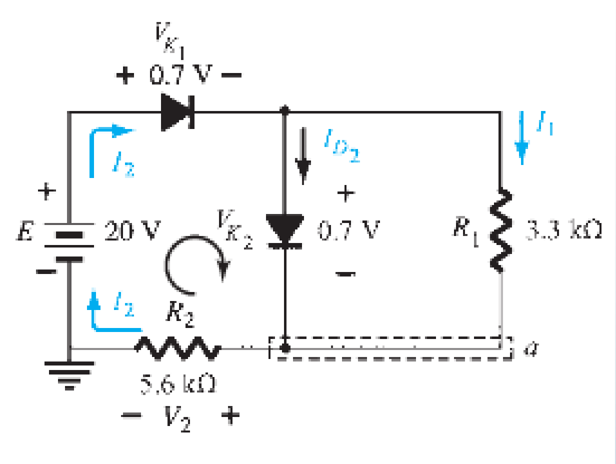


$$I = 20\text{ mA} = \frac{E - V_{\text{LED}}}{R} = \frac{8\text{ V} - 2\text{ V}}{R}$$

$$R = \frac{6\text{ V}}{20\text{ mA}} = \mathbf{300\ \Omega}$$

EXAMPLE 2.13 Determine the currents I_1, I_2, and I_{D_2} for the network of Fig. 2.37.





$$I_1 = \frac{V_{K_2}}{R_1} = \frac{0.7\text{ V}}{3.3\text{ k}\Omega} = \mathbf{0.212\text{ mA}}$$

Applying Kirchhoff's voltage law around the indicated loop in the clockwise direction yields

$$-V_2 + E - V_{K_1} - V_{K_2} = 0$$

and $$V_2 = E - V_{K_1} - V_{K_2} = 20\text{ V} - 0.7\text{ V} - 0.7\text{ V} = \mathbf{18.6\text{ V}}$$

with $$I_2 = \frac{V_2}{R_2} = \frac{18.6\text{ V}}{5.6\text{ k}\Omega} = \mathbf{3.32\text{ mA}}$$

At the bottom node a,

$$I_{D_2} + I_1 = I_2$$

and $$I_{D_2} = I_2 - I_1 = 3.32\text{ mA} - 0.212\text{ mA} \cong \mathbf{3.11\text{ mA}}$$

Rectifier Circuits

- One important application of diode is the **rectifier**
  - Converts AC to DC
  - Used to make dc power supplies

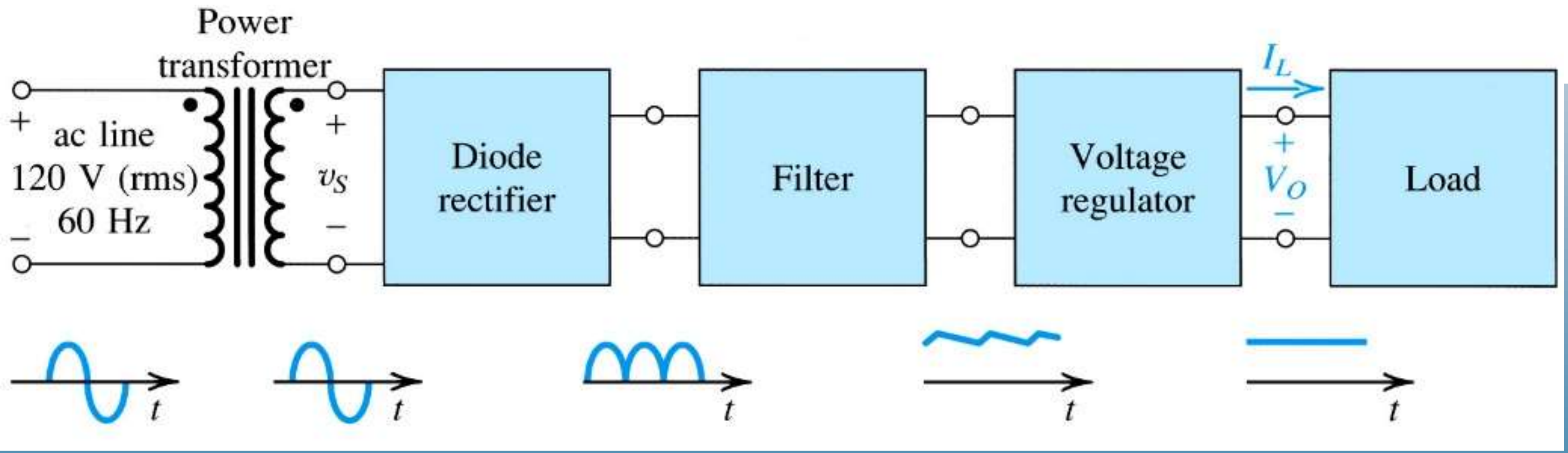
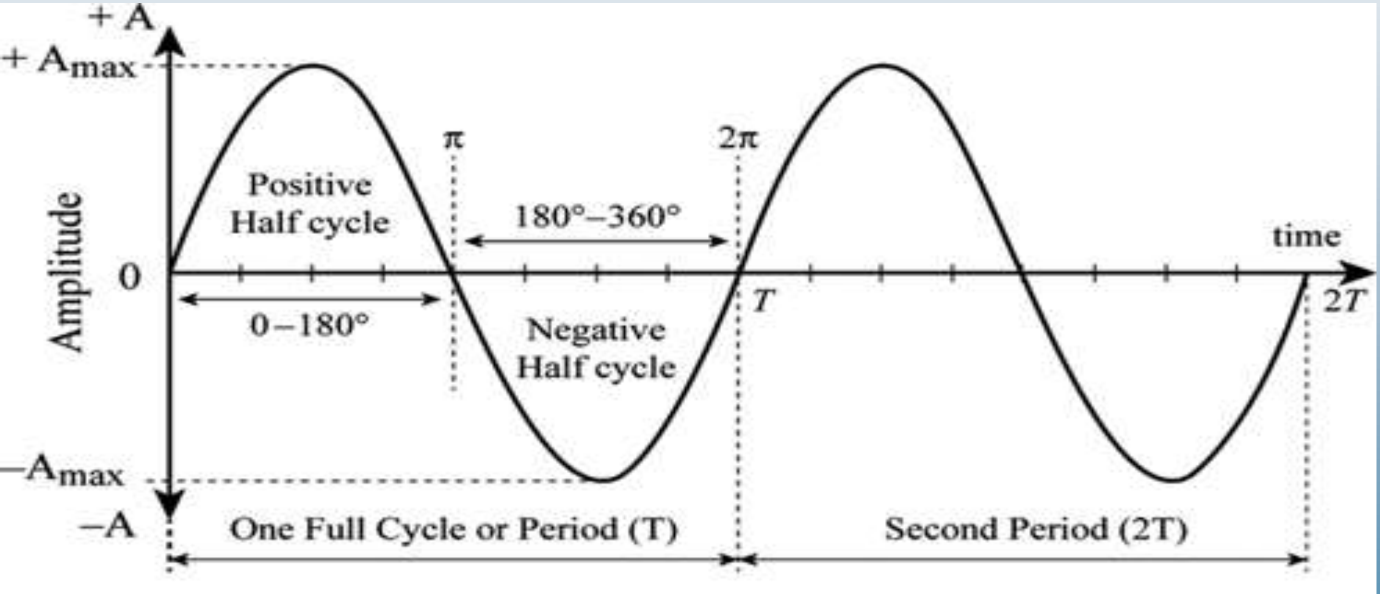


Figure: Block diagram of a dc power supply

Input AC signal

- Rectifier input: Sine, square, triangular waves
- Sine wave: Positive and negative half cycle
- $v_{in} = V_m \sin(\omega t)$. $v_{in} = 10\sin(\omega t)\,V$



2.6 Half-Wave Rectification

The process of removing one-half the input signal to establish a dc level is called half-wave rectification

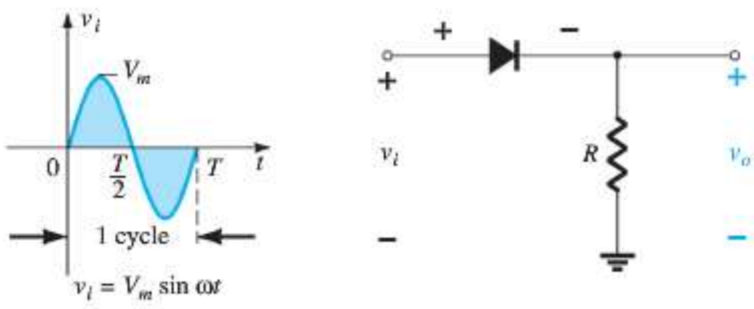


FIG. 2.44
Half-wave rectifier.

Ideal Approximation

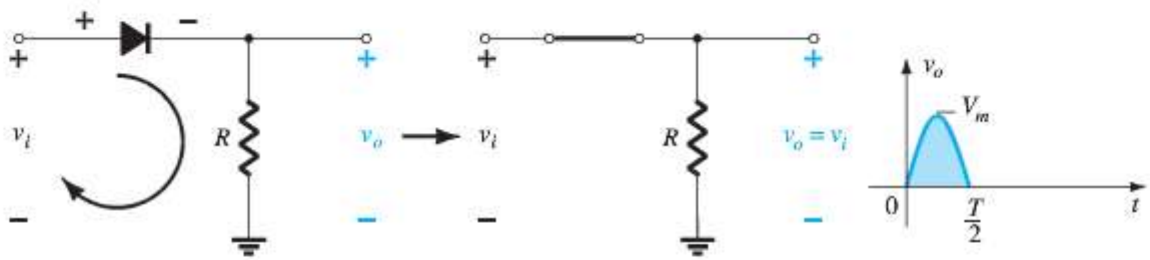


FIG. 2.45
Conduction region ($0 \rightarrow T/2$).

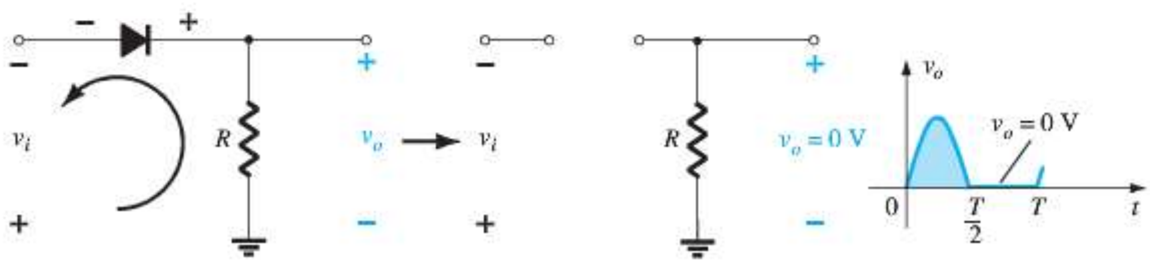


FIG. 2.46
Nonconduction region ($T/2 \rightarrow T$).

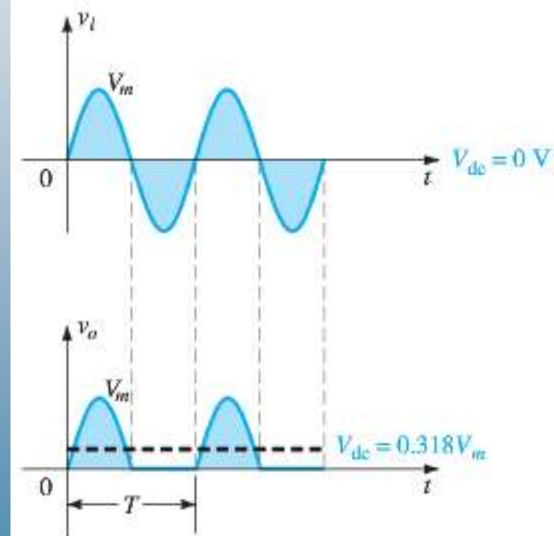


FIG. 2.47
Half-wave rectified signal.

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

The effect of using a real diode

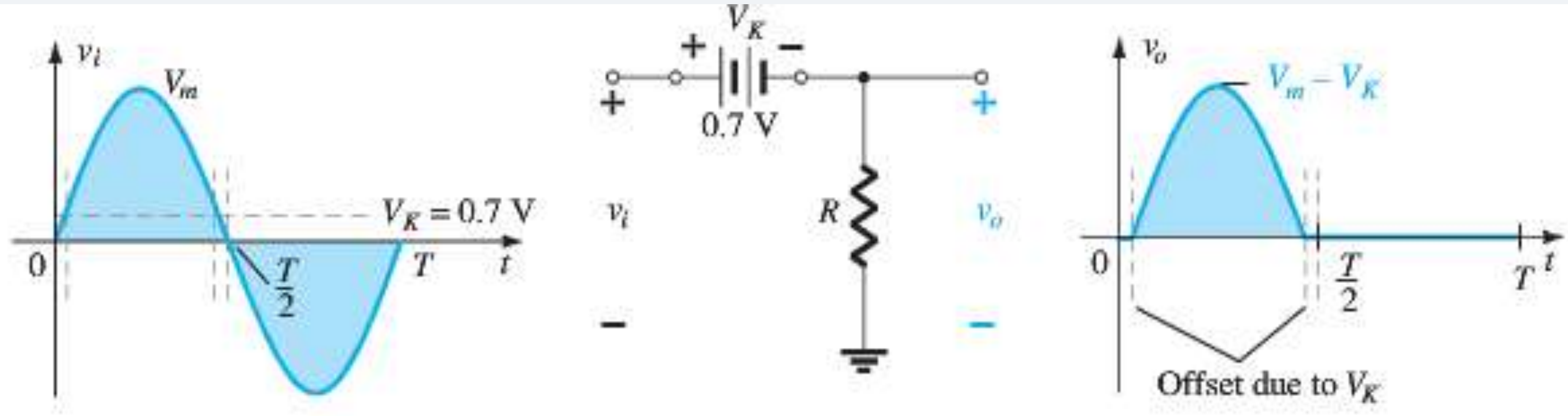


FIG. 2.48

Effect of V_K on half-wave rectified signal.

