INTEGRATED TECHNICAL EDUCATION CLUSTER
AT ALAMEERIA

# J-601-1448
# Electronic Principals

# Lecture #2
# Diode Applications

## Instructor:
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OCTOBER 2014

# Agenda

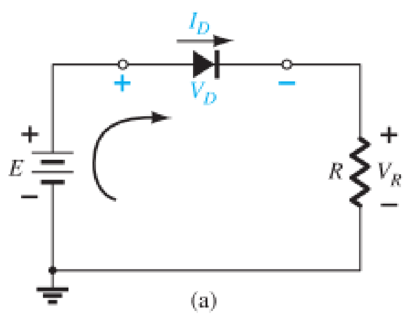
- Load Line analysis
- Series, Parallel and Series-Parallel Configurations
- AND/OR Gates
- Half and Full-wave Rectification
- Clippers, Clampers and Zener Diodes
- Voltage-Multiplier Circuits
- Practical Applications

# Introduction

- This lecture will develop a working knowledge of the diode in a variety of configurations using models appropriate for the area of application.
- Once the basic behavior of a device is understood, its function and response in an infinite variety of configurations can be examined.
- The analysis of electronic circuits can follow one of two paths: using the actual characteristics or applying an approximate model for the device.

# LOAD LINE ANALYSIS

# Load Line Analysis




The intersections of the load line on the characteristics can be determined by first applying Kirchhoff's voltage law in the clockwise direction

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

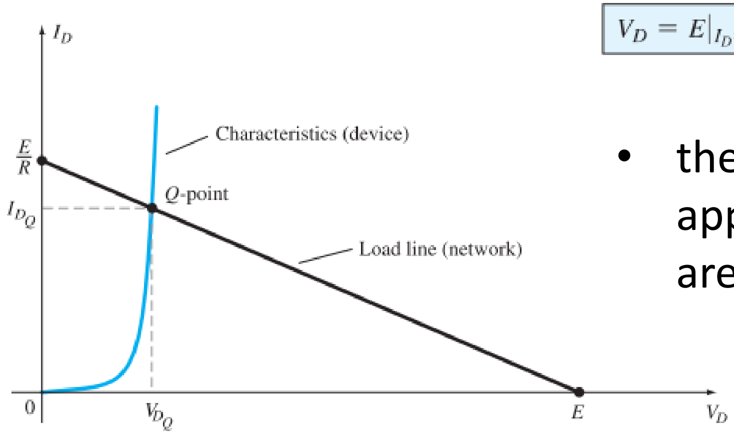
$$\boxed{E = V_D + I_D R}$$

- Solving for $V_D$

$$E = V_D + I_D R$$
$$= V_D + (0\text{ A})R$$
$$\boxed{V_D = E|_{I_D = 0\text{ A}}}$$

- Solving for $I_D$

$$E = V_D + I_D R$$
$$= 0\text{ V} + I_D R$$
$$\boxed{I_D = \frac{E}{R}\bigg|_{V_D = 0\text{ V}}}$$

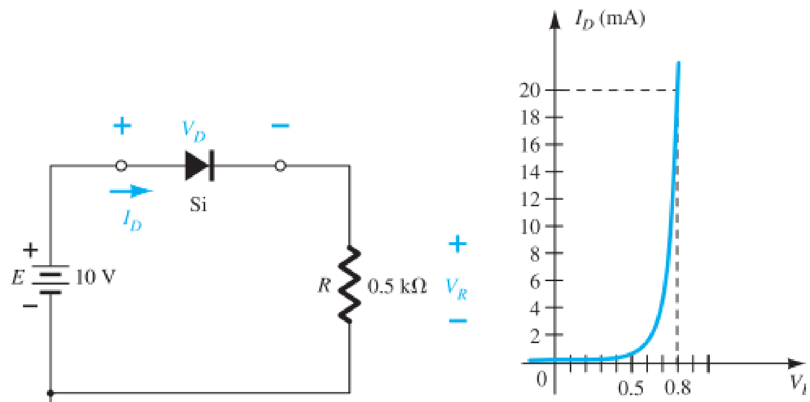



- the load line is determined simply by the applied network, whereas the characteristics are defined by the chosen device.

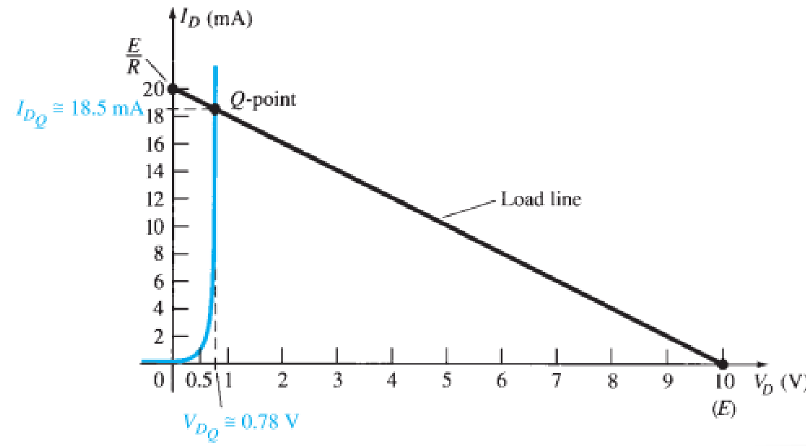
# Example

**EXAMPLE 2.1** For the series diode configuration of Fig. 2.3a, employing the diode characteristics of Fig. 2.3b, determine:

a. $V_{D_Q}$ and $I_{D_Q}$.
b. $V_R$.




(a) (b)




***Solution:***

a. Eq. (2.2): $I_D = \left.\frac{E}{R}\right|_{V_D=0\text{ V}} = \frac{10\text{ V}}{0.5\text{ k}\Omega} = 20\text{ mA}$

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

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

$$V_{D_Q} \cong \mathbf{0.78\ V}$$

$$I_{D_Q} \cong \mathbf{18.5\ mA}$$

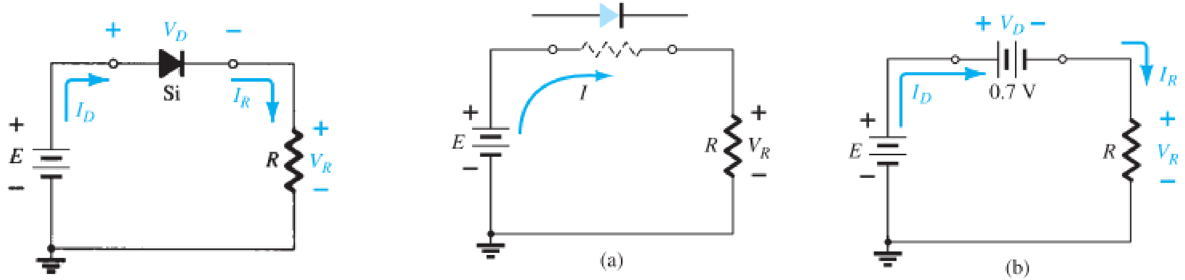
The level of $V_D$ is certainly an estimate, and the accuracy of $I_D$ is limited by the chosen scale. A higher degree of accuracy would require a plot that would be much larger and perhaps unwieldy.

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

# SERIES, PARALLEL AND SERIES-PARALLEL CONFIGURATIONS

# Series Diode Configuration

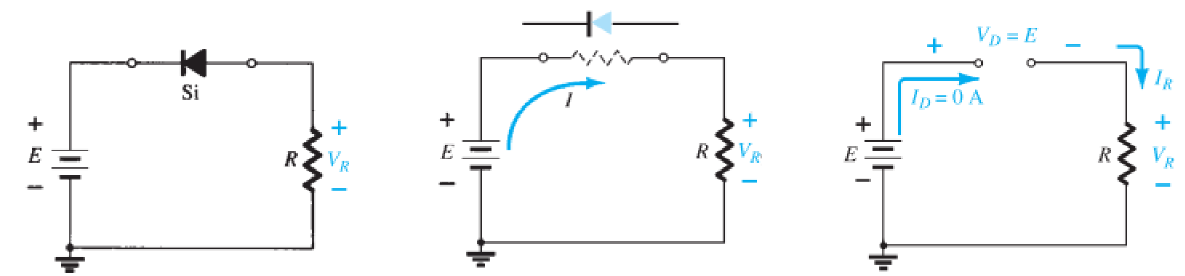
- It’s assumed that the forward resistance of the diode is usually so small compared to the other series elements of the network that it can be ignored.
- In general, a diode is in the “on” state if the current established by the applied sources is such that its direction matches that of the arrow in the diode symbol, and $V_D \geq 0.7V$ for silicon, $V_D \geq 0.3V$ for germanium, and $V_D \geq 1.2V$ for gallium arsenide.




$$V_D = V_K$$

$$V_R = E - V_K$$

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




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

# Example

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

***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

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

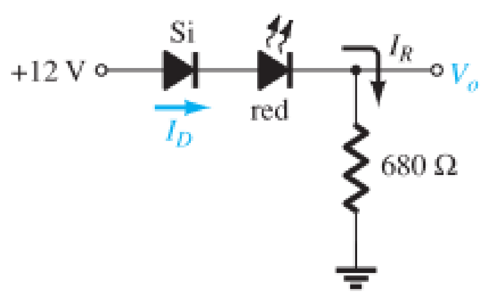



**FIG. 2.19**
*Circuit for Example 2.7.*

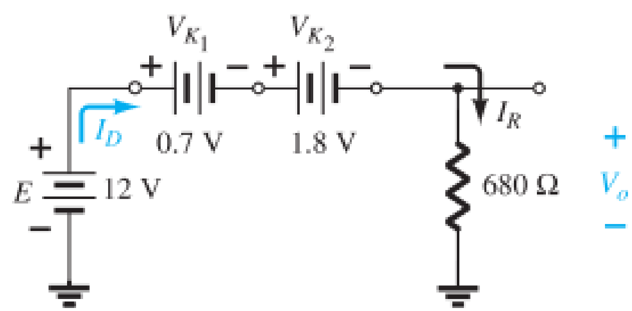



**FIG. 2.20**
*Determining the unknown quantities for Example 2.7.*

# Parallel Configuration

## Design Problem

**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.

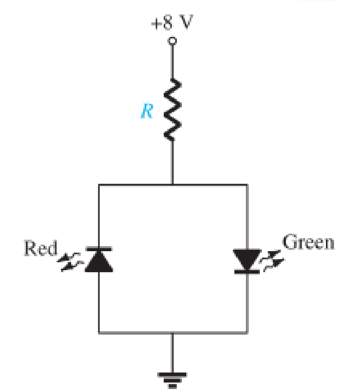



**FIG. 2.30**
*Network for Example 2.11.*

***Solution:*** The application of a positive supply voltage results in a conventional current that matches the arrow of the green diode and turns it on.

