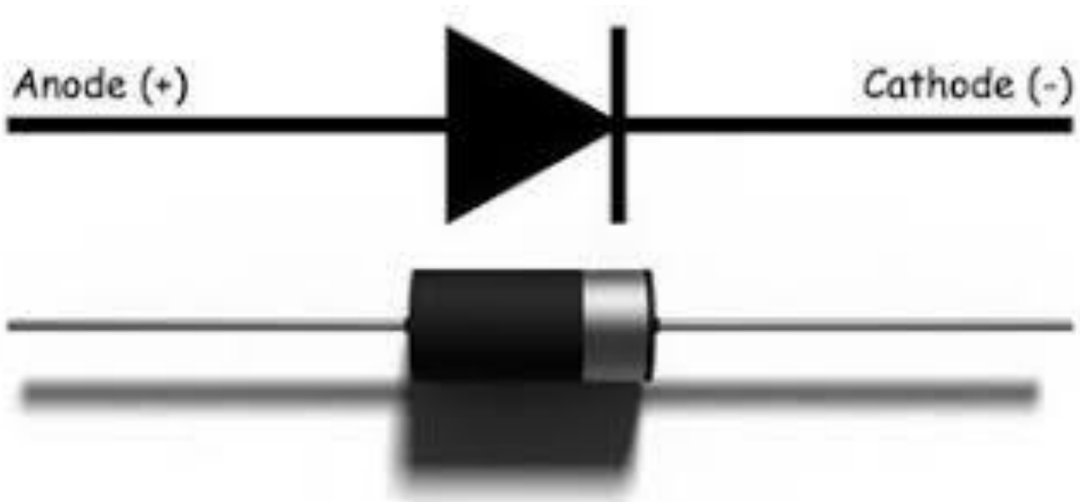
# DIODE APPLICATIONS

# Topic Outcomes

- Understand the concept of load-line analysis and how it is applied to diode networks.
- Become familiar with the use of equivalent circuits to analyze series, parallel, and series-parallel diode networks.
- Understand the process of rectification to establish a dc level from a sinusoidal ac input.
- Be able to predict the output response of a clipper and clamper diode configuration.
- Become familiar with the analysis of and the range of applications for Zener diodes.
- Become familiar with special purpose diodes such as Zener diodes, varactor diodes, LEDs, quantum dots, and photodiodes, solar cell and other several types of diodes.

# Diode



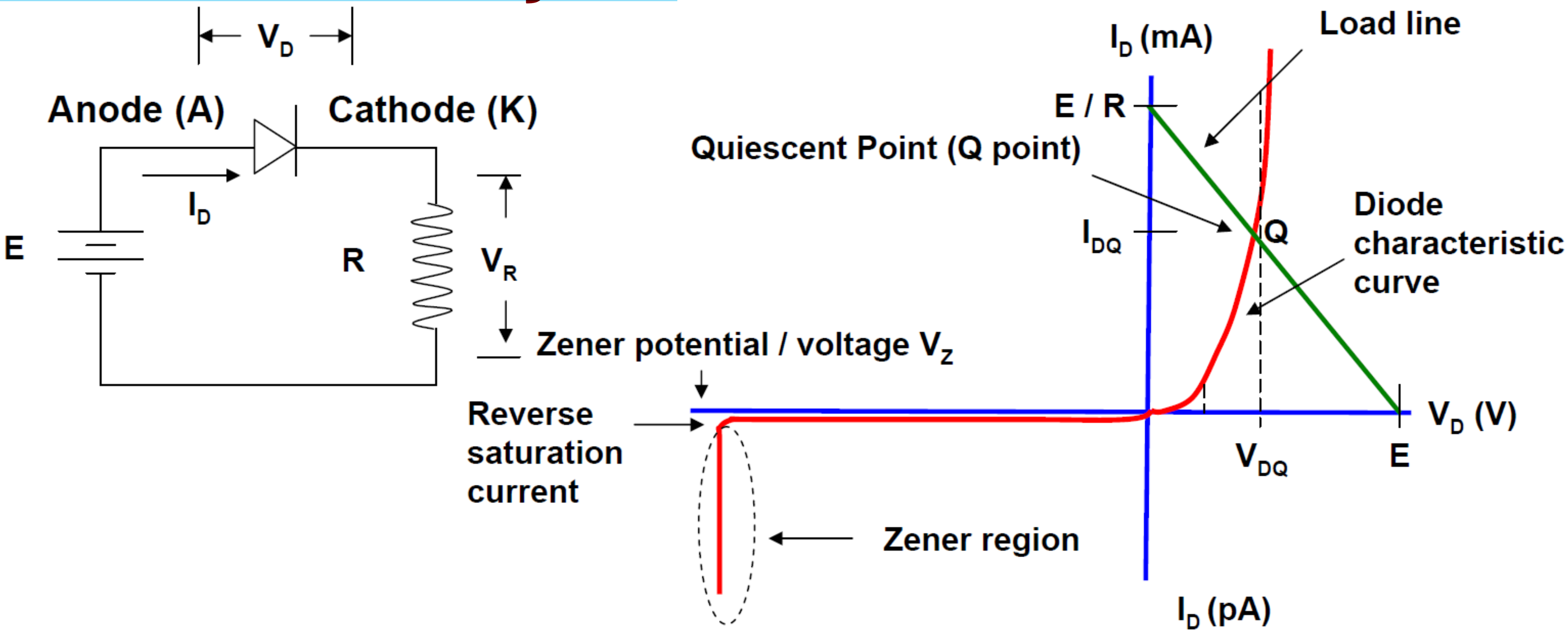
# Introduction

# Introduction

- *The analysis of electronic circuits can follow one of two paths: using the actual characteristics or applying an approximate model for the device.*

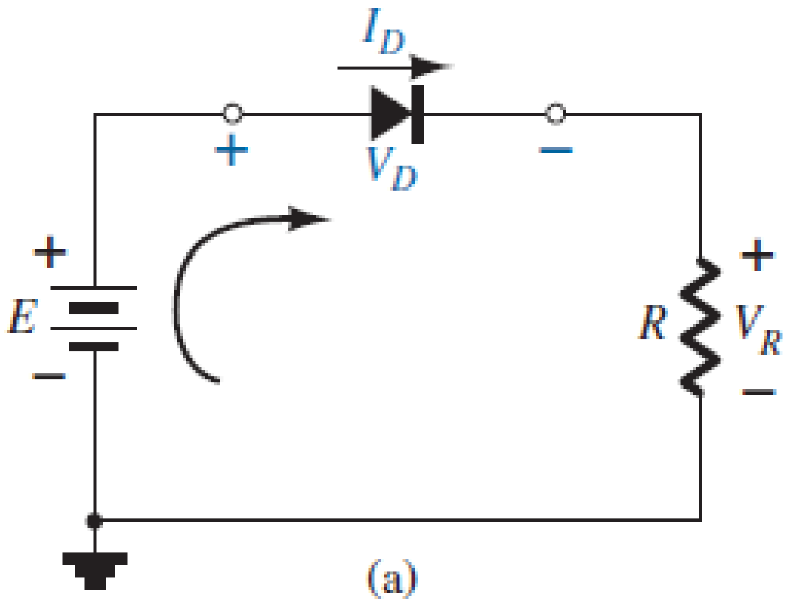
# Load line Analysis

# Load Line Analysis




- The diode in the circuit is **forward biased**.
- The intersection of the **characteristic curve** of the diode and the **load line** defines the **current** and **voltage levels** of the network.

# Loadline Analysis



(a)

- Applying Kirchhoff's voltage law in the clockwise direction, the following equation can be derived:

$$E - V_D - V_R = 0 \qquad E = V_D + I_D R$$

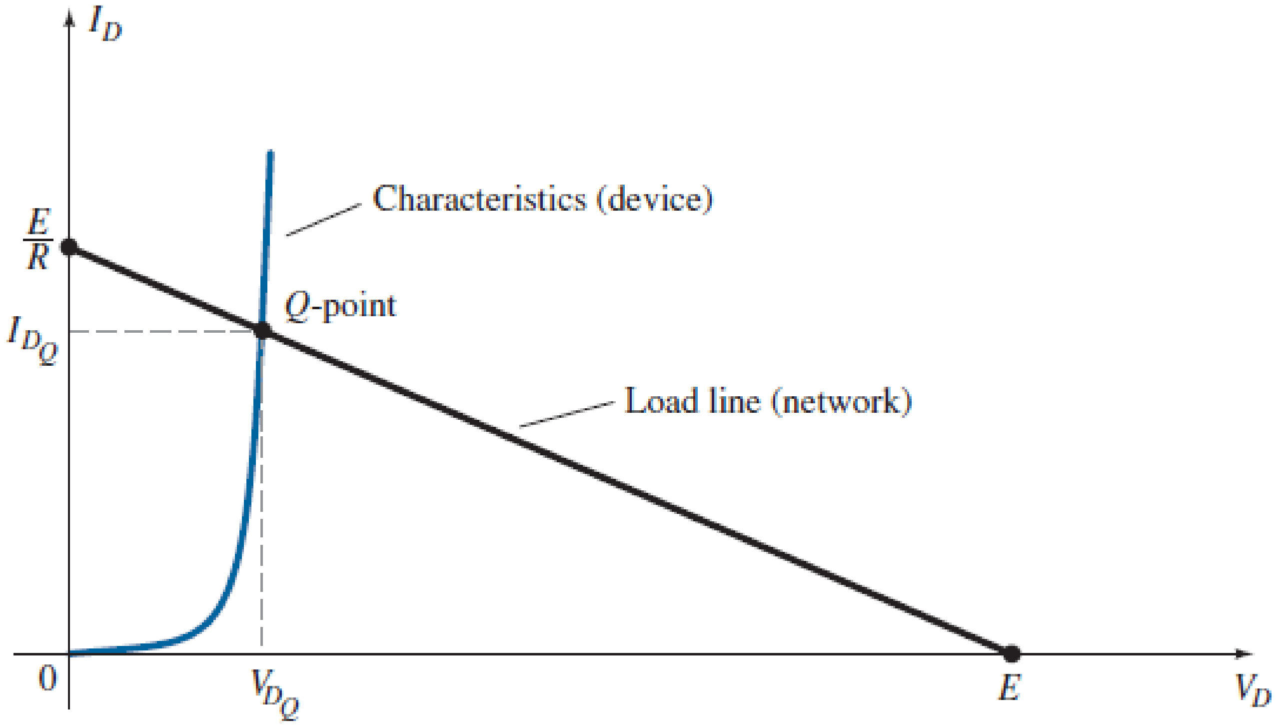
- Based on the equation above, if $V_D$ is equal to zero, $I_D = E / R$.
- Also, if $I_D$ is equal to zero, $V_D = E$.
- A **straight line** drawn between the two points defined when $V_D = 0$ and $I_D = 0$ yields the **load line** of the network.
- The **point of intersection** between the **straight line** and the **characteristic curve** of the diode is the point of operation of the network, and it is called the **Quiescent (Q) point**.
- The value of the current ID can be computed as:

$$I_D = \frac{E - V_D}{R} \qquad I_D = I_S(e^{\frac{V_D}{nV_T}} - 1)$$

- The above two equations can be solved simultaneously to determine unknown parameters, although this process could be cumbersome.

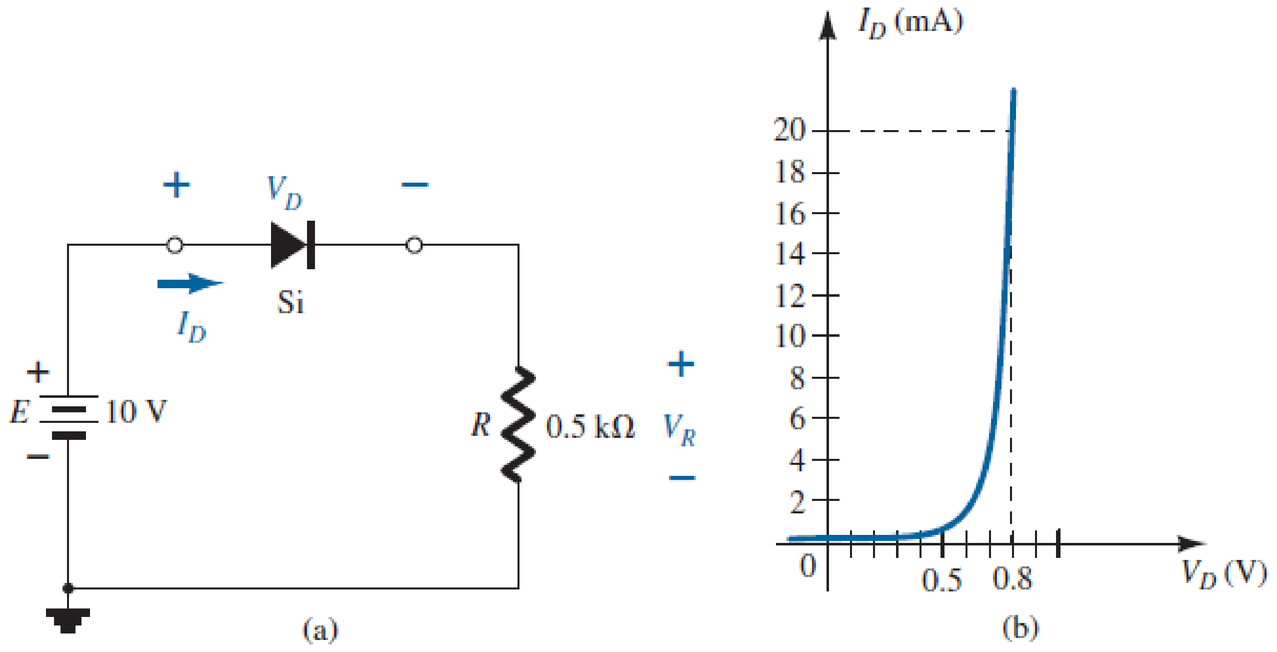
# Loadline Analysis

- An easier approach is to use **approximate analysis** in which we assume that the voltage across a diode is fixed once it is forward biased.
- For a **forward biased diode**, the voltage drop across the diode can be assumed to be:
  - **0.7 V for Silicon**
  - **0.3 V for Ge**
  - **1.2 V for GaAs**

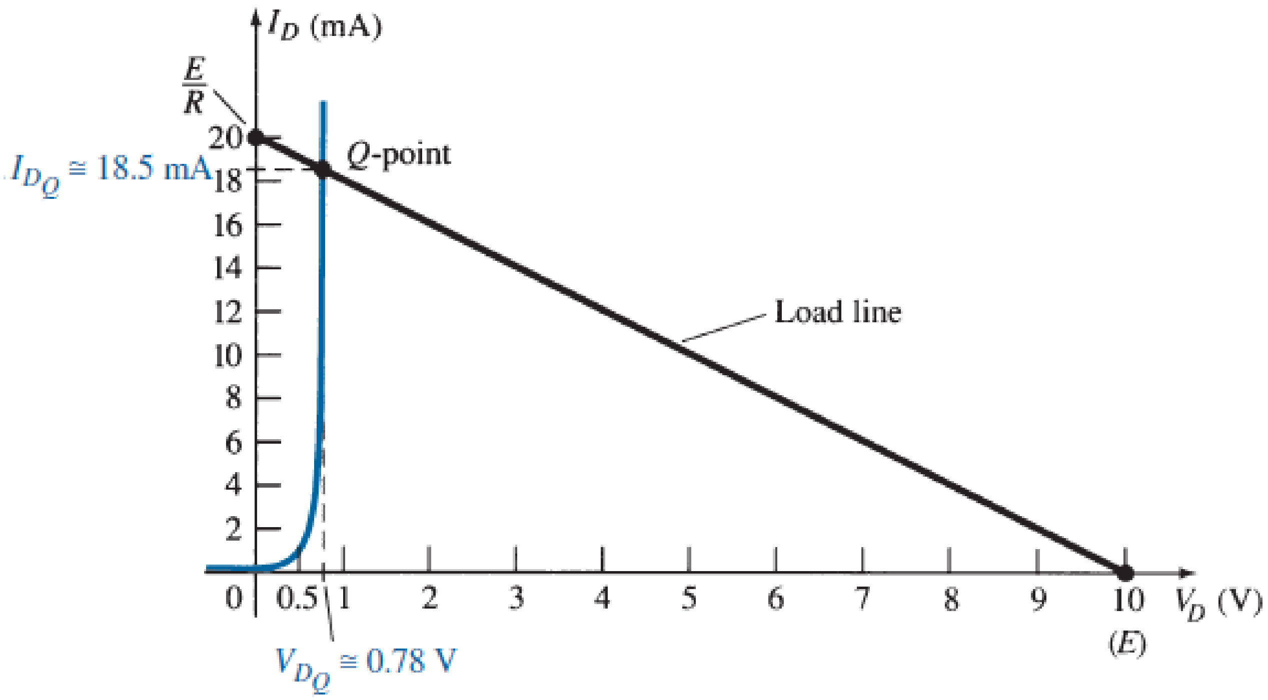


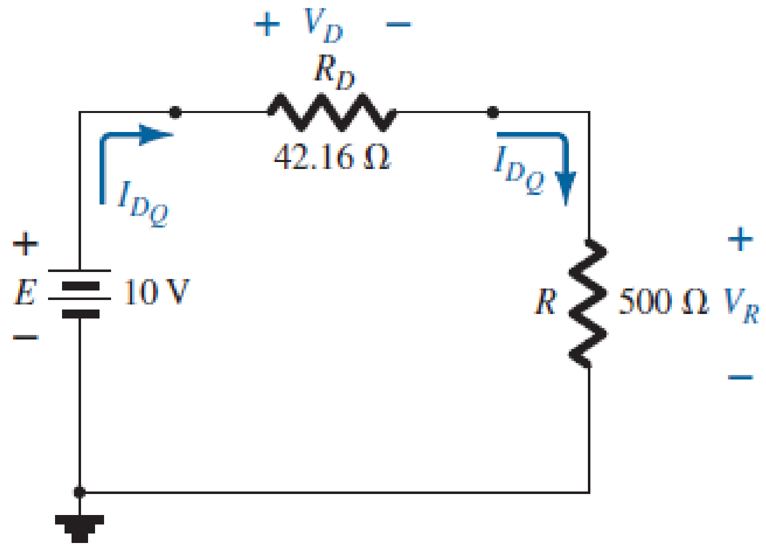
# Loadline Analysis

- For the series diode configuration of Fig. 3a, employing the diode characteristics determine:
- a. $V_{D_Q}$ and $I_{D_Q}$ .
- b. $V_R$.



# Loadline Analysis



# Diode Configurations

# Diode Configurations

- For each configuration the **state of each diode must first be determined**. Which diodes are "on" and which are "off"?
- For each configuration, mentally replace the diodes with resistive elements and note the resulting current direction as **established by the applied voltages**. If the resulting **direction is a "match" with the arrow in the diode** symbol, **conduction through the diode will occur** and the device is in the **"on" state**.
- The description above is, of course, **contingent on the supply having a voltage greater than the "turn-on" voltage** (VT) of each diode.

# Diode Configurations

- If a diode **is in the “on” state**, one can either **place a 0.7-V** drop across the element, or the network can be redrawn with the VT equivalent circuit.
- **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.
- For general purposes, keep the following in mind for the analysis to follow:
    1. An **open circuit** can **have any voltage across** its terminals, but the **current is always 0 A**.
    2. A **short circuit has a 0-V drop** across its terminals, but the **current is limited only by the surrounding network**.

# Series Diode Configurations

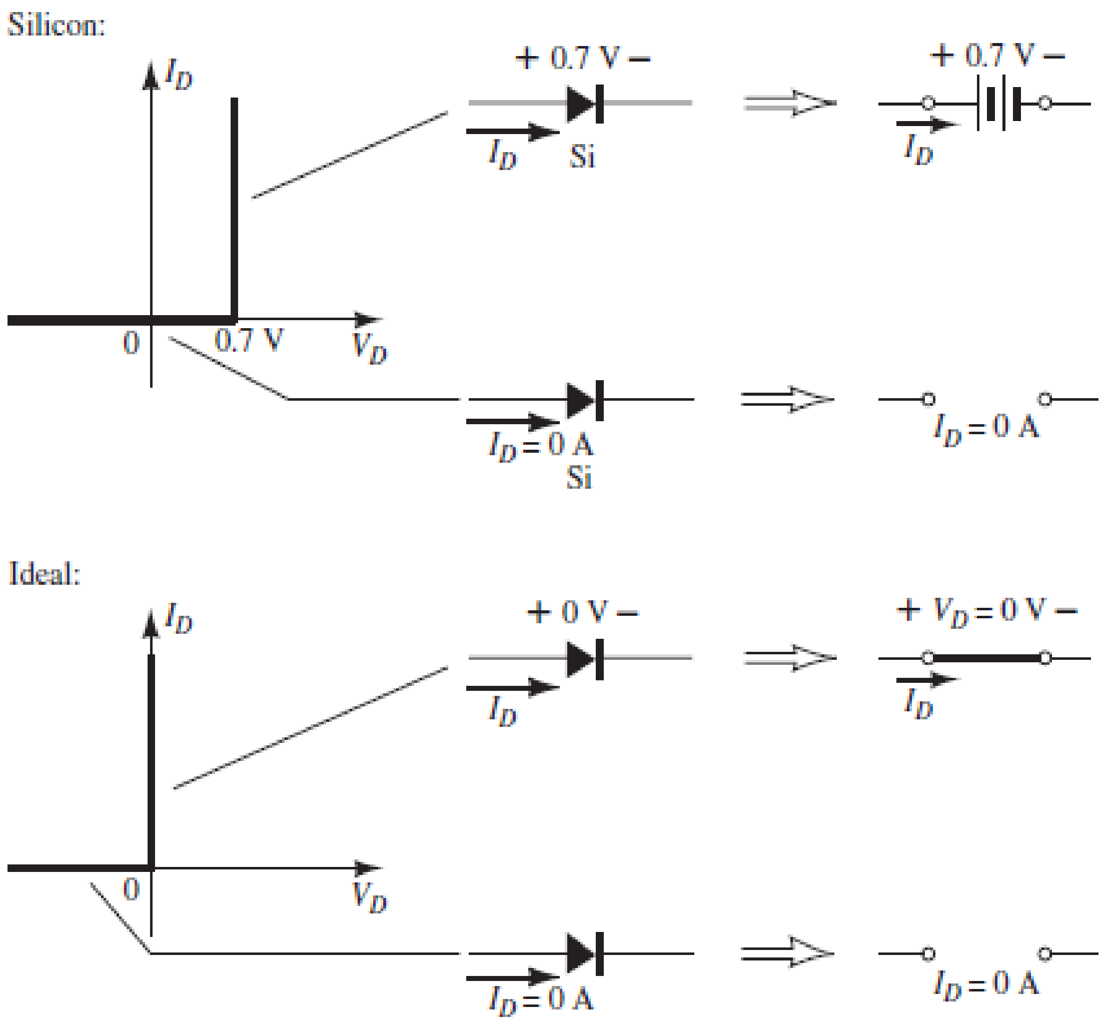
- In general, a diode is in the “on” state if the current established by the applied sources is such that its direction matches that of the arrow in the diode symbol, and $V_D = 0.7$ V for silicon, $V_D = 0.3$ V for germanium, and $V_D = 1.2$ V for gallium arsenide.

- For series diode configuration, the diode is connected in series with the other components.

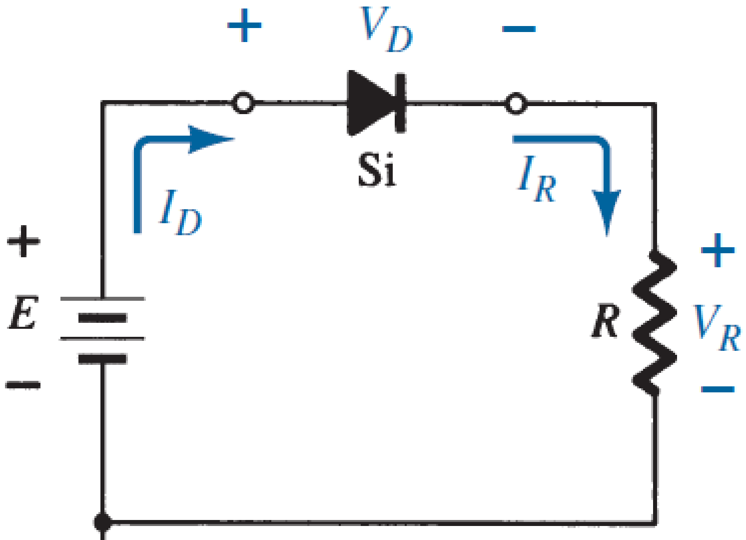
- Note: For our computation on the diode configuration, we assumed that the forward resistance of the diode is usually so small compared to the other series elements of the network that it can be ignored.

# Series Diode Configurations

- Approximate and Ideal Semiconductor Diode Models.



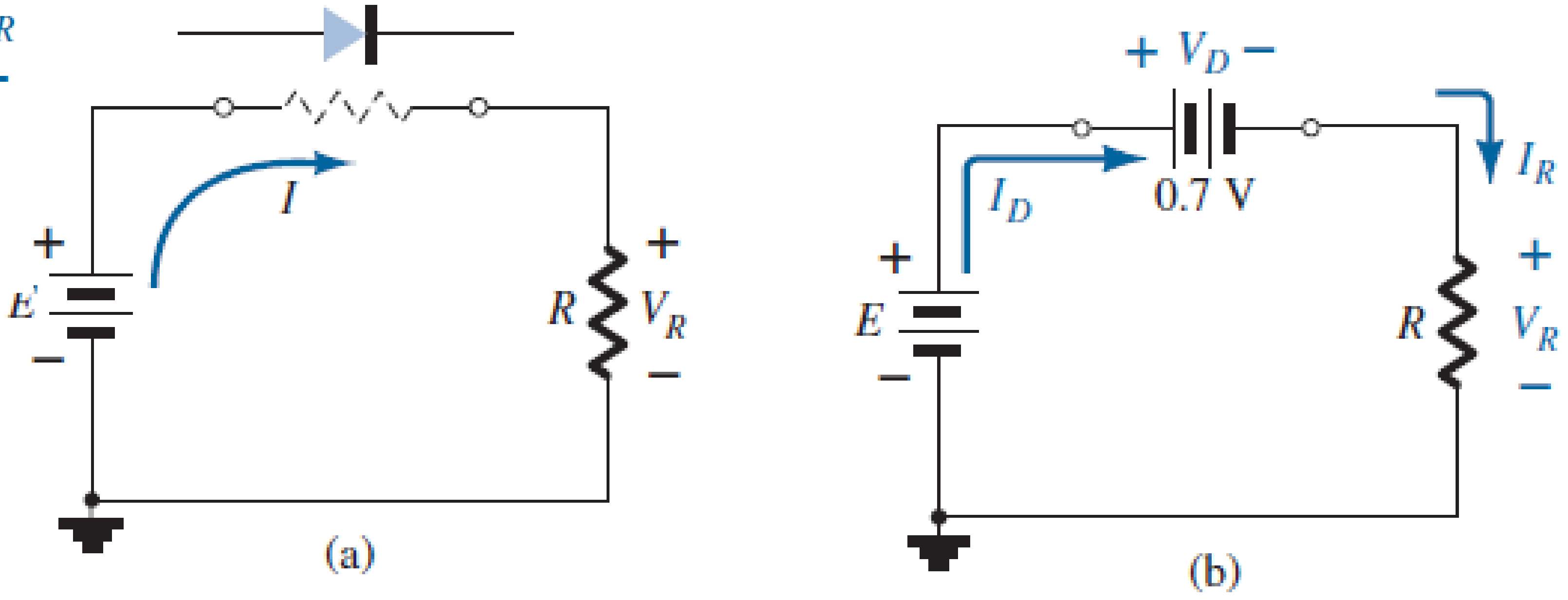
# Series Diode Configurations




Series Diode Configuration
Forward Bias

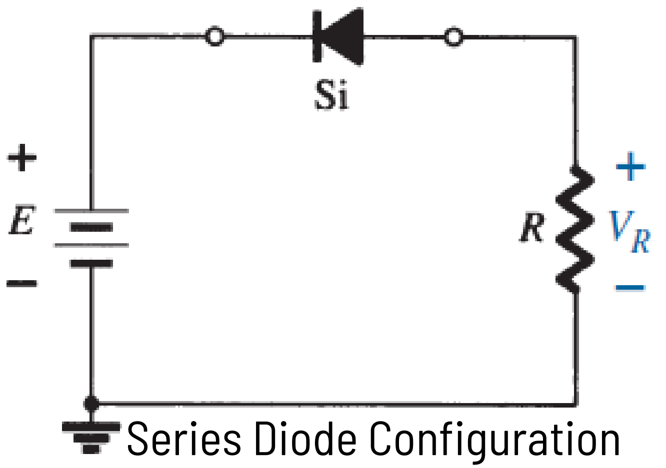
$$V_R = E - V_K$$

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

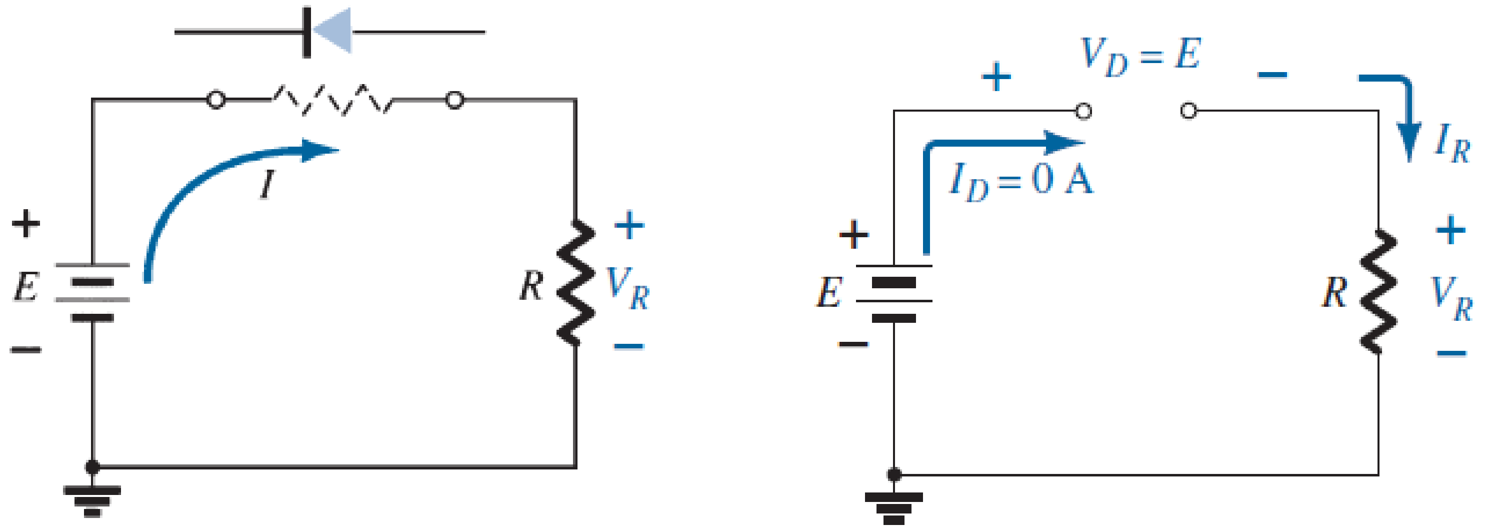



*(a) Determining the state of the diode; (b) substituting the equivalent model for the "on" diode*