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

The Half-Wave Rectifier

- Average Value (DC Component) of v_o, $V_o = \frac{Integration\ over\ one\ cycle}{Length\ of\ a\ Period} = \frac{\int_0^{2\pi} v_o d\theta}{2\pi}$

$$= \frac{\int_0^{\pi}(v_o - V_K)d\theta + \int_{\pi}^{2\pi} 0 d\theta}{2\pi}$$

$$= \frac{\int_0^{\pi}(V_m \sin\theta - V_K)d\theta}{2\pi}$$

$$= \frac{V_m}{2\pi}\int_0^{\pi} \sin\theta \, d\theta - \frac{V_K}{2\pi}\int_0^{\pi} d\theta$$

$$= \frac{V_m}{2\pi}[-\cos\theta]_0^{\pi} - \frac{V_K}{2\pi}[\theta]_0^{\pi}$$

$$= -\frac{V_m}{2\pi}[\cos\theta]_0^{\pi} - \frac{V_K}{2\pi}\pi$$

$$= -\frac{V_m}{2\pi}(-2) - \frac{V_K}{2} = \frac{V_m}{\pi} - \frac{V_K}{2}$$

$$V_o = \frac{V_m}{\pi} - \frac{V_K}{2} = 0.318\, V_m - 0.5\, V_K$$

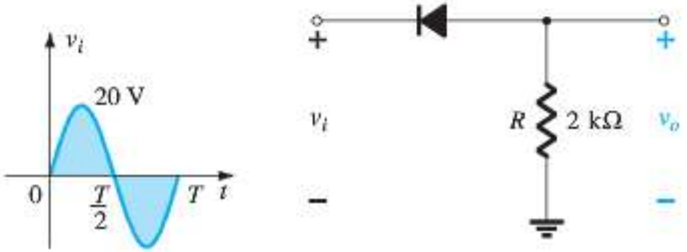
- Peak diode current $=(V_s - V_D)/\mathrm{R}$

EXAMPLE 2.16

a. Sketch the output v_o and determine the dc level of the output for the network of Fig. 2.49.

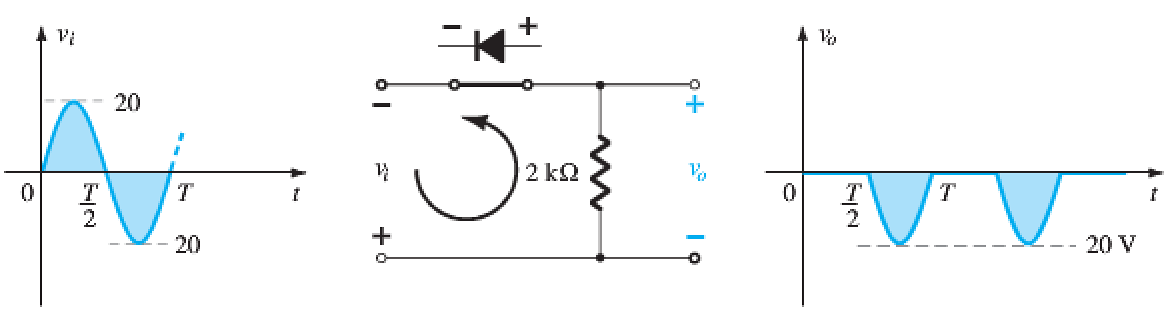
b. Repeat part (a) if the ideal diode is replaced by a silicon diode.

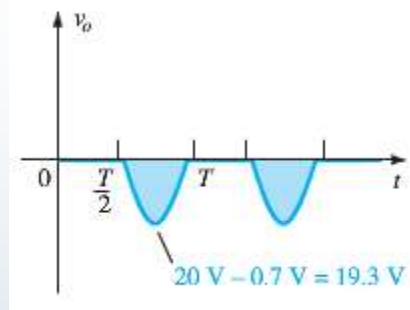
c. Repeat parts (a) and (b) if V_m is increased to 200 V, and compare solutions using Eqs. (2.7) and (2.8).



a. In this situation the diode will conduct during the negative part of the input as shown in Fig. 2.50, and v_o will appear as shown in the same figure. For the full period, the dc level is

$$V_{dc} = -0.318V_m = -0.318(20\text{ V}) = \mathbf{-6.36\text{ V}}$$





$$V_{dc} \cong -0.318(V_m - 0.7\text{ V}) = -0.318(19.3\text{ V}) \cong \mathbf{-6.14\text{ V}}$$

$$V_{dc} = -0.318\, V_m = -0.318(200\text{ V}) = \mathbf{-63.6\text{ V}}$$

$$V_{dc} = -0.318(V_m - V_K) = -0.318(200\text{ V} - 0.7\text{ V})$$
$$= -(0.318)(199.3\text{ V}) = \mathbf{-63.38\text{ V}}$$

which is a difference that can certainly be ignored for most applications.

2.7 Full-Wave Rectification

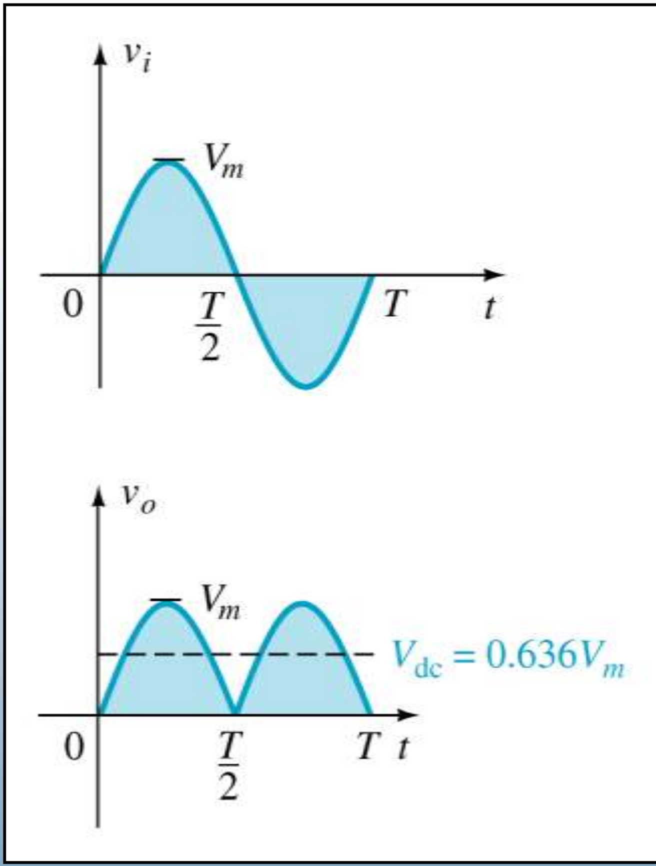
The rectification process can be improved by using a full-wave rectifier circuit.

Full-wave rectification: output for both positive and negative half cycle

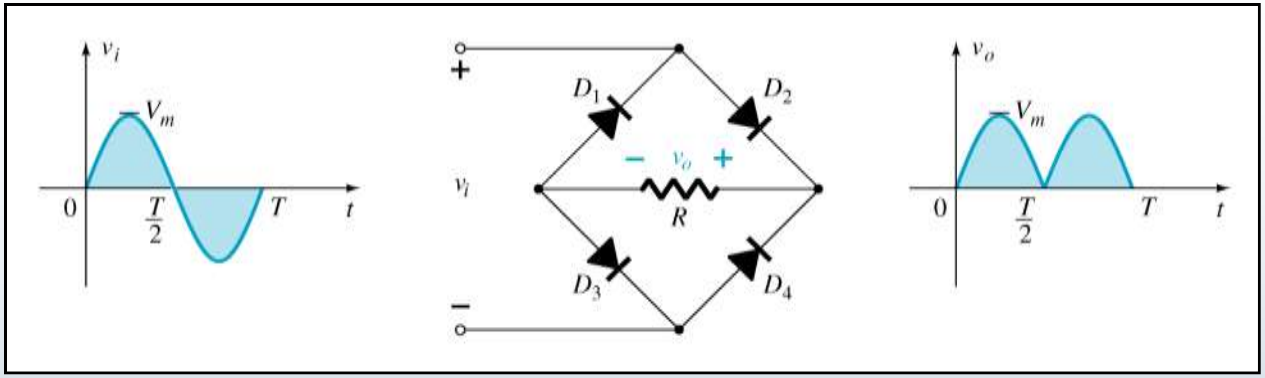
Full-wave rectification produces a larger DC output:

$$\text{Half-wave: } V_{dc} = \frac{V_m}{\pi} = 0.318V_m$$

$$\text{Full-wave: } V_{dc} = \frac{2*V_m}{\pi} = 0.636V_m$$

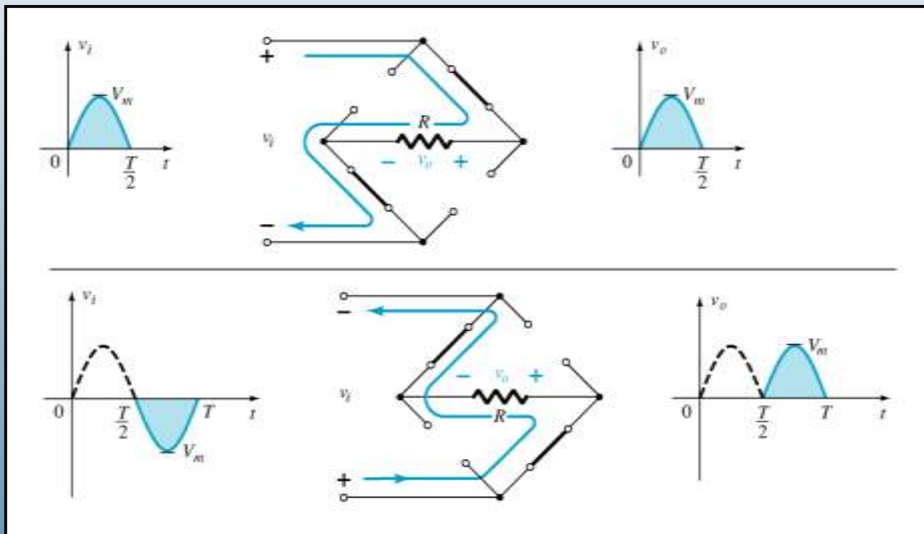


Full-Wave Rectification



Bridge Rectifier

A full-wave rectifier with four diodes that are connected in a bridge configuration



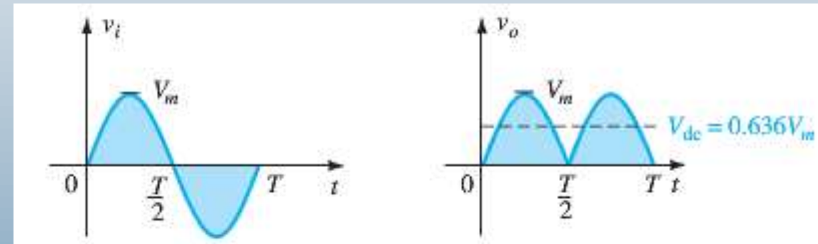


FIG. 2.57

Input and output waveforms for a full-wave rectifier.

$$V_{dc} = 2[\text{Eq. } (2.7)] = 2(0.318V_m)$$

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

The effect of using a real diode

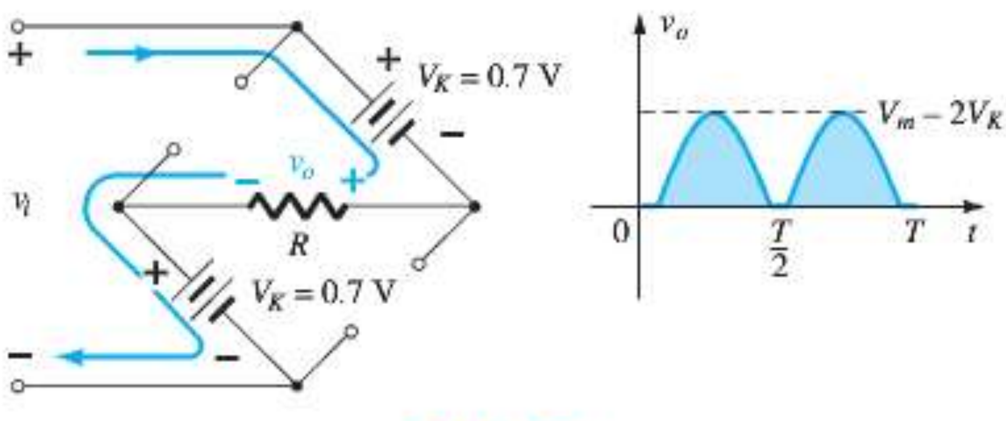


FIG. 2.58

Determining $V_{o_{max}}$ for silicon diodes in the bridge configuration.

$$v_i - V_K - v_o - V_K = 0$$
$$v_o = v_i - 2V_K$$

The peak value of the output voltage v_o is therefore

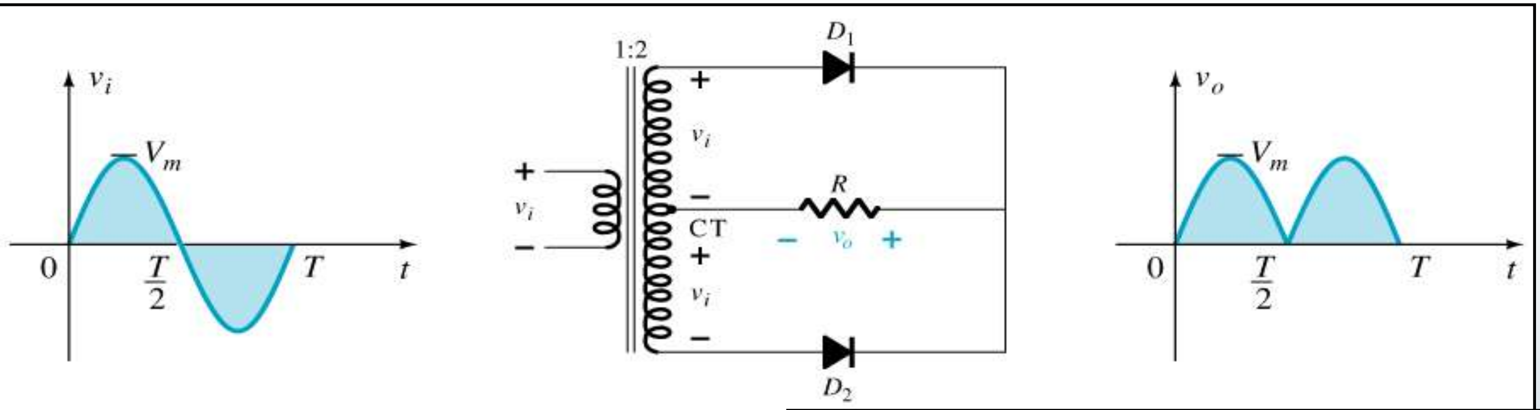
$$V_{o_{max}} = V_m - 2V_K$$

For situations where $V_m \gg 2V_K$, the following equation can be applied for the average value with a relatively high level of accuracy:

$$\boxed{V_{dc} \cong 0.636(V_m - 2V_K)} \qquad \textbf{(2.11)}$$

Then again, if V_m is sufficiently greater than $2V_K$, then Eq. (2.10) is often applied as a first approximation for V_{dc}.