The polarity of the voltage across the green diode is such that it reverse biases the red diode by the same amount. The result is the equivalent network of Fig. 2.31.

Applying Ohm's law, we obtain

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

and

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

What about blue LED?

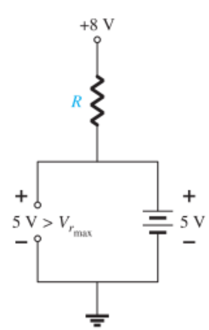



**FIG. 2.32**
*Network of Fig. 2.31 with a blue diode.*

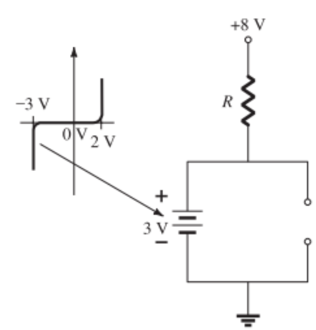



**FIG. 2.33**
*Demonstrating damage to the red LED if the reverse breakdown voltage is exceeded.*

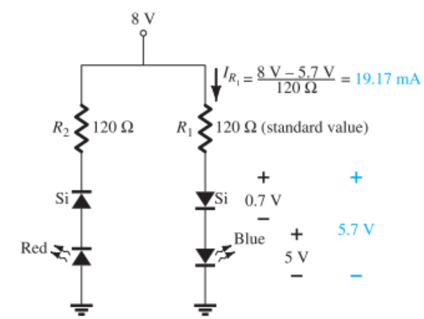



**FIG. 2.34**
*Protective measure for the red LED of Fig. 2.33.*

# Series-Parallel Configuration..

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

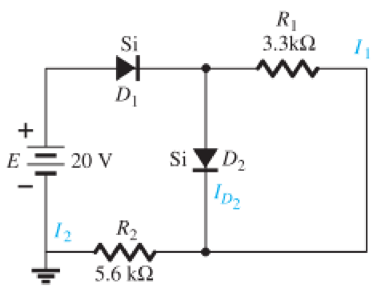



**FIG. 2.37**
*Network for Example 2.13.*

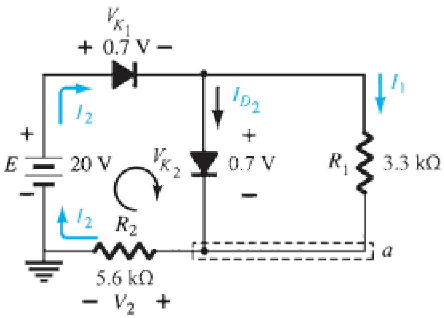



**FIG. 2.38**
*Determining the unknown quantities for Example 2.13.*

***Solution:*** The applied voltage (pressure) is such as to turn both diodes on, as indicated by the resulting current directions in the network of Fig. 2.38. Note the use of the abbreviated notation for "on" diodes and that the solution is obtained through an application of techniques applied to dc series–parallel networks. We have

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

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

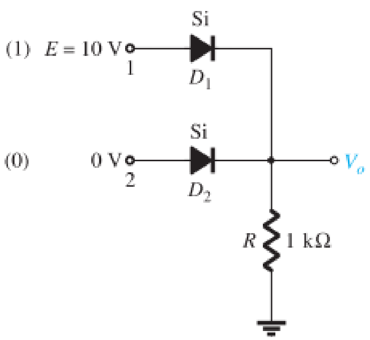
# AND/OR GATES

# AND/OR Gate

- Positive logic: Logic 1→ E volt , Logic 0 → 0 volt

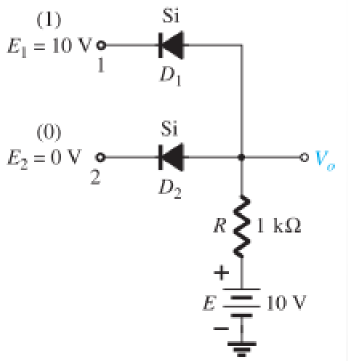
Positive logic OR gate

| $V_{i1}$ | $V_{i2}$ | $V_o$ |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |




Positive logic AND gate

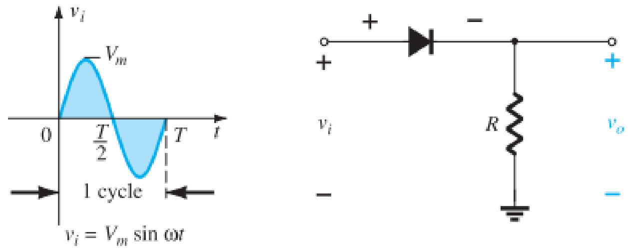
| $V_{i1}$ | $V_{i2}$ | $V_o$ |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |



# HALF AND FULL-WAVE RECTIFICATION

# Half-wave Rectifier

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



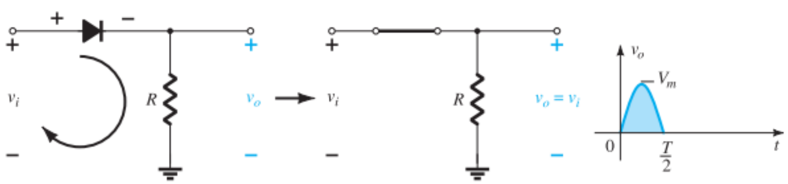




**FIG. 2.45**
*Conduction region ($0 \to T/2$).*

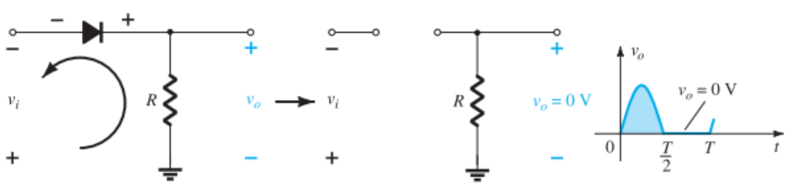
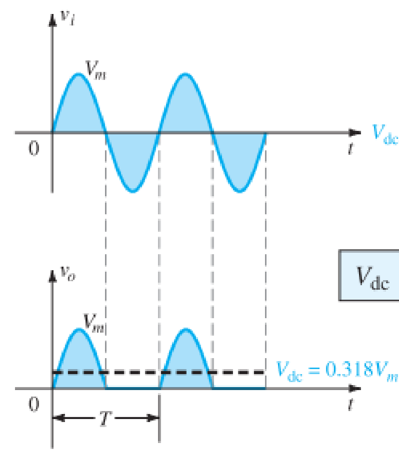


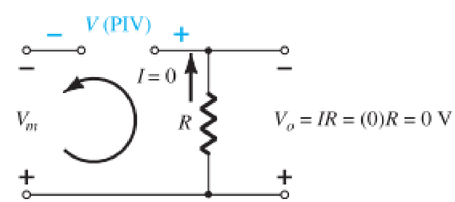

**FIG. 2.46**
*Nonconduction region ($T/2 \to T$).*



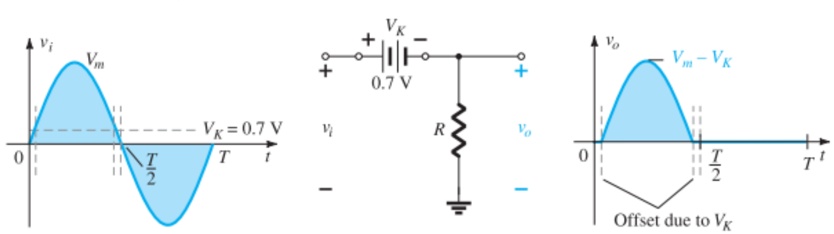

$$V_{dc} = 0.318\, V_m$$ half-wave

**FIG. 2.47**
*Half-wave rectified signal.*

$$\text{PIV rating} \geqq V_m$$ half-wave rectifier




- Effect of $V_K$ on half-wave rectified signal.