# Series Diode Configurations




Series Diode Configuration
Reverse Bias

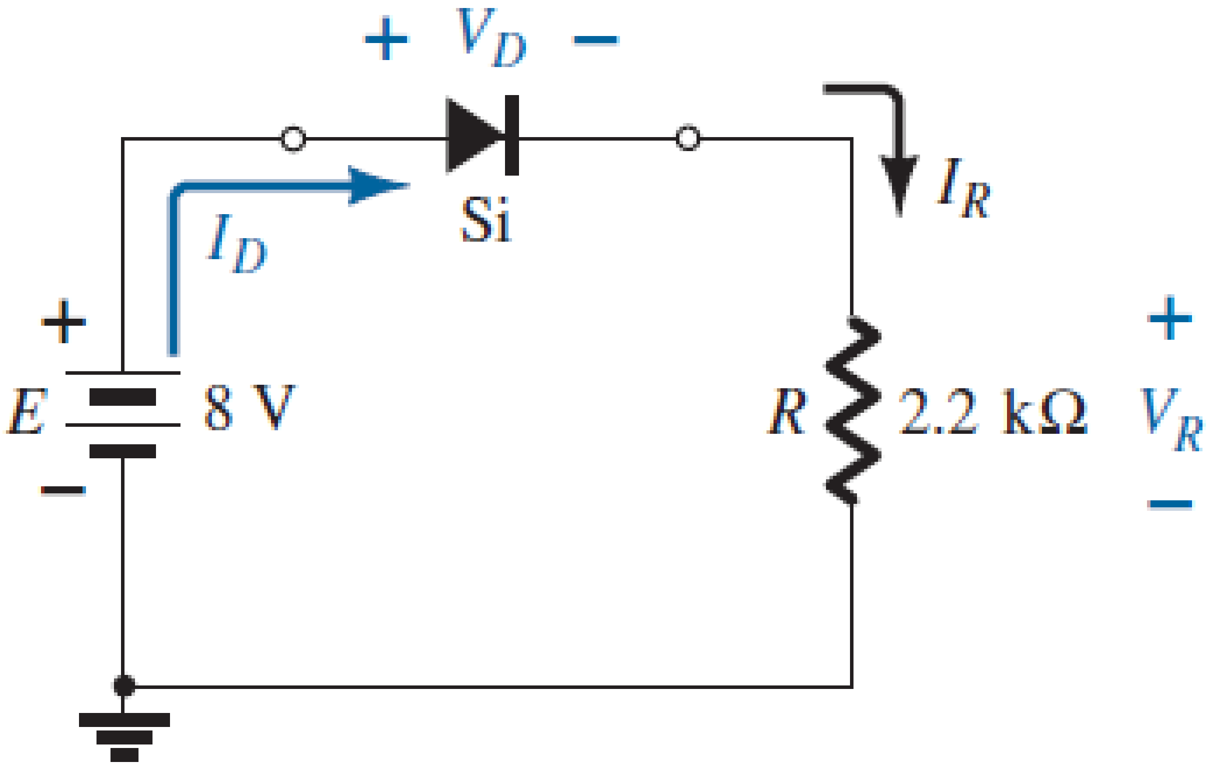



*(a) Determining the state of the diode; (b) substituting the equivalent model for the "off" diode*

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

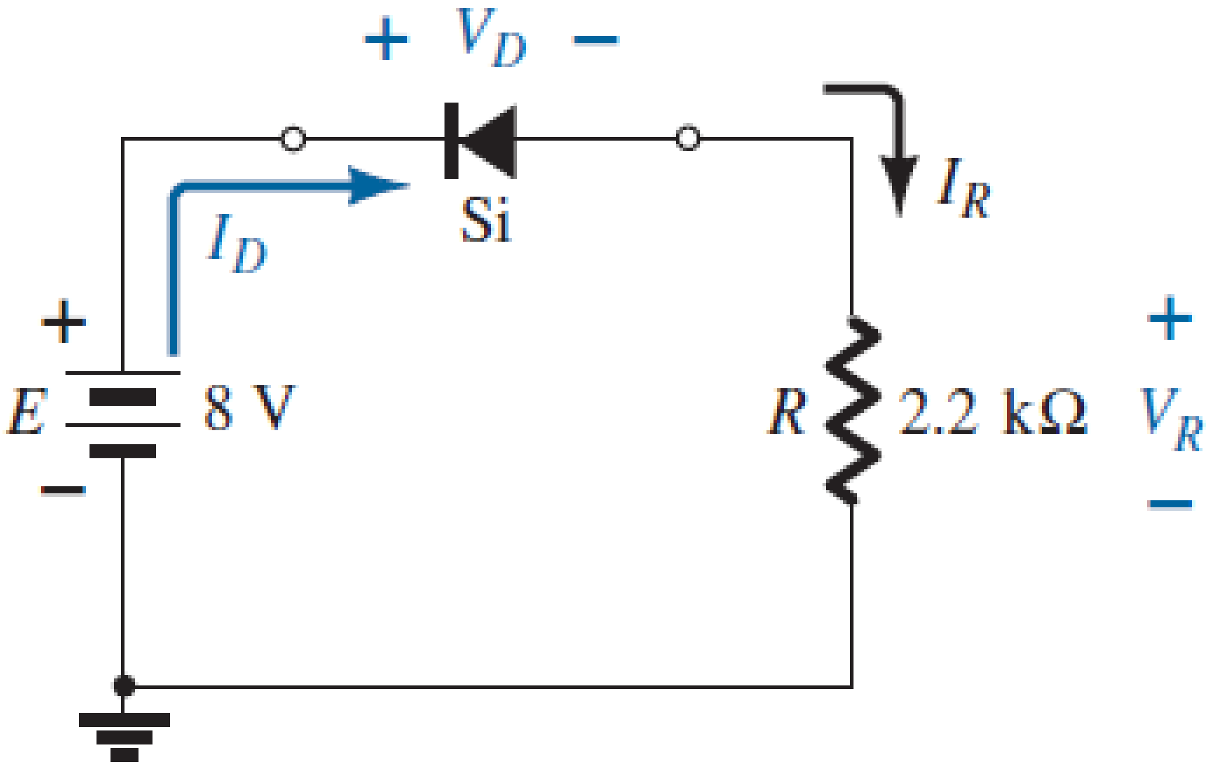
# Series Diode Configurations

- Examples: For the series diode configuration, determine $V_D$, $V_R$, and $I_D$.



# Series Diode Configurations

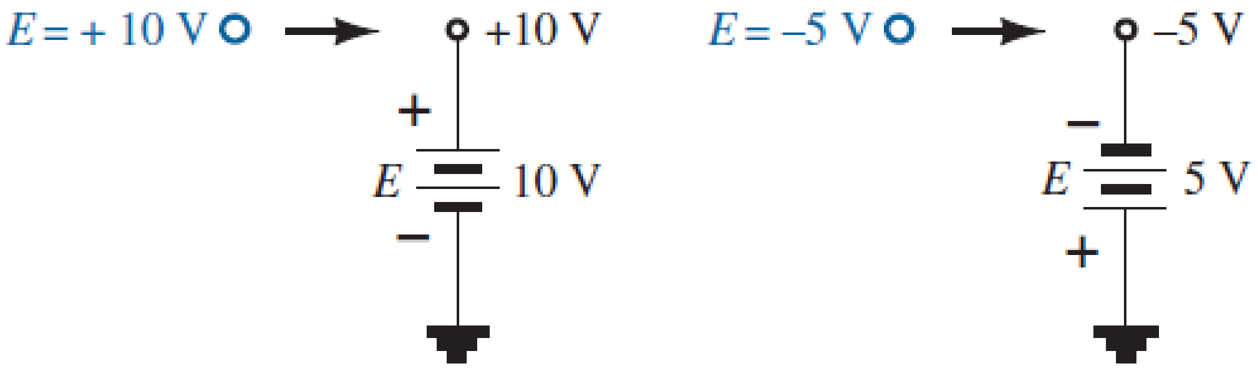
- Examples: Repeat with the diode reversed.



# Series Diode Configurations

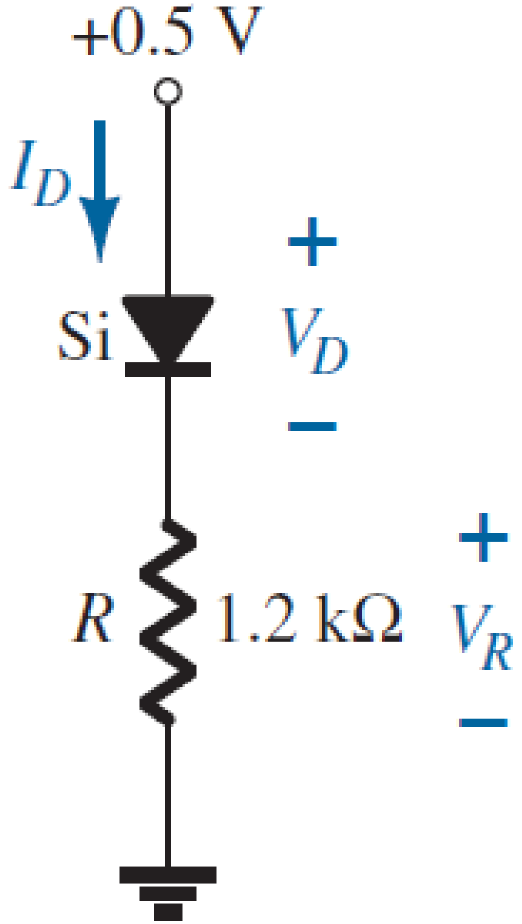
- An open circuit can have any voltage across its terminals, but the current is always 0 A. A short circuit has a 0-V drop across its terminals, but the current is limited only by the surrounding network.

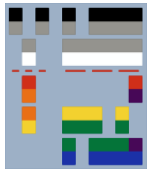
- Source notation.



# Series Diode Configurations

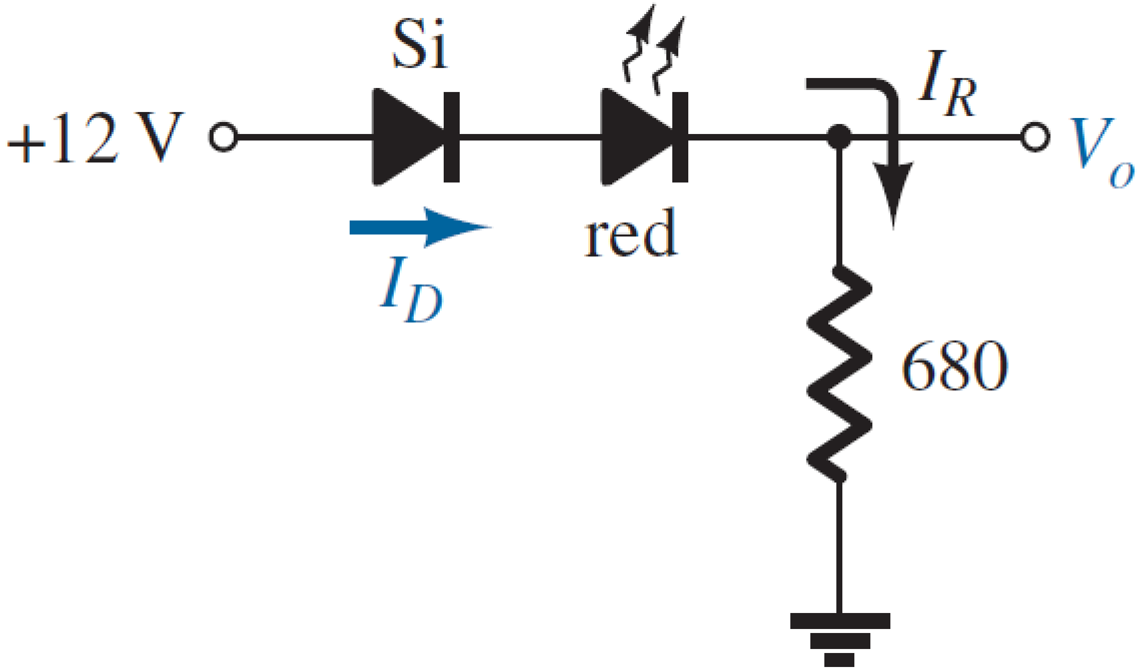
- Examples: For the series diode configuration, determine $V_D$, $V_R$, and $I_D$.



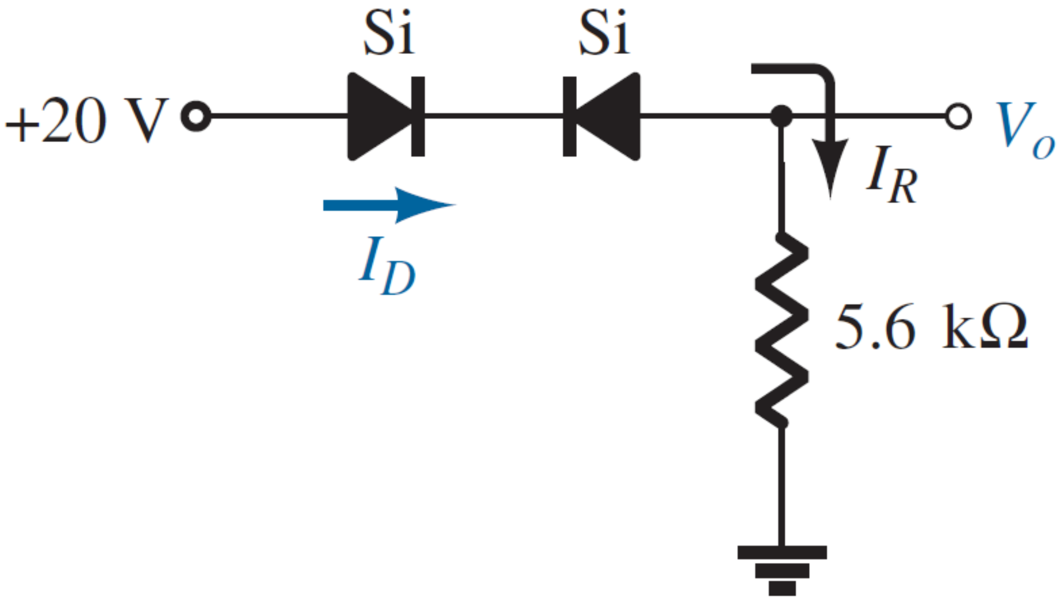
# Series Diode Configurations

- Examples: For the series diode configuration, determine $V_o$, and $I_D$, if the voltage drop of LED is 1.8V.



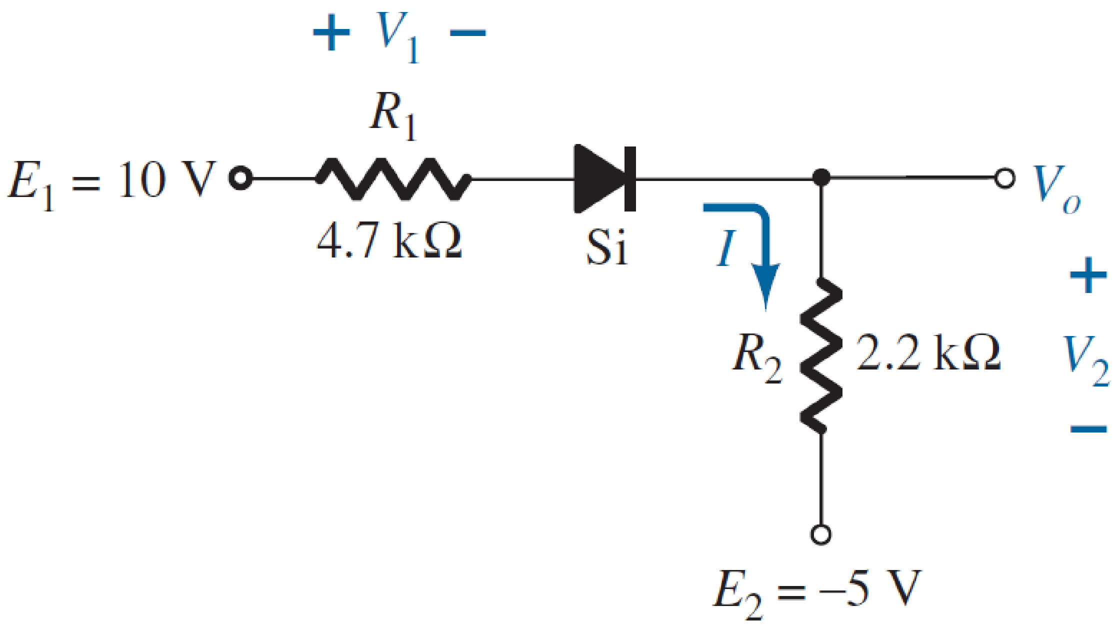
# Series Diode Configurations

- Examples: Determine $I_D$, and $V_{D2}$.and $V_0$.



# Series Diode Configurations

- Examples: Determine I, $V_1$, $V_2$, and $V_o$ for the series dc configuration



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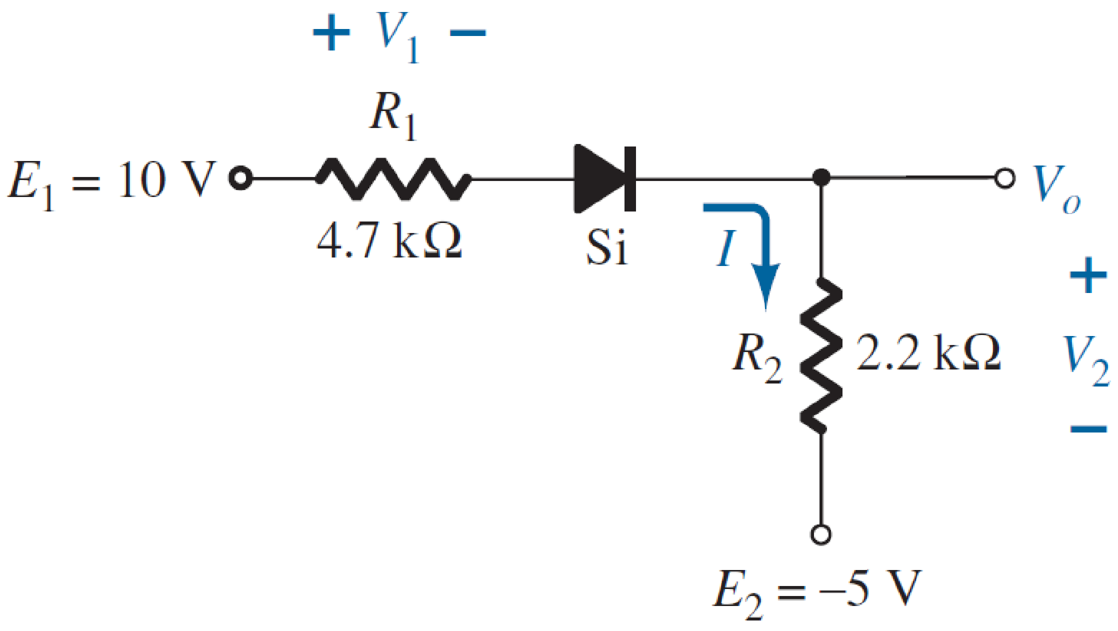
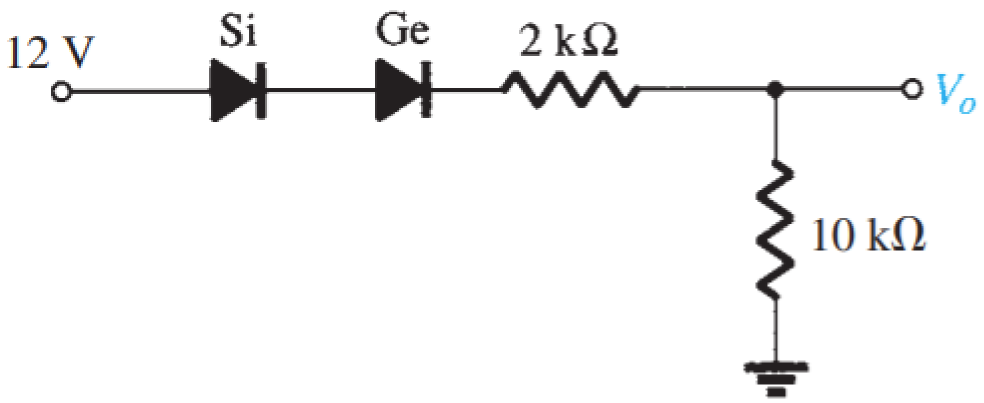
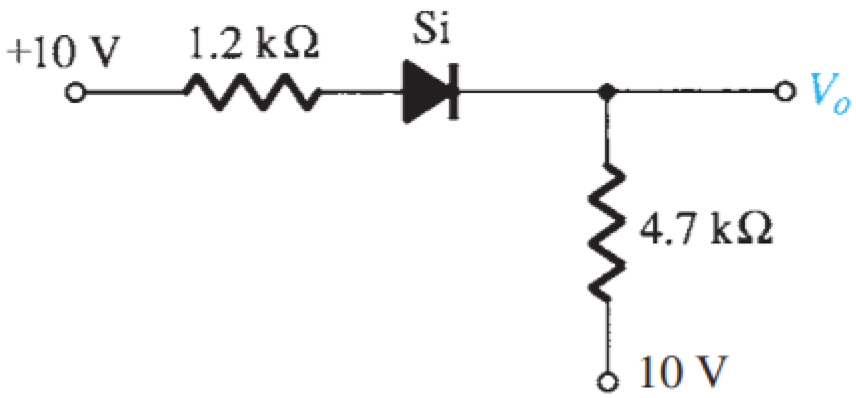
- Examples: Determine I, $V_1$, $V_2$, and $V_o$ for the series dc configuration



# Series Diode Configurations



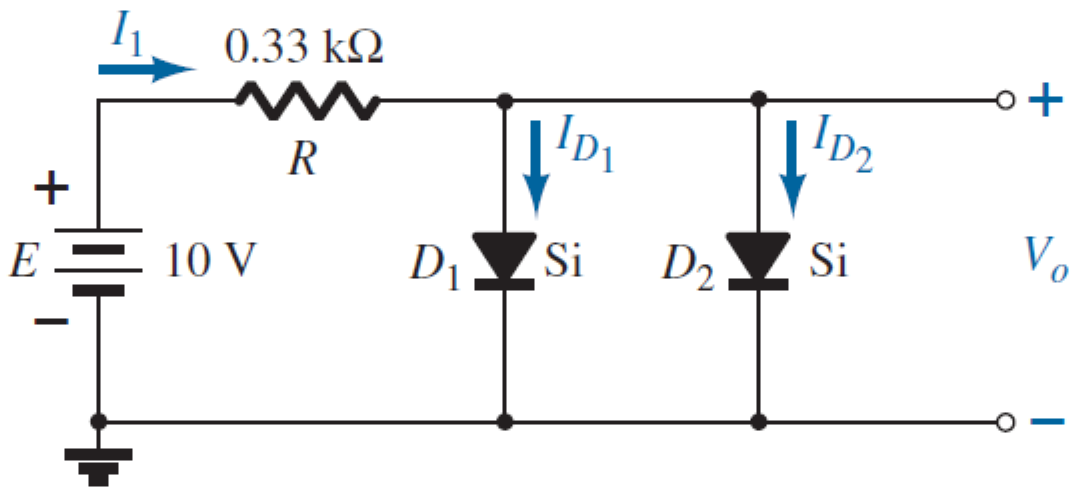

(a)



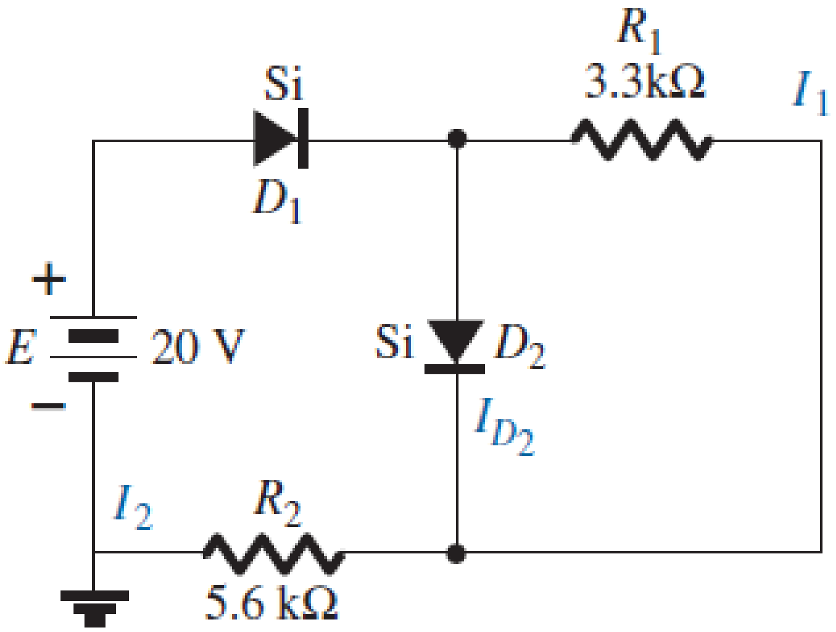

(b)

# Parallel and Series-Parallel Diode Configurations

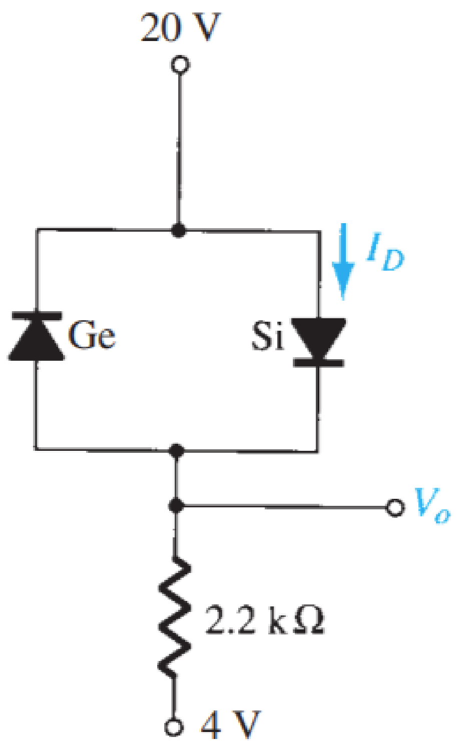
- Example: Determine the currents $I_1$, $I_2$, and $I_{D2}$



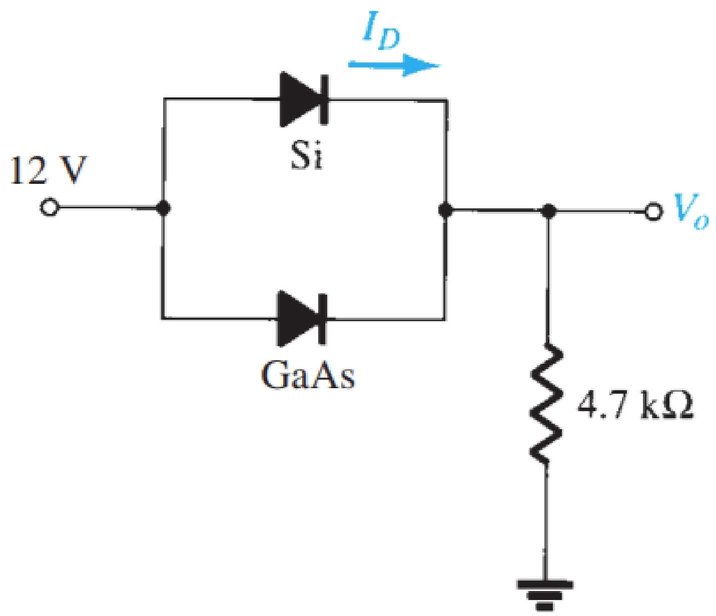
# Parallel and Series-Parallel Diode Configurations



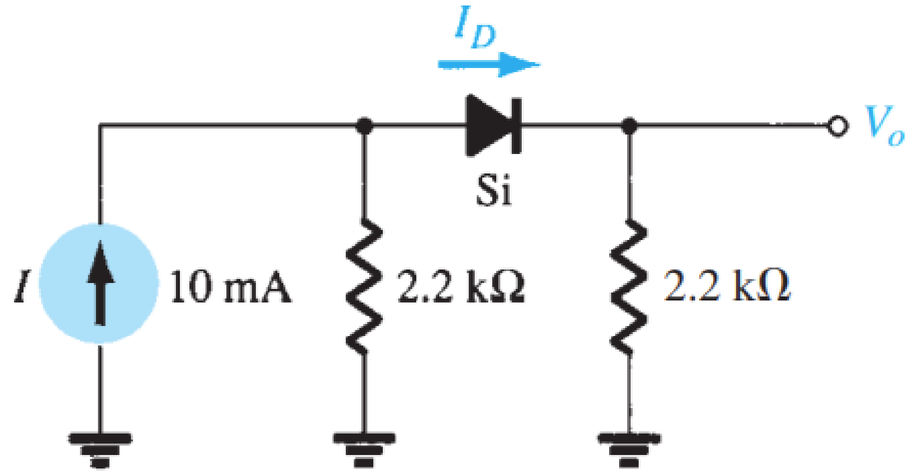
# Parallel and Series-Parallel Diode Configurations



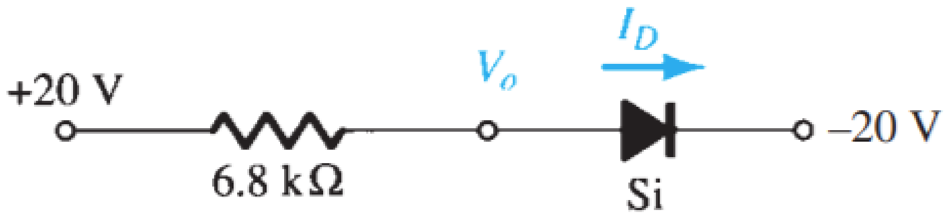
# Parallel and Series-Parallel Diode Configurations



# Parallel and Series-Parallel Diode Configurations




(a)



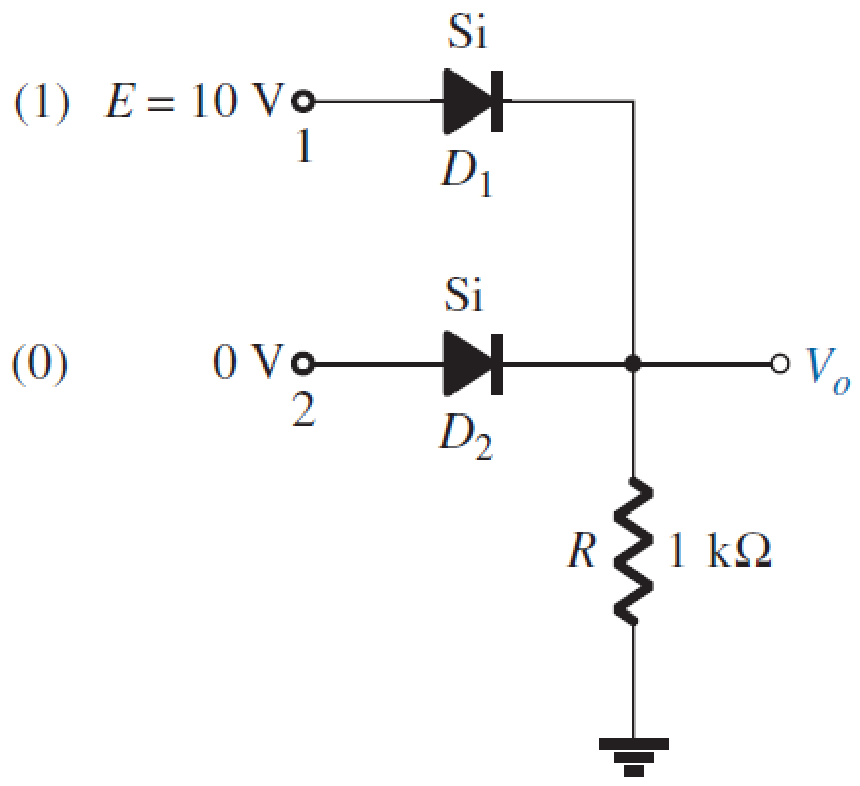

(b)

# AND/OR gates

- **AND** gate has two or more inputs and only one output. The output of logic **AND** gate is HIGH if all inputs are HIGH. For other input, the output is LOW.
- **OR** gate has two or more inputs and only one output. The output of the **OR** gate is HIGH if one or more inputs are HIGH.