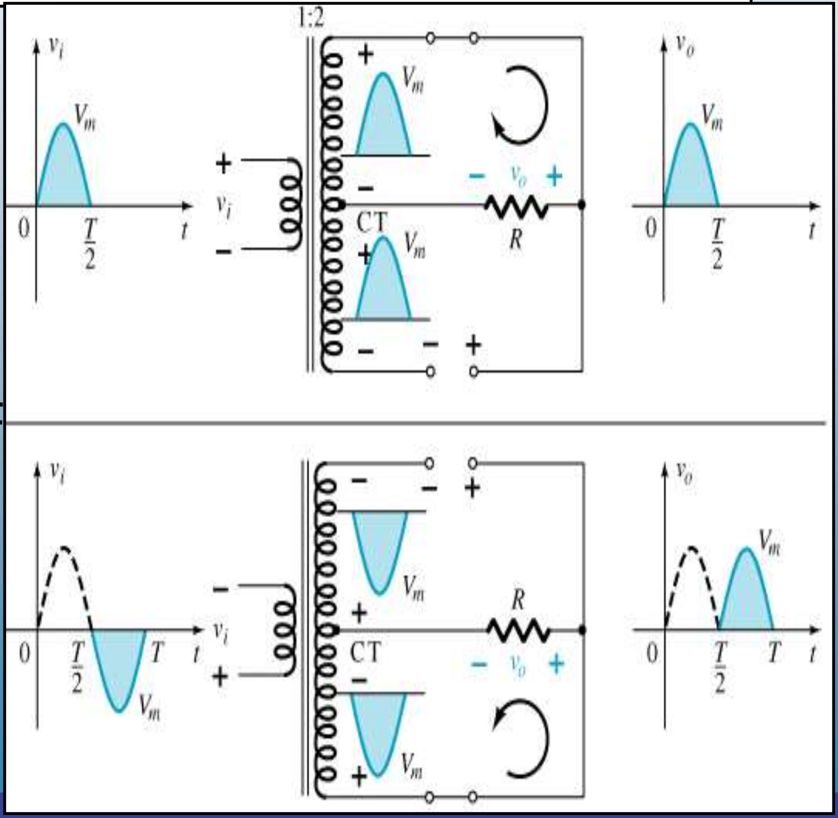
Full-Wave Rectification



Center-Tapped Transformer Rectifier

- Requires two diodes and a center-tapped transformer.
- (+) half cycle: D_1 ON; D_2 OFF
- (-) half cycle: D_1 OFF; D_2 ON

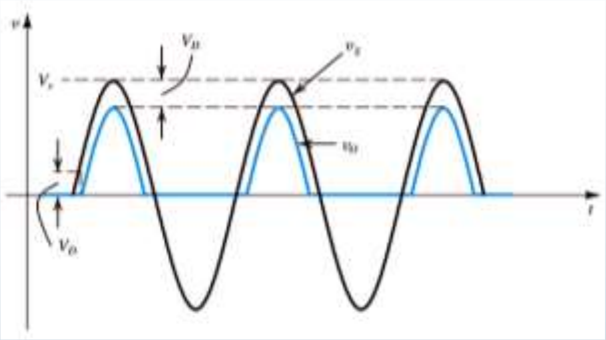
$V_{DC} = 0.636V_m$



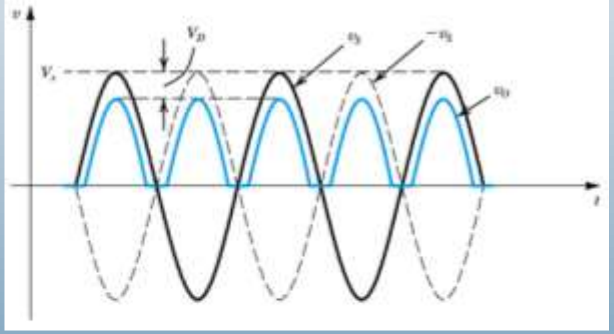
Needs a bigger transformer, because the peak is only half the secondary voltage.

Summary of Rectifier Waveforms

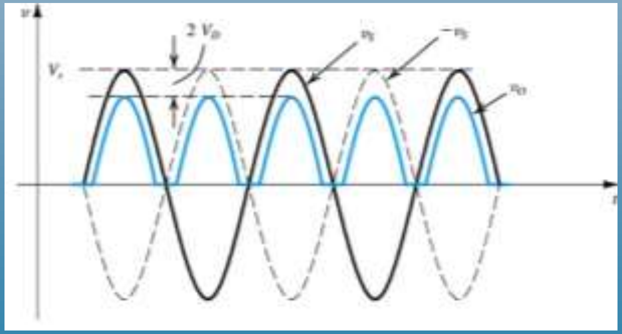
Half-Wave Rectifier



Full-Wave Rectifier



Bridge Rectifier



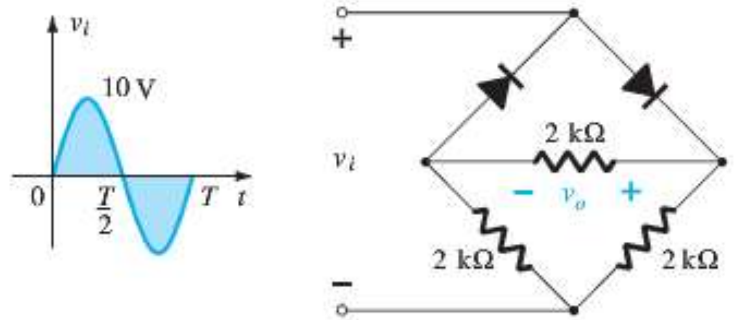
Summary of Rectifier Circuits

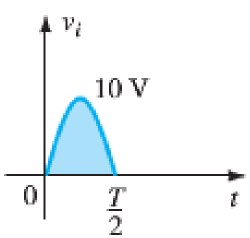
In the center tapped transformer rectifier circuit, the peak AC voltage is the transformer secondary voltage to the tap.

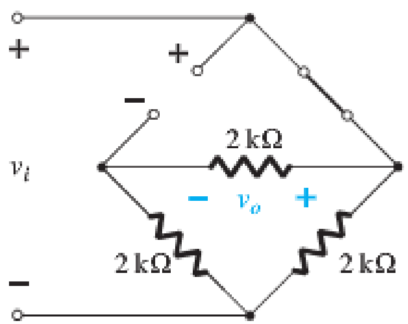
Rectifier	Ideal V_{DC}	Realistic Si V_{DC}
Half Wave Rectifier	$V_{DC} = 0.318V_m$	$V_{DC} = 0.318(V_m - 0.7\text{V})$
Bridge Rectifier	$V_{DC} = 0.636V_m$	$V_{DC} = 0.636(V_m - 2(0.7\text{ V}))$
Center-Tapped Transformer Rectifier	$V_{DC} = 0.636V_m$	$V_{DC} = 0.636(V_m - 0.7\text{ V})$

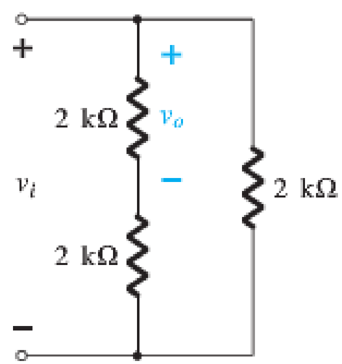
V_m = the peak AC voltage

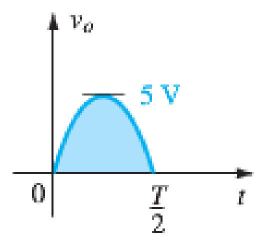
EXAMPLE 2.17 Determine the output waveform for the network of Fig. 2.64 and calculate the output dc level and the required PIV of each diode.

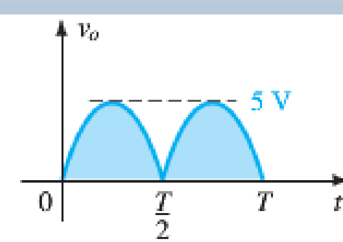










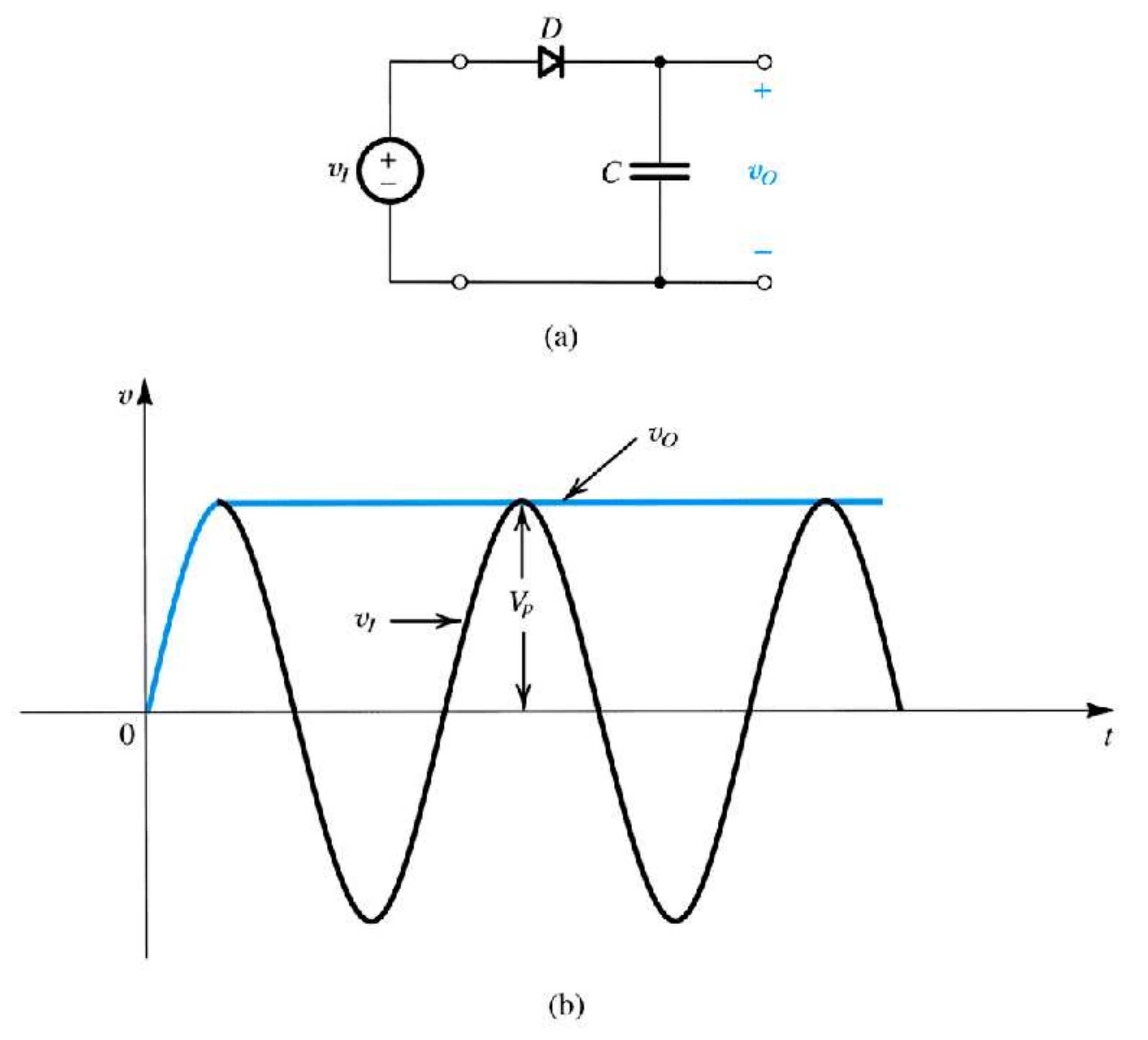


$$V_{o_{\text{max}}} = \tfrac{1}{2}V_{i_{\text{max}}} = \tfrac{1}{2}(10\text{ V}) = 5\text{ V}$$