Cross Over distortion

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

# Full-wave Rectifier

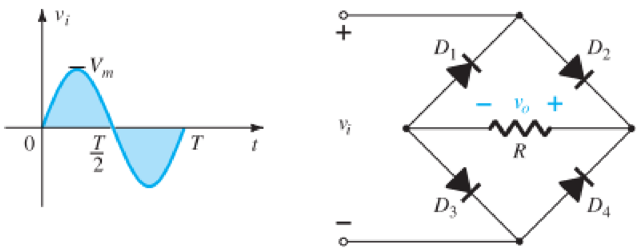



FIG. 2.53
*Full-wave bridge rectifier.*

$V_{dc} = 0.636\ V_m$ full-wave

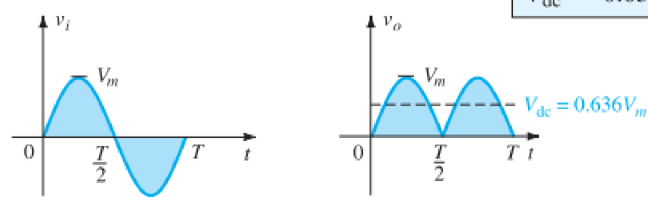



FIG. 2.57
*Input and output waveforms for a full-wave rectifier.*

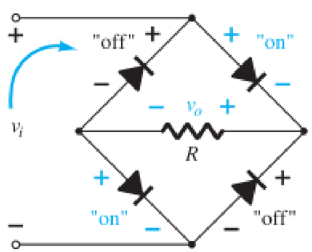



FIG. 2.54
*Network of Fig. 2.53 for the period $0 \rightarrow T/2$ of the input voltage $v_i$.*

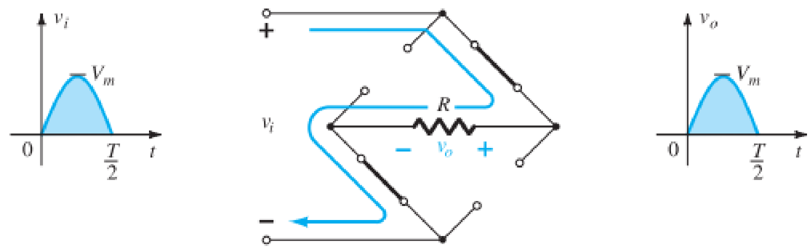



FIG. 2.55
*Conduction path for the positive region of $v_i$.*

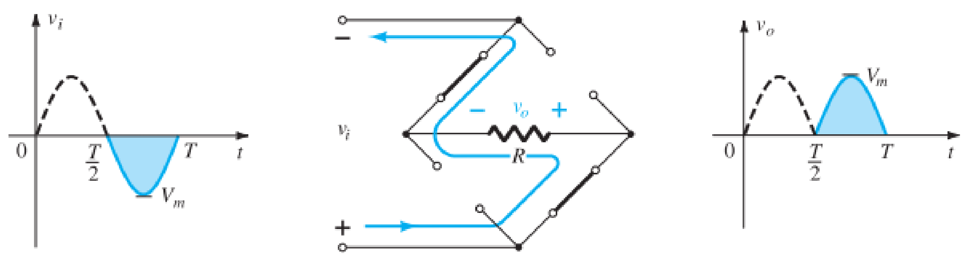
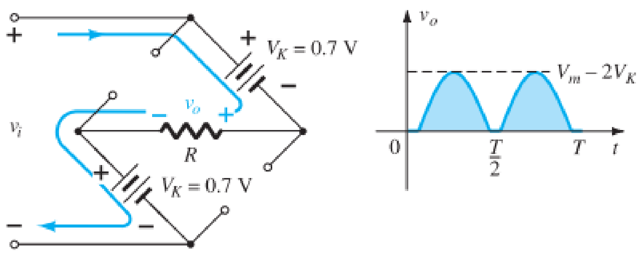



FIG. 2.56
*Conduction path for the negative region of $v_i$.*

# Center-tapped transformer full-wave rectifier

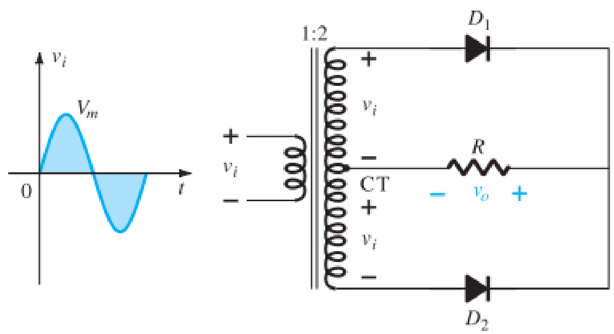
Determining $V_{o\,max}$ for diodes in the bridge configuration

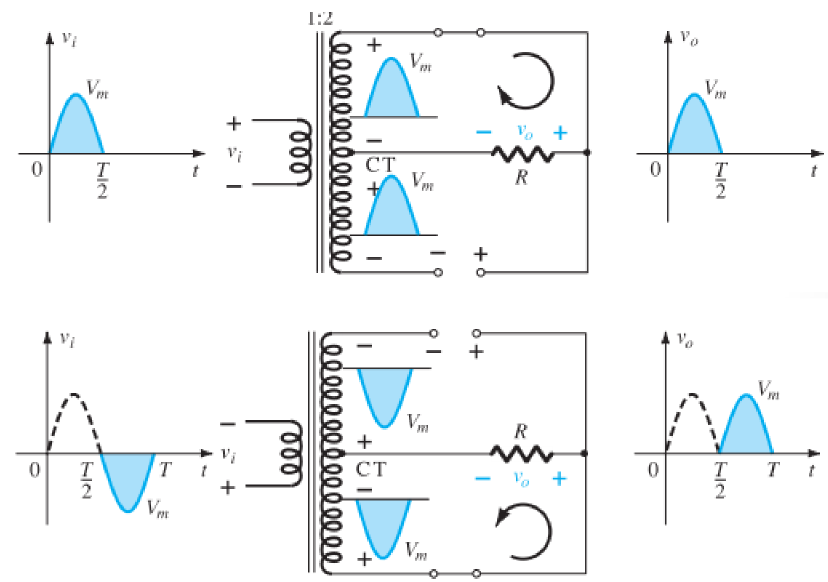



$$V_{dc} \cong 0.636(V_m - 2V_K)$$

$$PIV \geqq V_m$$ full-wave bridge rectifier

- **Center-tapped transformer full-wave rectifier.**



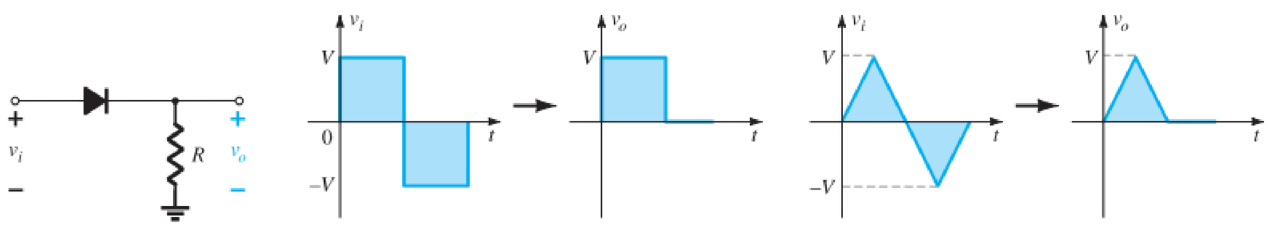

$$PIV \geqq 2V_m$$ CT transformer, full-wave rectifier

# CLIPPERS, CLAMPERS AND ZENER DIODES

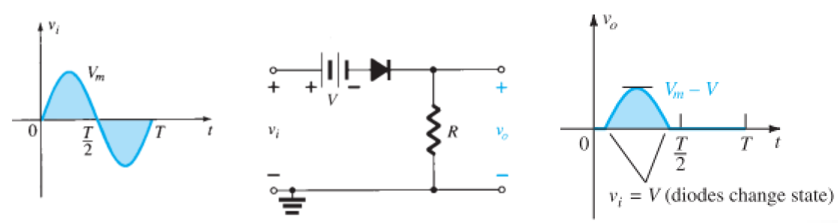
# Clippers

- Clippers are networks that employ diodes to “clip” away a portion of an input signal without distorting the remaining part of the applied waveform.