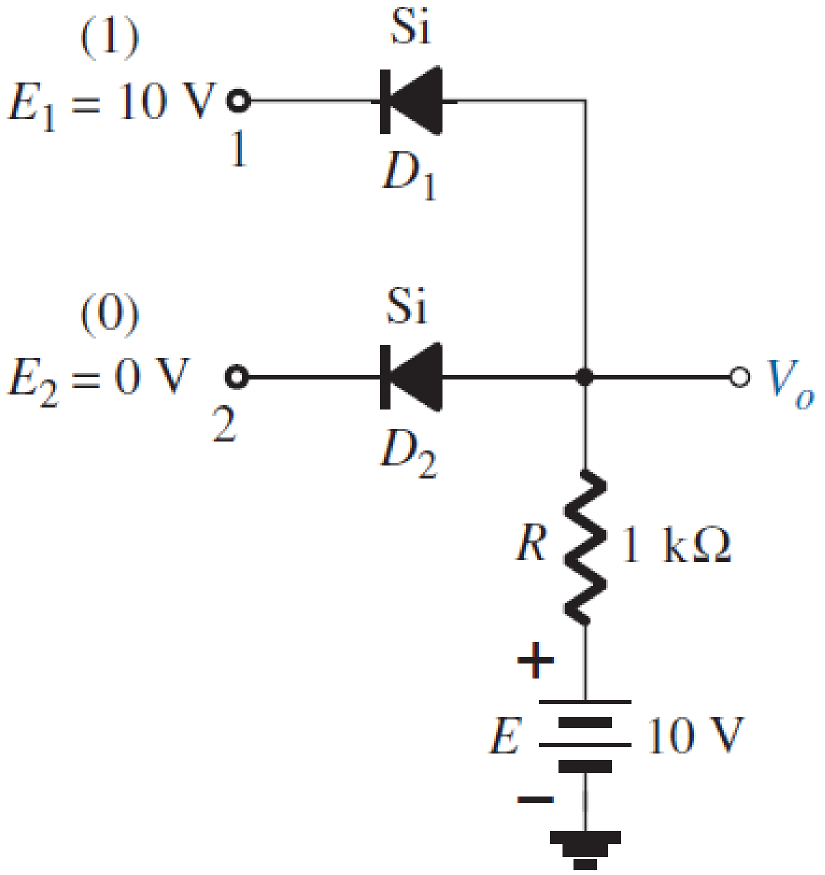
# AND/OR gates

- Determine $V_o$ for the network.



# AND/OR gates

- Determine the output level for the positive logic AND gate. An AND gate is one where a 1 output is only obtained when a 1 input appears at each and every input.



# Rectifiers

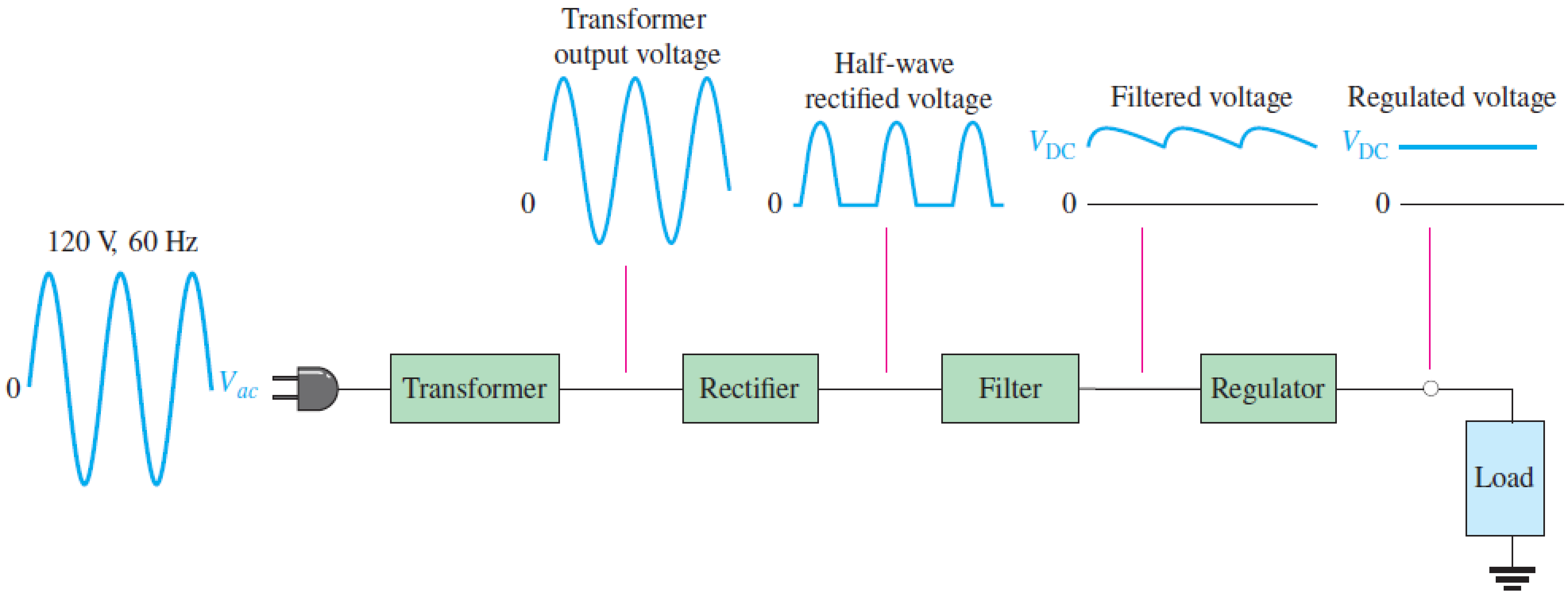
# Rectifiers

- **Rectification** - the process of converting an ac signal into a dc signal
- Rectifiers are used in power supplies to **convert ac** voltages to **dc voltages**.
- The power available from electric power companies are supplied **using ac voltages** but many electrical and electronic devices **need dc voltages**, so there is a need to convert ac voltages to dc voltages.

- Types:

1. Half-wave rectification
2. Full-wave rectification
   a. Center-tapped
   b. Bridge type

# The Basic DC Power Supply

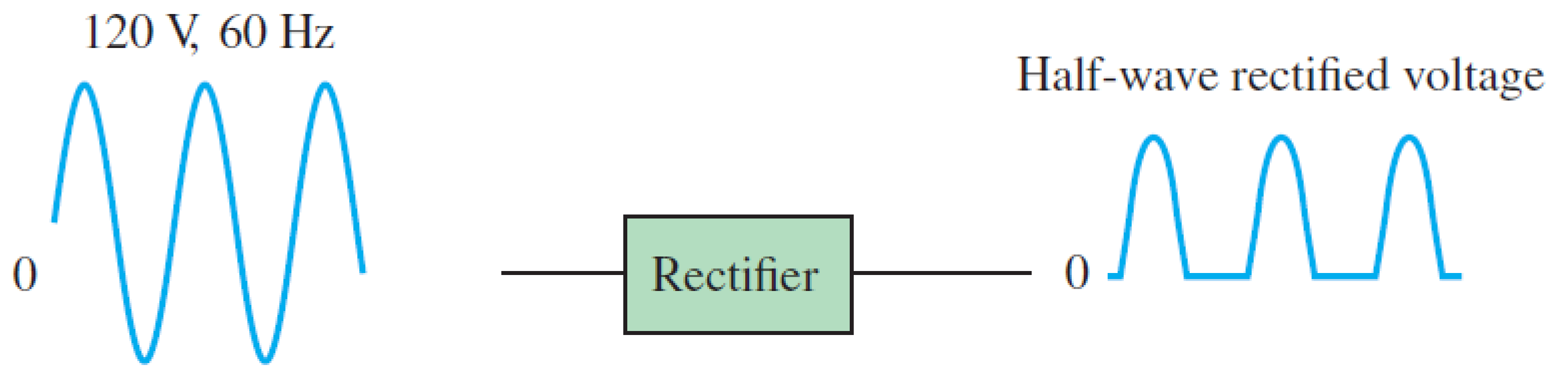


# The Basic DC Power Supply

- A **transformer** changes ac voltages based on the turns ratio between the primary and secondary.
- The **rectifier** converts the ac input voltage to a pulsating dc voltage, called a half-wave rectified voltage
- The **filter** eliminates the fluctuations in the rectified voltage and produces a relatively smooth dc voltage.
- The **regulator** is a circuit that maintains a constant dc voltage for variations in the input line voltage or in the load.

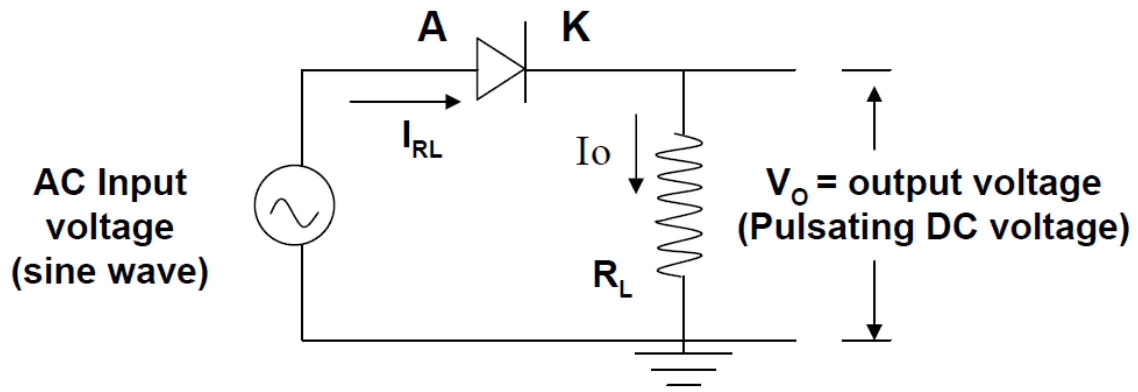
# The Basic DC Power Supply

- Rectifier

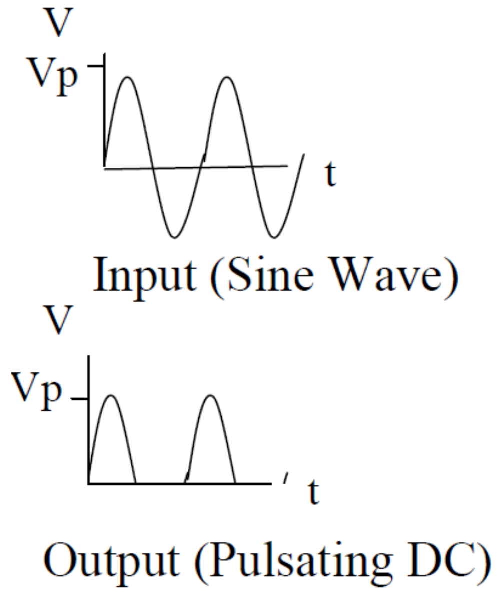


# Half wave rectifier

- Simplest rectifier circuit.
- A half-wave rectifier produces an output voltage during **one-half (180°)** of the input ac signal. One half of the input signal (negative half cycle) is removed to establish a dc voltage.
- A half-wave rectifier using a semiconductor diode is shown



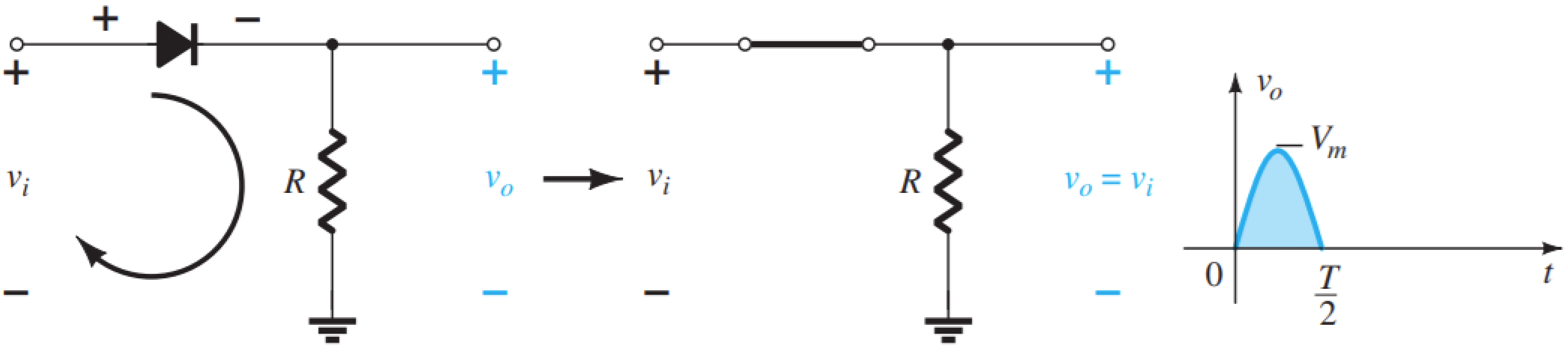

**Half-wave rectifier circuit**




**Half-wave rectifier Output**

# Half wave rectifier

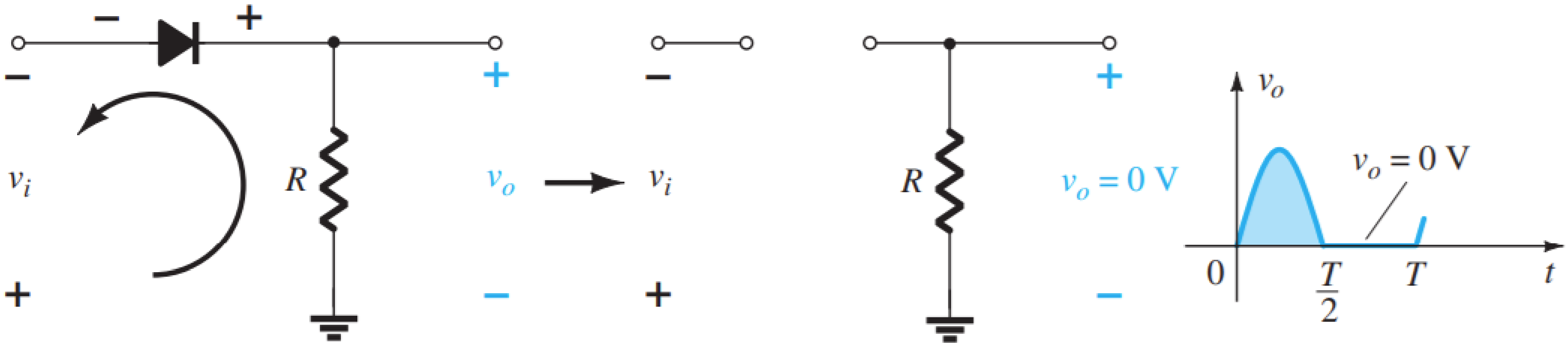
- During the interval $t = 0 \rightarrow T/2$ in the figure, the polarity of the applied voltage $v_i$ is such as to establish "pressure" in the direction indicated and turn on the diode with the polarity appearing above the diode.
- Substituting the short-circuit equivalence for the ideal diode will result in the equivalent circuit below, where it is fairly obvious that the output signal is an exact replica of the applied signal. The two terminals defining the output voltage are connected directly to the applied signal via the short-circuit equivalence of the diode.




**Conduction Region**

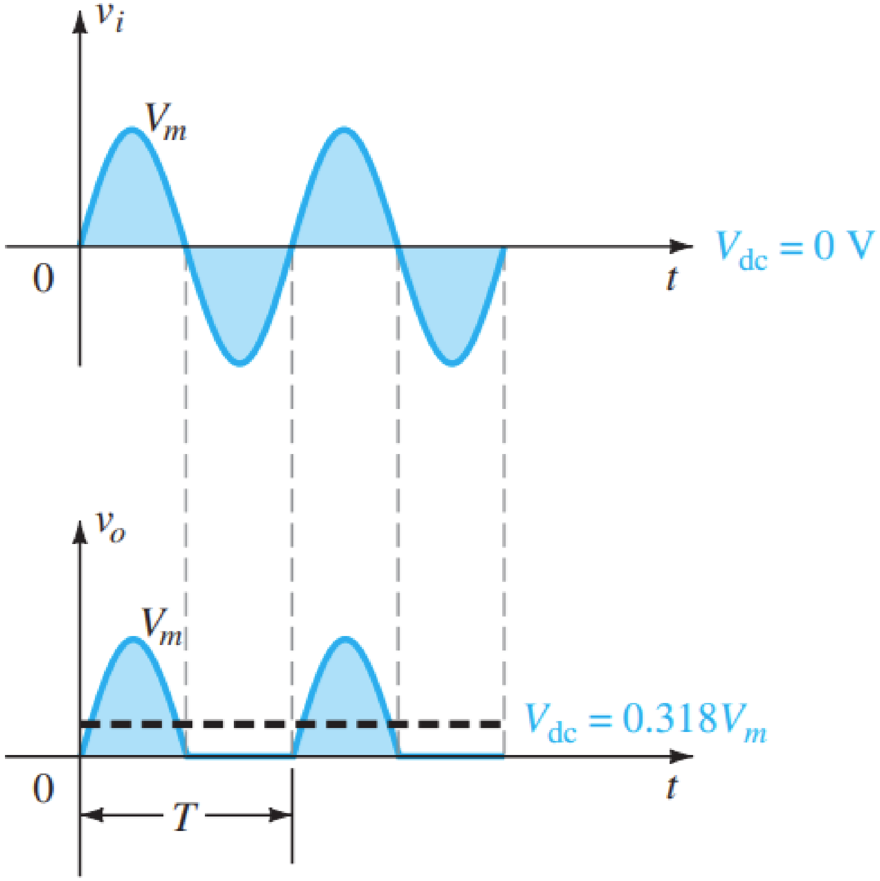
# Half wave rectifier

- For the period $T/2 \rightarrow T$, the polarity of the input vi is as shown and the resulting polarity across the ideal diode produces an "off" state with an open-circuit equivalent. The result is the absence of a path for charge to flow and $v_o = iR = (0)R$ for the period $T/2 \rightarrow T$.




**Nonconduction Region**

# Half wave rectifier



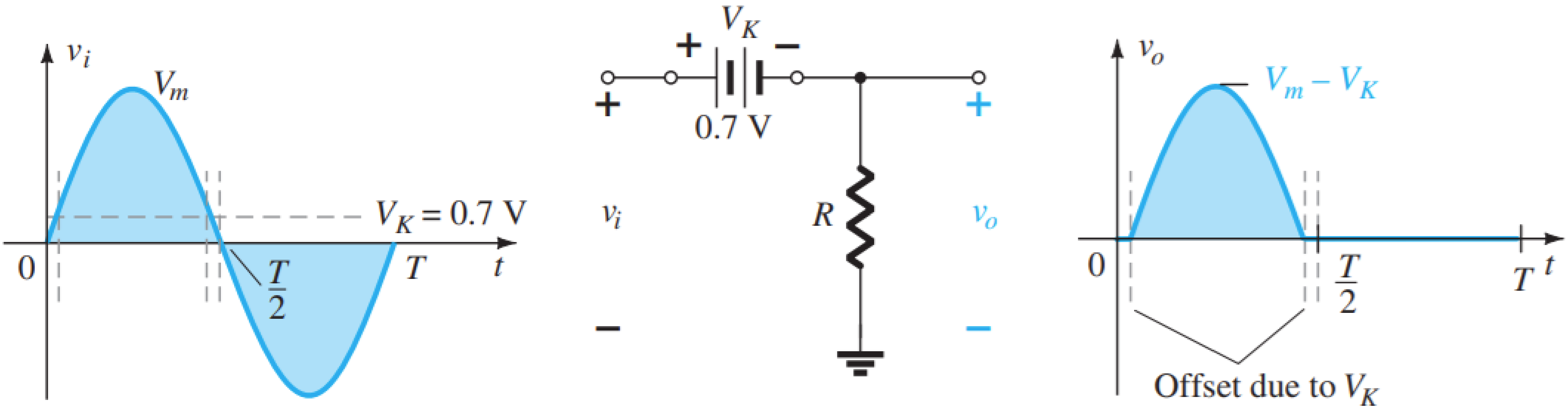

**Half wave rectified signal**

# Half-wave rectifier

- The output signal $v_o$ now has a net positive area above the axis over a full period and an average value determined by:

$$V_{dc} = \frac{V_m}{\pi} = 0.318\, V_m \rightarrow \textit{for } V_m >> V_K$$

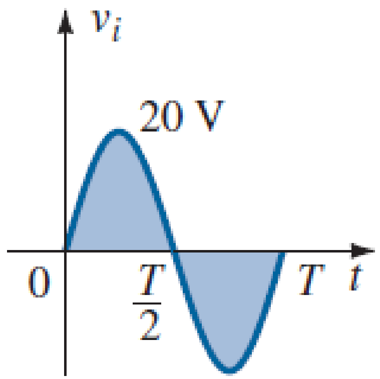
$$V_{dc} \cong \frac{V_m - V_K}{\pi} = 0.318(V_m - V_K) \rightarrow \textit{for a relative high level of accuracy}$$

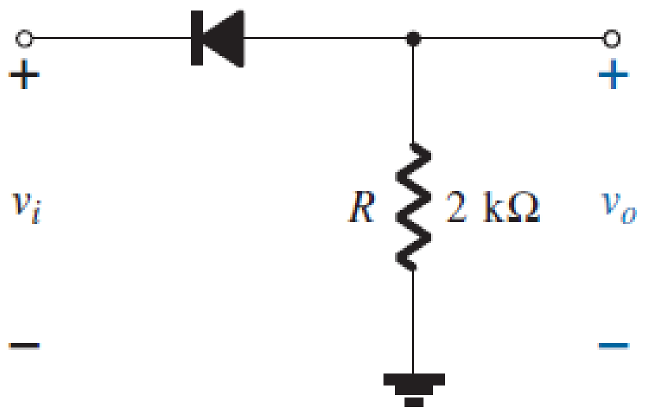



**Effect of $V_K$ on half-wave rectified signal**

# Half-wave rectifier

- Example
- a. Sketch the output $V_o$ and determine the dc level of the output for the network.
- 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 for $V_{dc}$ using ideal and Silicon diodes.

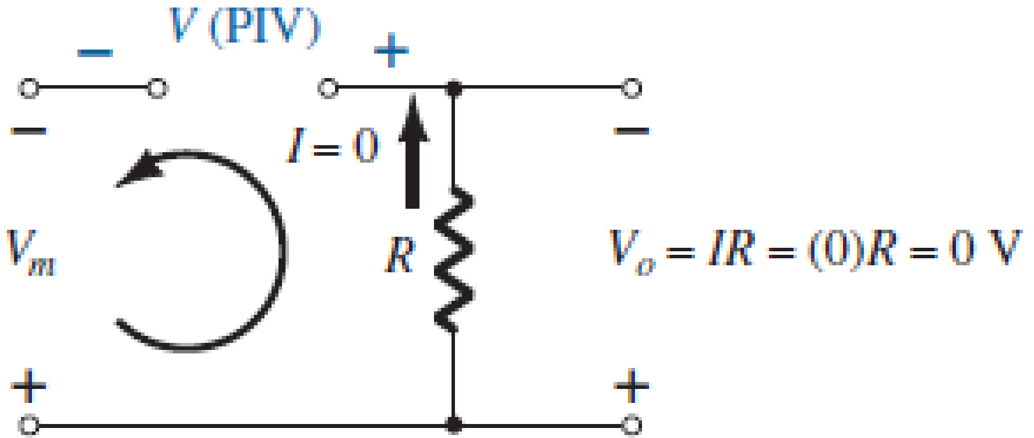


# Half-wave rectifier

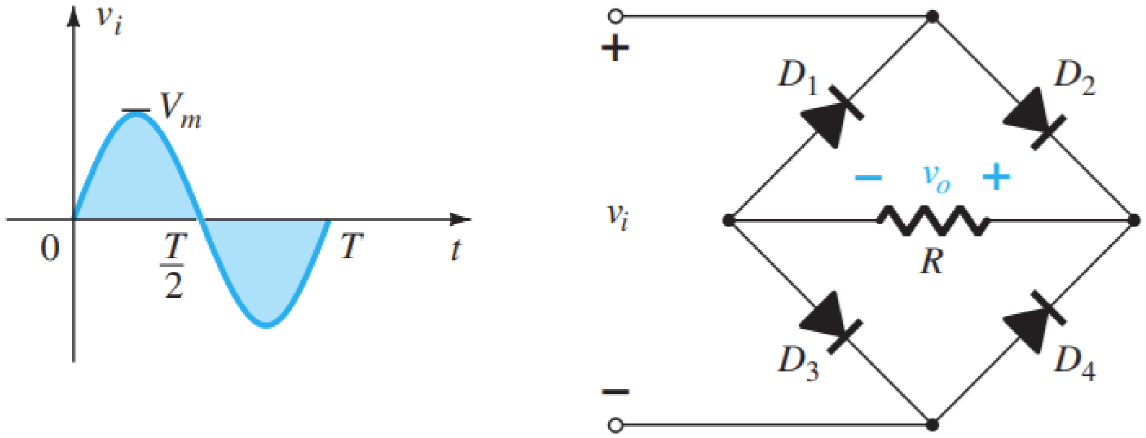
- PIV (PRV)
  - The peak inverse voltage (PIV) [or PRV (peak reverse voltage)] rating of the diode is of primary importance in the design of rectification systems.
  - It is the voltage rating that must not be exceeded in the reverse-bias region or the diode will enter the Zener avalanche region.