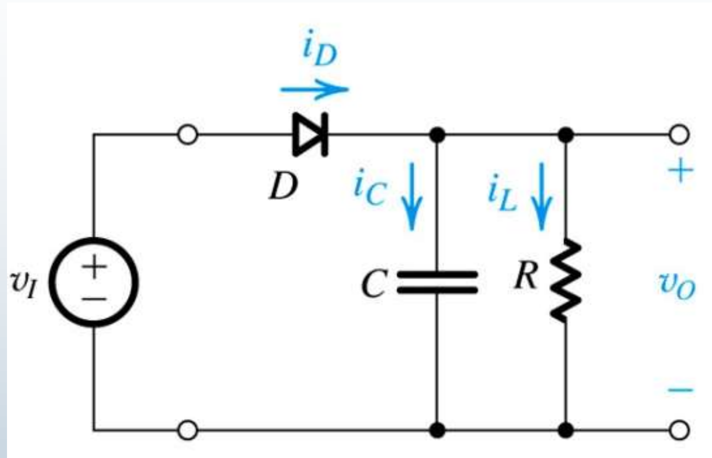
The effect of removing two diodes from the bridge configuration is therefore to reduce the available dc level to the following:

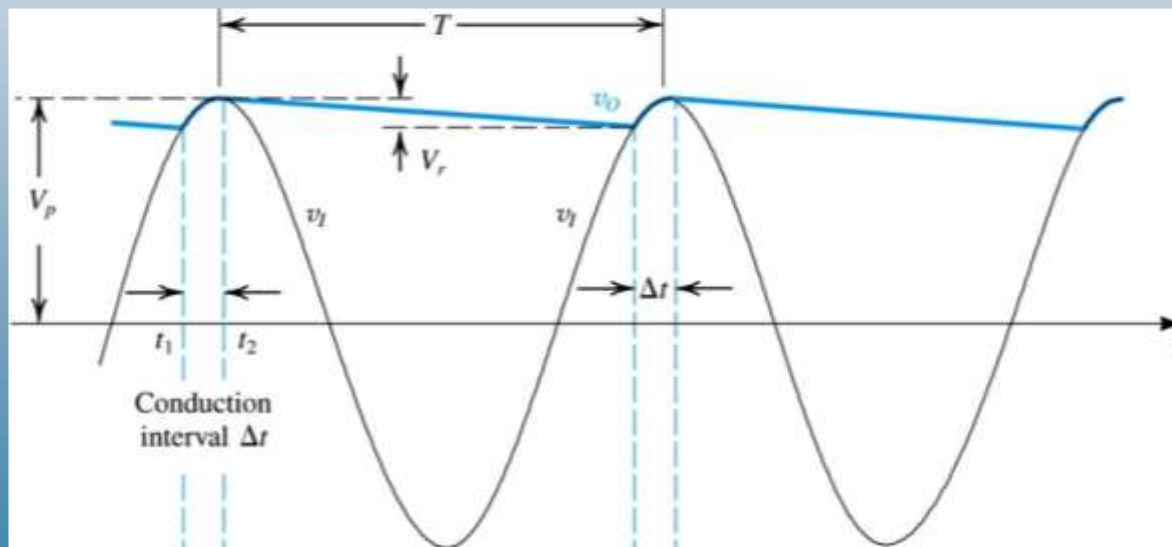
$$V_{\text{dc}} = 0.636(5\text{ V}) = \mathbf{3.18\ V}$$

The Rectifier with a Filter Capacitor - The Peak Rectifier

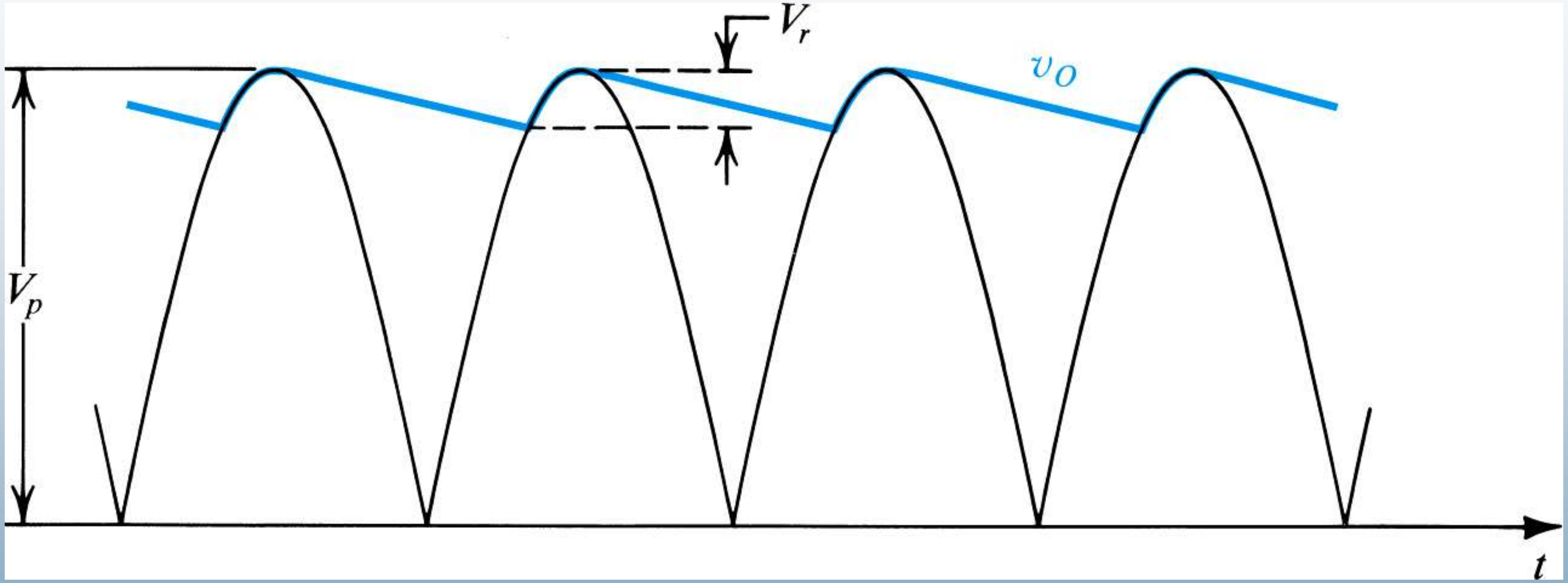


The Peak Rectifier with a Load Resistor – A More Practical Circuit





The full-wave peak rectifier



- The ripple is smaller than half-wave rectifier
- $V_r = \frac{V_p}{C * R_L}$
- Ripple voltage inversely proportional to filter capacitor

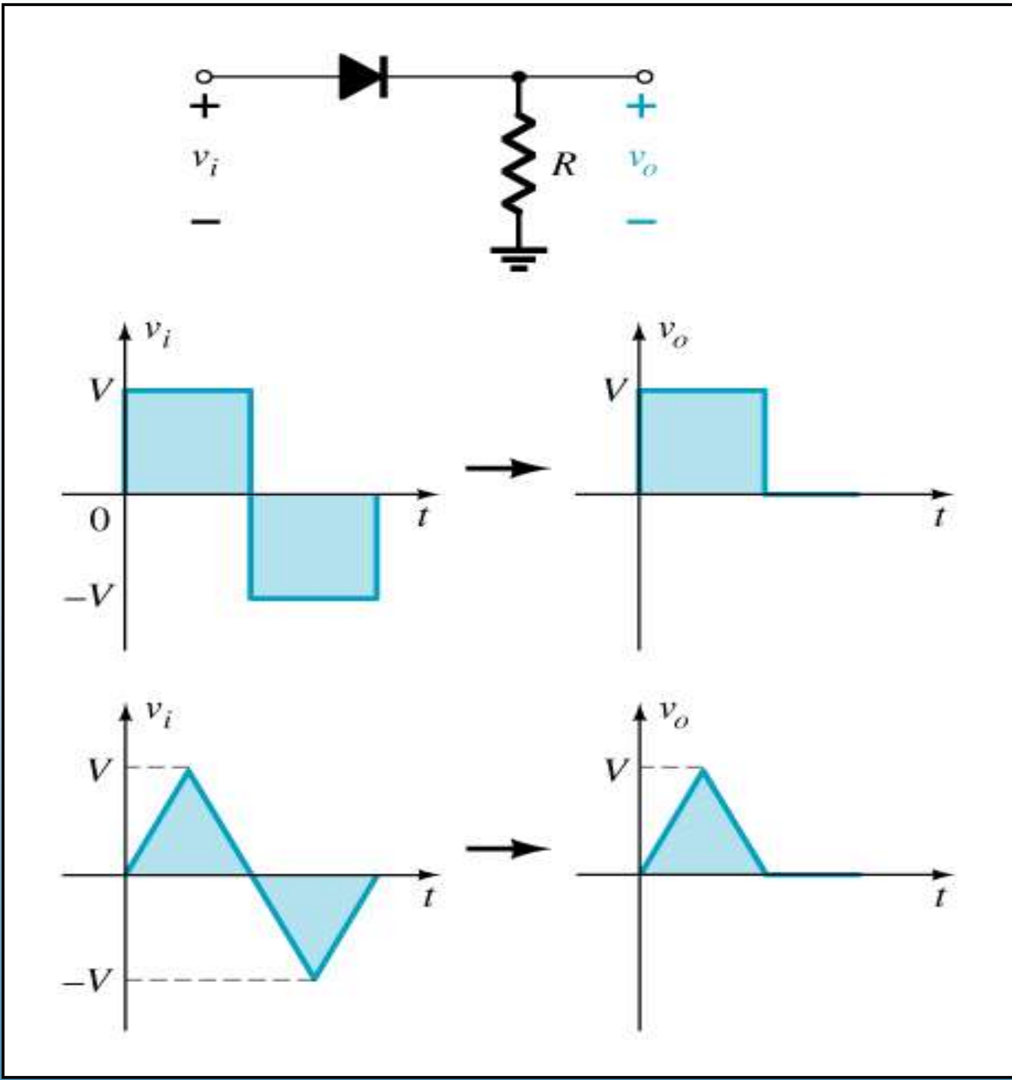
2.8 Diode Clippers

- Clippers are networks that employ diodes to “clip” away or removes a portion of an input signal without distorting the remaining part of the applied waveform.
- The half-wave rectifier is an example of the simplest form of diode clipper—one resistor and a diode.
- Depending on the orientation of the diode, the positive or negative region of the applied signal is “clipped” off.
- Two general categories of clippers: series and parallel.
  - Series clippers: The diode in series with the load
  - Parallel clippers: The diode in parallel to the load

Diode Series Clippers

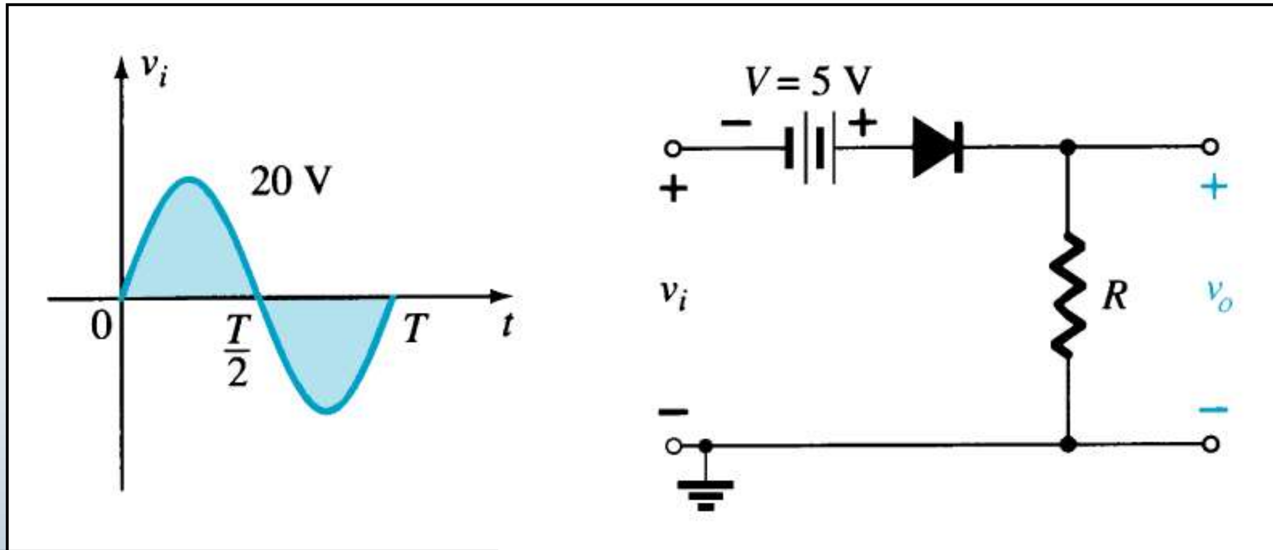
The diode in a series clipper "clips" any voltage that does not forward bias it:

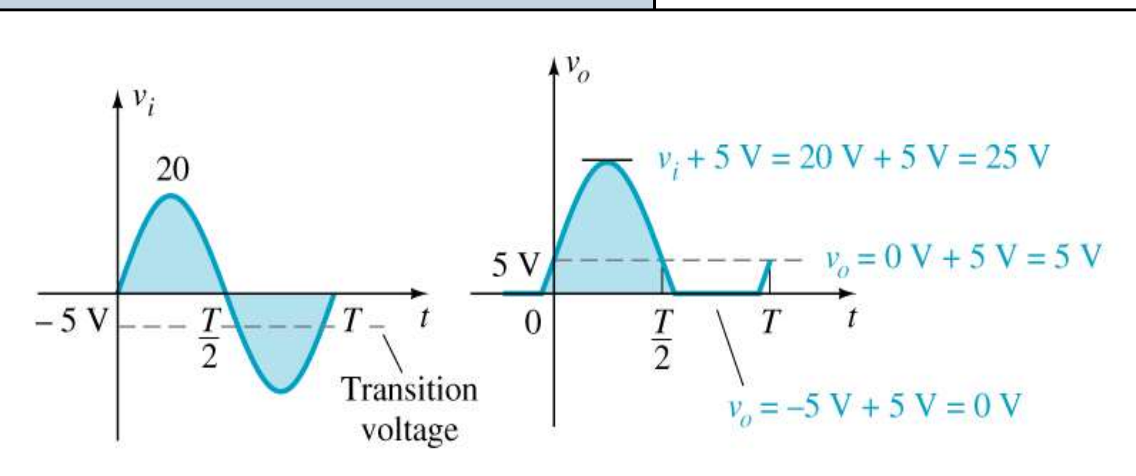
- Series Clipper: Diode and Load resistance (R_L) in series
- Clips negative portion of the input: Negative Clipper
- A reverse-biasing polarity
- A forward-biasing polarity less than 0.7 V (for a silicon diode)



Biased Clippers

Adding a DC source in series with the clipping diode changes the effective forward bias of the diode.