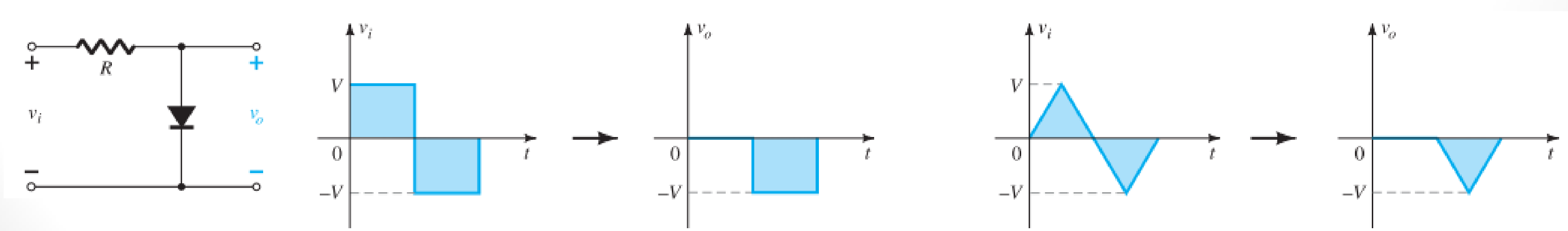
- **Series**



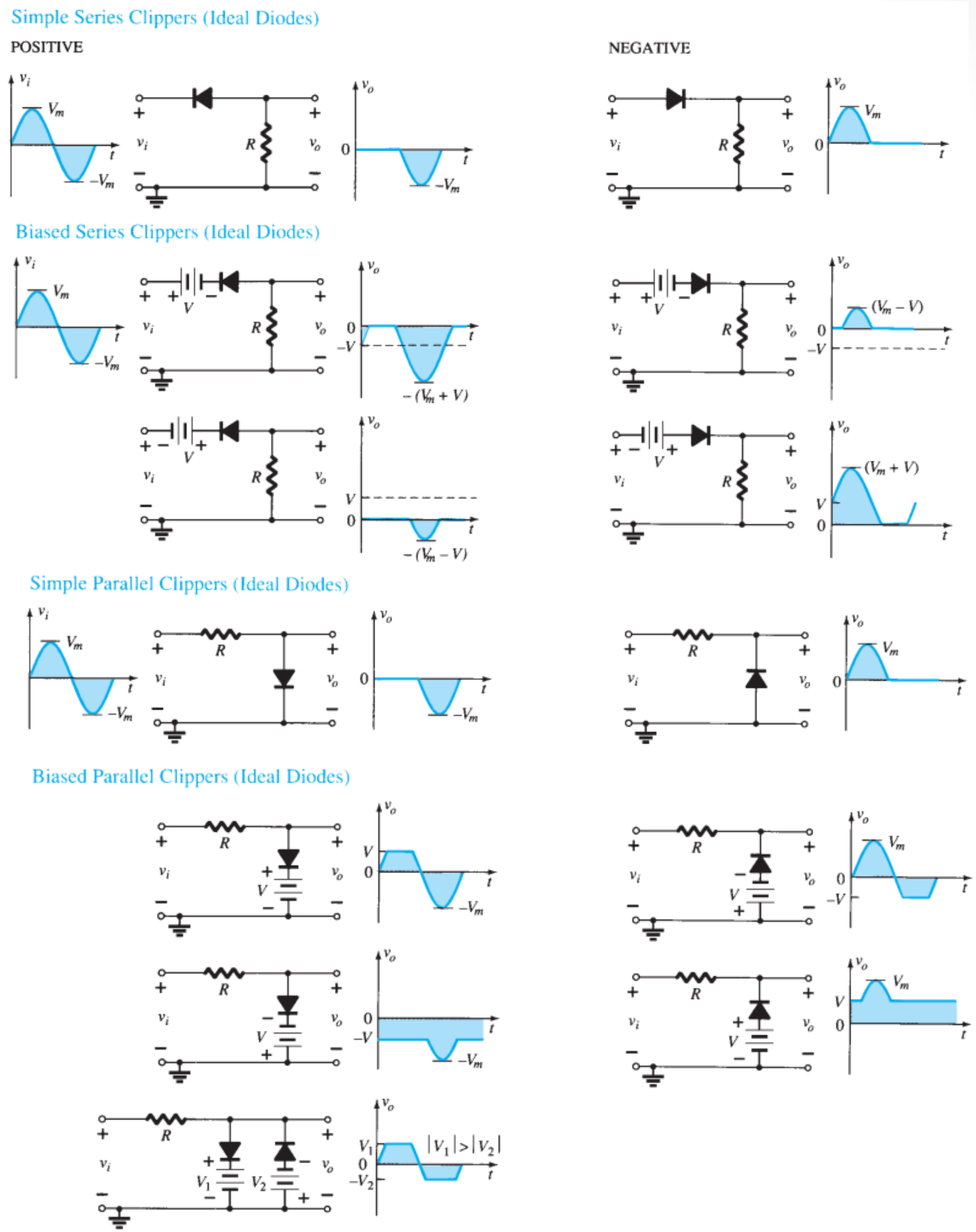

Clipper with DC supply →




- **Parallel**



# Clipping Circuits

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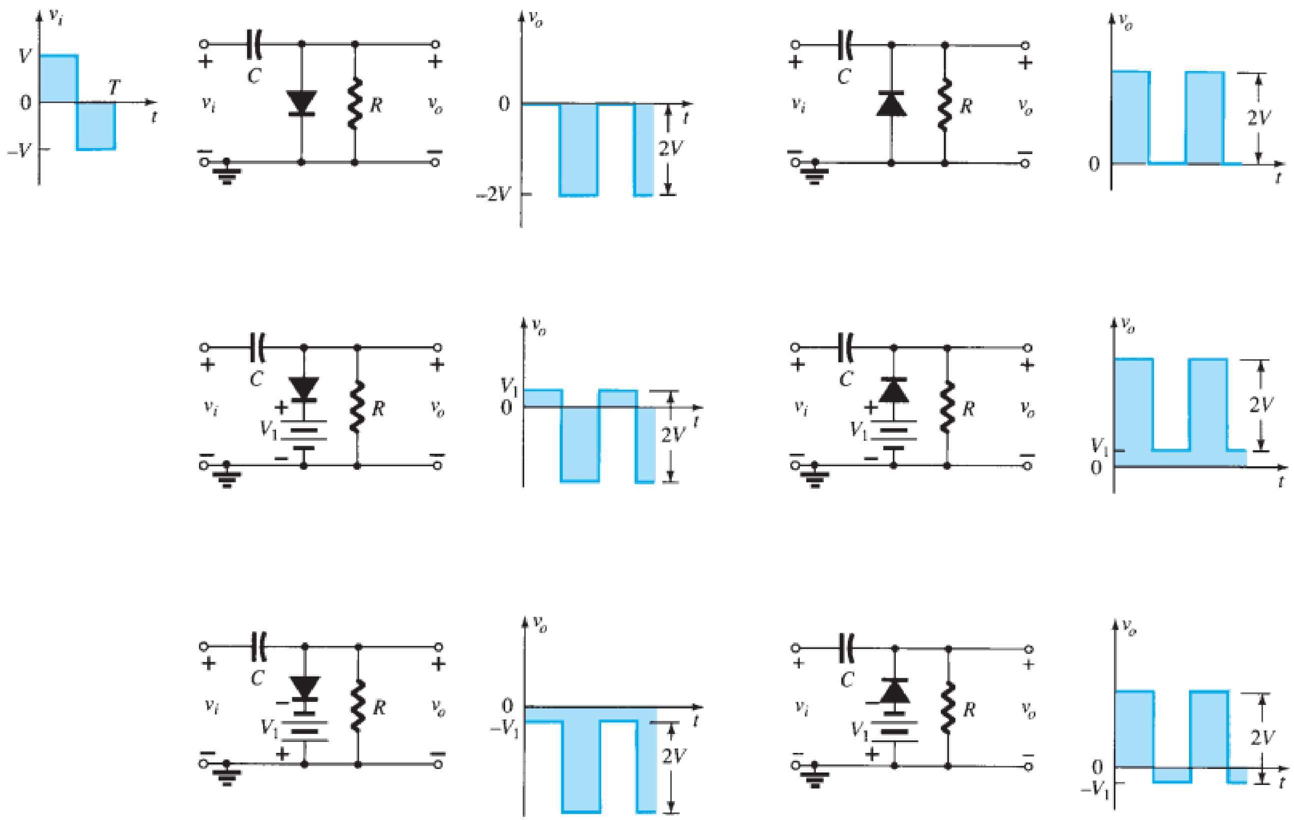
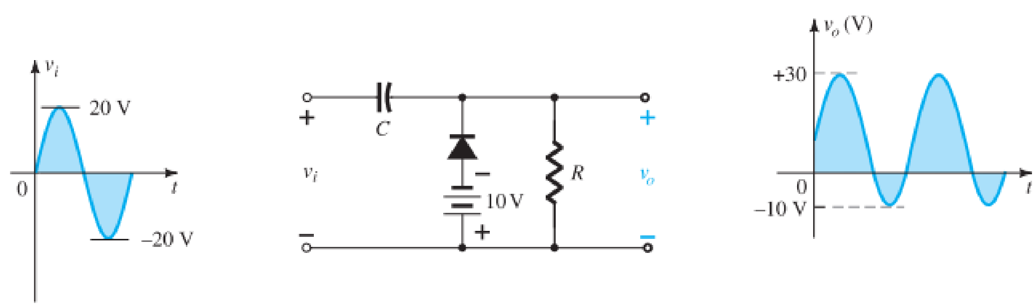
# Clampers

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

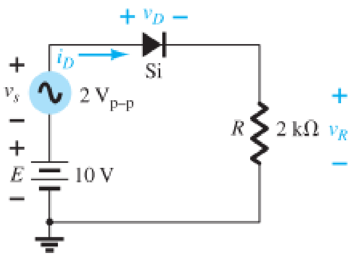



Clamping network with a sinusoidal input.

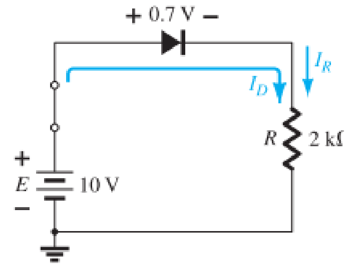


# Networks with a Dc and AC sources

- The response of any network with both an ac and a dc source can be found by finding the response to each source independently and then combining the results.