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

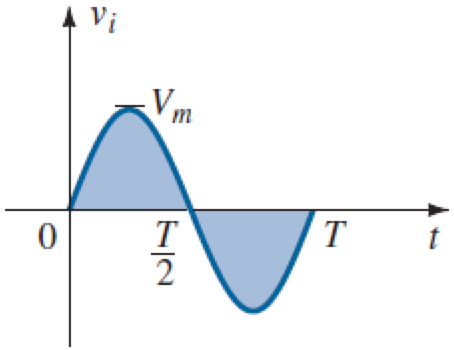


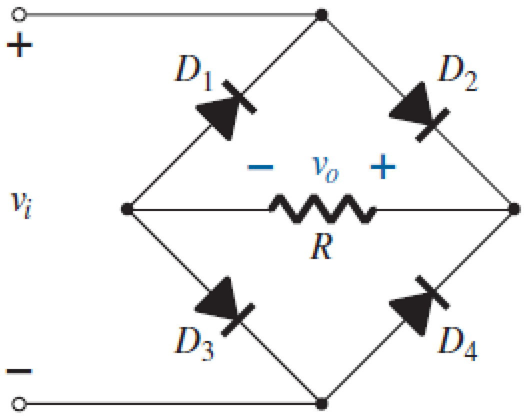
# Full wave rectifier – Bridge type

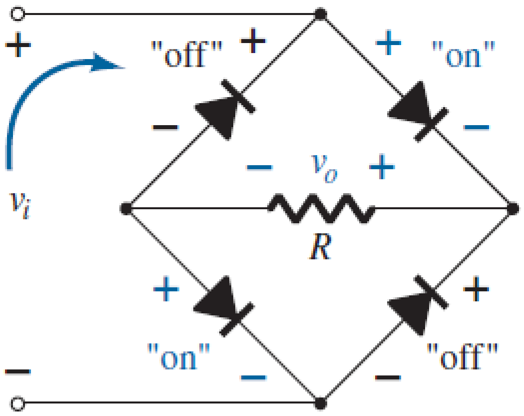
- A ***full-wave rectifier*** produces an output voltage during ***the entire cycle*** $(360°)$ of the input ac signal which means it uses both cycle of the input signal for its output.




**Full wave rectifier circuit**

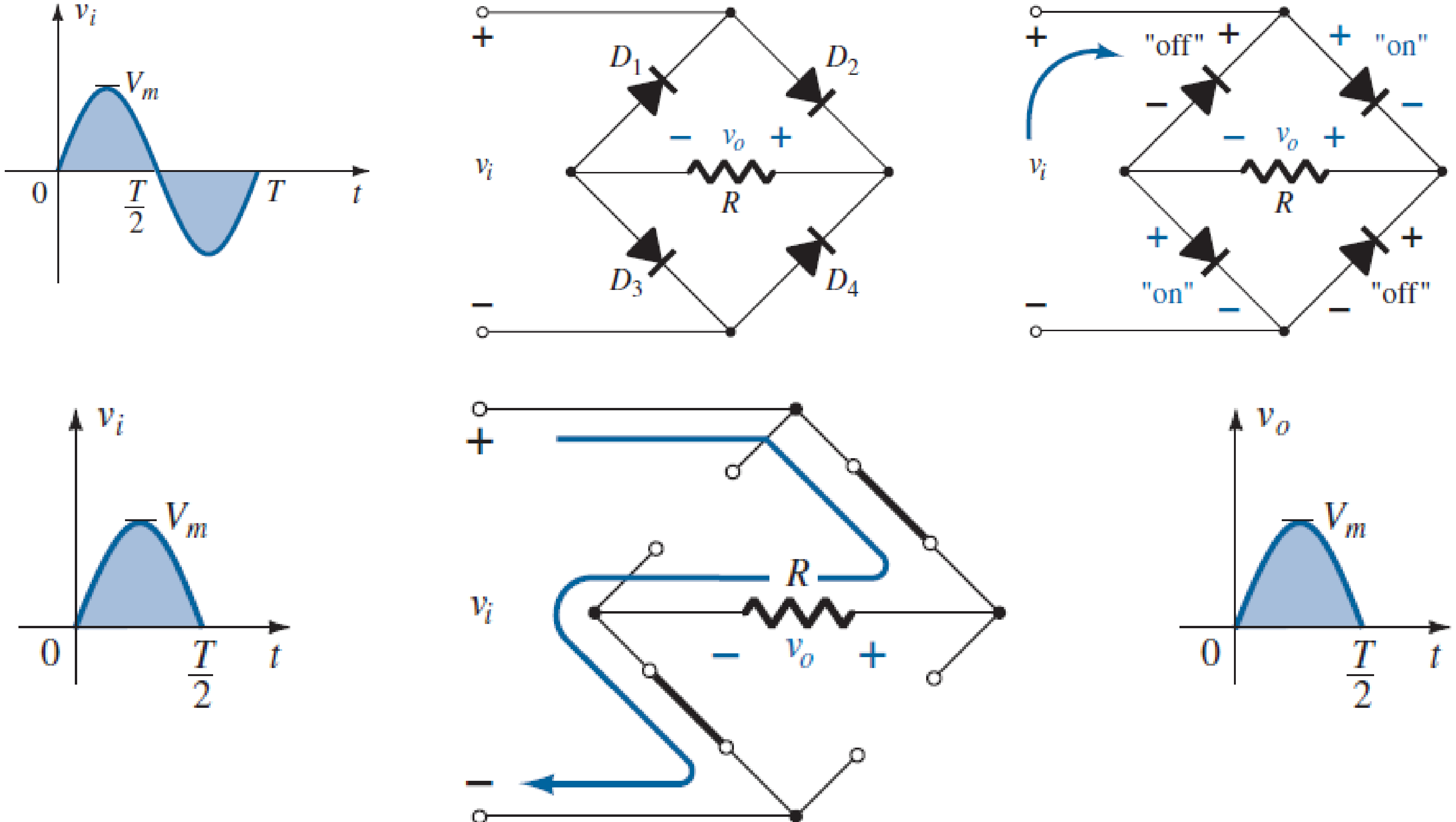


# Full wave rectifier – Bridge type

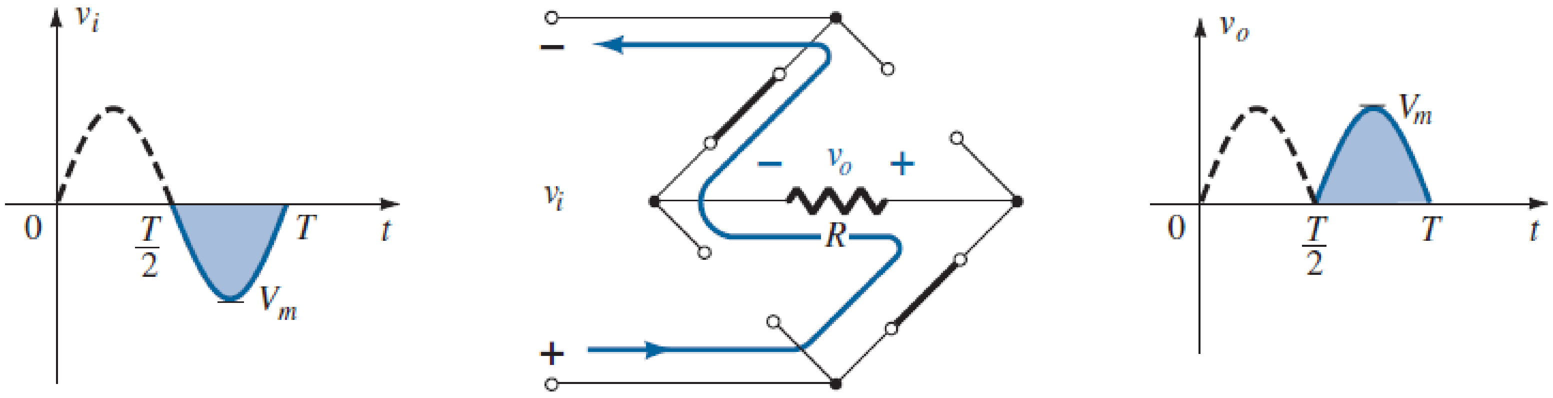
Full Wave Bridge Rectifier

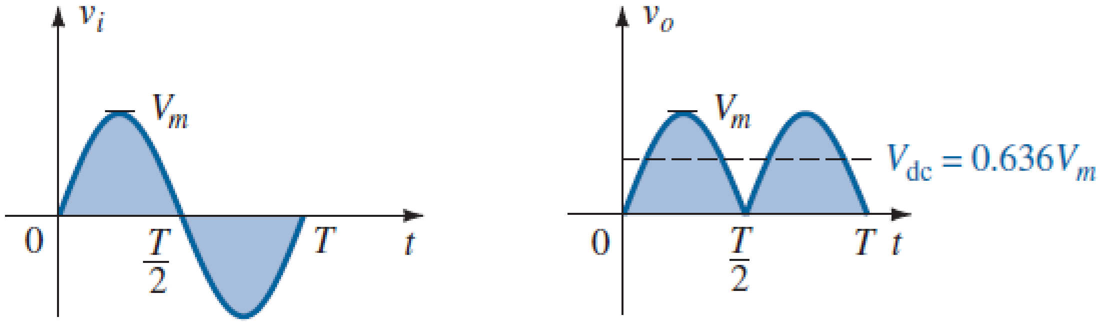



Conduction path for the positive region of $V_i$.

# Full wave rectifier – Bridge type

Conduction path for the negative region of $V_i$.

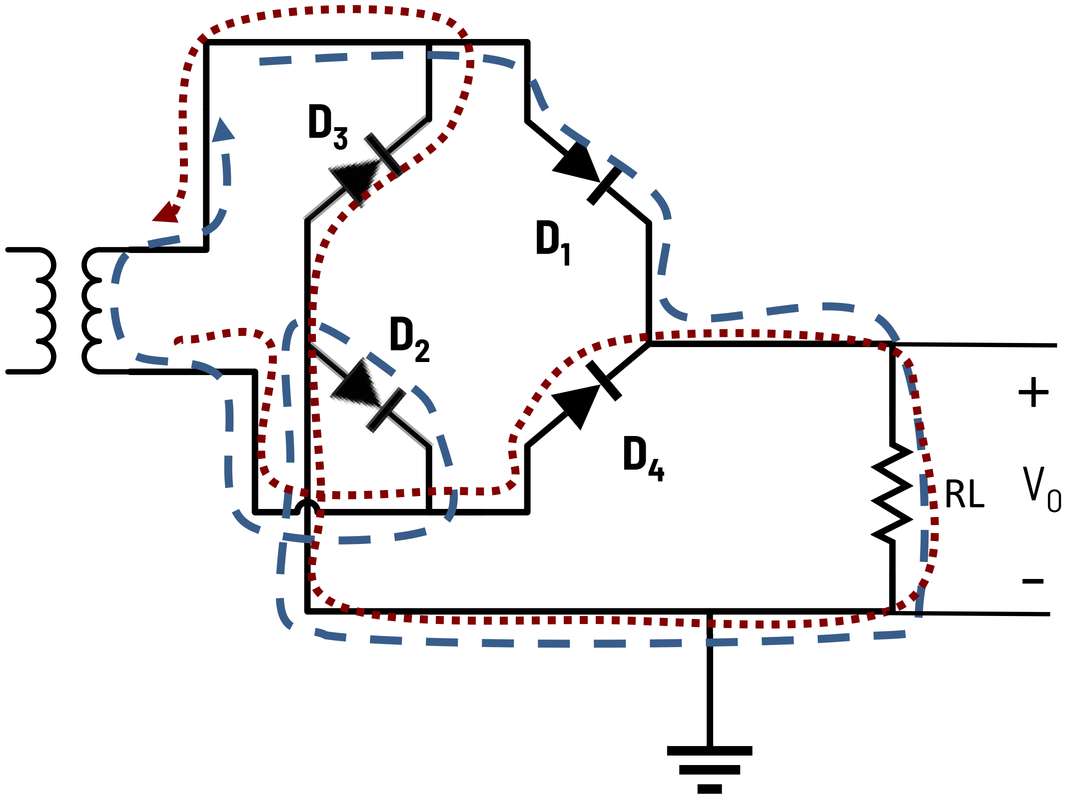


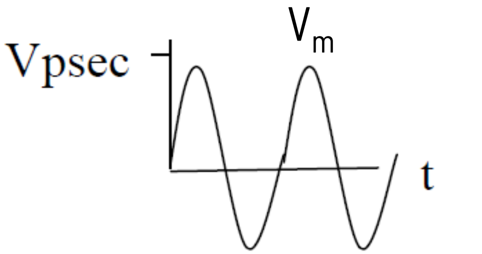




Input and output waveforms for a full-wave rectifier.

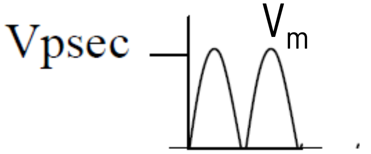
# Full wave rectifier – Bridge type

- $D_1$ and $D_2$ are forward biased during the positive half-cycle of the input. $D_3$ and $D_4$ are reverse biased.
- $D_3$ and $D_4$ are forward biased during the negative half-cycle of the input. $D_1$ and $D_2$ are reverse biased.




Voltage at Secondary



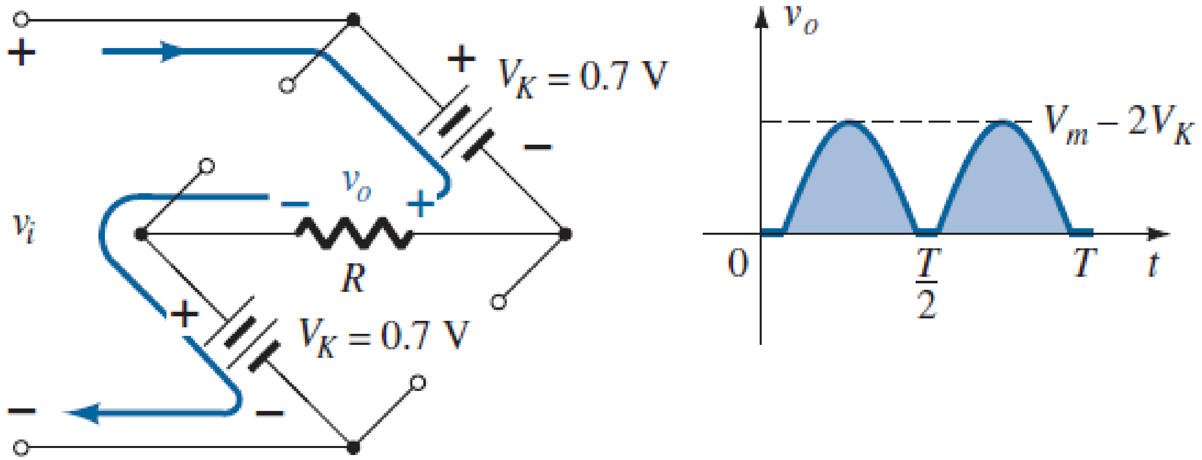

Vo = Output Voltage
(Pulsating DC)

**Full wave rectified signal**

Current flow during positive half of input signal

Current flow during negative half of input signal

# Full wave rectifier – Bridge type




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

# Full wave rectifier – Bridge type

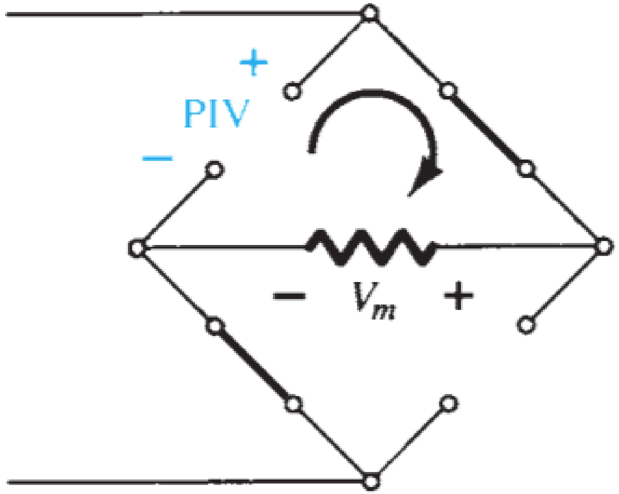
- In a full wave rectifier, the polarity across RL does not change even there is a change in polarity in the input voltages.
- The output voltage is:

$$V_{dc} = \frac{2V_m}{\pi} = 0.636\, V_m \rightarrow \textit{for ideal diodes}$$

$$V_{dc} = \frac{2(V_m - 2V_K)}{\pi} = 0.636(V_m - 2V_K) \rightarrow \textit{for practical diodes}$$

- The required PIV (Peak Inverse Voltage) of each diode (ideal) can be determined from the figure obtained at the peak of the positive region of the input signal. For the indicated loop the maximum voltage across R is V m and the PIV rating is defined by

$$PIV \geq V_m$$

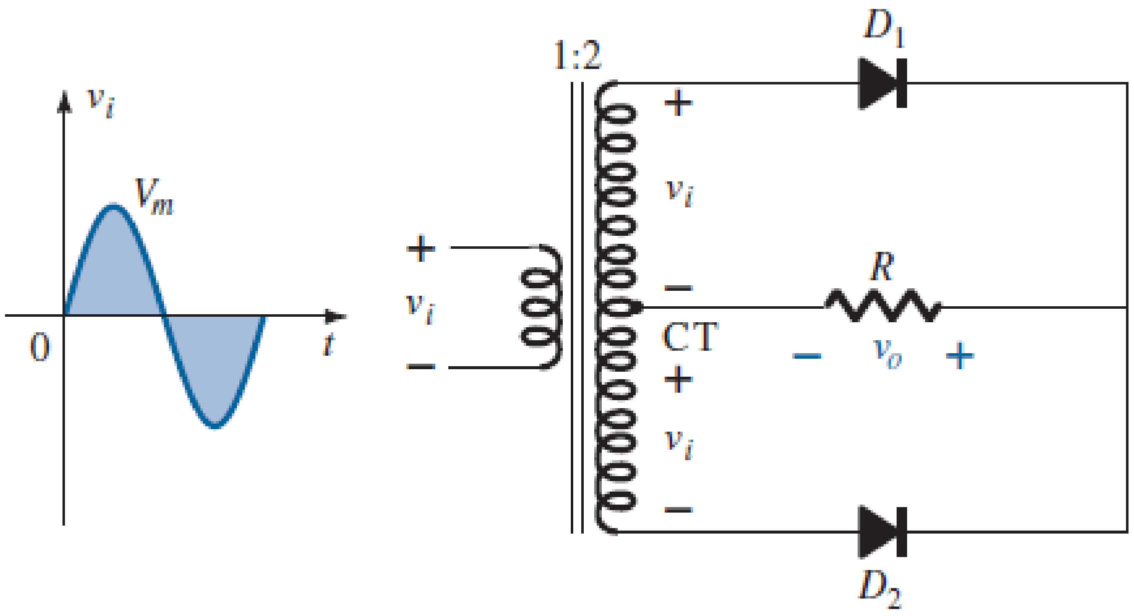


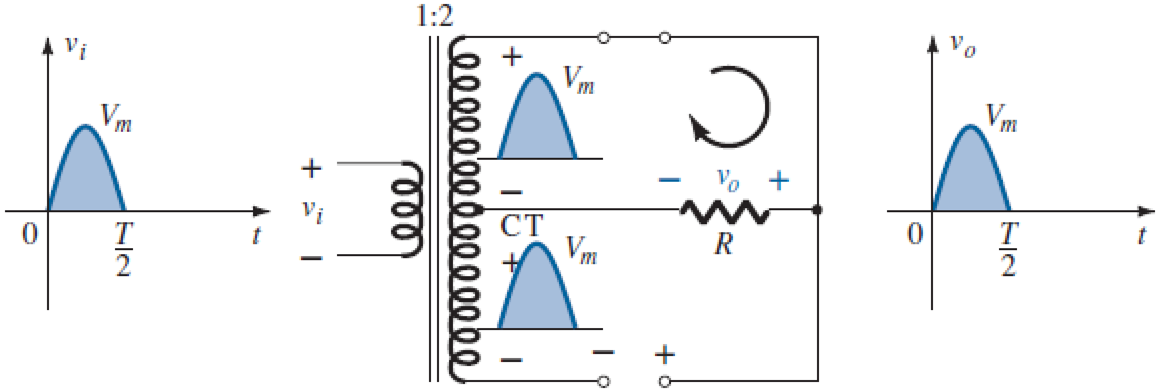

**Determining required PIV**

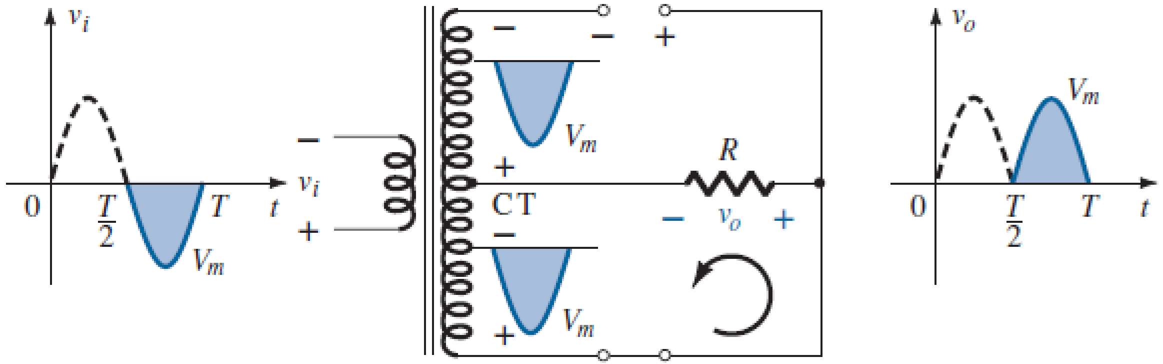
# Full wave rectifier – Center tapped

- A second popular full-wave rectifier with only two diodes but requiring a center-tapped (CT) transformer to establish the input signal across each section of the secondary of the transformer. During the positive portion of vi applied to the primary of the transformer with a positive pulse across each section of the secondary coil. $D_1$ assumes the short-circuit equivalent and $D_2$ the open circuit equivalent, as determined by the secondary voltages and the resulting current directions.

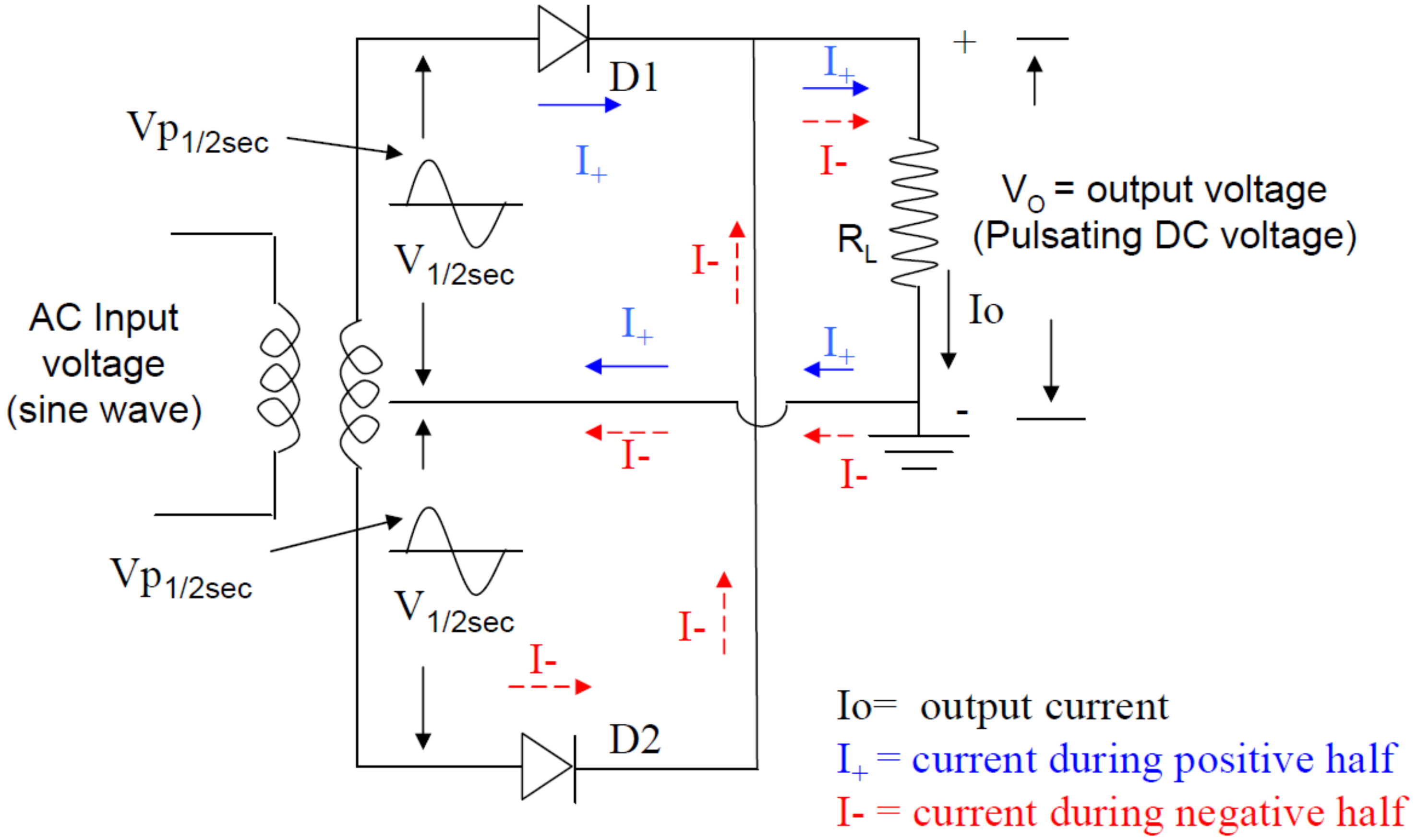
# Full wave rectifier – Center tapped

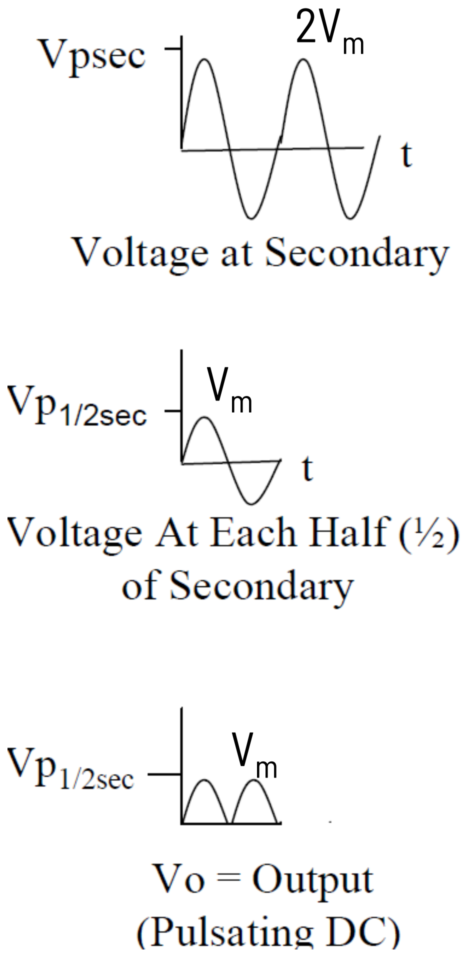


# Full wave rectifier – Center tapped



# Full wave rectifier – Center tapped

- Output voltages

$$V_{dc} = \frac{2V_m}{\pi} = 0.636\, V_m \rightarrow \textit{for ideal diodes}$$

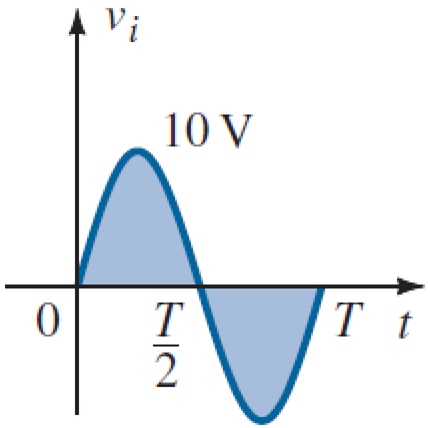
$$V_{dc} = \frac{2(V_m - 2V_K)}{\pi} = 0.636(V_m - 2V_K) \rightarrow \textit{for practical diodes}$$

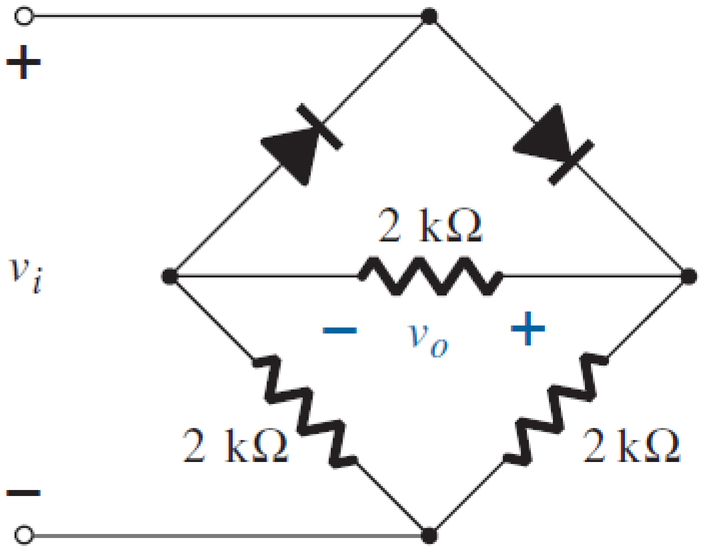
- Peak Inverse Voltage

$$PIV \geq 2V_m$$

# Full wave rectifier

- Example: Determine the output waveform for the network and calculate the output dc level and the required PIV of each diode.