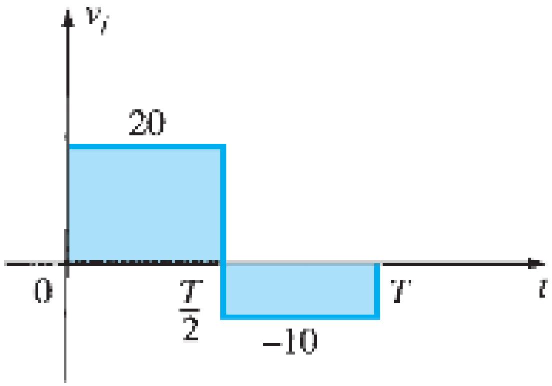


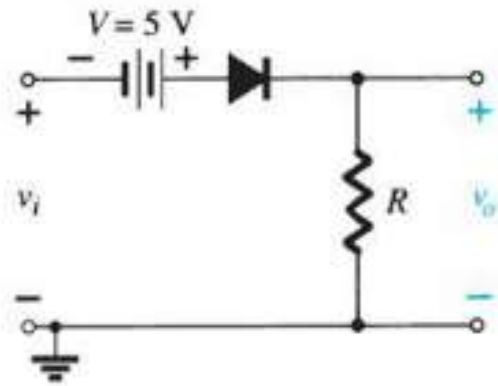
Biased Clipper: A DC source also present in the circuit

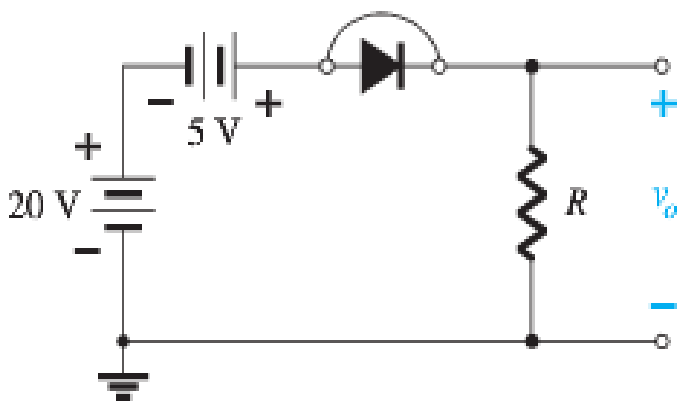
Series Clipper

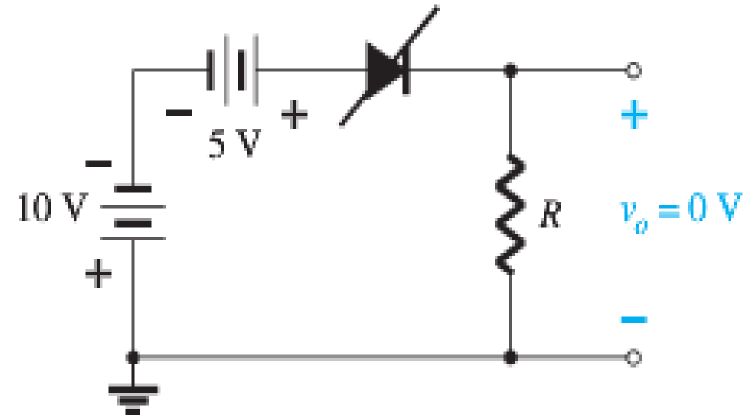
Negative Clipper

EXAMPLE 2.19 Find the output voltage for the network examined in Example 2.18 if the applied signal is the square wave of Fig. 2.77.







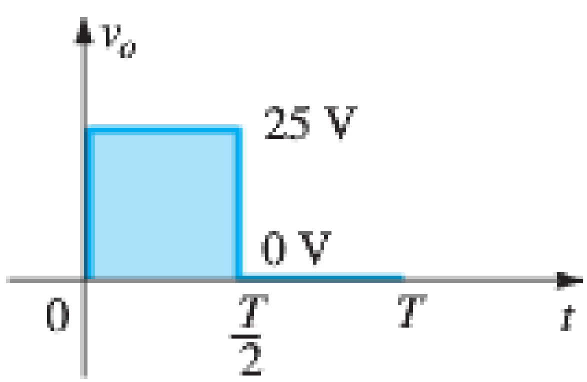


Positive half cycle

Diode FB/ON/Short

KVL: $-20V - 5V + V_o = 0$

$V_o = 25V$



Negative half cycle

Diode RB/OFF/Open

$I_D = 0A$

$V_o = 0V$

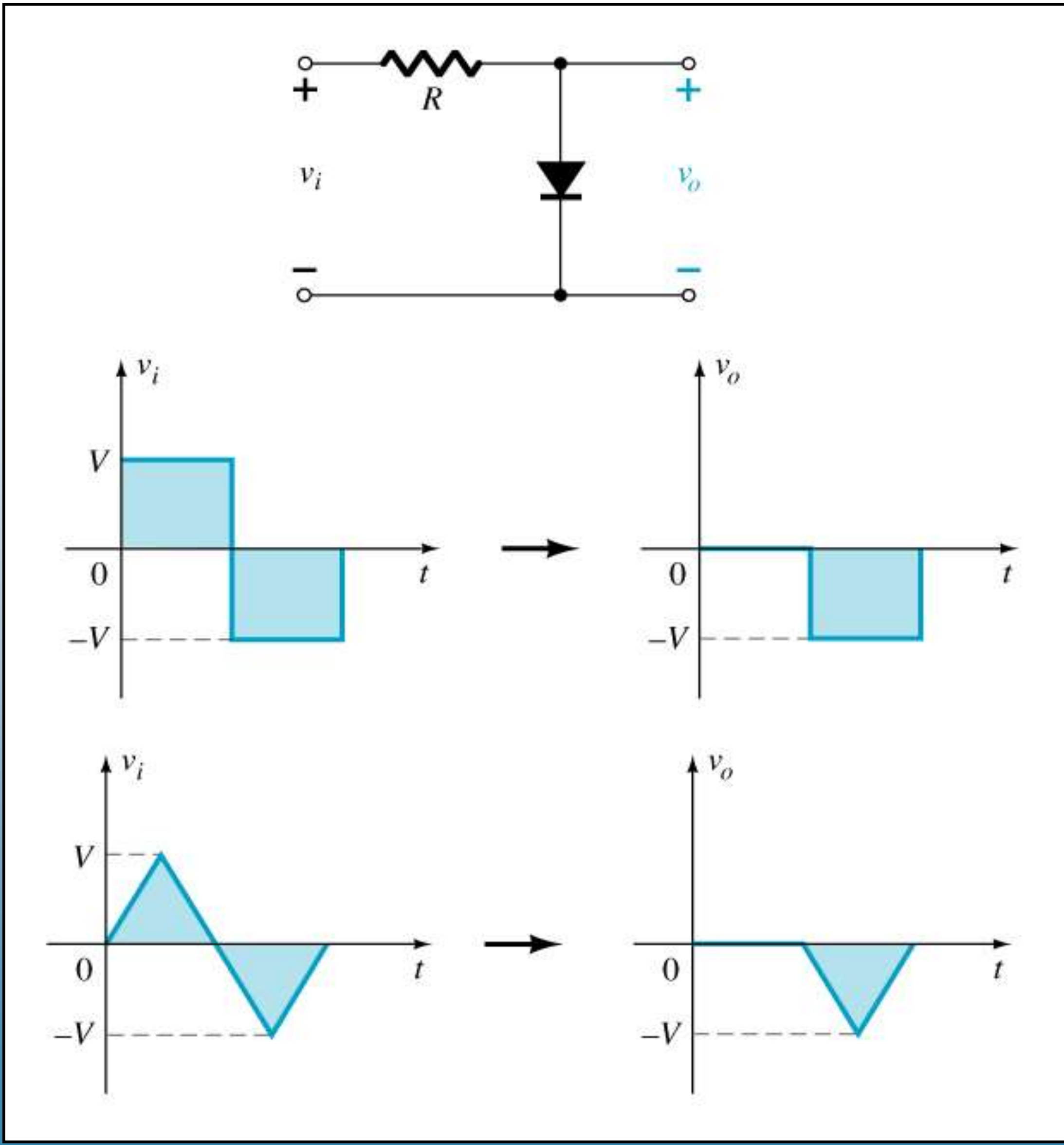
Parallel Clippers

The diode in a parallel clipper circuit "clips" any voltage that forward biases it.

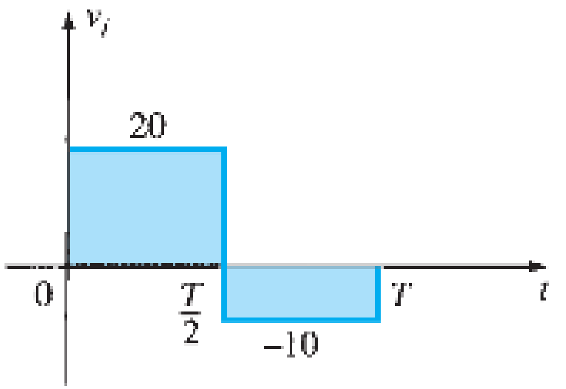
DC biasing can be added in series with the diode to change the clipping level.

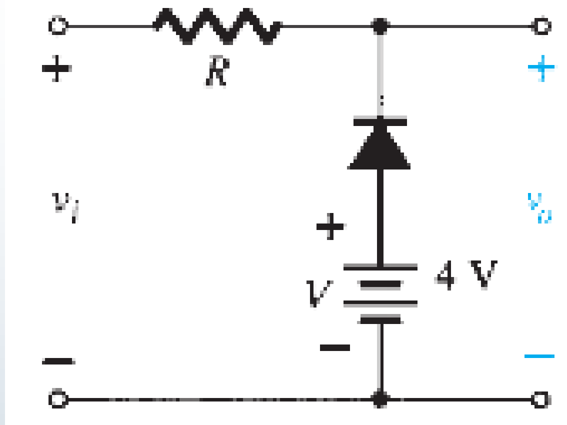
Parallel Clipper: Diode and Load resistance (R_L) in parallel

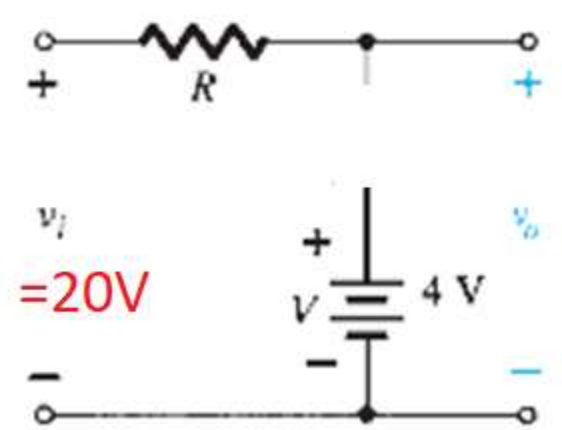
Clips positive portion of the input: Positive Clipper

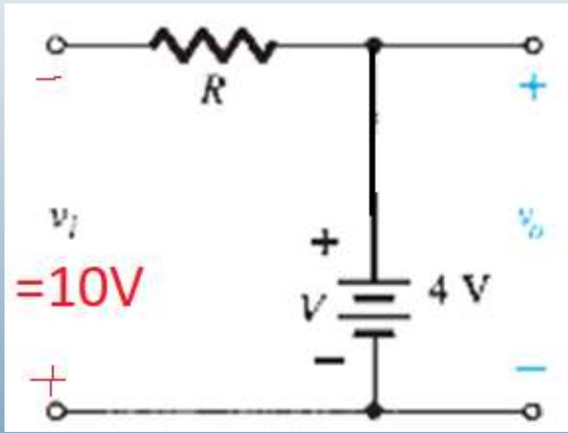


EXAMPLE 2.20 Determine v_o for the network of Fig. 2.82.