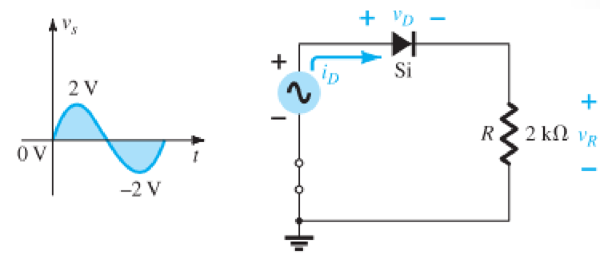

**DC Source**



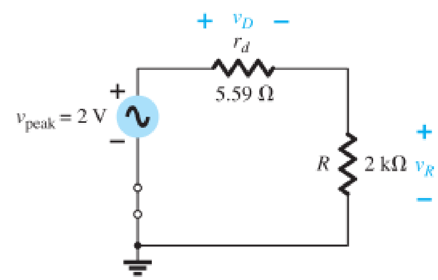

$$V_R = E - V_D = 10\text{ V} - 0.7\text{ V} = 9.3\text{ V}$$

$$I_D = I_R = \frac{9.3\text{ V}}{2\text{ k}\Omega} = 4.65\text{ mA}$$

**AC Source**



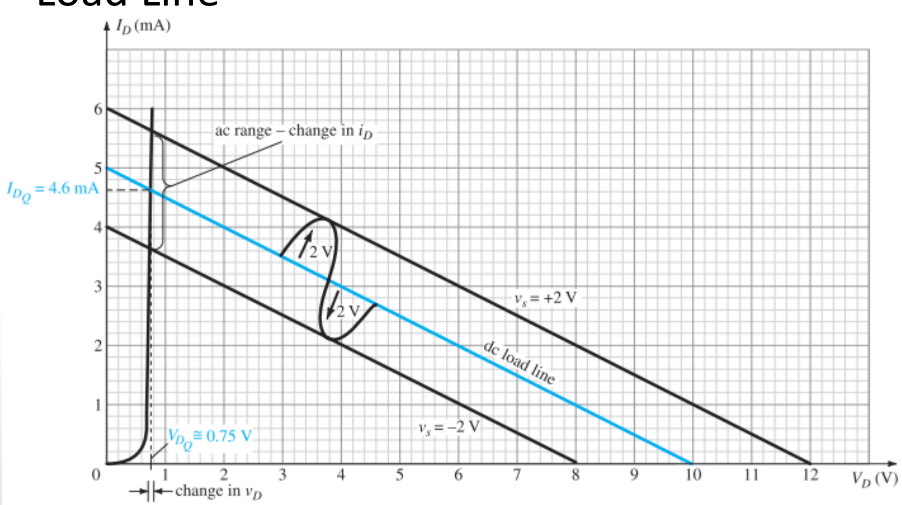

$$r_d = \frac{26\text{ mV}}{I_D} = \frac{26\text{ mV}}{4.65\text{ mA}} = 5.59\ \Omega$$



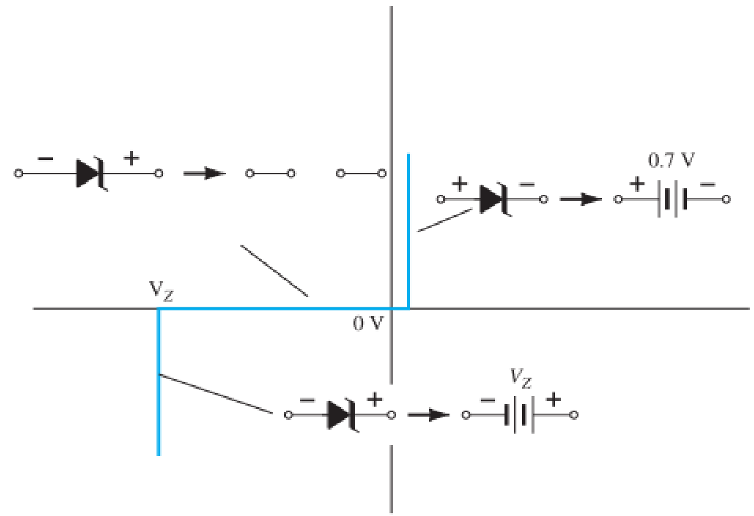

$$v_{R_{peak}} = \frac{2\text{ k}\Omega\,(2\text{ V})}{2\text{ k}\Omega + 5.59\ \Omega} \cong 1.99\text{ V}$$

$$v_{D_{peak}} = v_{s_{peak}} - v_{R_{peak}} = 2\text{ V} - 1.99\text{ V} = 0.01\text{ V} = 10\text{ mV}$$

## Load Line



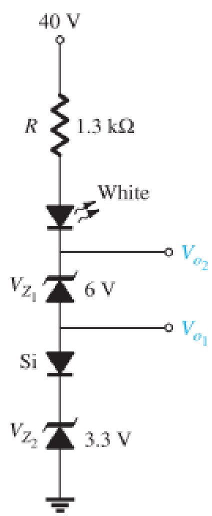
# Zener Diodes




## Example 1:

First we have to check that there is sufficient applied voltage to turn on all the series diode elements.

The white LED will have a drop of about 4 V across it, the 6-V and 3.3-V Zener diodes have a total of 9.3 V, and the forward-biased silicon diode has 0.7 V, for a total of 14 V.



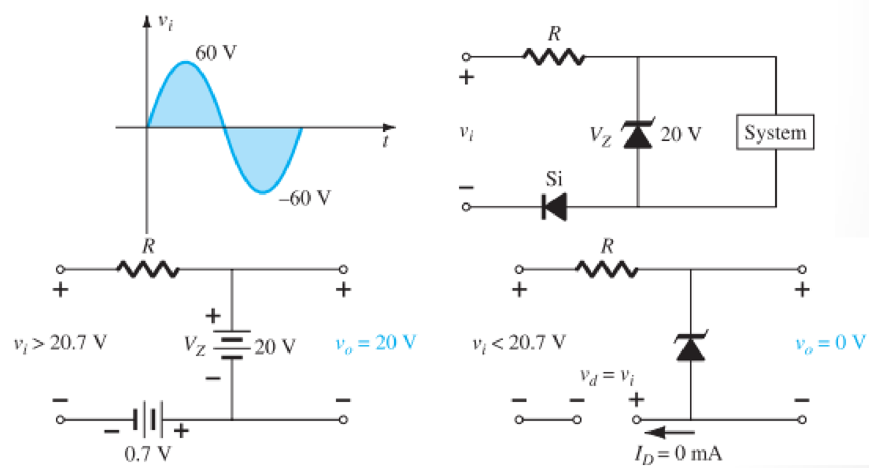

$$V_{o_1} = V_{Z_2} + V_K = 3.3\text{ V} + 0.7\text{ V} = \mathbf{4.0\text{ V}}$$

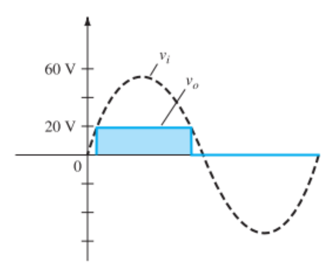
$$V_{o_2} = V_{o_1} + V_{Z_1} = 4\text{ V} + 6\text{ V} = \mathbf{10\text{ V}}$$

$$I_R = I_{LED} = \frac{V_R}{R} = \frac{40\text{ V} - V_{o_2} - V_{LED}}{1.3\text{ k}\Omega}$$

$$= \frac{40\text{ V} - 10\text{ V} - 4\text{ V}}{1.3\text{ k}\Omega} = \frac{26\text{ V}}{1.3\text{ k}\Omega} = \mathbf{20\text{ mA}}$$

## Example 2:



# Zener Diodes $V_i$ and R Fixed

1. Determine the state of the Zener diode by removing it from the network and calculating the voltage across the resulting open circuit.

$$V = V_L = \frac{R_L V_i}{R + R_L}$$

2. Substitute the appropriate equivalent circuit and solve for the desired unknowns.

$$V_L = V_Z$$

$$I_R = I_Z + I_L$$

$$I_Z = I_R - I_L$$

$$I_L = \frac{V_L}{R_L} \qquad I_R = \frac{V_R}{R} = \frac{V_i - V_L}{R}$$

$$P_Z = V_Z I_Z$$

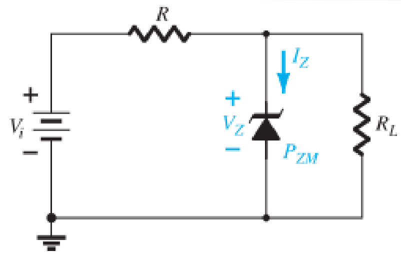



**FIG. 2.112**
*Basic Zener regulator.*

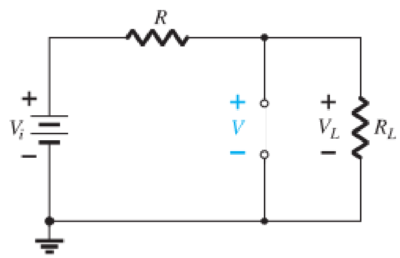



**FIG. 2.113**
*Determining the state of the Zener diode.*

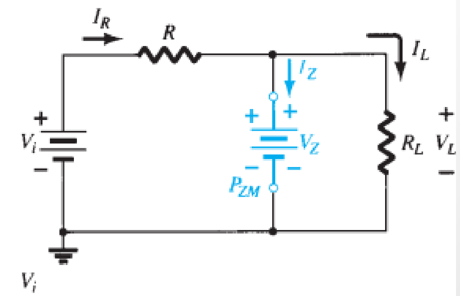



**FIG. 2.114**
*Substituting the Zener equivalent for the "on" situation.*

# Zener Diodes Fixed $V_i$, Variable $R_L$

$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$R_{L_{min}} = \frac{R V_Z}{V_i - V_Z}$$

$$I_{L_{max}} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L_{min}}}$$

$$V_R = V_i - V_Z$$

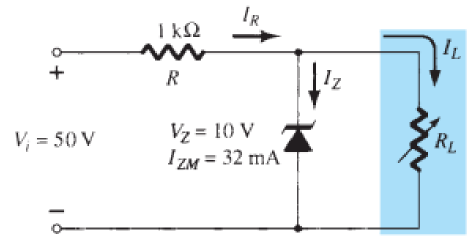
$$I_R = \frac{V_R}{R}$$

$$I_Z = I_R - I_L$$

$$I_{L_{min}} = I_R - I_{ZM}$$

$$R_{L_{max}} = \frac{V_Z}{I_{L_{min}}}$$

Example:




$$R_{L_{min}} = \frac{R V_Z}{V_i - V_Z} = \frac{(1\,\text{k}\Omega)(10\,\text{V})}{50\,\text{V} - 10\,\text{V}} = \frac{10\,\text{k}\Omega}{40} = \mathbf{250\,\Omega}$$