# Clippers

# Clippers

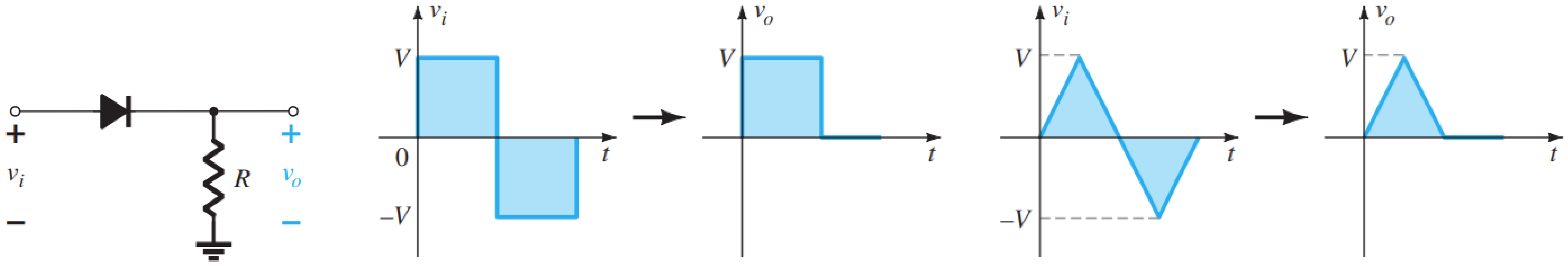
- have the ability to **“clip” off a portion** of the input signal **without distorting** the remaining part of the alternating waveform.
- The half-wave rectifier is an example of the simplest form of diode clipper—one resistor and diode.
- Depending on the orientation of the diode, the positive or negative region of the input signal is “clipped” off.
- There are two general categories of clippers: series and parallel. The series configuration is defined as one where the diode is in series with the load, while the parallel variety has the diode in a branch parallel to the load.

# Clippers

- General procedure for analyzing clipping networks:
  1. Make a mental sketch of the response of the network **based on the direction** of the diode and the **applied voltage levels**.
  2. **Determine** the applied voltage (**transition voltage**) that will **cause a change in state for the diode**.
  3. Be **continually aware** of the **defined terminals and polarity of $V_0$**.
  4. It can be helpful to **sketch the input signal above the output** and determine the **output at instantaneous values of the input**.

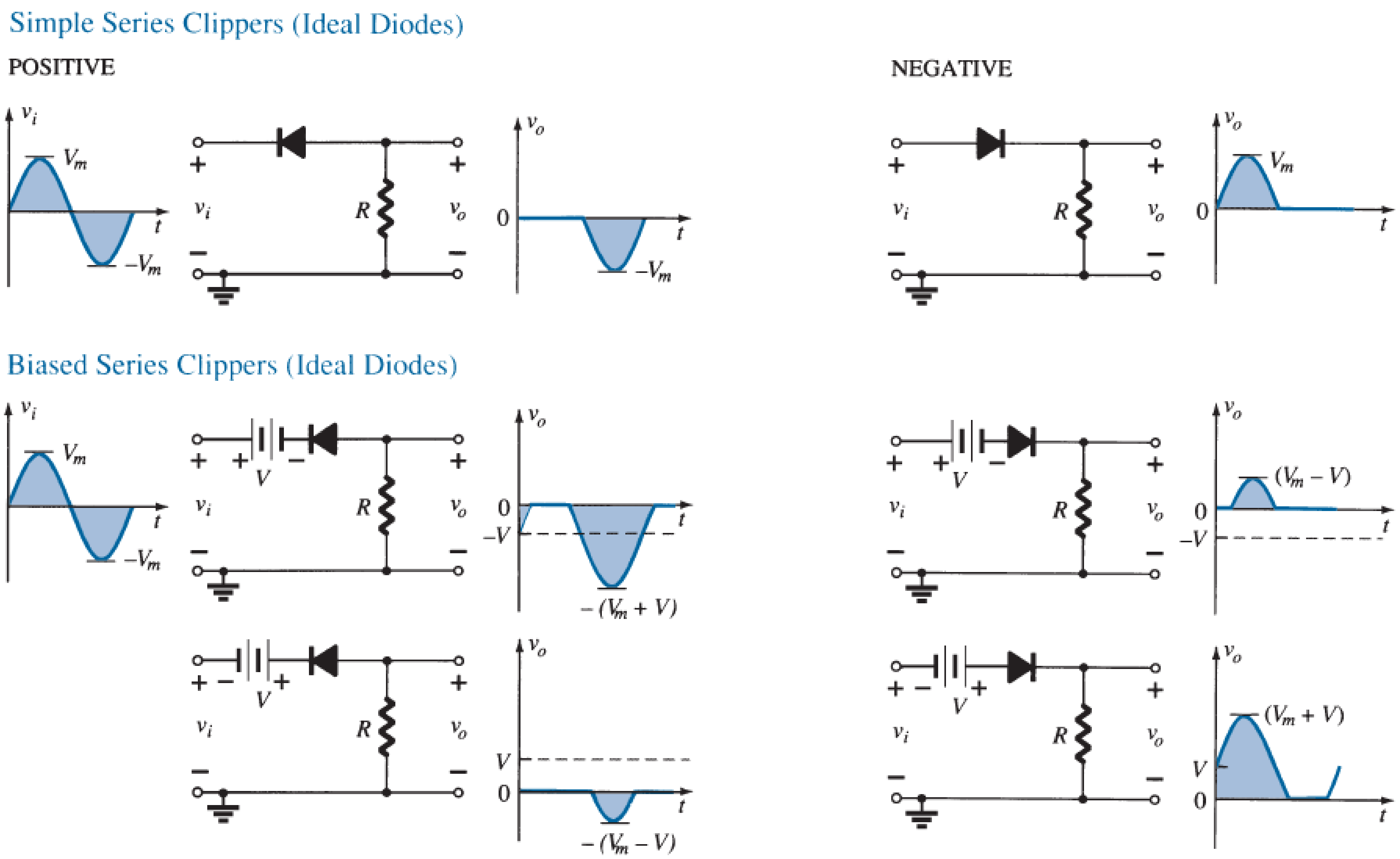
# Series Clippers

- A ***series clipper*** is one where the ***diode*** is in ***series with the load***.



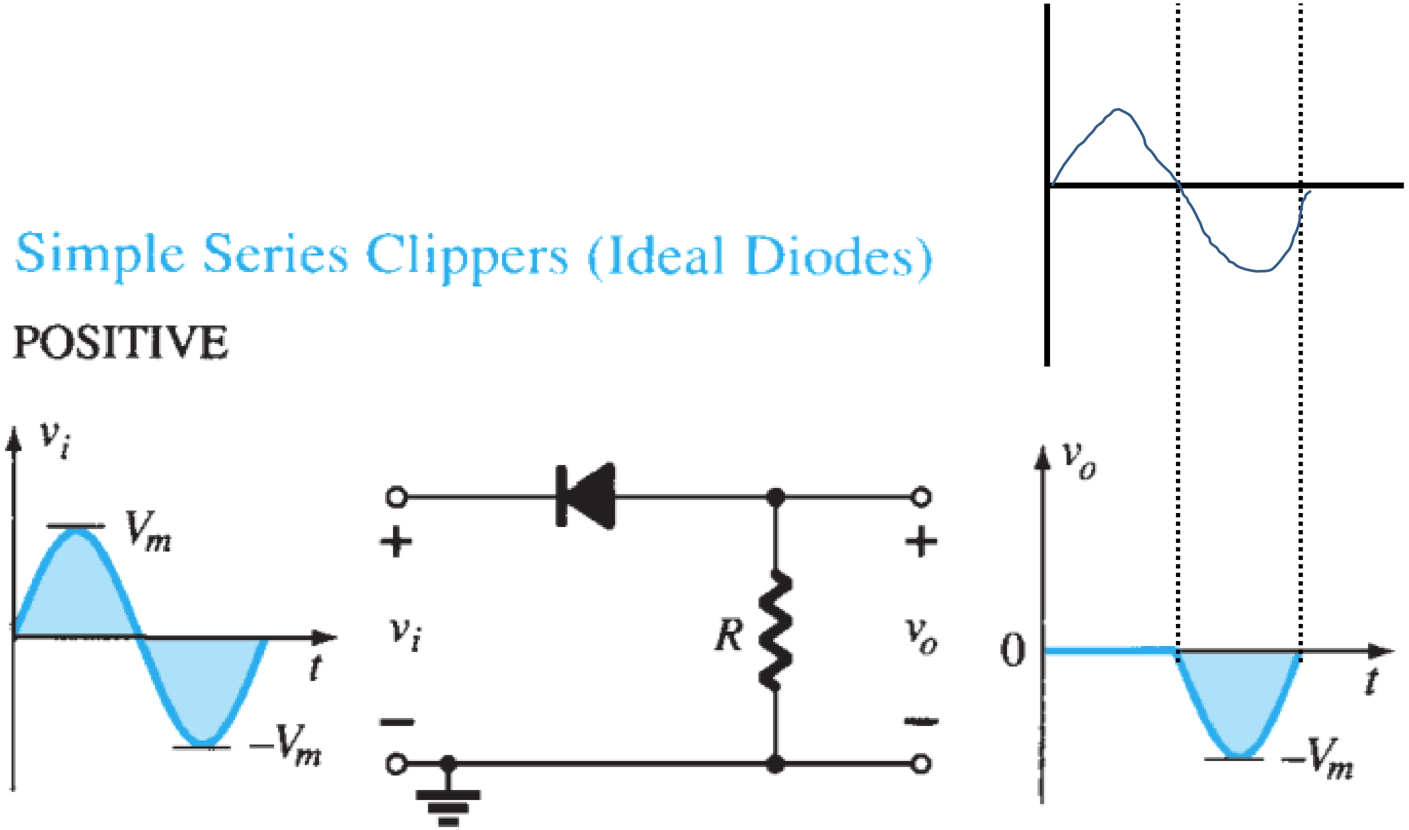

(a) (b)

# Series Clippers

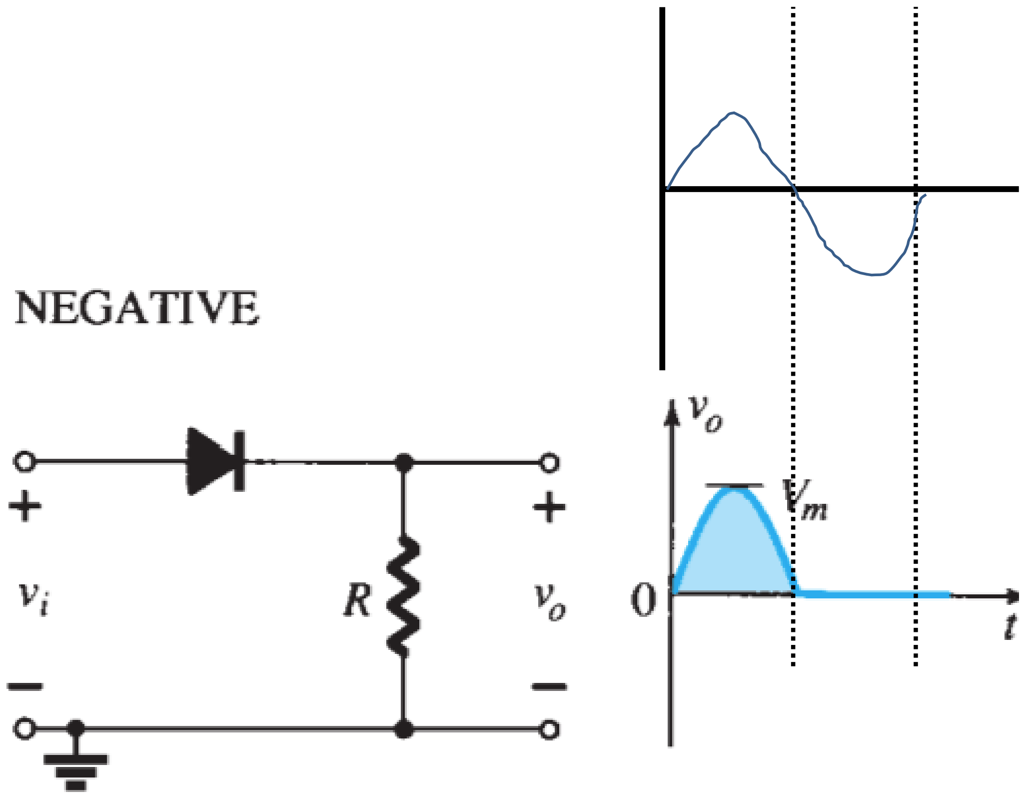


# Simple Series Clippers (Ideal Diodes)

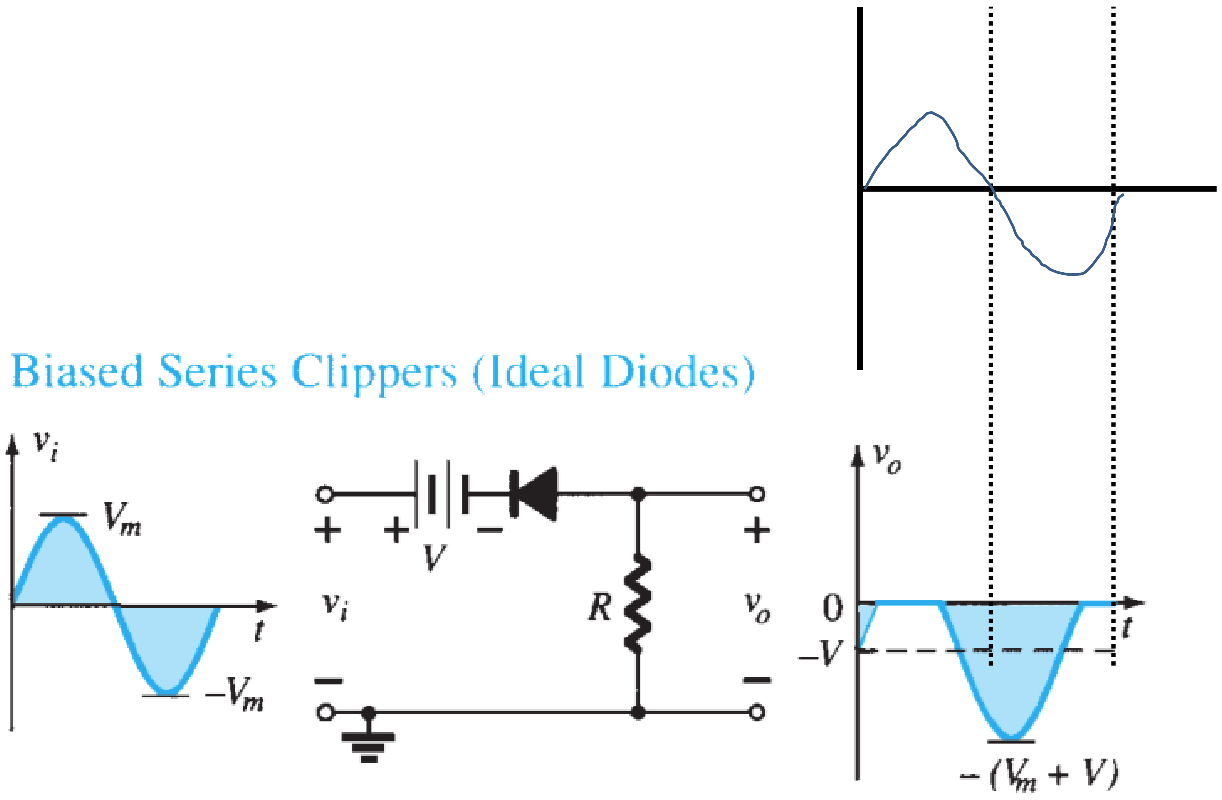
**POSITIVE**

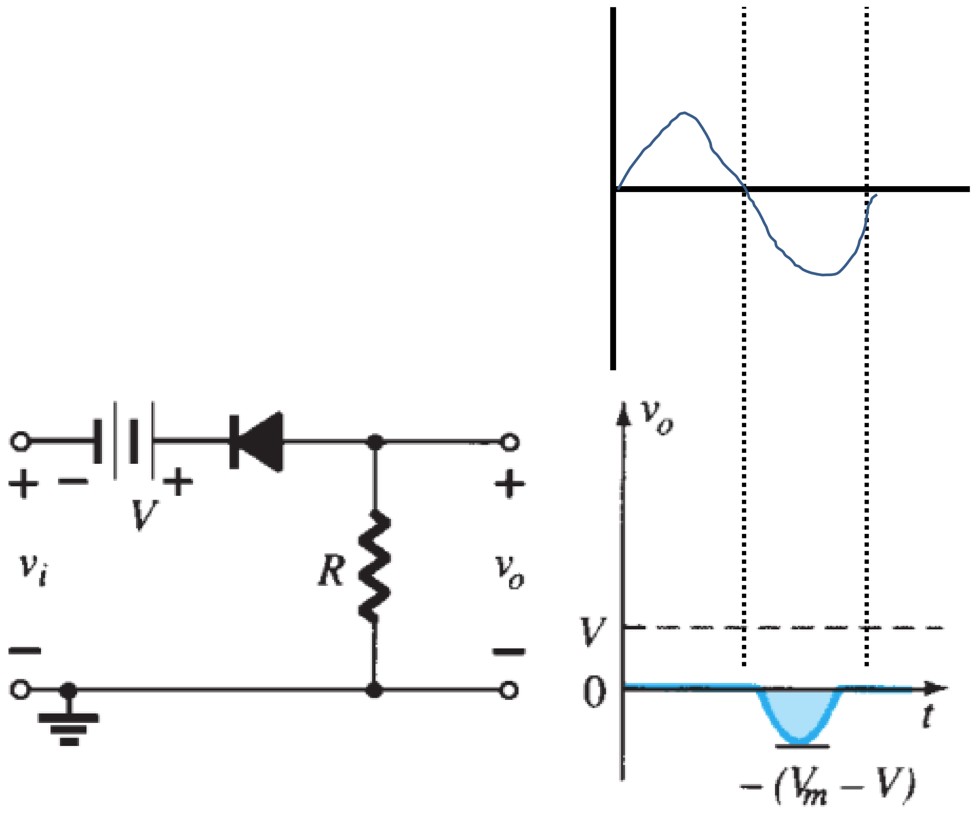


NEGATIVE

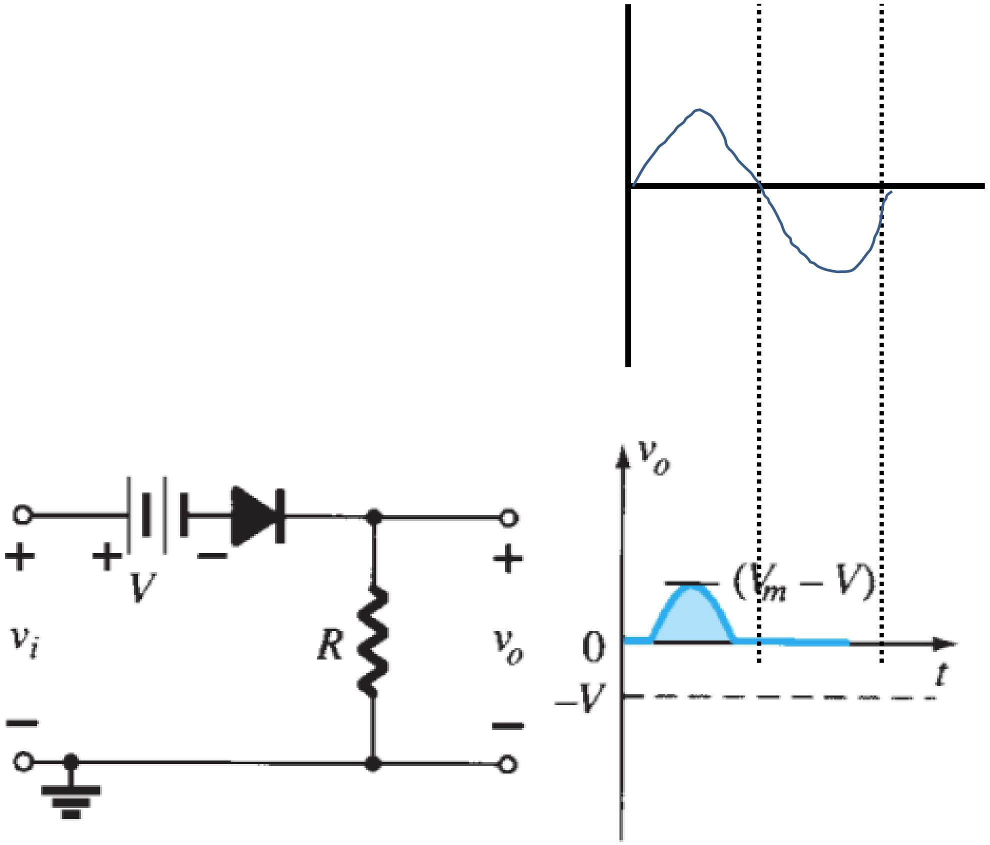


## Biased Series Clippers (Ideal Diodes)

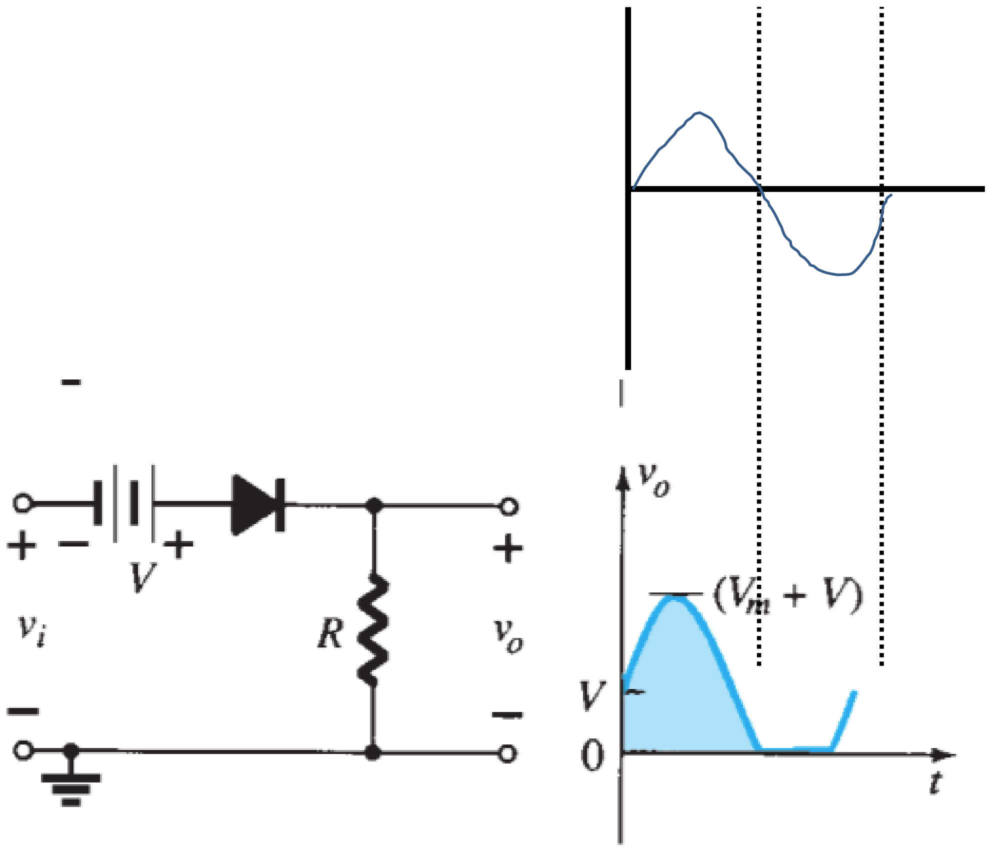




+ − V +
$v_i$
R
+
$v_o$
−
$v_o$
V
0
t
$-(V_m - V)$



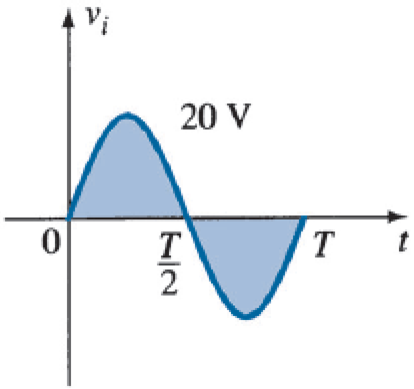
+
+
V
−
v_i
−
R
+
v_o
−
v_o
(V_m − V)
0
−V
t

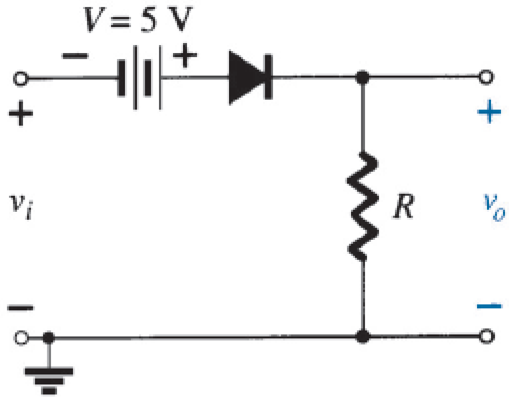


+
−
V
+
$v_i$
−
R
+
$v_o$
−
$v_o$
$(V_m + V)$
V
0
t

# Series Clippers

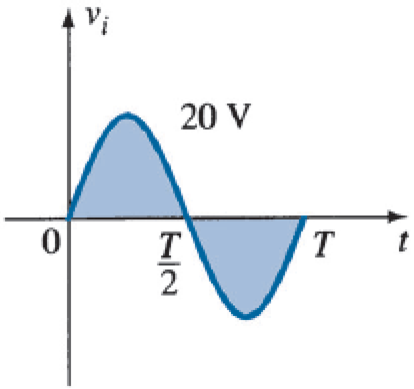
- Determine the output waveform for the sinusoidal input

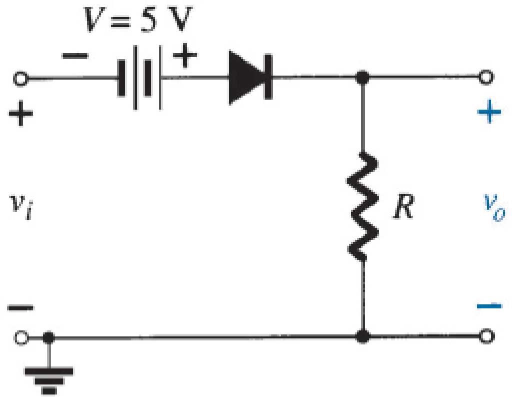


# Series Clippers

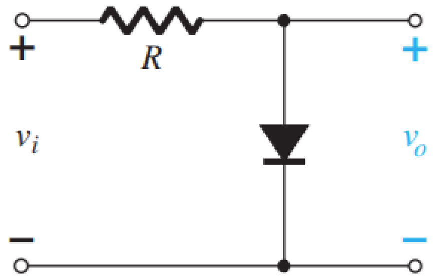
- Find the output voltage for the network examined if the applied signal is the square wave

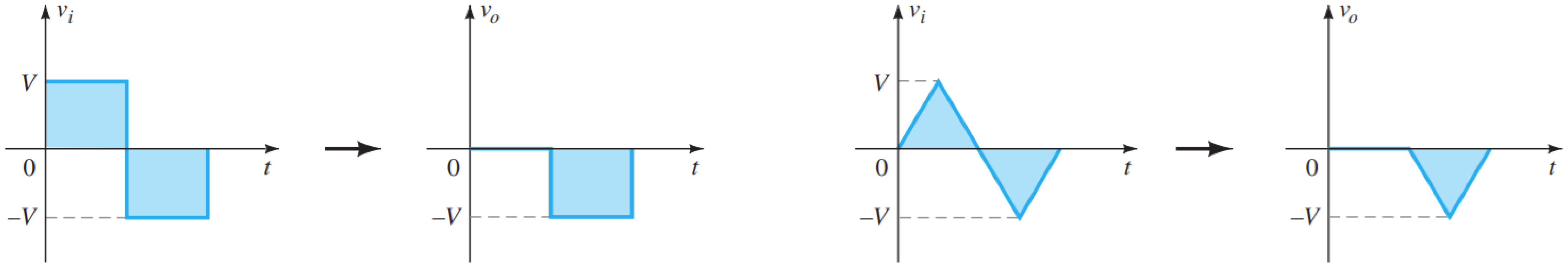


# Parallel Clippers

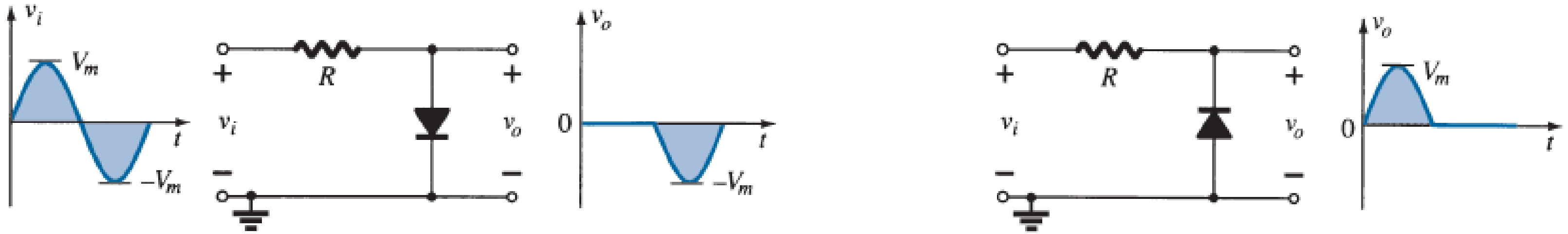
- A ***parallel clipper*** is one where the ***diode*** is in ***parallel with the load***.