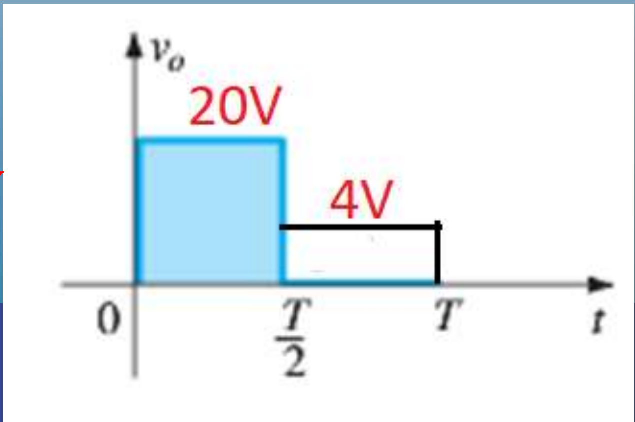




Positive half cycle

Diode RB/OFF/Open

$$V_o = V_{in} = 20V$$

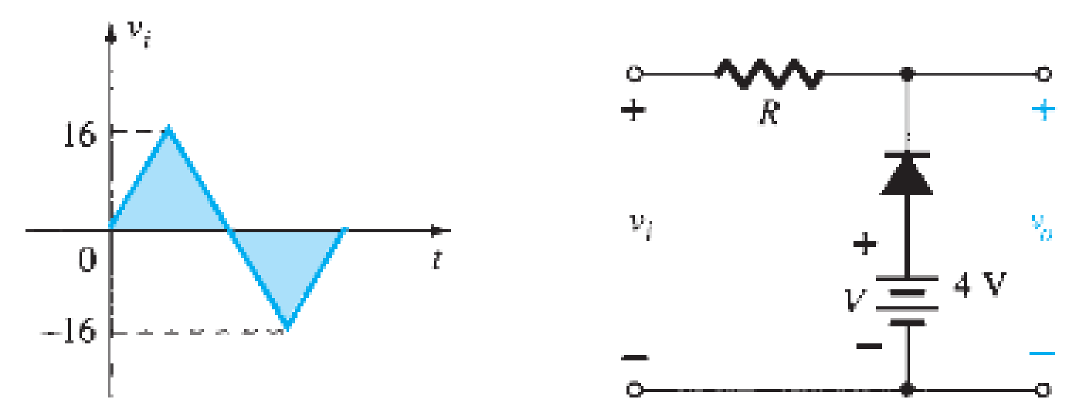


Negative half cycle

Diode FB/ON/Short

$$V_o = 4V$$

EXAMPLE 2.21 Repeat Example 2.20 using a silicon diode with $V_K = 0.7$ V.



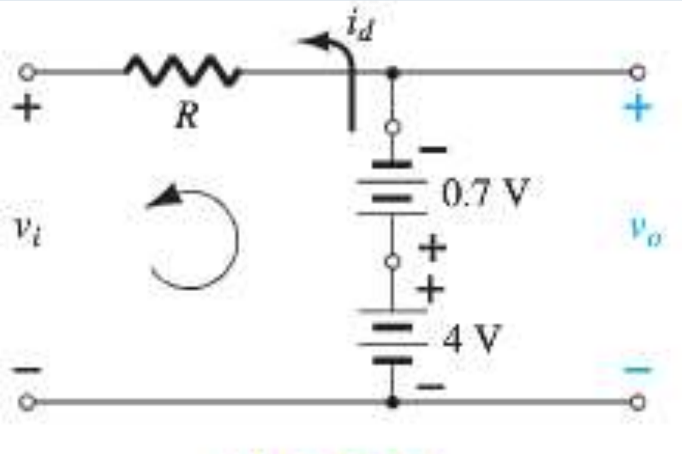


FIG. 2.86
Determining v_o for the diode of Fig. 2.82 in the "on" state.

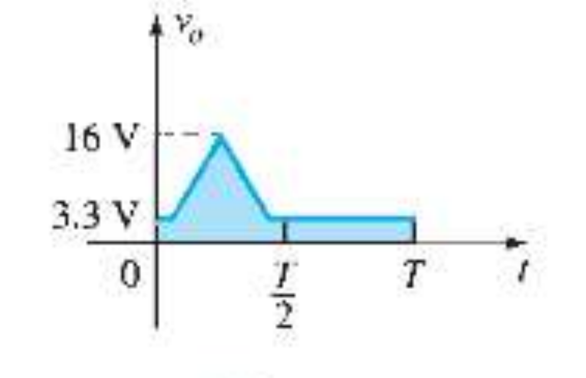
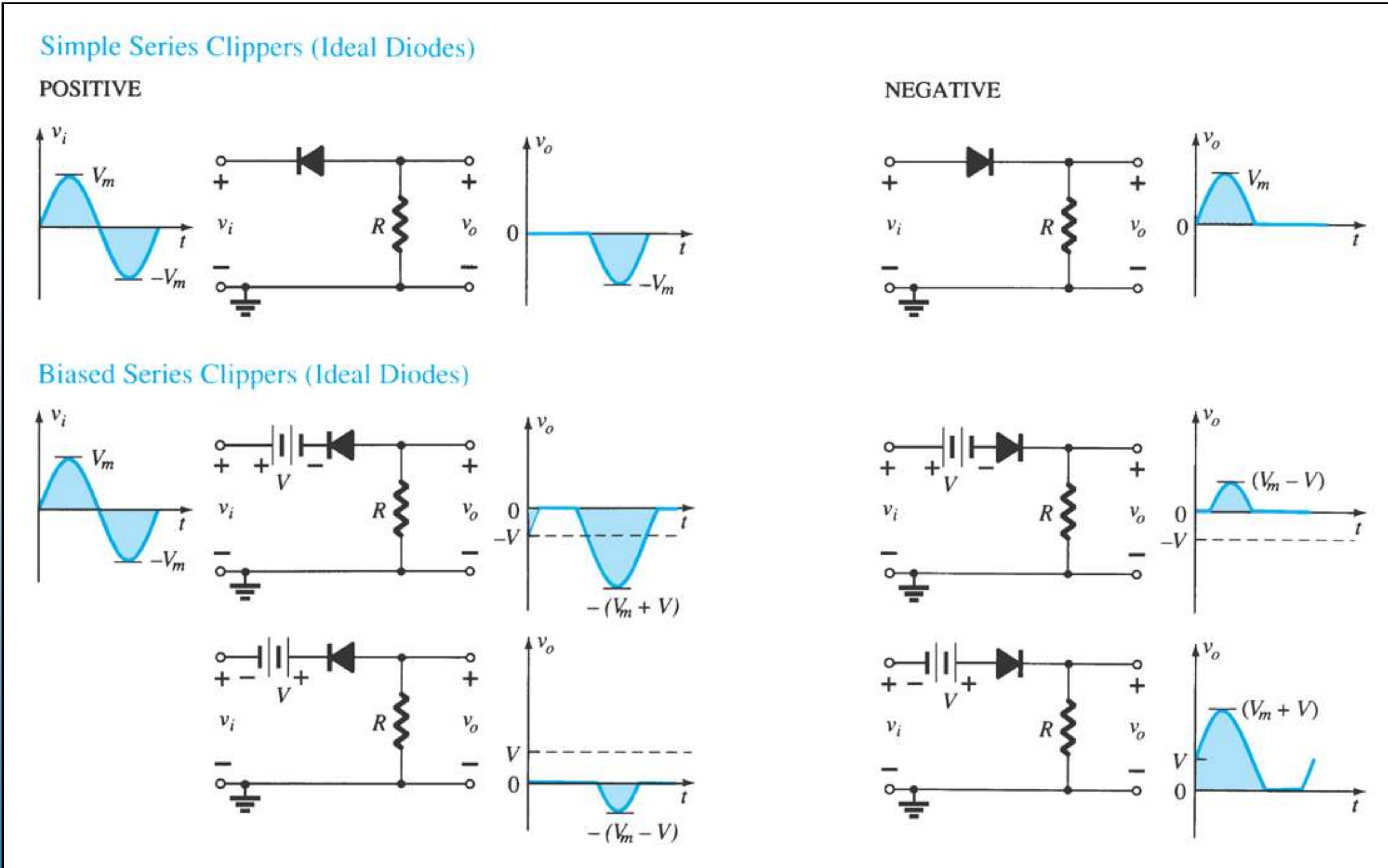
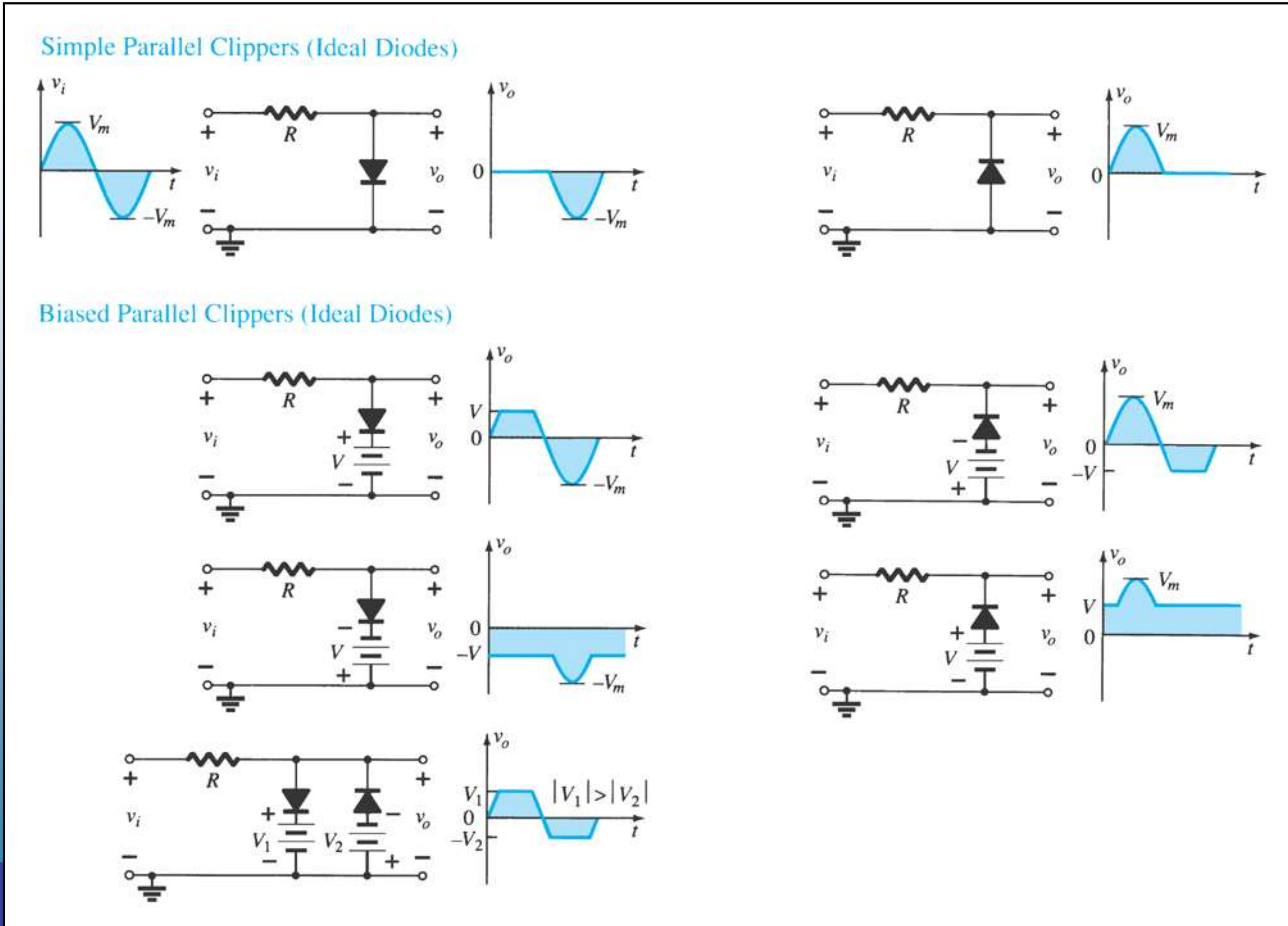


FIG. 2.87
Sketching v_o for Example 2.21.

Summary of Clipper Circuits

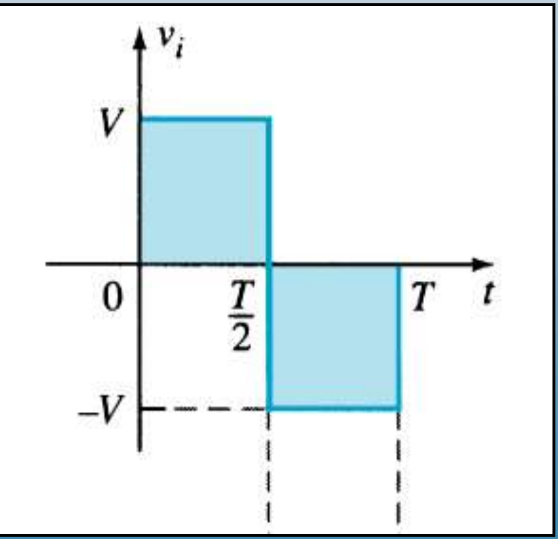


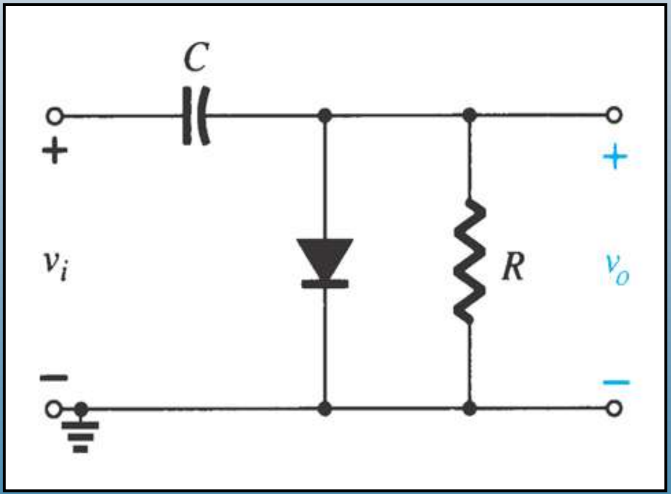
Summary of Clipper Circuits

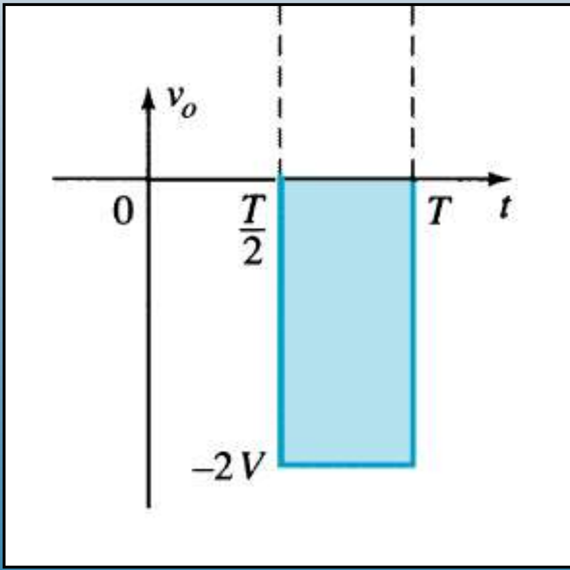


2.9 Clampers

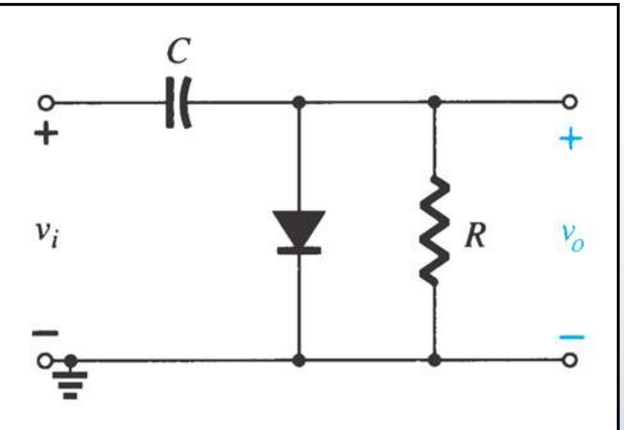
- A clamper is a network constructed of a diode, a resistor, and a capacitor that shifts a waveform to a different dc level without changing the appearance of the applied signal.
- Clamping networks have a capacitor connected directly from input to output with a resistive element in parallel with the output signal.
  - The diode is also in parallel with the output signal but may or may not have a series dc supply as an added element.
  - Peak-peak or swing of input and output must be same.