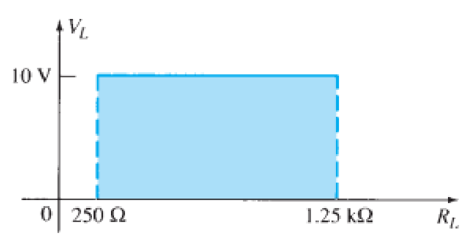
$$V_R = V_i - V_Z = 50\,\text{V} - 10\,\text{V} = \mathbf{40\,V}$$

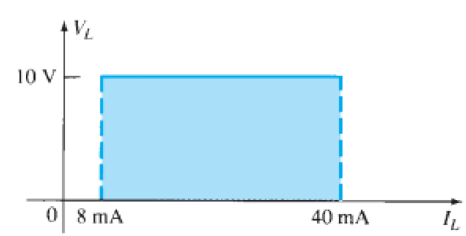
$$I_R = \frac{V_R}{R} = \frac{40\,\text{V}}{1\,\text{k}\Omega} = \mathbf{40\,mA}$$

$$I_{L_{min}} = I_R - I_{ZM} = 40\,\text{mA} - 32\,\text{mA} = \mathbf{8\,mA}$$

$$R_{L_{max}} = \frac{V_Z}{I_{L_{min}}} = \frac{10\,\text{V}}{8\,\text{mA}} = \mathbf{1.25\,k\Omega}$$

$$P_{max} = V_Z I_{ZM} = (10\,\text{V})(32\,\text{mA}) = \mathbf{320\,mW}$$



# Zener Diodes Fixed $R_L$, Variable $V_i$

$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$\boxed{V_{i_{\min}} = \frac{(R_L + R)V_Z}{R_L}}$$

$$\boxed{I_{R_{\max}} = I_{ZM} + I_L}$$

$$V_{i_{\max}} = V_{R_{\max}} + V_Z$$

$$\boxed{V_{i_{\max}} = I_{R_{\max}} R + V_Z}$$

**EXAMPLE 2.28** Determine the range of values of $V_i$ that will maintain the Zener diode of Fig. 2.121 in the "on" state.

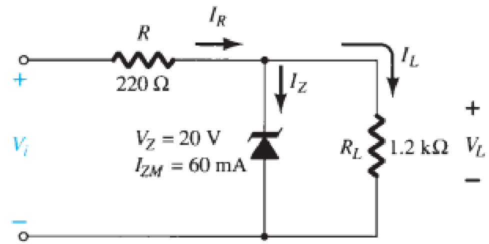



**FIG. 2.121**
*Regulator for Example 2.28.*

$$V_{i_{\min}} = \frac{(R_L + R)V_Z}{R_L} = \frac{(1200\ \Omega + 220\ \Omega)(20\ \text{V})}{1200\ \Omega} = \mathbf{23.67\ V}$$

$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{20\ \text{V}}{1.2\ \text{k}\Omega} = 16.67\ \text{mA}$$

$$\begin{aligned} I_{R_{\max}} &= I_{ZM} + I_L = 60\ \text{mA} + 16.67\ \text{mA} \\ &= 76.67\ \text{mA} \end{aligned}$$

$$\begin{aligned} V_{i_{\max}} &= I_{R_{\max}} R + V_Z \\ &= (76.67\ \text{mA})(0.22\ \text{k}\Omega) + 20\ \text{V} \\ &= 16.87\ \text{V} + 20\ \text{V} \\ &= \mathbf{36.87\ V} \end{aligned}$$

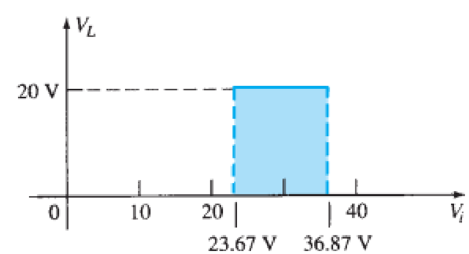



**FIG. 2.122**
*$V_L$ versus $V_i$ for the regulator of Fig. 2.121.*

# VOLTAGE-MULTIPLIER CIRCUITS

# Voltage Doubler

- Half wave voltage doubler

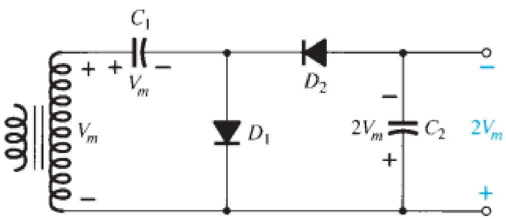
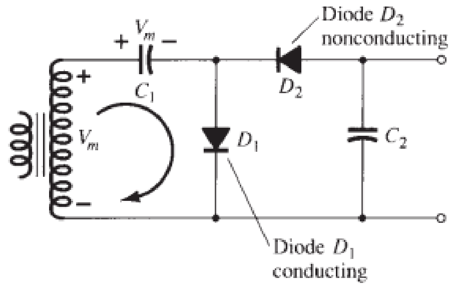
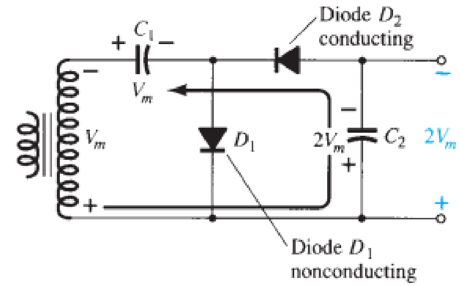
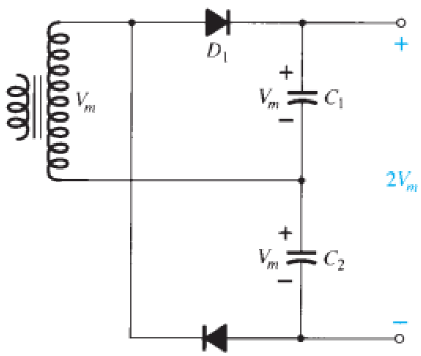



**FIG. 2.123**
*Half-wave voltage doubler.*




- Full wave voltage doubler



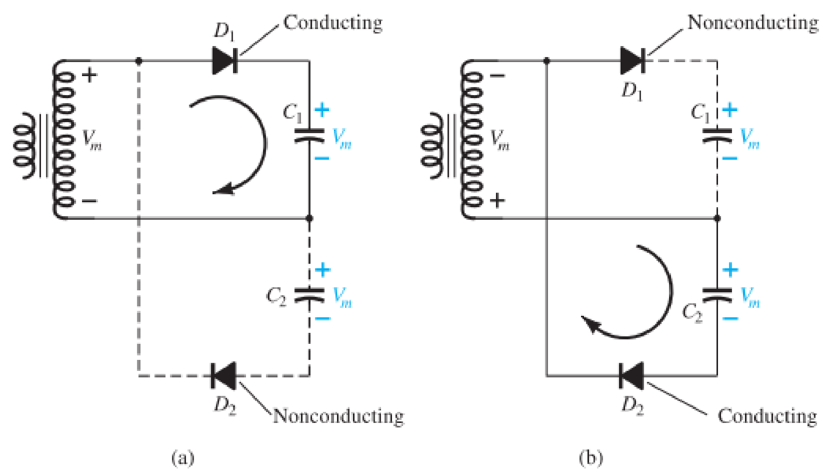




**FIG. 2.126**
*Alternate half-cycles of operation for full-wave voltage doubler.*

# Voltage Tripler and Quadrupler

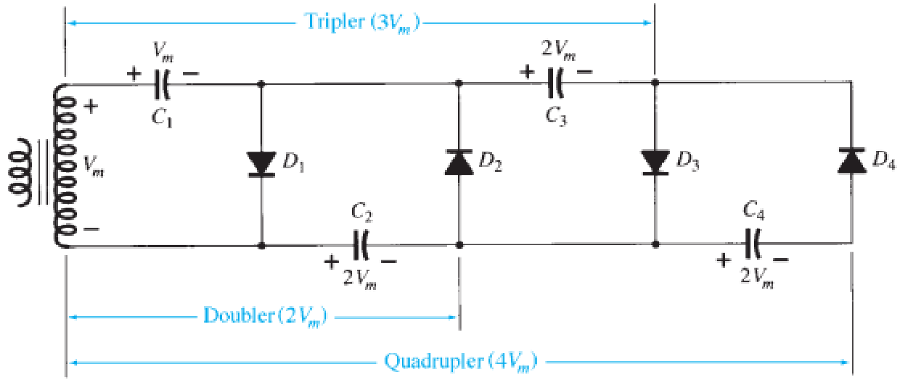
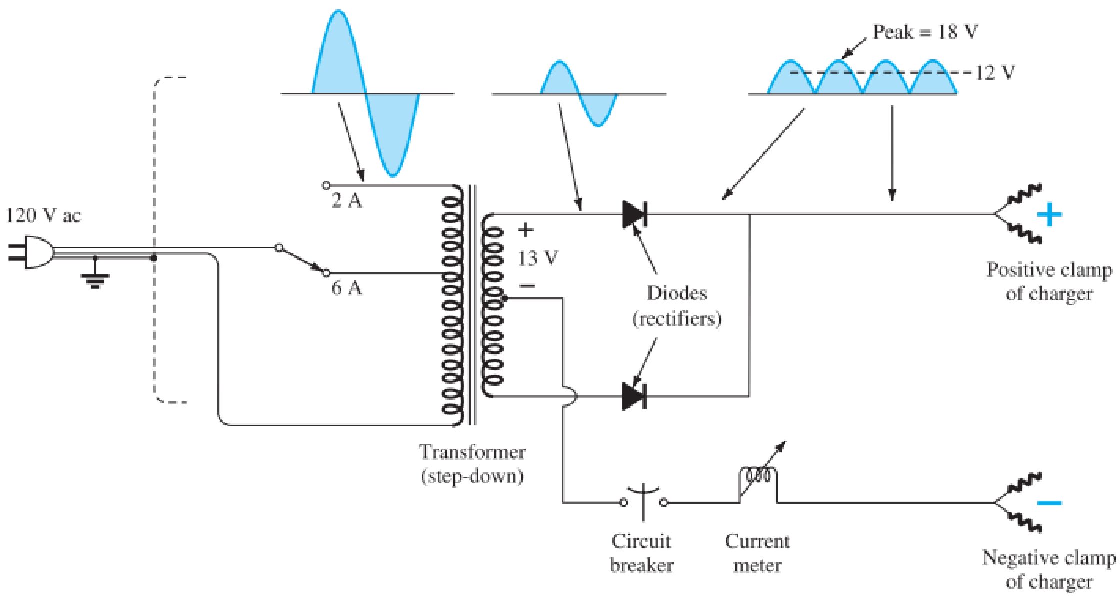