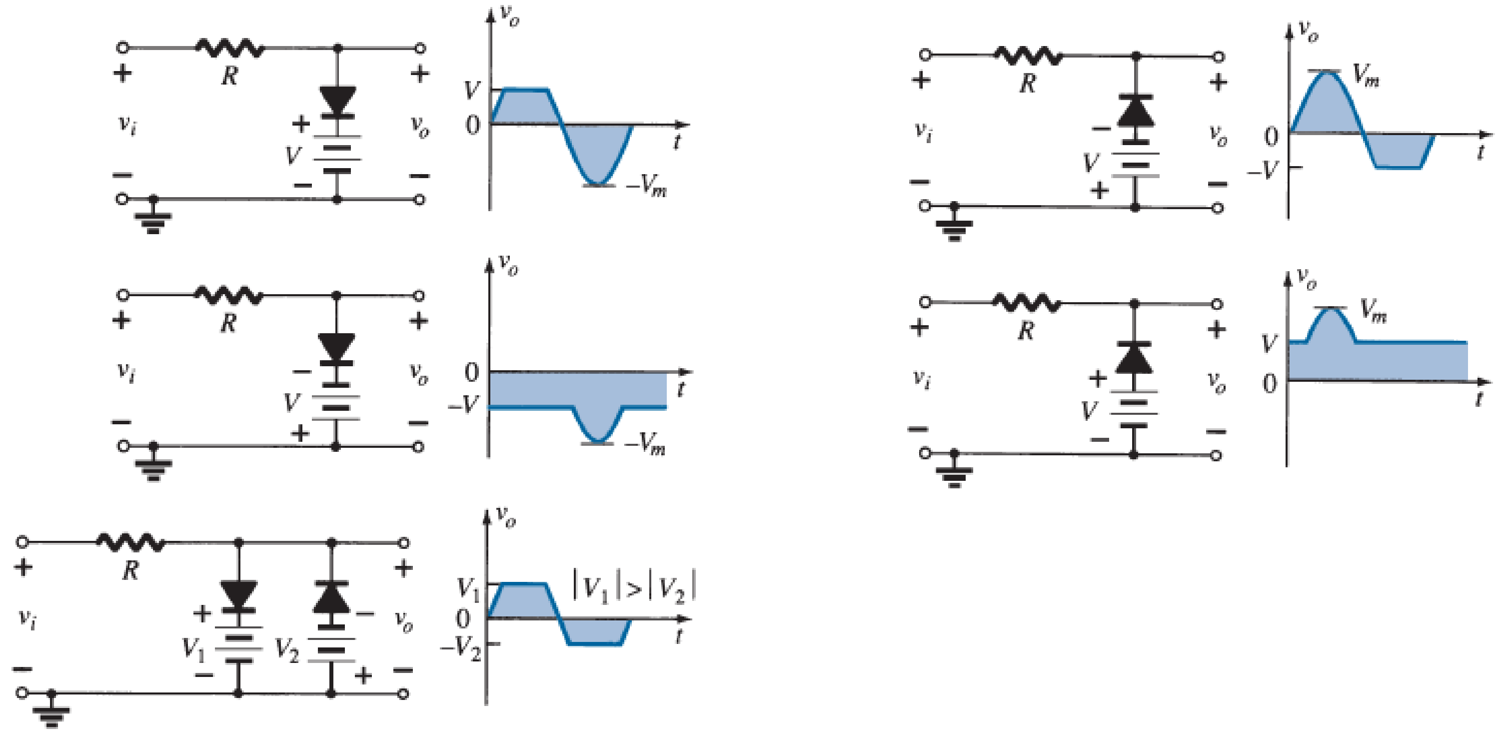



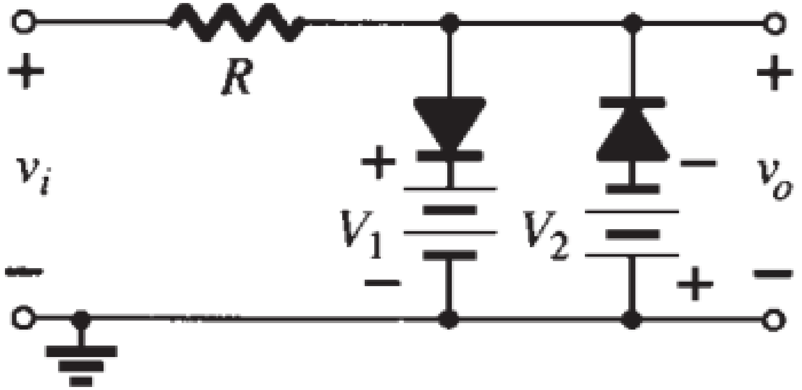
# Parallel Clippers

## Simple Parallel Clippers (Ideal Diodes)

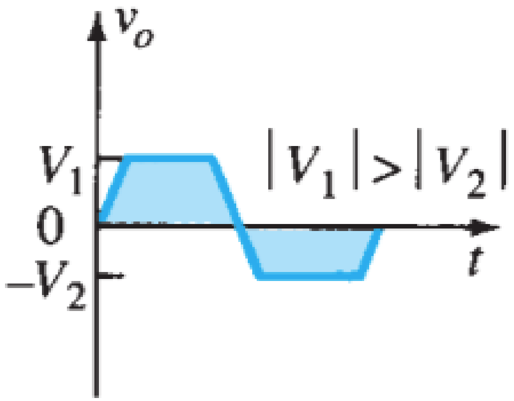



## Biased Parallel Clippers (Ideal Diodes)





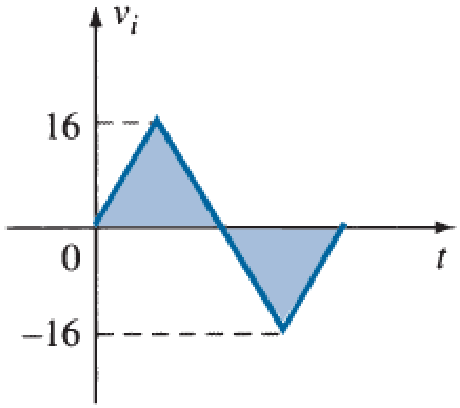
R
+
−
$v_i$
$V_1$
$V_2$
$v_o$

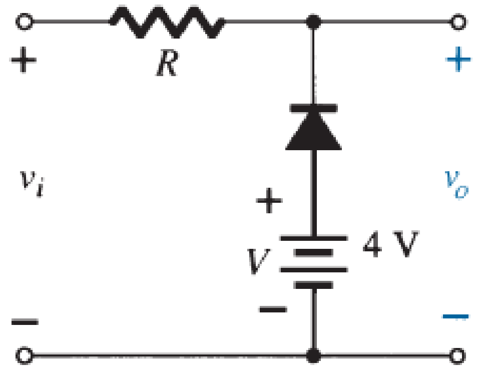



$v_o$
$V_1$
0
$-V_2$
$t$
$|V_1| > |V_2|$

# Parallel Clippers

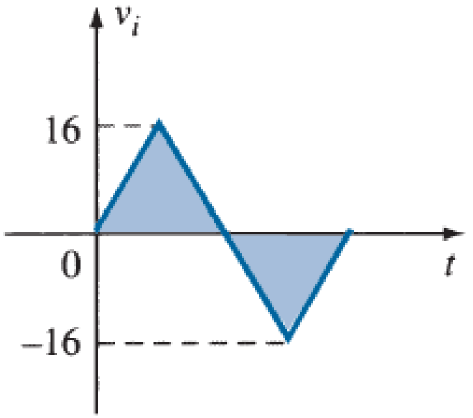
- Determine vo for the network

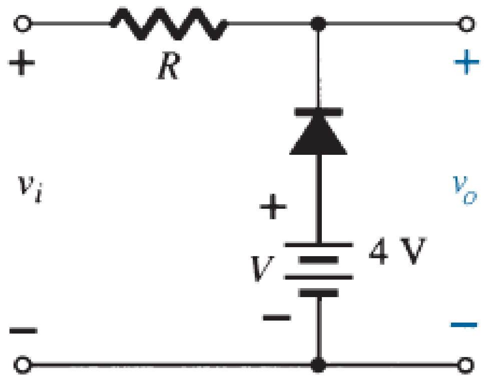


# Parallel Clippers

- Repeat using a silicon diode with VK = 0.7 V.



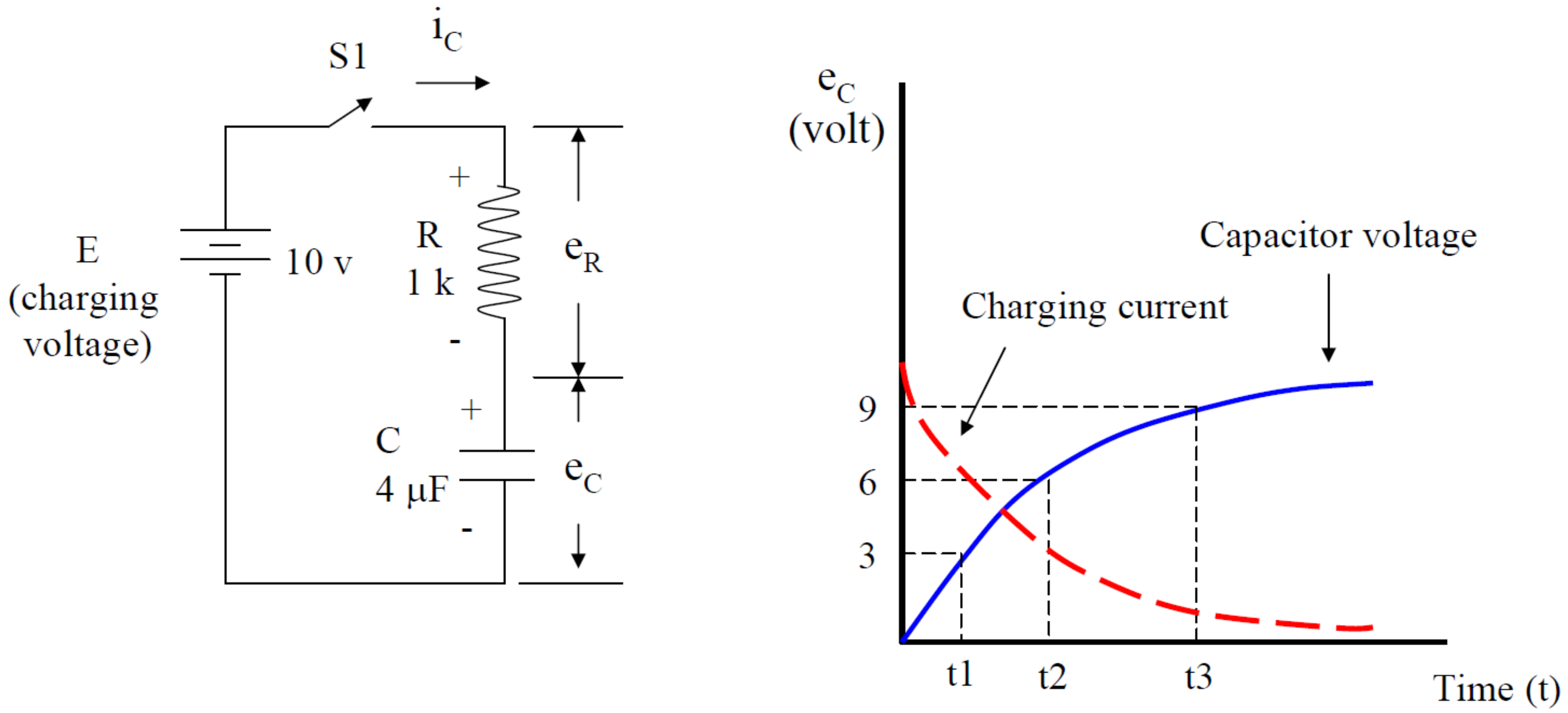
# Clampers

# 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.
- The clamping network is one that will **“clamp” a signal to a different dc level**.
- The network must have a **capacitor**, a **diode**, and a **resistive element**, but it can **also employ an independent dc supply** to introduce an additional shift.
- The **magnitude of R and C** must be chosen such that the time constant $\boldsymbol{\tau} = \mathbf{RC}$ is **large enough** to ensure that the voltage across the capacitor does not discharge significantly during the interval the diode is non-conducting.
- Throughout the analysis we will assume that for all practical purposes the capacitor will fully charge or discharge in five time constants.

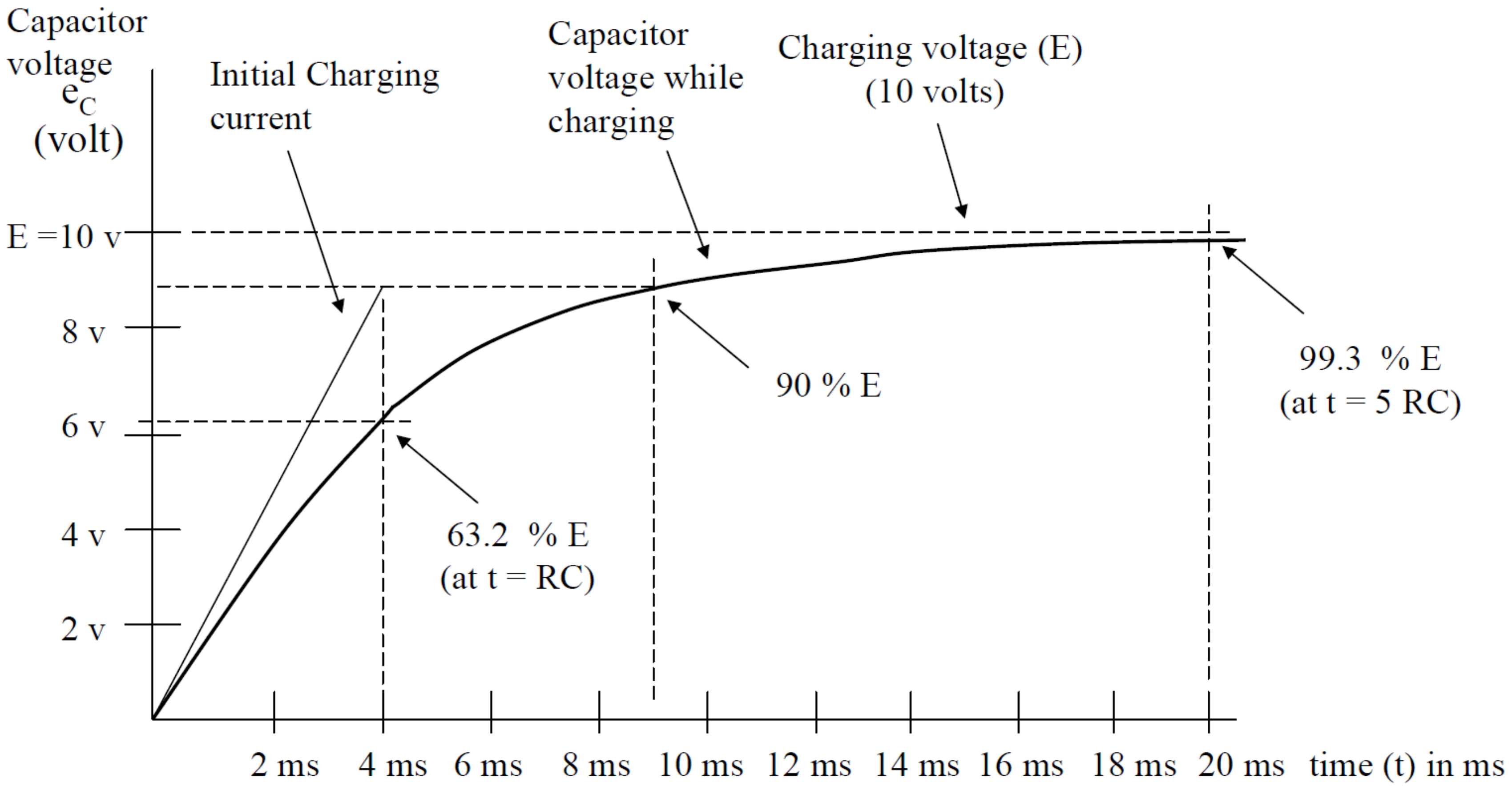
# Clampers

- When $S_1$ is closed, capacitor C will be charged **towards the supply voltage E**. As the capacitor voltage increases the **charging current decreases**.




**Simple RC Circuit**

# RC Time Constant, $\tau$

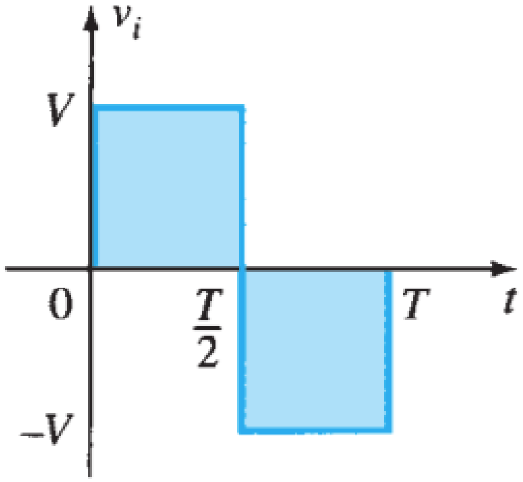


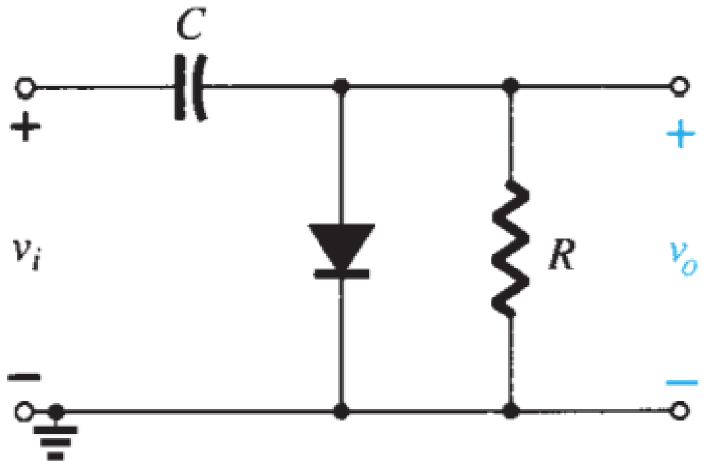

- **Regardless of the value of E, R and C, the capacitor is charged to 63.2 % E when t = RC, to 90 % E at t = 2.2 RC, and to 99.3 % E at t = 5 RC.**
- **In the diagram, it was assumed that E = 10 volts, R = 1 kΩ, and C = 4 $\mu$F.Thus RC = 4 ms**

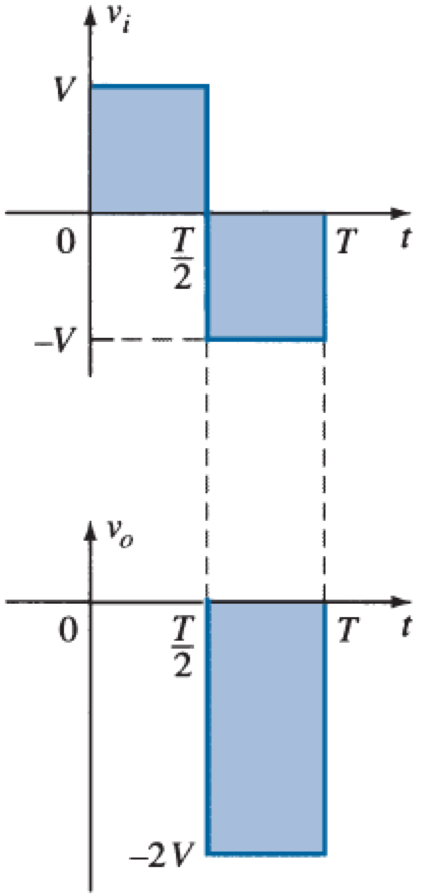
# Clampers

- In general, the following steps may be helpful when analyzing clamping networks:
  1. Step 1: Start the analysis by examining the response of the portion of the input signal that will forward bias the diode.
  2. Step 2: During the period that the diode is in the “on” state, assume that the capacitor will charge up instantaneously to a voltage level determined by the surrounding network.
  3. Step 3: Assume that during the period when the diode is in the “off” state the capacitor holds on to its established voltage level.
  4. Step 4: Throughout the analysis, maintain a continual awareness of the location and defined polarity for $v_o$ to ensure that the proper levels are obtained.
  5. Step 5: Check that the total swing of the output matches that of the input.

# Clampers

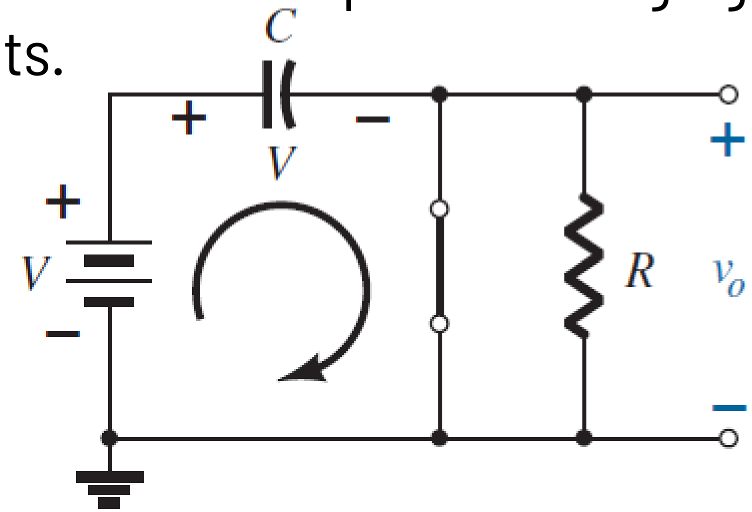


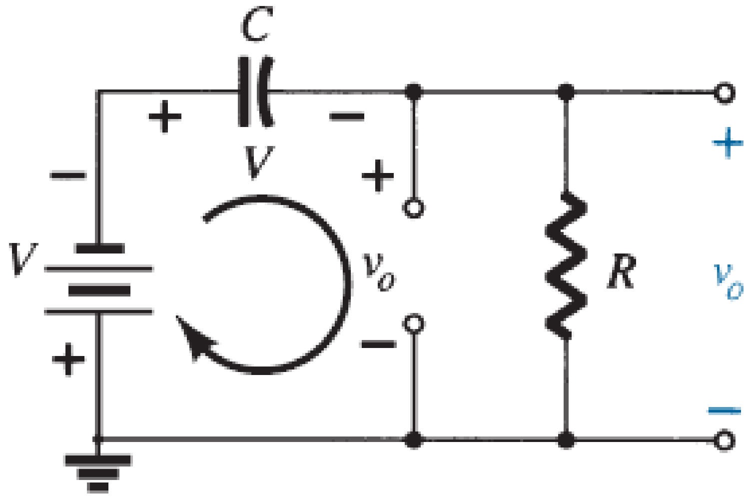




**Clamper**

Diode “on” and the capacitor charging to V volts.

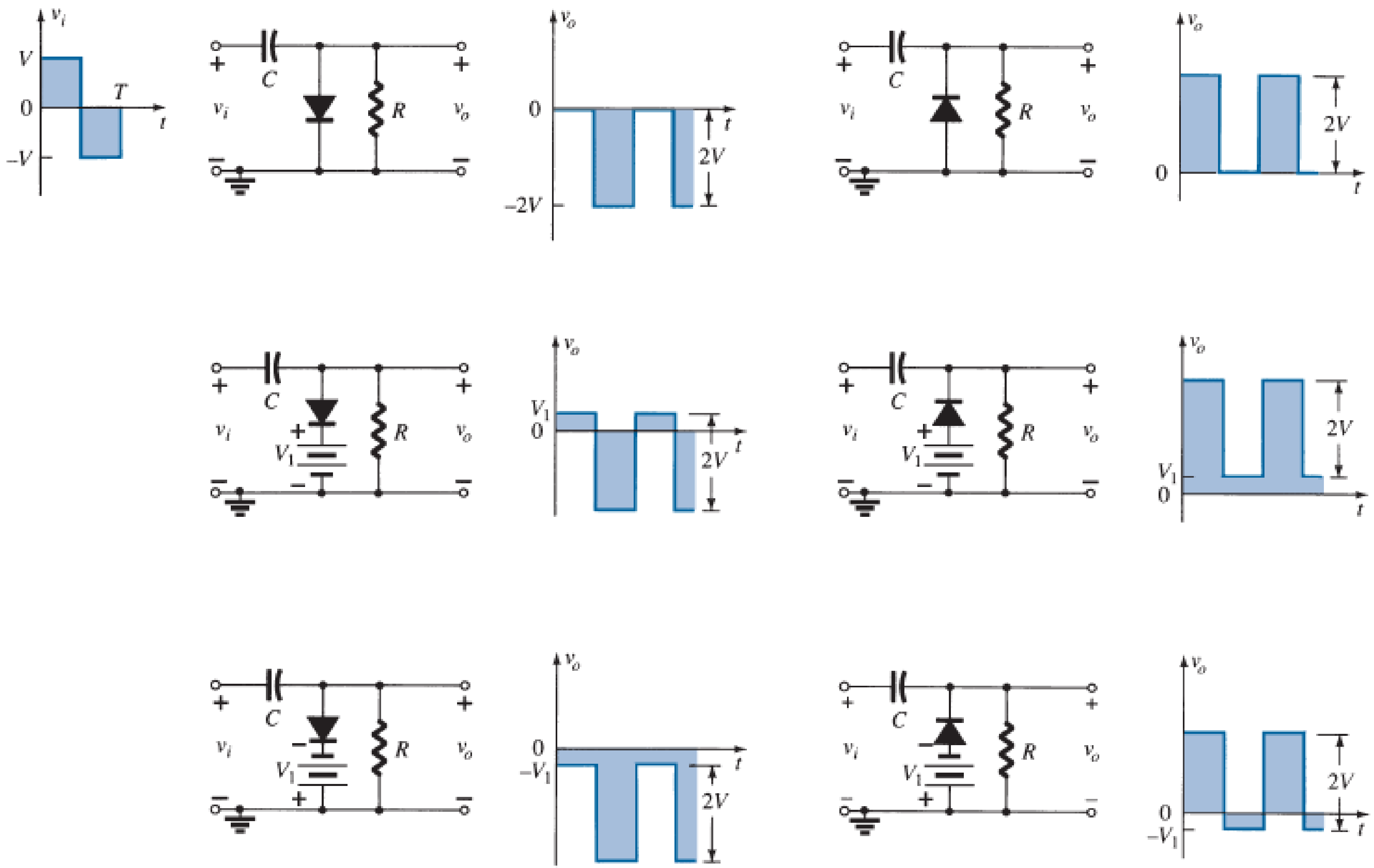



Determining $v_o$ with the diode “off.”



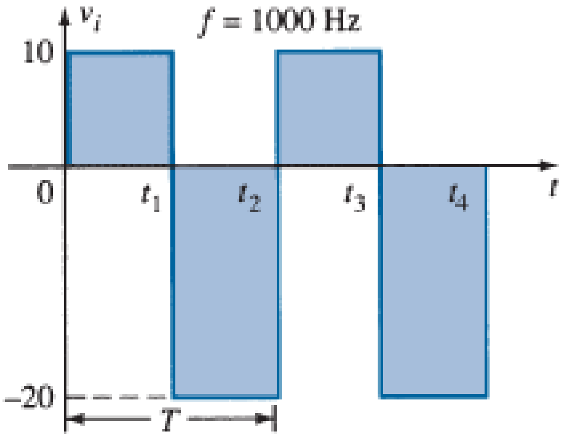
# Clampers

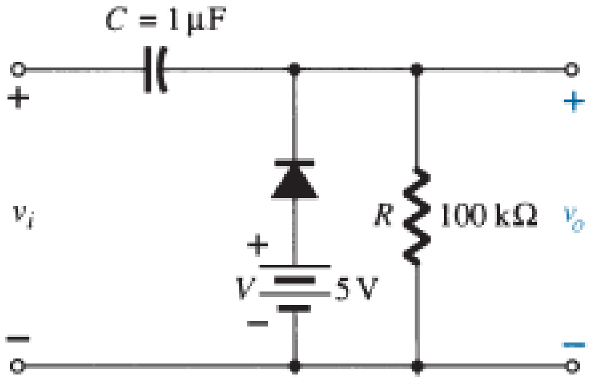
Clamping Networks



# Clampers

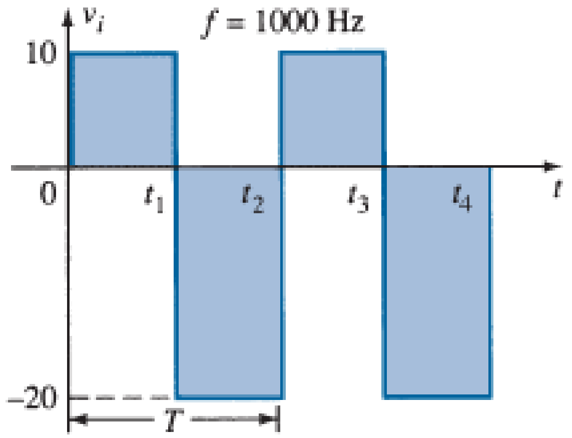
- Example: Determine $v_o$

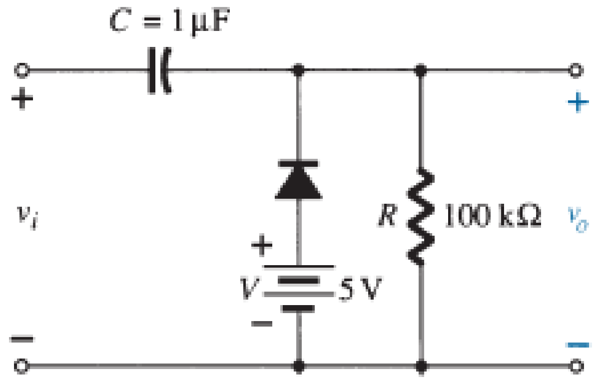


# Clampers

- Example: Determine $v_o$ if Si Diode is used ($V_K = 0.7V$)



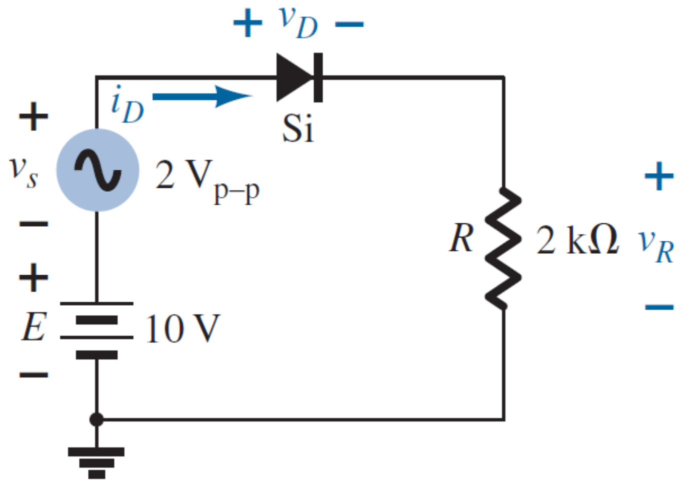



# Network with AC and DC Source

# Network with AC and DC Source

- 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.