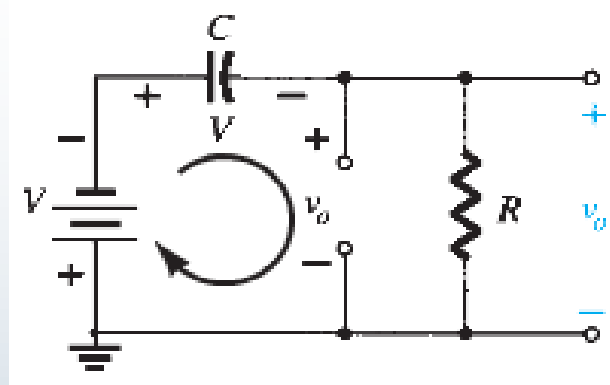


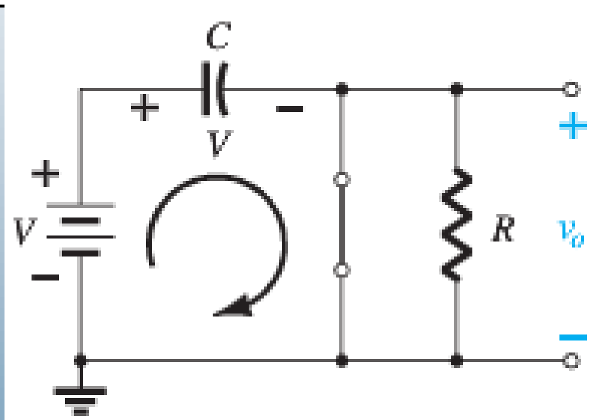




2.9 Clampers







1. Check in which cycle diode is FB/ON?

Positive half cycle.

1. Positive half cycle: Capacitor charges. Diode FB/ON.

Find capacitor voltage (V). Find output (v_o).

$$v_o = 0V.$$

KVL: $-V_{in} + V = 0 \leftrightarrow V = V_{in}$.

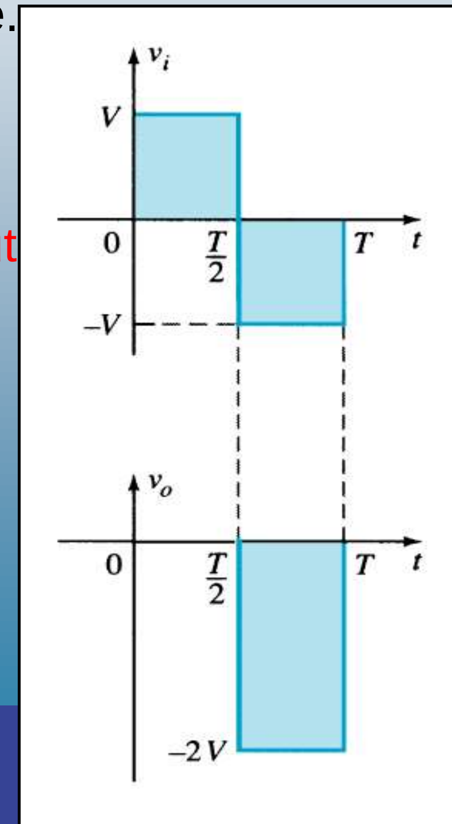
1. Negative half cycle: Capacitor discharges. Capacitor voltage and polarity will not change.

Diode RB/OFF. Find output (v_o).

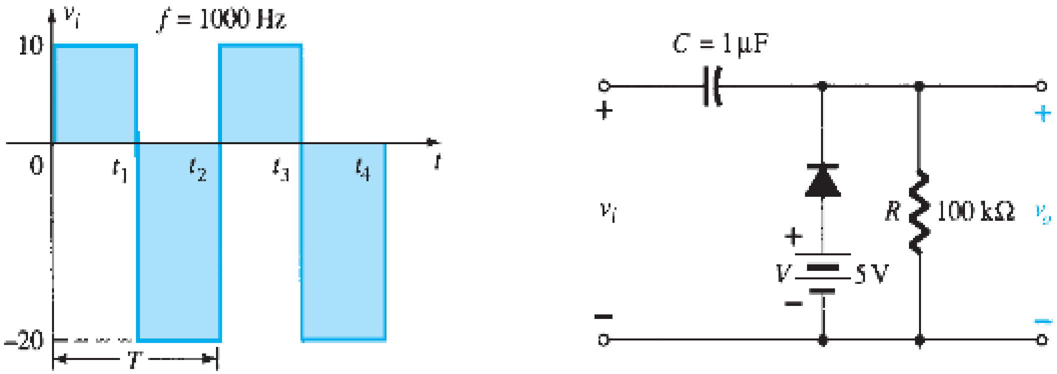
$$v_o \neq 0V.$$

KVL: $+V_{in} + V + v_o = 0 \leftrightarrow v_o = -2V_{in}$.

Peak-peak or swing of input and output must be same



EXAMPLE 2.22 Determine v_o for the network of Fig. 2.93 for the input indicated.



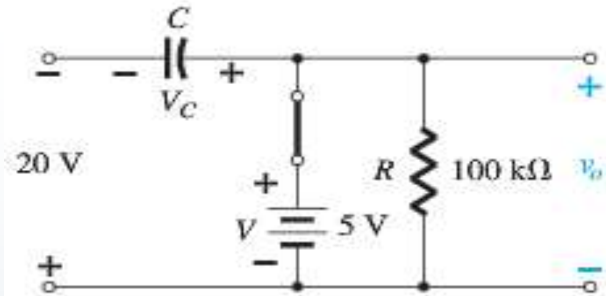


FIG. 2.94
Determining v_o and V_C with the diode in the "on" state.

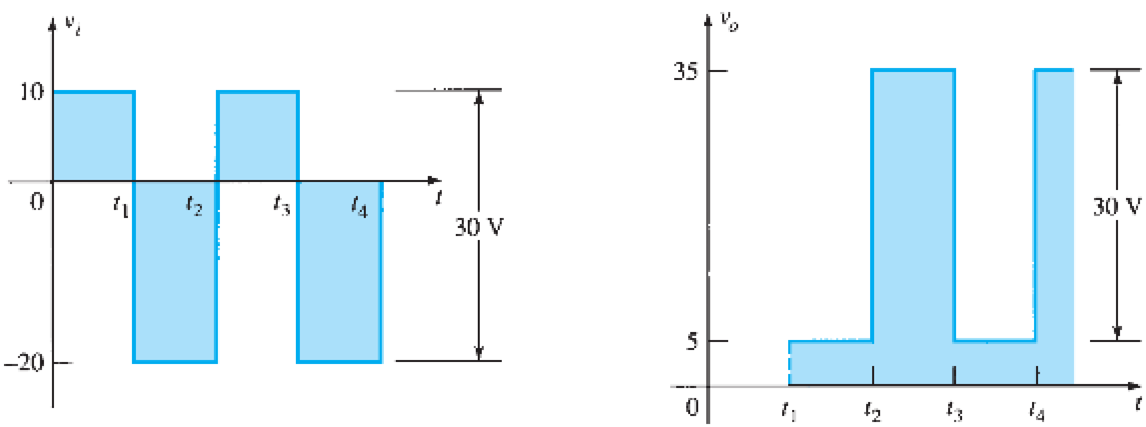


FIG. 2.96
v_i and v_o for the clamper of Fig. 2.93.

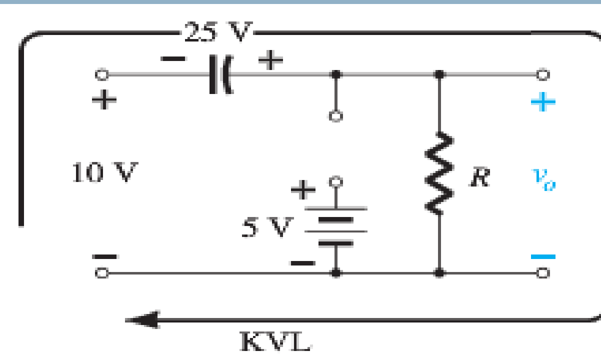
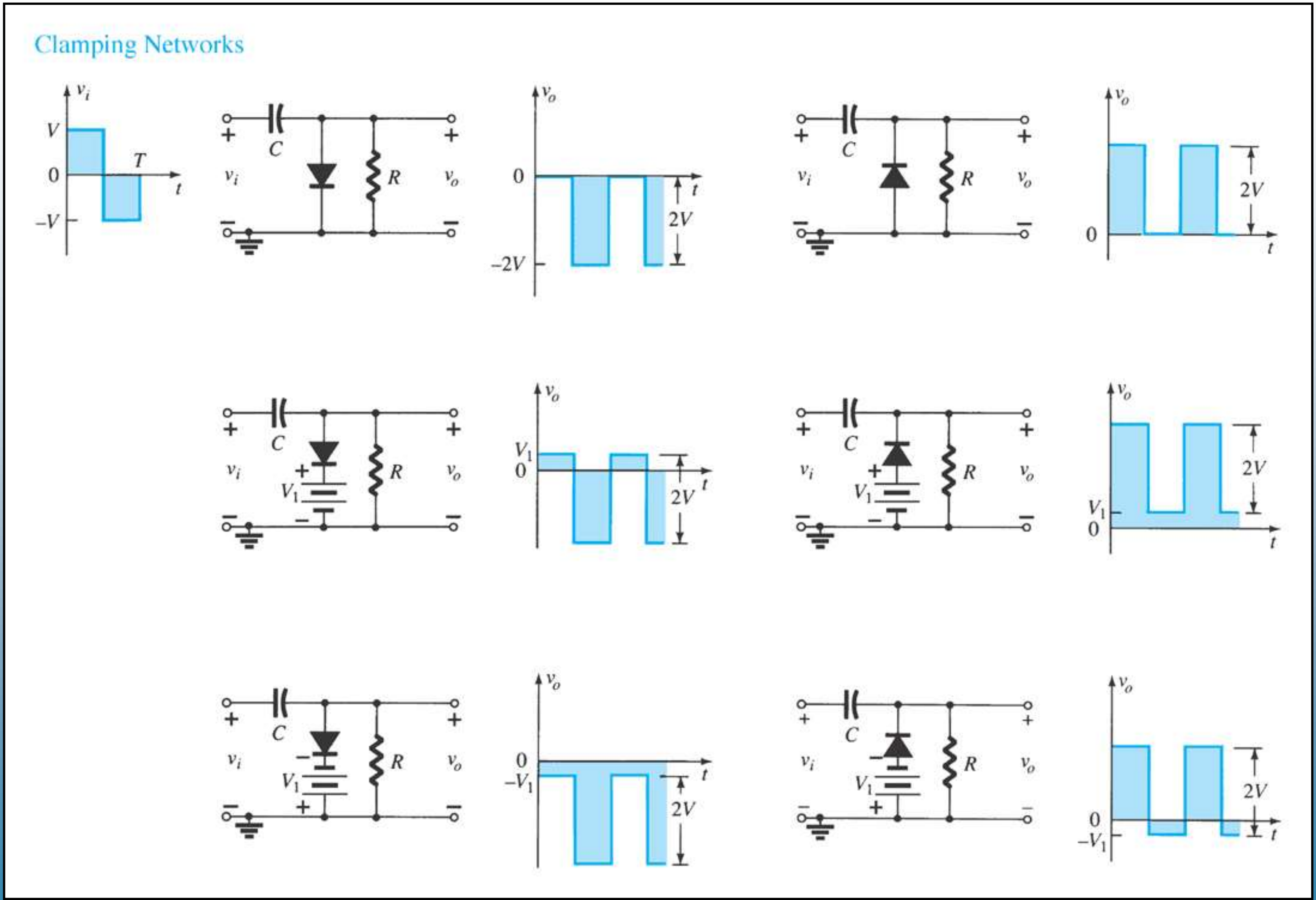


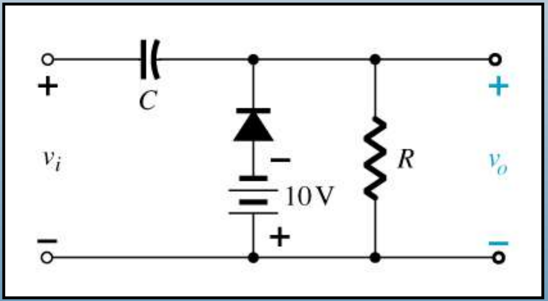
FIG. 2.95
Determining v_o with the diode in the "off" state.