**FIG. 2.127**
*Voltage tripler and quadrupler.*

# PRACTICAL APPLICATIONS

# Rectification

- Battery Charger



# Protective Configurations

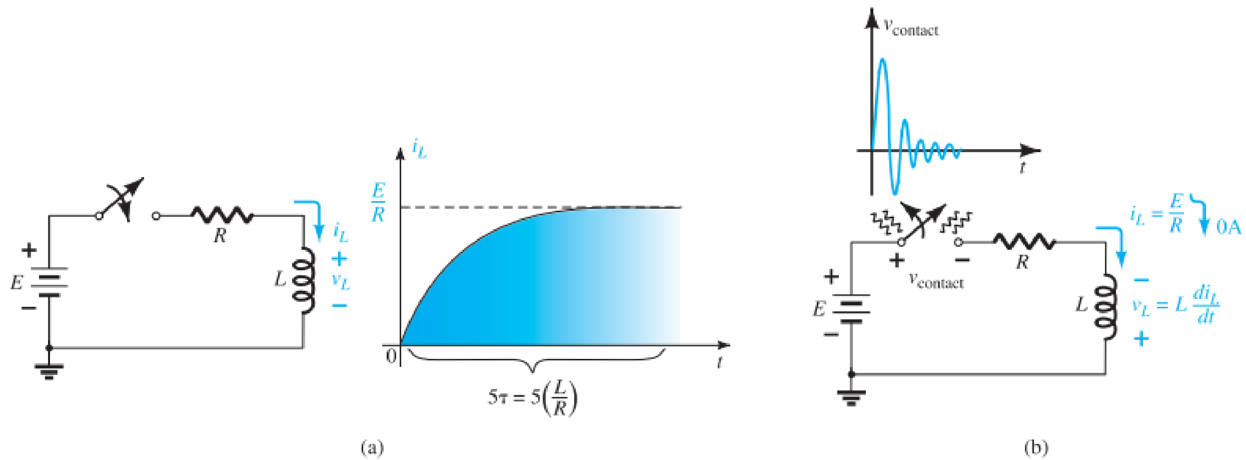



**FIG. 2.131**

*(a) Transient phase of a simple RL circuit; (b) arcing that results across a switch when opened in series with an RL circuit.*

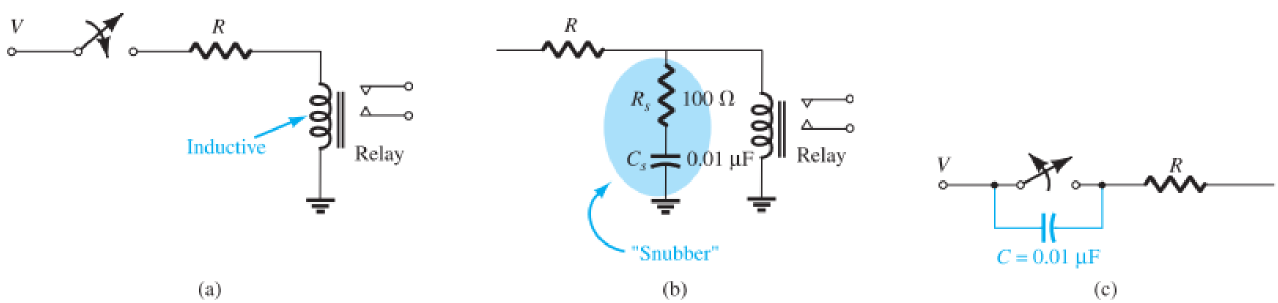



**FIG. 2.132**

*(a) Inductive characteristics of a relay; (b) snubber protection for the configuration of part (a); (c) capacitive protection for a switch.*

# Protective Configurations ..

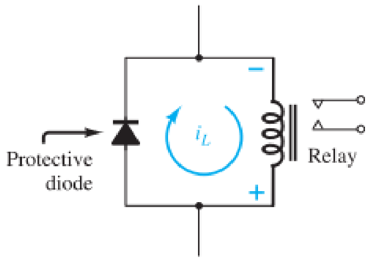



**FIG. 2.133**
*Diode protection for an RL circuit.*

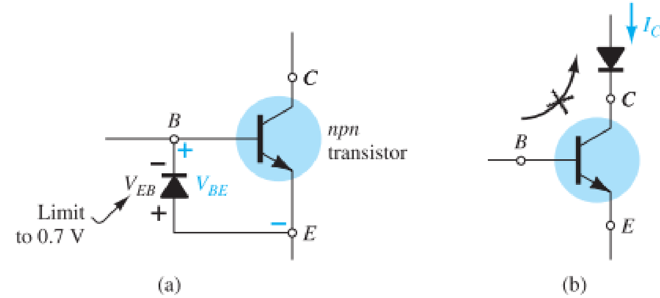



**FIG. 2.134**
*(a) Diode protection to limit the emitter-to-base voltage of a transistor; (b) diode protection to prevent a reversal in collector current.*

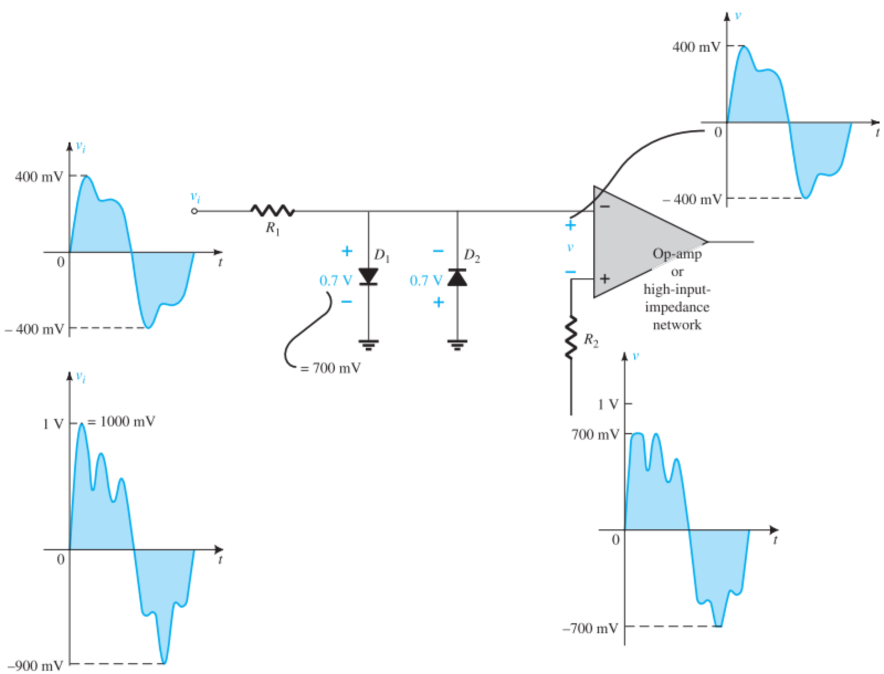



**FIG. 2.135**
*Diode control of the input swing to an op-amp or a high-input-impedance network.*

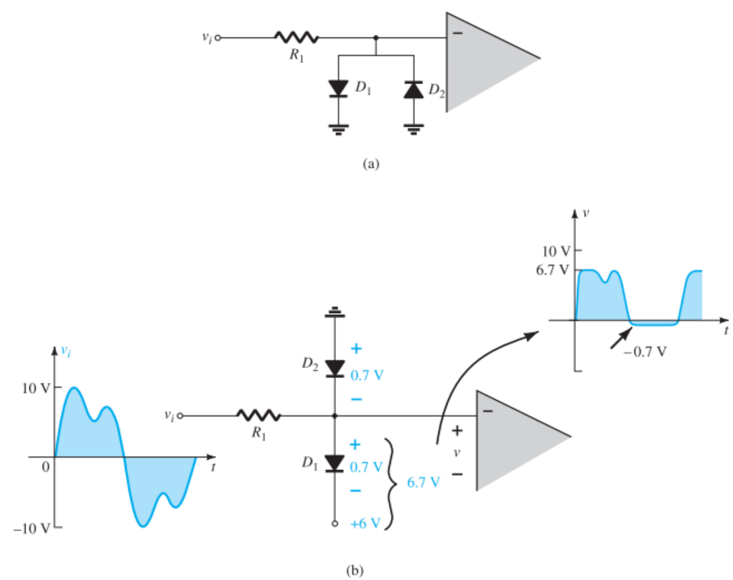



**FIG. 2.136**
*(a) Alternate appearances for the network of Fig. 2.135; (b) establishing random levels of control with separate dc supplies.*