# Network with AC and DC Source



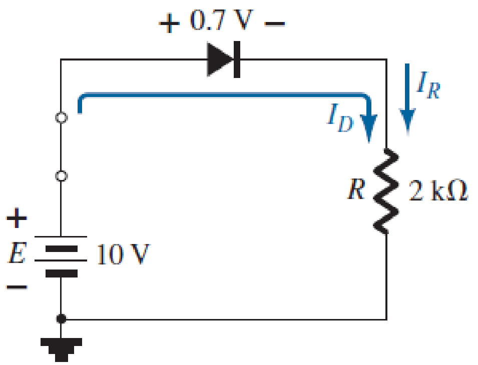

- DC source
  - The network is redrawn for the dc source. Note that the ac source was removed by simply replacing it with a short-circuit equivalent to the condition vs = 0 V.
- AC source
  - The dc source is also replaced by a short-circuit equivalent. The diode will be replaced by the ac resistance, as determined by equation rd =ΔVd/ΔId—the current in the equation being the quiescent or dc value.

# Network with AC and DC Source

- DC Source

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

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

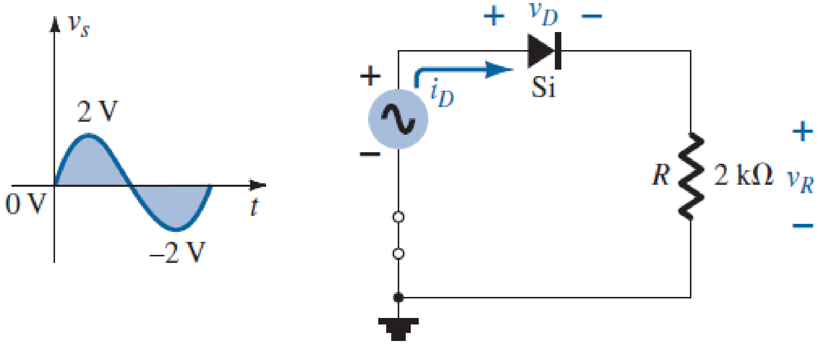


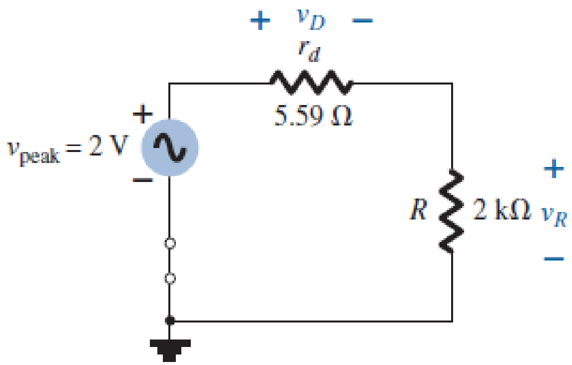

- AC Source

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

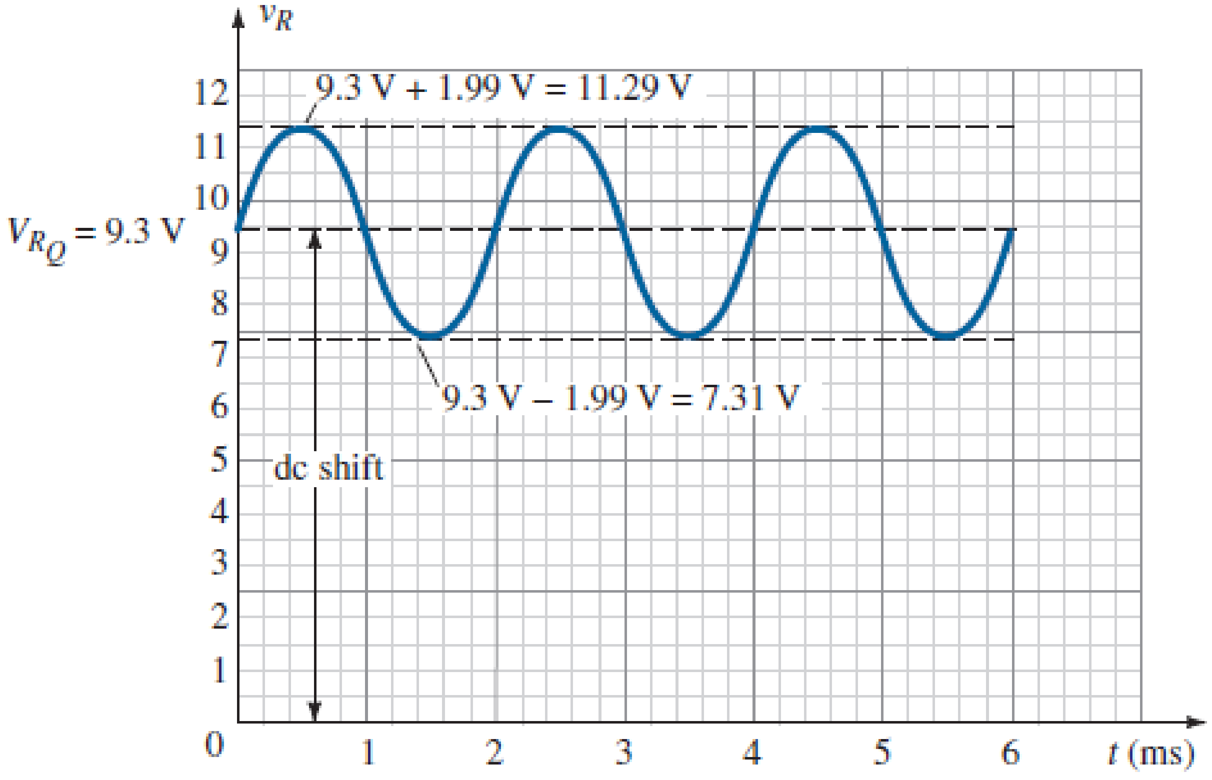
$$v_{R_{\text{peak}}} = \frac{2\ \text{k}\Omega\ (2\ \text{V})}{2\ \text{k}\Omega + 5.59\ \Omega} \cong 1.99\ \text{V}$$

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

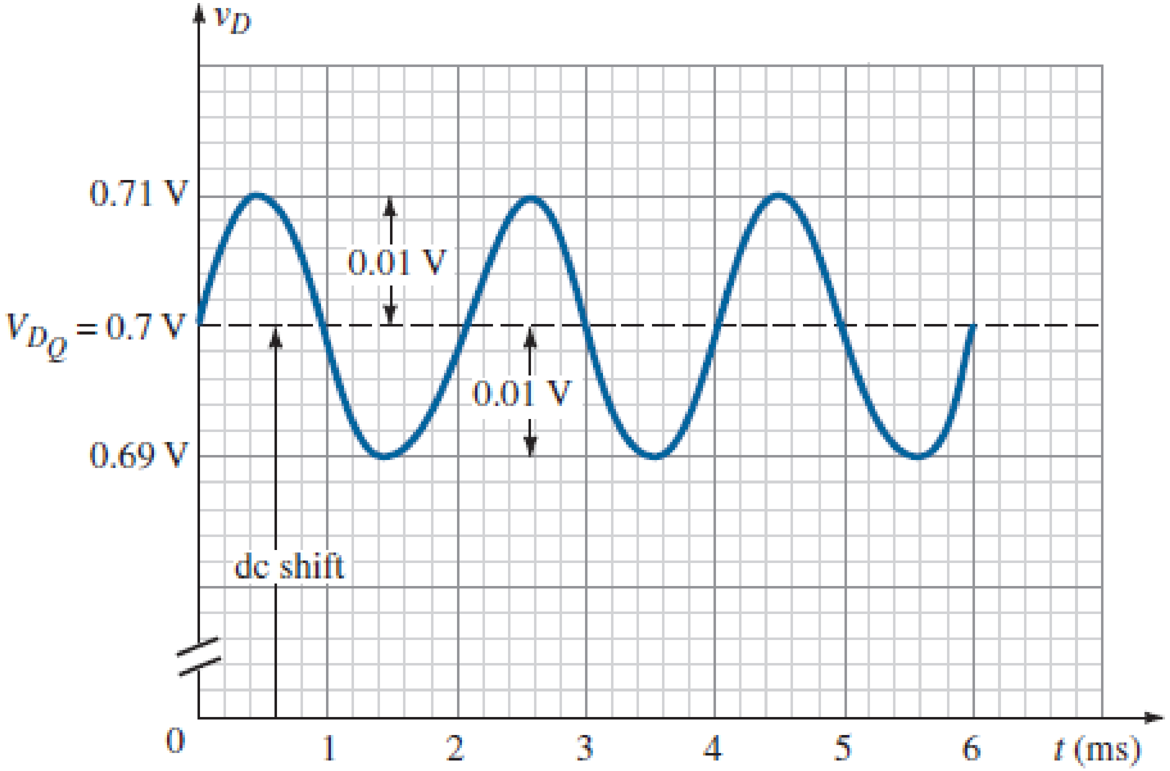


# Network with AC and DC Source




(a)



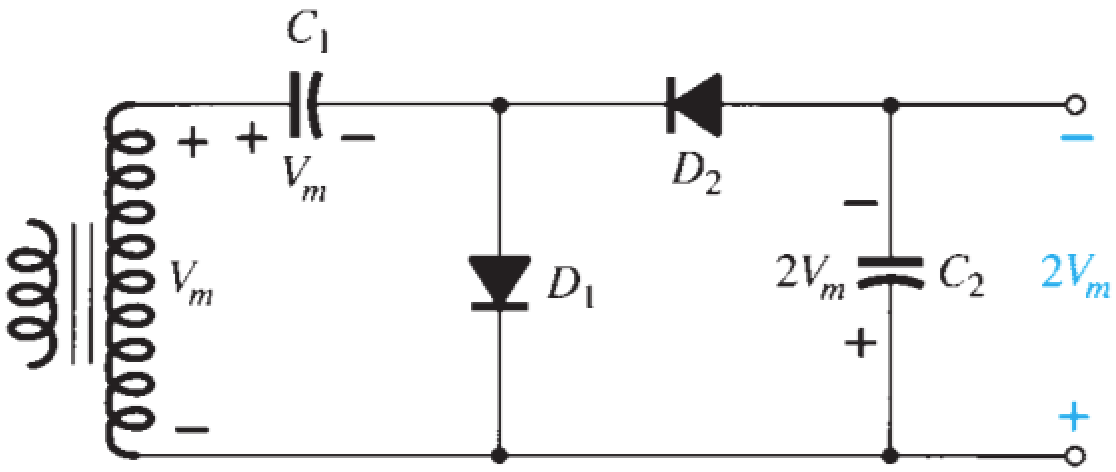

(b)

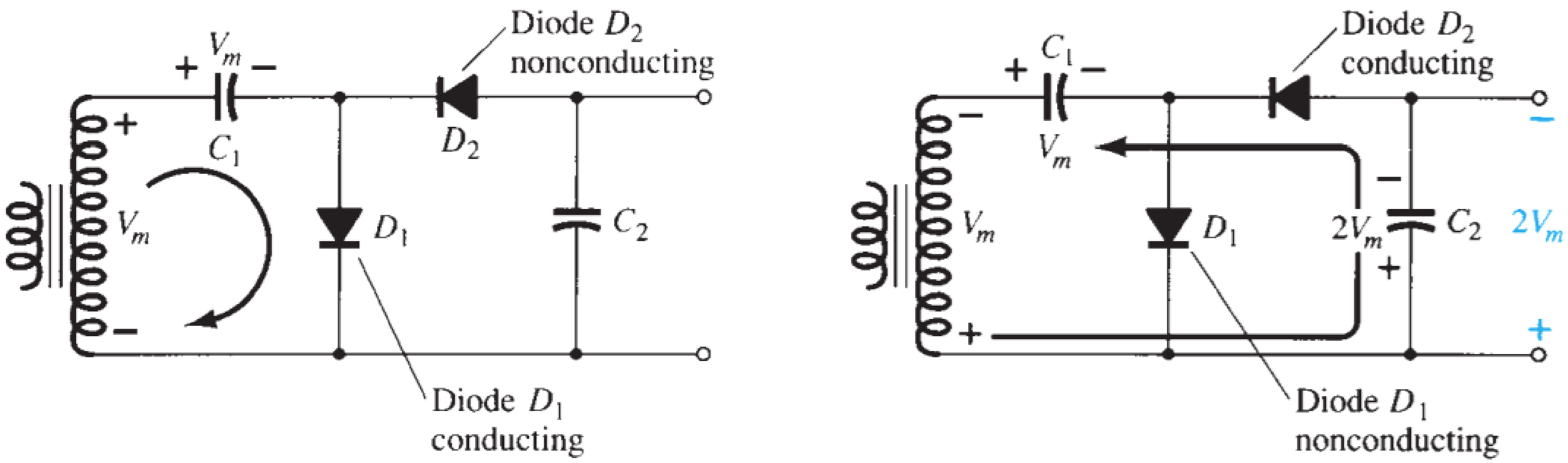
# Voltage Multipliers

# Voltage Multipliers

- Voltage-multiplier circuits are employed to **maintain a relatively low transformer peak voltage** while **stepping up the peak output voltage** to two, three, four, or more times the peak rectified voltage.
- Voltage multiplier circuits are typically made up of ***diodes*** and ***capacitors***.
- In the analysis of voltage multiplier circuits, it is assumed that the capacitors are ***not discharged significantly***, and the capacitor voltage ***does not change*** significantly while it is discharging.

# Half wave voltage doubler

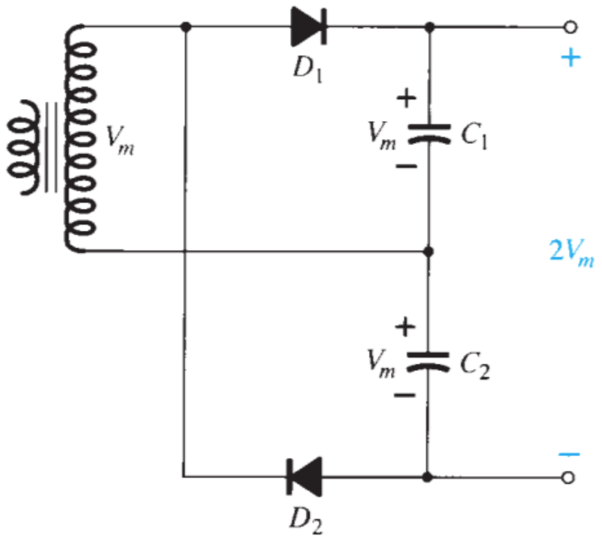


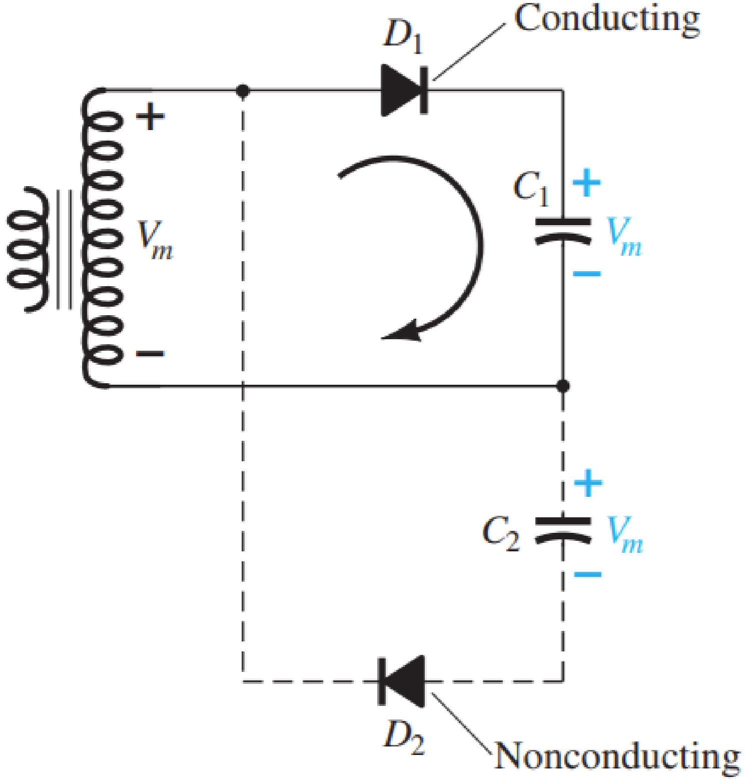




(a)

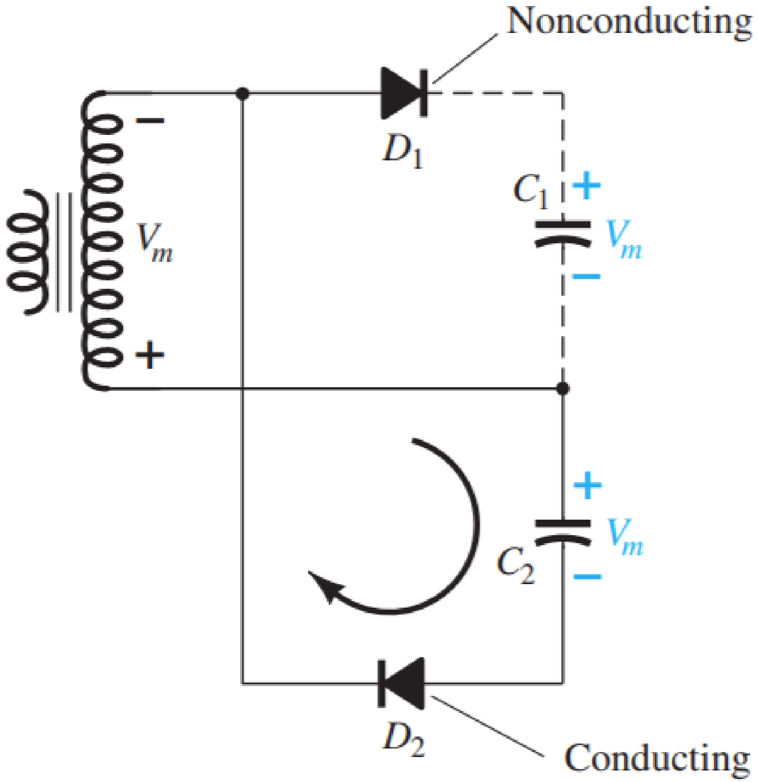
(b)

# Full wave voltage doubler



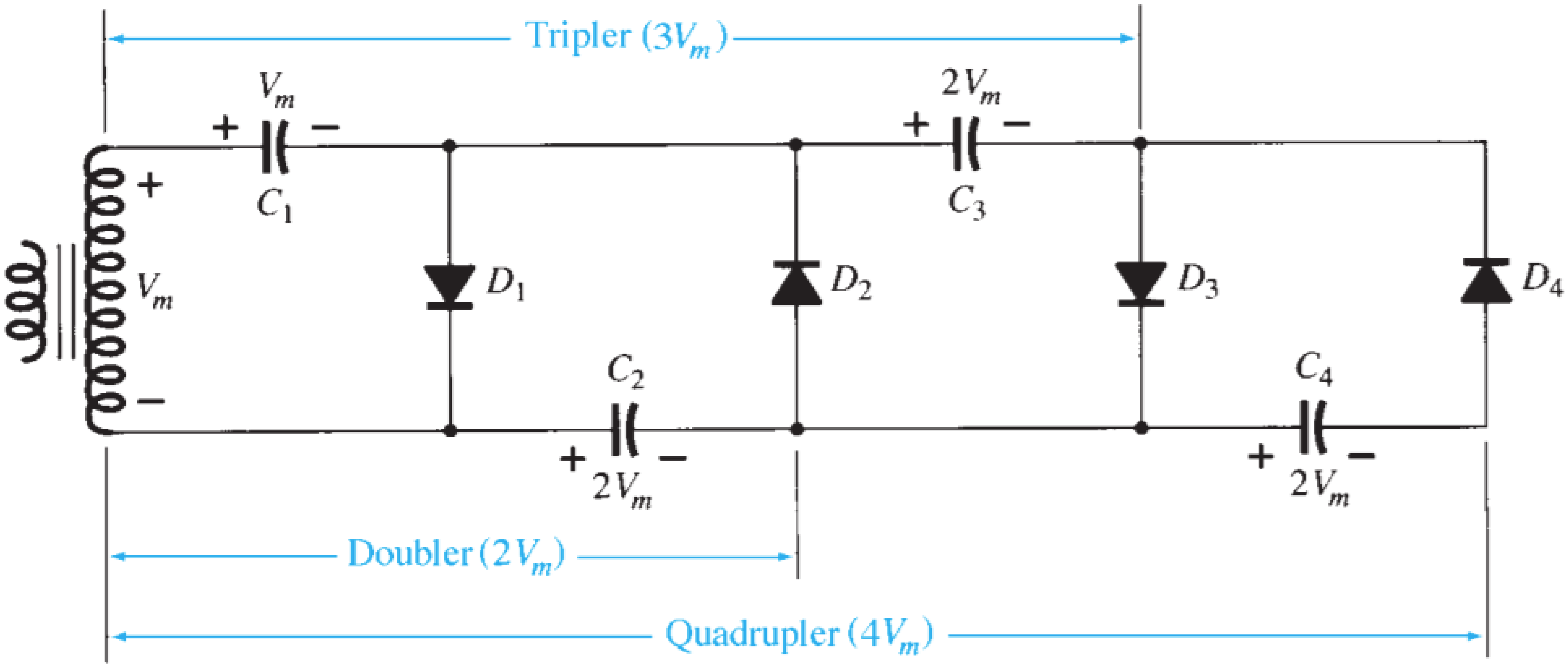




(a)




(b)

# Voltage Tripler and Quadrupler



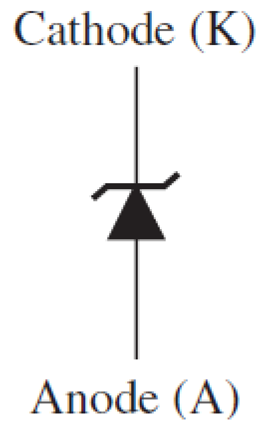
# Special Purpose Diodes

# Special Purpose Diodes

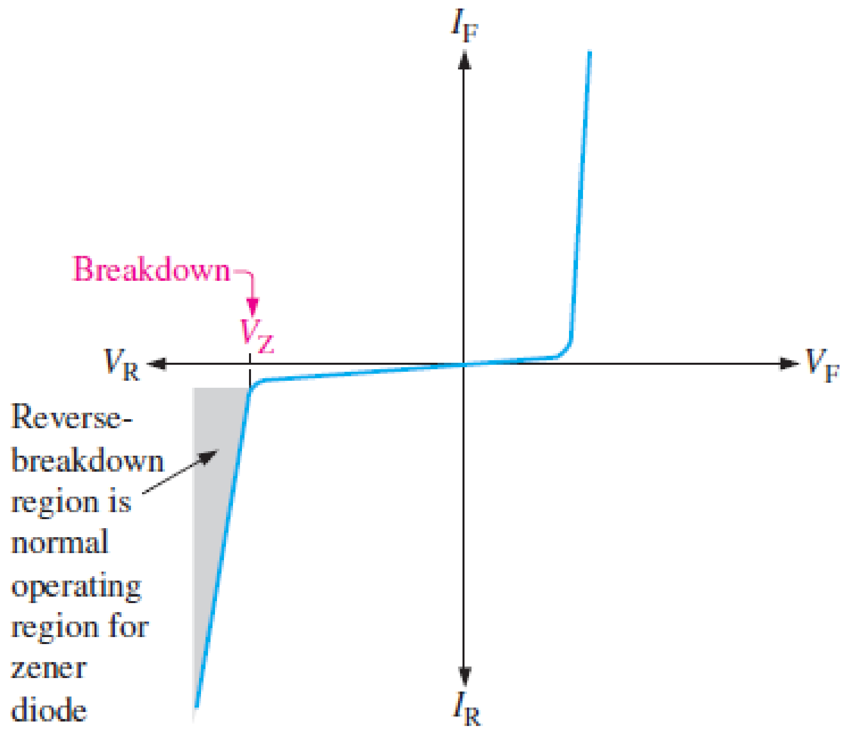
- **Zener Diodes** – Operates on **reversed biased condition**, maintain its voltage when the breakdown is reached
- **Schottky Diode (Hot carrier diode)** – used in **high frequency range** due to its **quick response time** and lower noise figure
- **Photo diode** – Light sensitive diode that **narrows the depletion region when there is a presence of light**
- **Light Emitting Diode (LED)** – **give off visible light** when it is properly biased

# Zener Diodes

- A **zener diode** is a silicon pn junction device that is designed for operation in the reverse-breakdown region.




**Zener diode symbol**

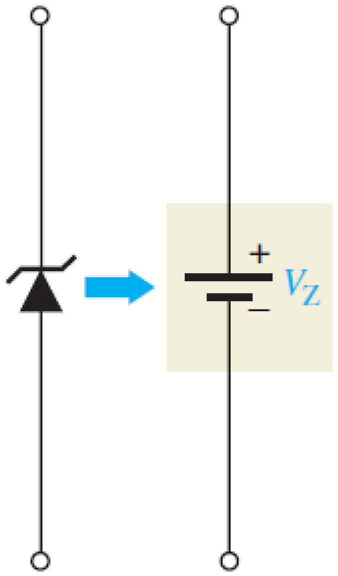



**General zener diode V-I characteristic**

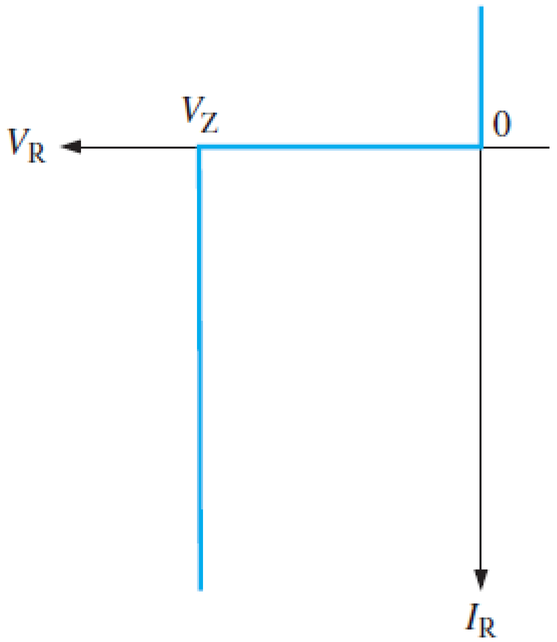
# Zener Diodes

- **Zener Regulation**: The ability to keep the reverse voltage across its terminals essentially constant is the key feature of the zener diode. A zener diode operating in breakdown can act as a low-current voltage regulator because it maintains a nearly constant voltage across its terminals over a specified range of reverse-current values.

- **Zener Equivalent Circuits**

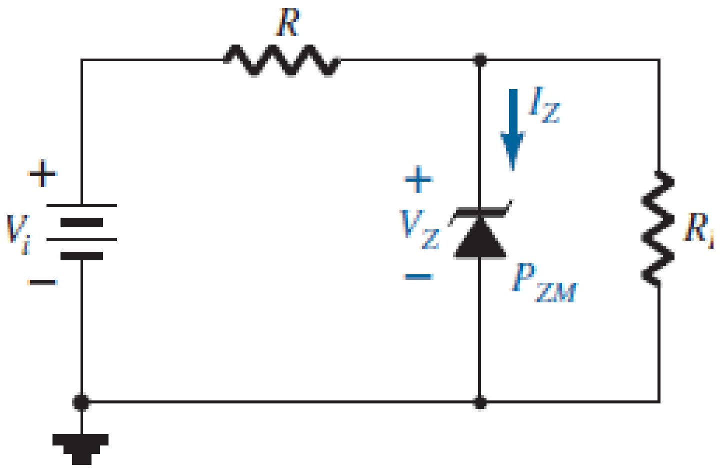



(a) Ideal model



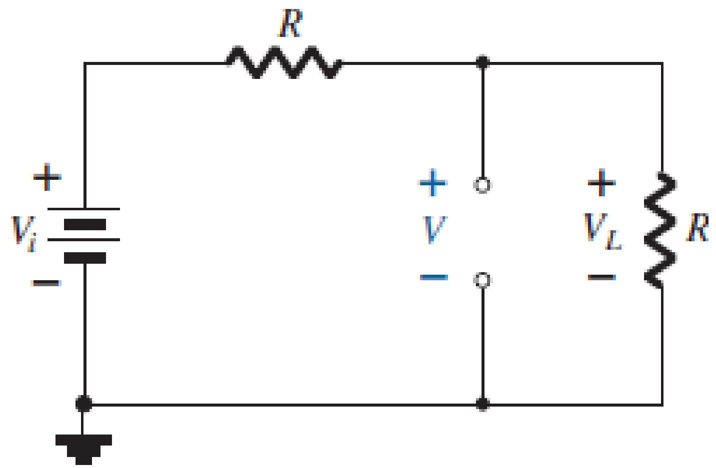

(b) Ideal characteristic curve

# Zener Diode Applications




- Vi 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.