Summary of Clamper Circuits

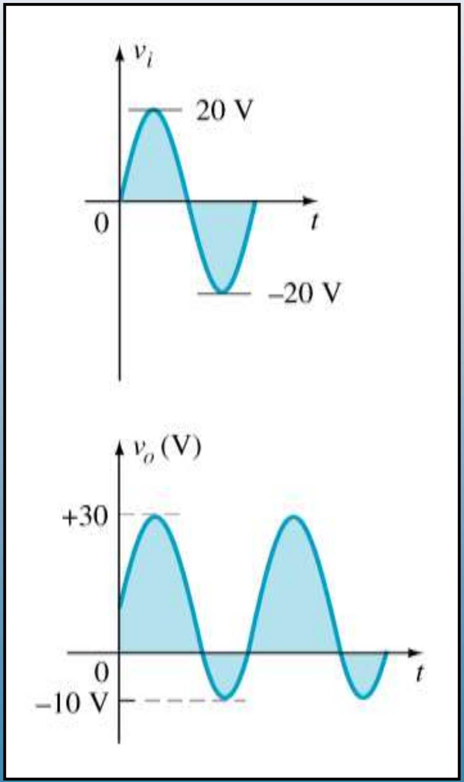


Biased Clamper Circuits with sine input

The input signal can be any type of waveform such as a sine, square, or triangle wave.



The DC source lets you adjust the DC camping level.



2.11 Zener Diodes

Zener diode works exactly similar as Semiconductor diode in Forward Bias (FB)

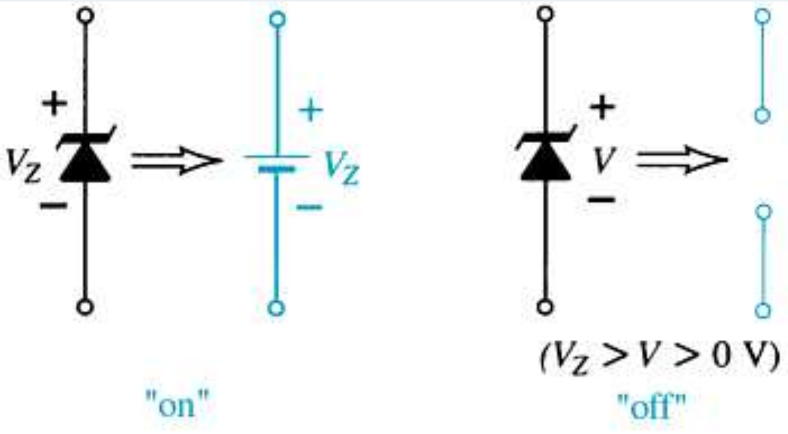
The Zener is a diode that is operated in reverse bias at the Zener Voltage (V_z).

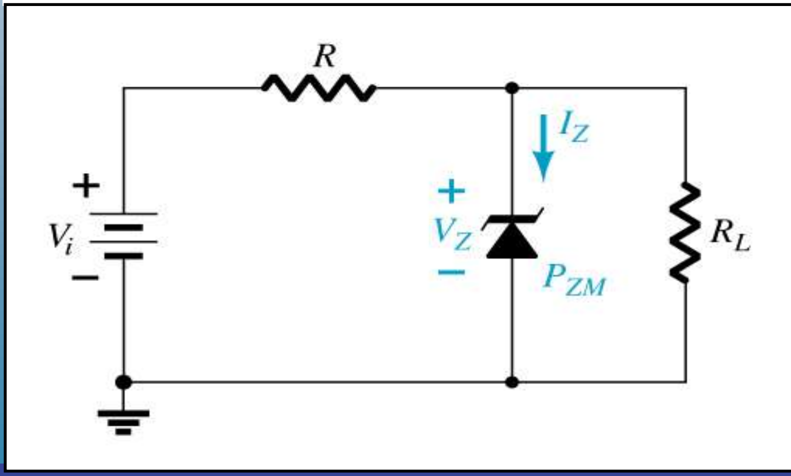
RB: When $V_i \geq V_Z$

- The Zener is on
- Voltage across the Zener is V_Z
- Zener current: $I_Z = I_R – I_{RL}$
- The Zener Power: $P_Z = V_Z I_Z$

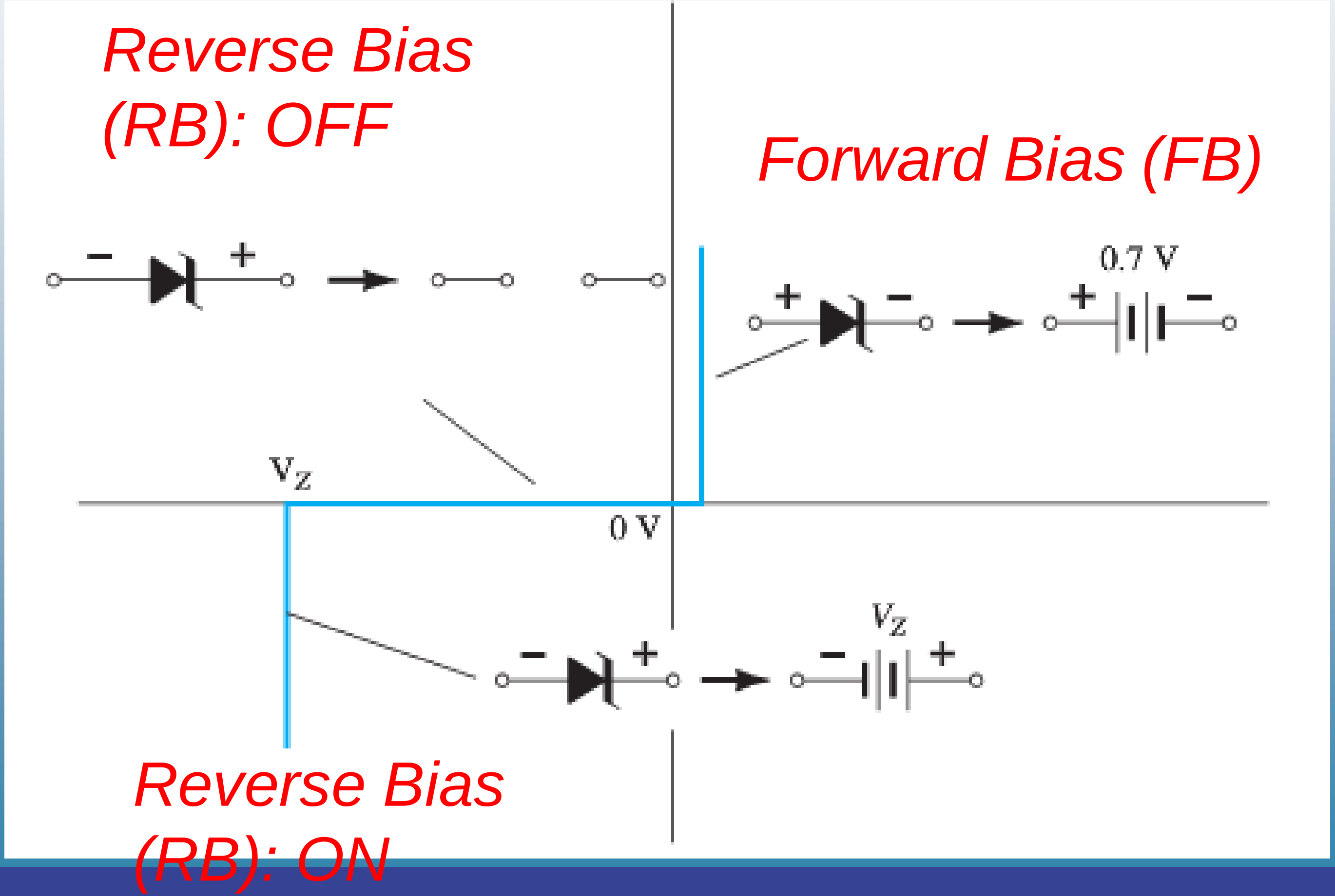
RB: When $V_i < V_Z$

- The Zener is off
- The Zener acts as an open circuit



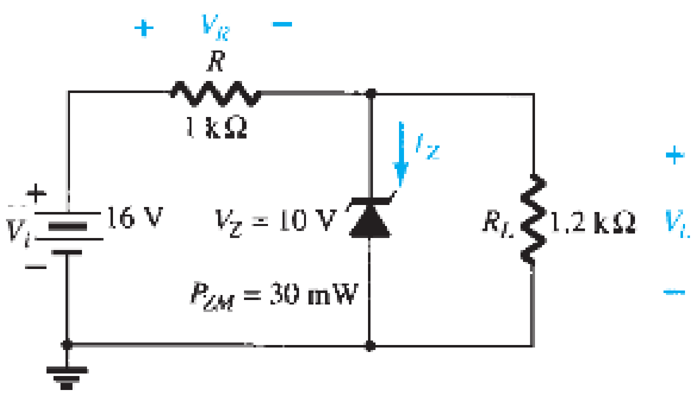


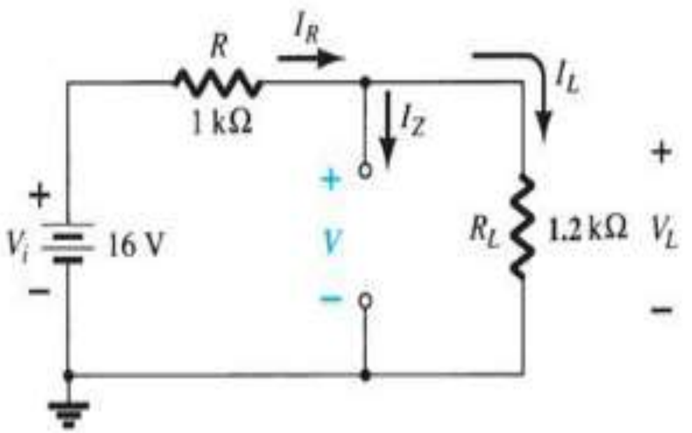
Approximate equivalent circuits for the Zener diode in the three possible regions of application



EXAMPLE 2.26

a. For the Zener diode network of Fig. 2.115, determine V_L, V_R, I_Z, and P_Z.
b. Repeat part (a) with $R_L = 3\ \text{k}\Omega$.





$$V = \frac{R_L V_i}{R + R_L} = \frac{1.2\ \text{k}\Omega(16\ \text{V})}{1\ \text{k}\Omega + 1.2\ \text{k}\Omega} = 8.73\ \text{V}$$

$V_L = V = \mathbf{8.73\ V}$

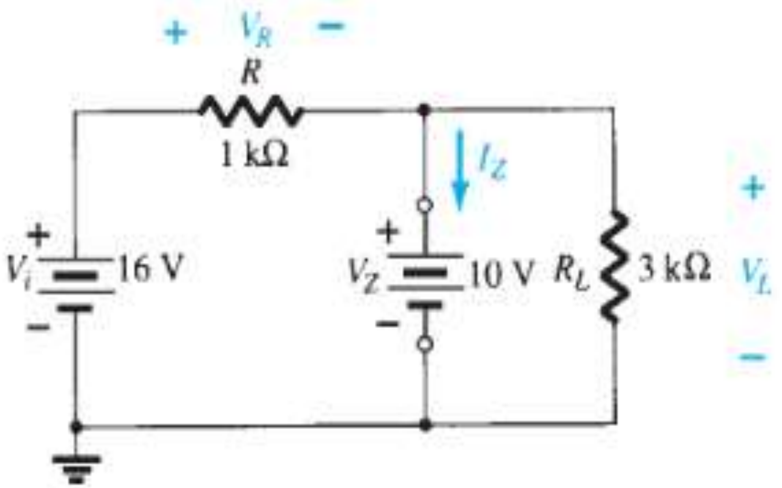
$V_R = V_i - V_L = 16\ \text{V} - 8.73\ \text{V} = \mathbf{7.27\ V}$

$I_Z = \mathbf{0\ A}$

$P_Z = V_Z I_Z = V_Z(0\ \text{A}) = \mathbf{0\ W}$

EXAMPLE 2.26

a. For the Zener diode network of Fig. 2.115, determine V_L, V_R, I_Z, and P_Z.
b. Repeat part (a) with $R_L = 3\text{ k}\Omega$.



$$V = \frac{R_L V_i}{R + R_L} = \frac{3\text{ k}\Omega(16\text{ V})}{1\text{ k}\Omega + 3\text{ k}\Omega} = 12\text{ V}$$

$$V_L = V_Z = \mathbf{10\ V}$$

$$V_R = V_i - V_L = 16\text{ V} - 10\text{ V} = \mathbf{6\ V}$$

$$I_L = \frac{V_L}{R_L} = \frac{10\text{ V}}{3\text{ k}\Omega} = 3.33\text{ mA}$$

$$I_R = \frac{V_R}{R} = \frac{6\text{ V}}{1\text{ k}\Omega} = 6\text{ mA}$$

$$\begin{aligned} I_Z &= I_R - I_L\ [\text{Eq. (2.18)}] \\ &= 6\text{ mA} - 3.33\text{ mA} \\ &= \mathbf{2.67\ mA} \end{aligned}$$

The power dissipated is

$$P_Z = V_Z I_Z = (10\text{ V})(2.67\text{ mA}) = \mathbf{26.7\ mW}$$

which is less than the specified $P_{ZM} = 30\text{ mW}$.