# Polarity Insurance

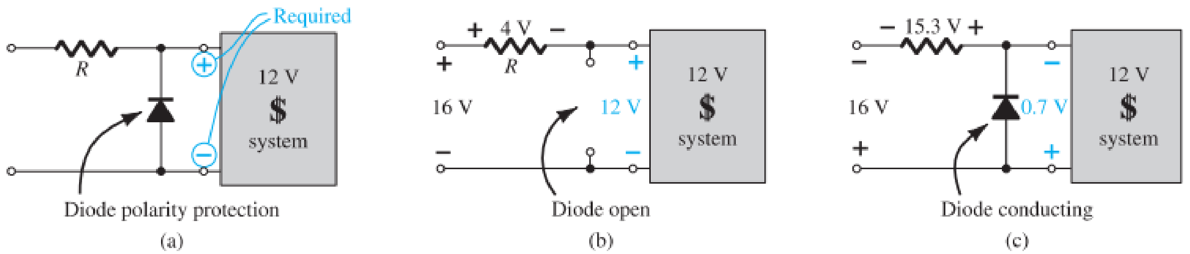



**FIG. 2.137**
*(a) Polarity protection for an expensive, sensitive piece of equipment; (b) correctly applied polarity; (c) application of the wrong polarity.*

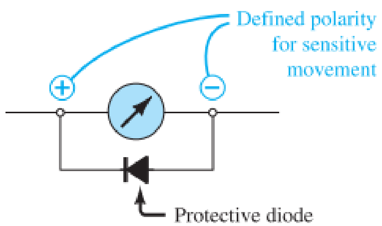



**FIG. 2.138**
*Protection for a sensitive meter movement.*

# Controlled Battery-Powered Backup

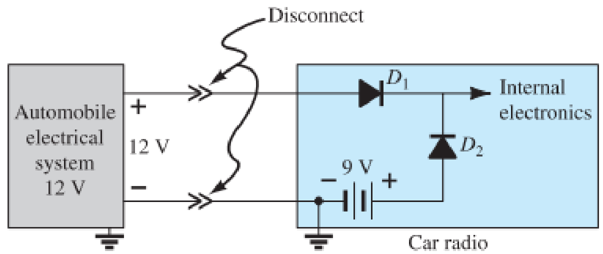



**FIG. 2.139**
*Backup system designed to prevent the loss of memory in a car radio when the radio is removed from the car.*

# Polarity Detector

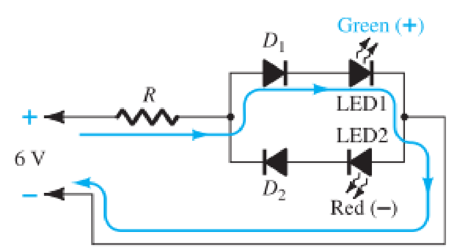



**FIG. 2.140**
*Polarity detector using diodes and LEDs.*

# Display

EXIT

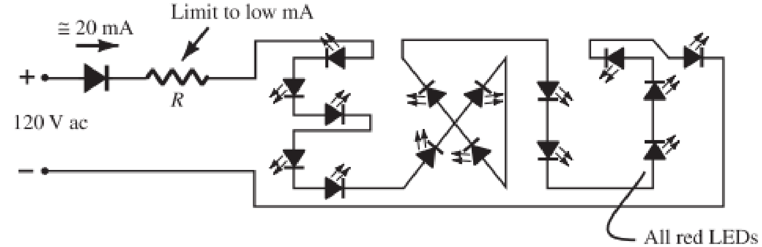



**FIG. 2.141**
*EXIT sign using LEDs.*

# Settings Voltage Reference levels

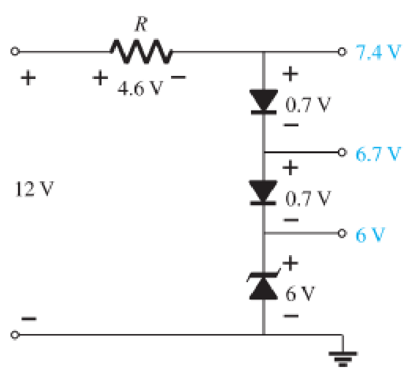



**FIG. 2.142**
*Providing different reference levels using diodes.*

# Establishing a Voltage Level Insensitive to the Load Current

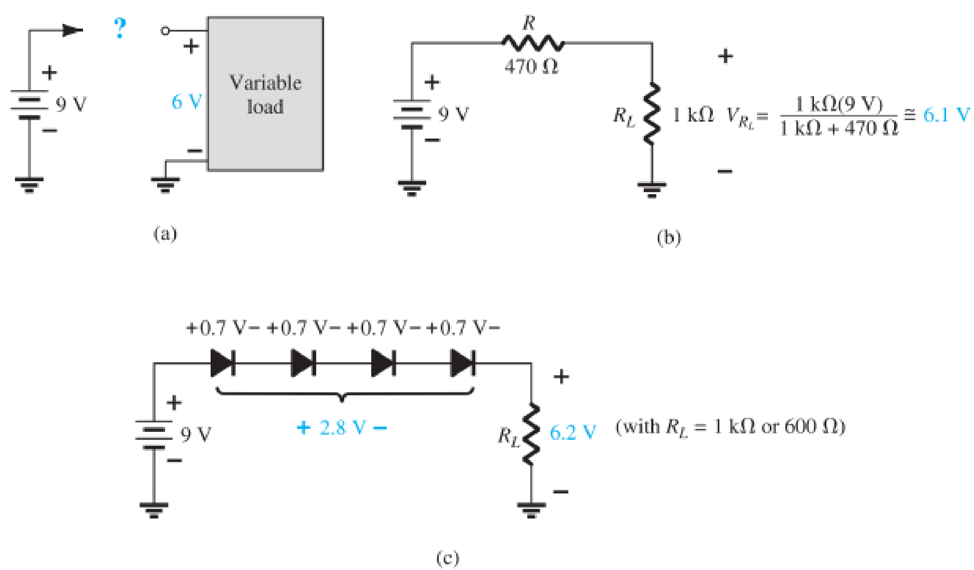



**FIG. 2.143**
*(a) How to drive a 6-V load with a 9-V supply (b) using a fixed resistor value. (c) Using a series combination of diodes.*

# AC Regulator and Square-Wave Generator

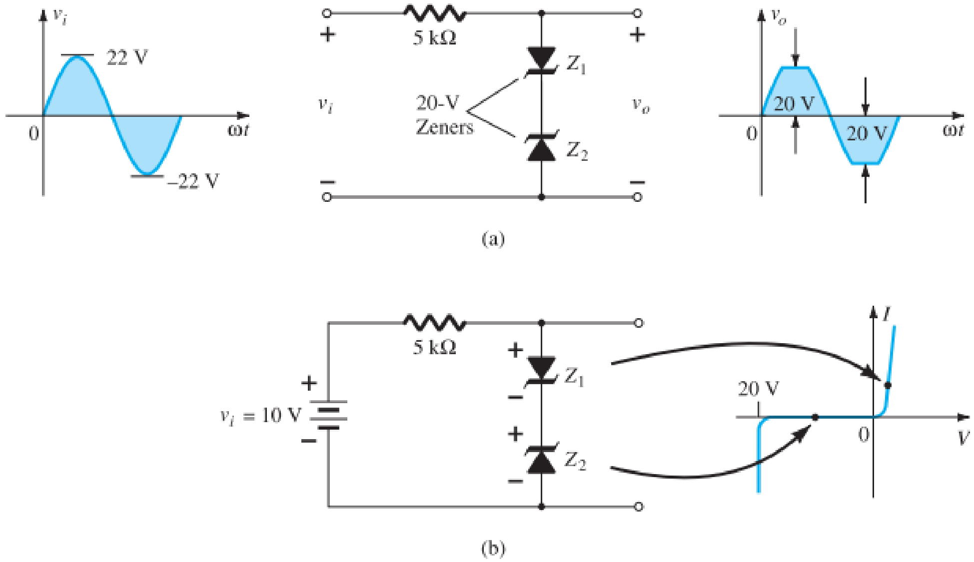



**FIG. 2.144**

*Sinusoidal ac regulation: (a) 40-V peak-to-peak sinusoidal ac regulator; (b) circuit operation at $v_i = 10$ V.*

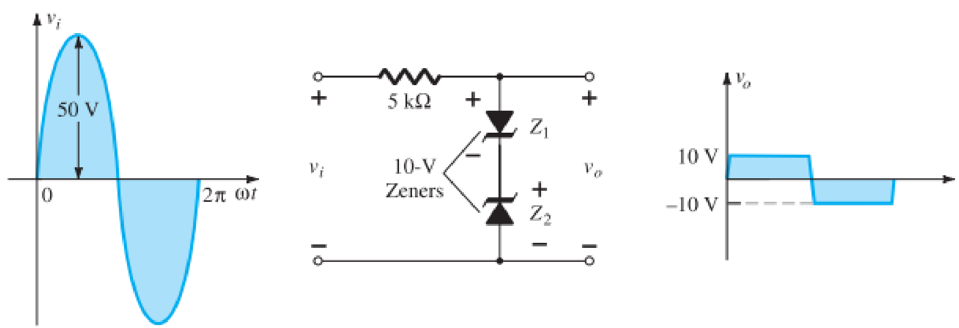



**FIG. 2.145**

*Simple square-wave generator.*

- For more details, refer to:
  - Chapter 2, Electronic Devices and Circuits, Boylestad.
- The lecture is available online at:
  - https://speakerdeck.com/ahmad_elbanna
- For inquires, send to:
  - ahmad.elbanna@fes.bu.edu.eg
  - ahmad.elbanna@ejust.edu.eg