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




  - 2. Substitute the appropriate equivalent circuit and solve for the desired unknowns. $I_R = I_Z + I_L$

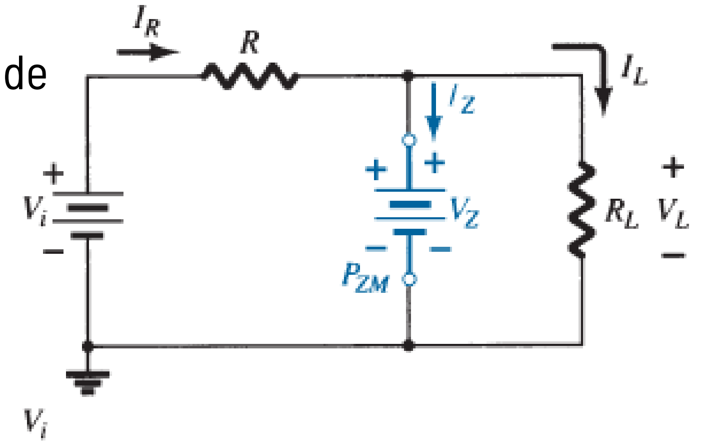
Zener Voltage = Load Voltage

$$\boxed{V_L = V_Z}$$

$$\boxed{I_Z = I_R - I_L}$$

Power dissipation of Zener Diode

$$\boxed{P_Z = V_Z I_Z}$$

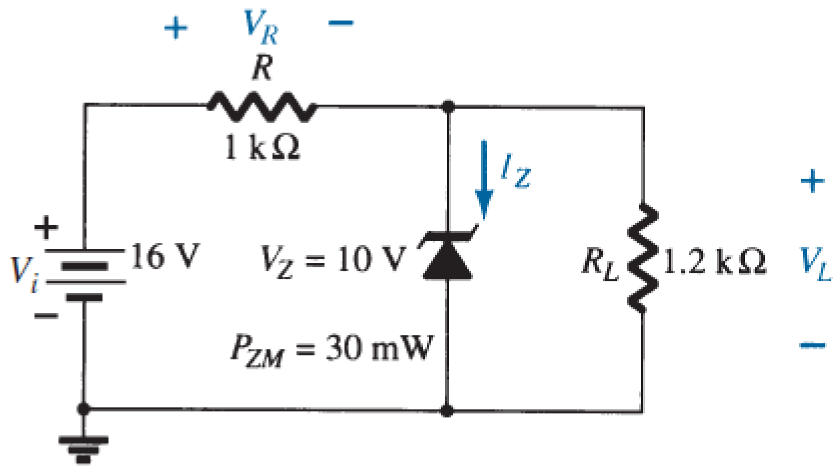



$$I_L = \frac{V_L}{R_L} \quad \text{and} \quad I_R = \frac{V_R}{R} = \frac{V_i - V_L}{R}$$

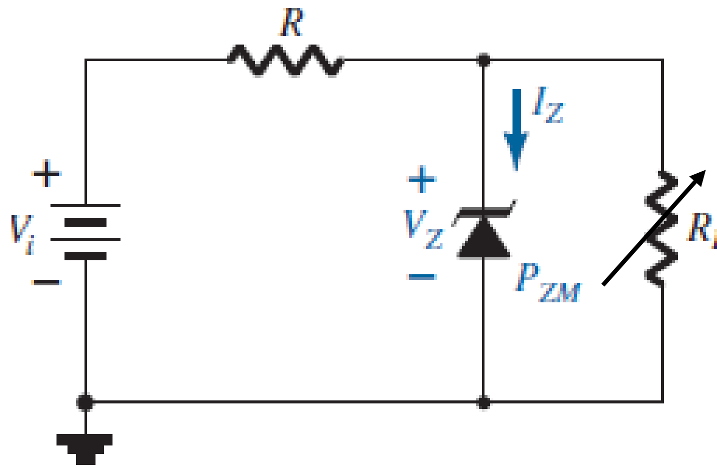
Load Resistance ($R_L$) Current

Resistance (R) Current

# Zener Diode Applications




- Example:a. For the Zener diode network, determine $V_L$, $V_R$, $I_Z$, and $P_Z$.
- b. Repeat part (a) with RL = 3 kΩ.




# Zener Diode Applications

- Fixed Vi, Variable RL
    - Due to offset voltage $V_Z$, there is a specific range of resistor values (and therefore load current) that will ensure that the Zener is in the "on" state.

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

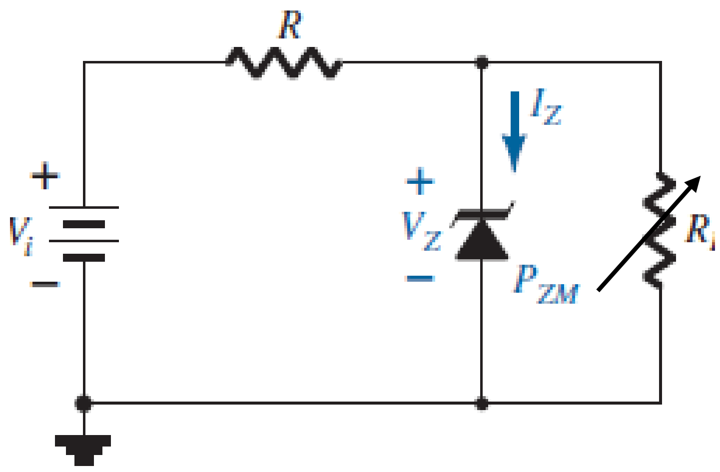
- To determine the minimum load resistance that will turn the Zener diode on, simply calculate the value of $R_L$ that will result in a load voltage $V_L = V_Z$.

Solving for minimum $R_l$, we have

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

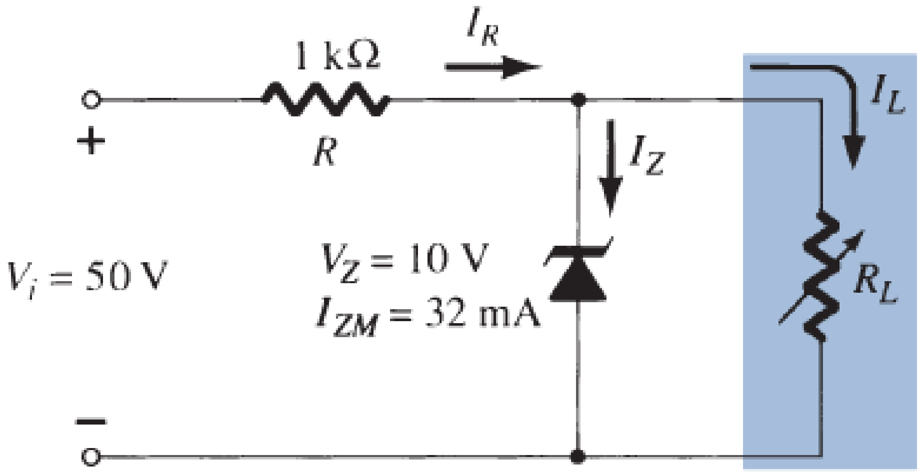
$$I_{L_{\max}} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L_{\min}}}$$

# Zener Diode Applications



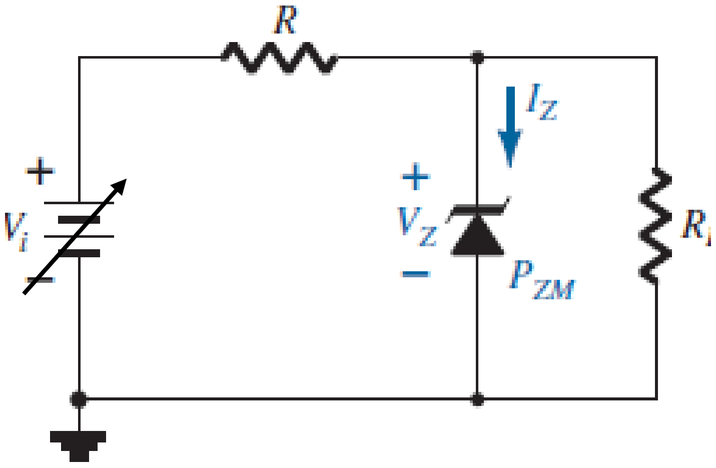

- Fixed Vi, Variable RL
  - Once the diode is in the "on" state, the voltage across R remains fixed at $V_R = V_i - V_Z$
  - and IR remains fixed at $I_R = \frac{V_R}{R}$
  - The Zener current $I_Z = I_R - I_L$ resulting in a minimum $I_Z$ when $I_L$ is a maximum and a maximum $I_Z$ when $I_L$ is a minimum value, since $I_R$ is constant.
  - Since $I_Z$ is limited to $I_{ZM}$ as provided on the data sheet, it does affect the range of $R_L$ and therefore $I_L$. Substituting $I_{ZM}$ for $I_Z$ establishes the minimum $I_L$ as $I_{L_{min}} = I_R - I_{ZM}$ and the maximum load resistance as $R_{L_{max}} = \frac{V_Z}{I_{L_{min}}}$

# Zener Diode Applications




- Example:
  - a. Determine the range of $R_L$ and $I_L$ that will result in $V_{RL}$ being maintained at 10 V.
  - b. Determine the maximum wattage rating of the diode.

# Zener Diode Applications




- Fixed $R_L$, Variable $V_i$
  - *The* voltage $V_i$ must be sufficiently large to turn the Zener diode on. The minimum turn-on voltage $V_i = V_{imin}$ is determined by

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

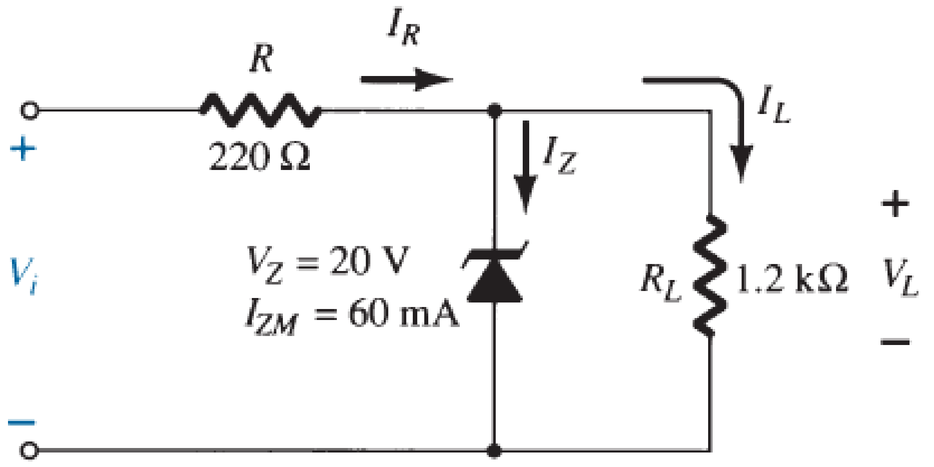
$$\boxed{V_{i_{\min}} = \frac{(R_L + R)V_Z}{R_L}}$$

  - The maximum value of Vi is limited by the maximum Zener current $I_{ZM}$. Since $I_{ZM} = I_R - I_L$, $\boxed{I_{R_{\max}} = I_{ZM} + I_L}$
  - Since $I_L$ is fixed at $V_Z/R_L$ and $I_{ZM}$ is the maximum value of $I_Z$, the maximum $V_i$ is defined by

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

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

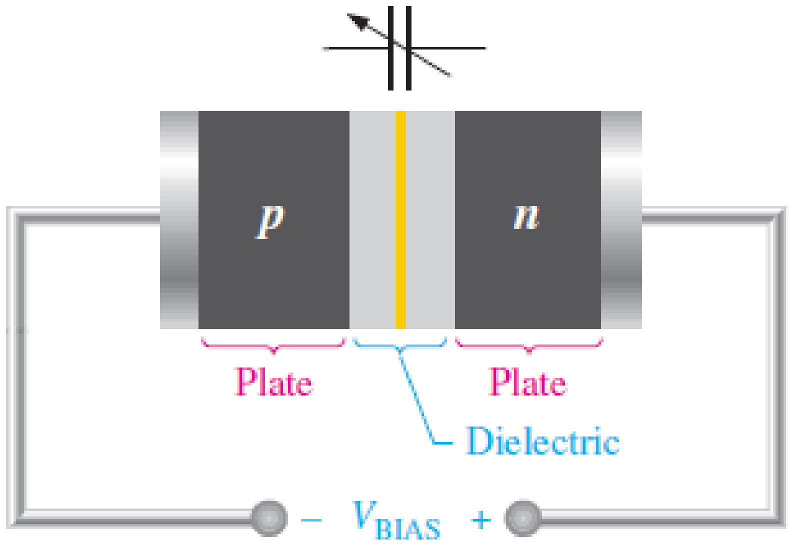
# Zener Diode Applications



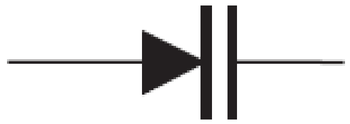

- Example: Determine the range of values of Vi that will maintain the Zener diode in the “on” state.

# Varactor Diodes

- A **varactor** is a diode that always operates in reverse bias and is doped to maximize the inherent capacitance of the depletion region. The depletion region acts as a capacitor dielectric because of its nonconductive characteristic. The p and n regions are conductive and act as the capacitor plates
- They are used in the RF design arena and provide a method of varying the capacitance within a circuit by applying control voltage.



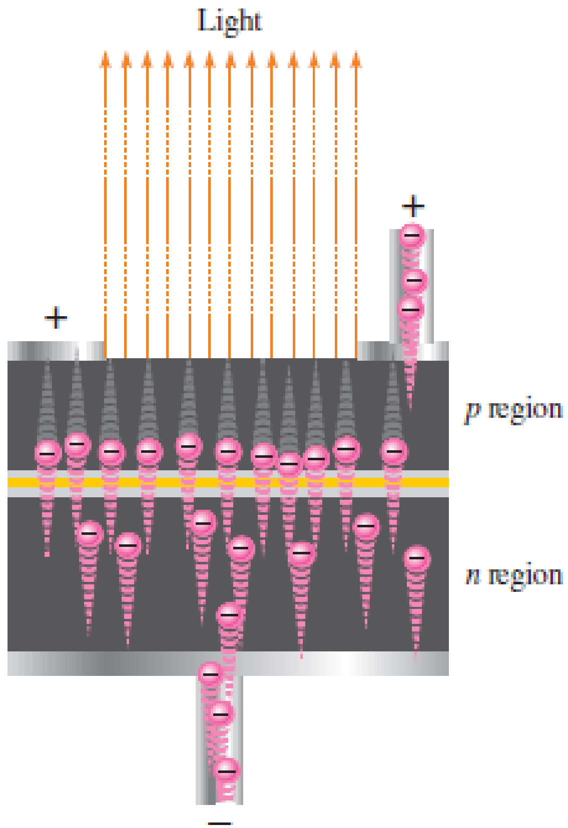

**The reverse-biased varactor diode acts as a variable capacitor.**



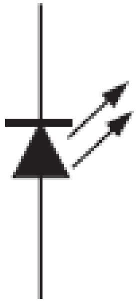
**Varactor Diode Symbol**

# Light-emitting diode

- The basic operation of the light-emitting diode (LED) is as follows. When the device is forward-biased, electrons cross the pn junction from the n-type material and recombine with holes in the p-type materials.
- A large exposed surface area on one layer of the semiconductive material permits the photons to be emitted as visible light. This process, called **electroluminescence**




**Electroluminescence in a forward-biased LED.**



**LED Symbol**

# Light-emitting diode

- LED Semiconductor Materials

| Typical LED Characteristics | | | |
|---|---|---|---|
| Semiconductor Material | Wavelength | Colour | $V_F$ @ 20mA |
| GaAs | 850-940nm | Infra-Red | 1.2v |
| GaAsP | 630-660nm | Red | 1.8v |
| GaAsP | 605-620nm | Amber | 2.0v |
| GaAsP:N | 585-595nm | Yellow | 2.2v |
| AlGaP | 550-570nm | Green | 3.5v |
| SiC | 430-505nm | Blue | 3.6v |
| GaInN | 450nm | White | 4.0v |

# Light-emitting diode

(a) Typical small LEDs for indicators

Helion 12 V overhead light with socket and module

120 V, 3.5 W screw base for low-level illumination

120 V, 1 W small screw base candelabra style

6 V, bayonet base for flashlights, etc.

(b) Typical LEDs for lighting applications

# Photodiode

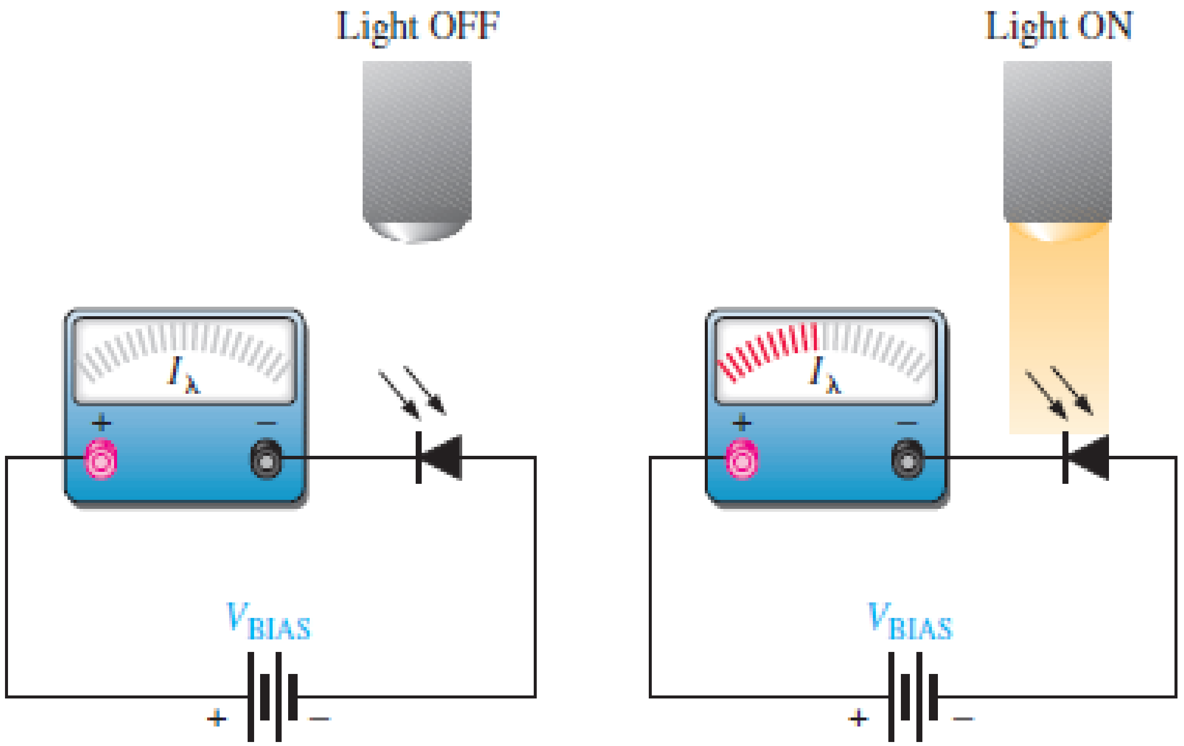
- The **photodiode** is a device that operates in reverse bias where $I_\lambda$ is the reverse light current. The photodiode has a small transparent window that allows light to strike the pn junction.


(a) Reverse-bias operation using standard symbol

(b) Typical devices

(c) Alternate symbol

# Photodiode

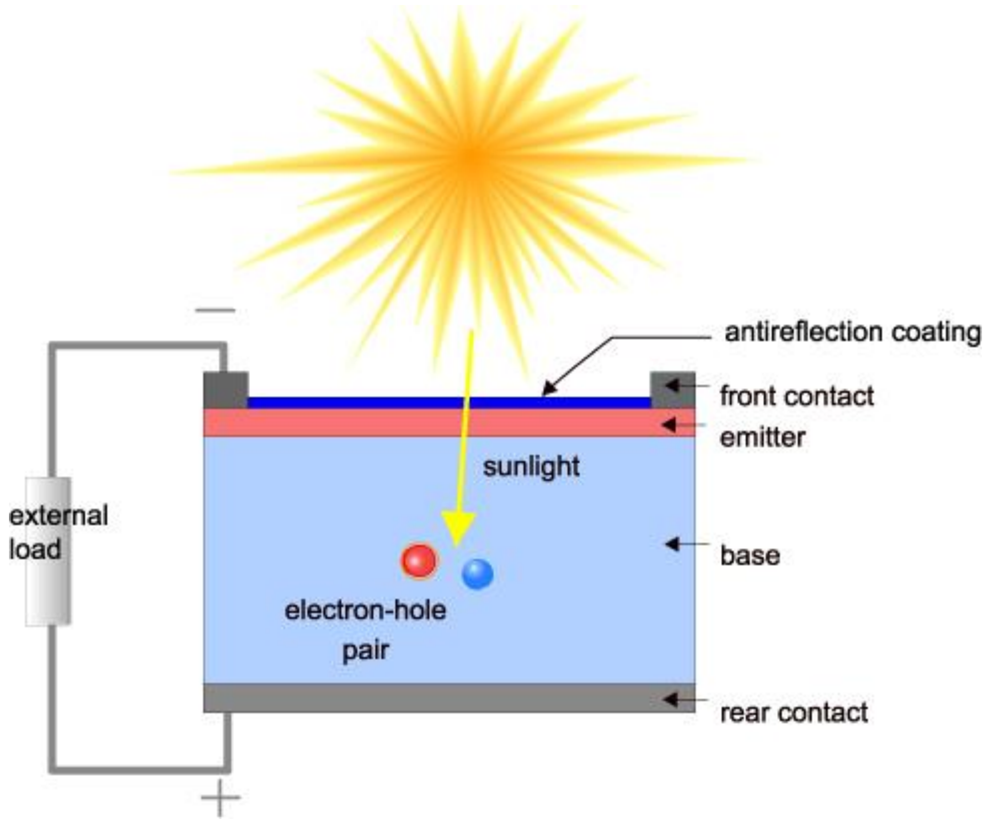



(a) No light, no current except negligible dark current

(b) Where there is incident light, resistance decreases and there is reverse current.

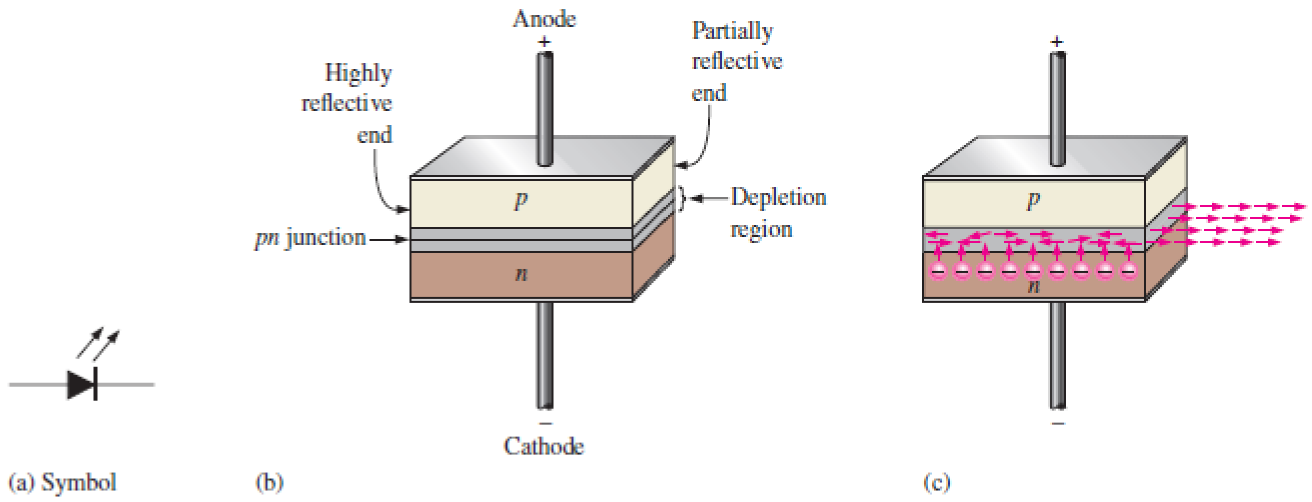
# The Solar Cell

- A solar cell, also known as a photovoltaic cell, is a type of semiconductor device that converts light into electrical energy. The basic structure of a solar cell consists of a p-n junction, which is created by doping a semiconductor material, such as silicon, with impurities to create a layer of positive charge (p-type) and a layer of negative charge (n-type). When light shines on the p-n junction, it excites electrons in the semiconductor, allowing them to flow from the n-type layer to the p-type layer, generating a current and creating a voltage across the junction.

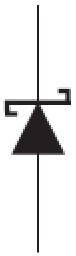


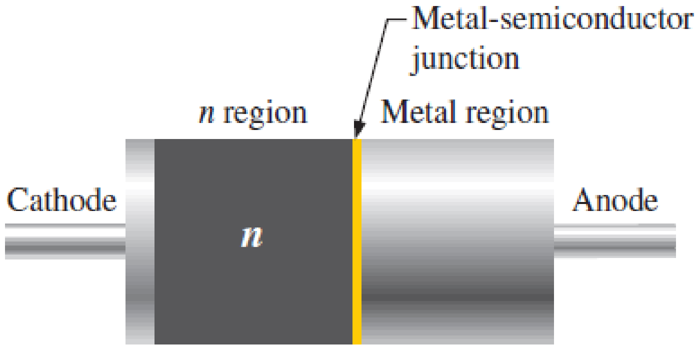
# LASER Diode

- The term ***laser*** stands for light amplification by stimulated emission of radiation. Laser light is monochromatic, which means that it consists of a single color and not a mixture of colors. Laser light is also called coherent light, a single wavelength, as compared to incoherent light, which consists of a wide band of wavelengths. The laser diode normally emits coherent light, whereas the LED emits incoherent light.



# The Schottky Diode

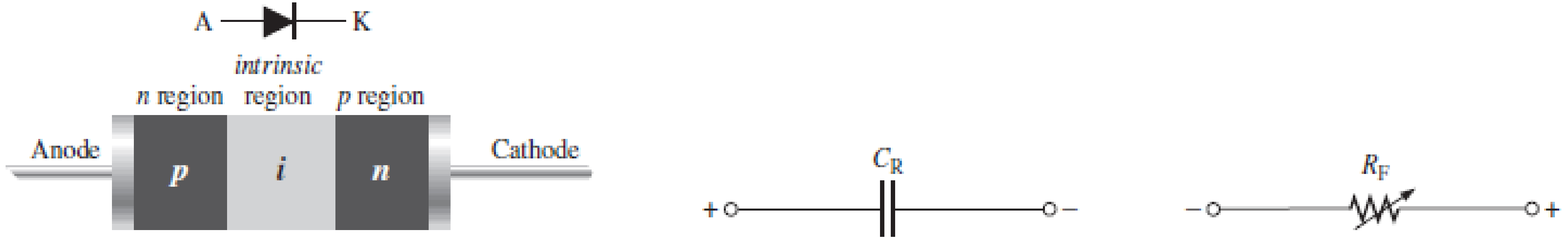





- Schottky diodes are high-current diodes used primarily in high-frequency and fast-switching applications. They are also known as hot-carrier diodes. The term hot-carrier is derived from the higher energy level of electrons in the n region compared to those in the metal region.
- A Schottky diode is formed by joining a doped semiconductor region (usually n-type) with a metal such as gold, silver, or platinum. Rather than a pn junction, there is a metal-to-semiconductor junction. The forward voltage drop is typically around 0.3 V because there is no depletion region as in a pn junction diode.
- The Schottky is a fast-switching diode, and most of its applications make use of this property. It can be used in high-frequency applications and in many digital circuits to decrease switching times

# The PIN Diode

- The PIN diode consists of heavily doped p and n regions separated by an intrinsic (i) region. When reverse-biased, the pin diode acts like a nearly constant capacitance. When forward-biased, it acts like a current-controlled variable resistance. The low forward resistance of the intrinsic region decreases with increasing current. The pin diode is used as a dc-controlled microwave switch operated by rapid changes in bias or as a modulating device that takes advantage of the variable forward-resistance characteristic




(a) Construction (b) Reverse-biased (c) Forward-biased

# Conclusions and Concepts

- The **characteristics of a diode** are **unaltered** by the network in which it is employed.
- The network simply determines the point of operation of the device.
- The operating point of a network is determined by **the intersection of the network equation** and an **equation** defining the **characteristics** of the device.
- For **most applications**, the characteristics of a diode can be defined simply by the **threshold voltage** in the forward-bias region and an **open circuit for applied voltages less than the threshold value**.
- To determine the state of a diode, simply think of it **initially as a resistor**, and **find the polarity of the voltage across it** and the **direction of conventional current** through it. If the **voltage across it has a forward-bias polarity** and the current has a direction that **matches the arrow** in the symbol , the **diode is conducting**.

# Conclusions and Concepts

- To determine the state of diodes used in a logic gate, first **make an educated guess** about the **state of the diodes,** and then test your assumptions . If your estimate is incorrect, refine your guess and try again until the analysis verifies the conclusions.
- **Rectification** is a process whereby an applied waveform of **zero average value** is changed to **one that has a dc level** . For applied signals of **more than a few volts**, the **ideal diode** approximations can normally be applied.
- It is very important that the **PIV rating** of a diode **be checked** when **choosing a diode** for a particular application. Simply **determine the maximum voltage across the diode** under **reverse-bias conditions** , and compare it to the nameplate rating.
    - For the **typical halfwave** and **full-wave bridge** rectifiers, it is the **peak value of the applied signal**. For the **CT (center tapped) transformer full-wave rectifier**, it is **twice the peak value** (which can get quite high).
- **Clippers** are networks that " clip " away part of the applied signal either **to create a specific type of signal** or to **limit the voltage** that can be applied to a network.
- **Clampers** are networks that " clamp " the input signal **to a different dc level**. In any event, the **peak-to-peak swing** of the applied signal **will remain the same**.

# End