# Applied Electronics

**Instructor:**

**Dr. Ahmad El-Banna**

DAY#1
SUMMER 2016

# Agenda

- Course Instructor
- Course References
- Course Contents
- Diodes and Its applications

# Course Instructor

- **Dr. Ahmad EL-Banna**
  - B.Sc. in Telecommunications and Electronics, Fac. of Eng. at Shoubra, Benha Univ. 2005.
  - 9-month Diploma in Embedded Systems, ITI, 2008.
  - M.Sc. in Telecommunications and Electronics, Fac. of Eng. at Shoubra, Benha Univ. 2011.
  - PhD. in Telecommunications and Electronics, E_JUST Univ., 2014.
  - Visiting Researcher , Wireless Communications Lab, Osaka University, 2013-2014.
  - Find more at
    - www.bu.edu.eg/staff/ahmad.elbanna

# Your turn !

- About You
  - Graduation
    - Year
    - Univ

# Course Contents

- Diodes
- Transistors
- Amplifiers
- Oscillators
- OP-Amp Applications.

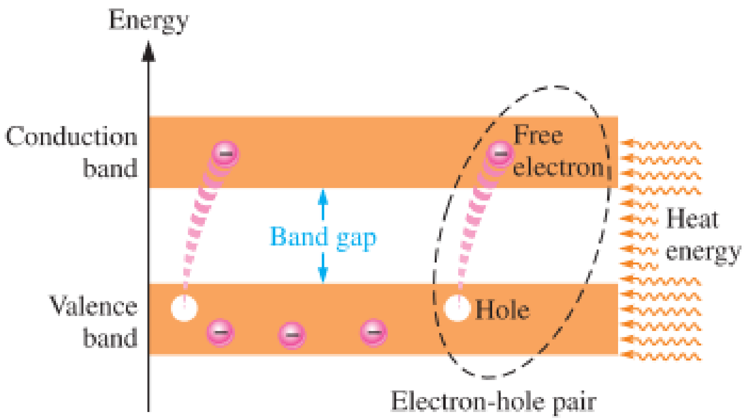
# Course References

- T. Floyd, **Electronic devices** - Conventional Current Version, 9th edition, Prentice Hall, 2012.
- Boylestad, **Electronic devices and circuit theory**, 11th edition.

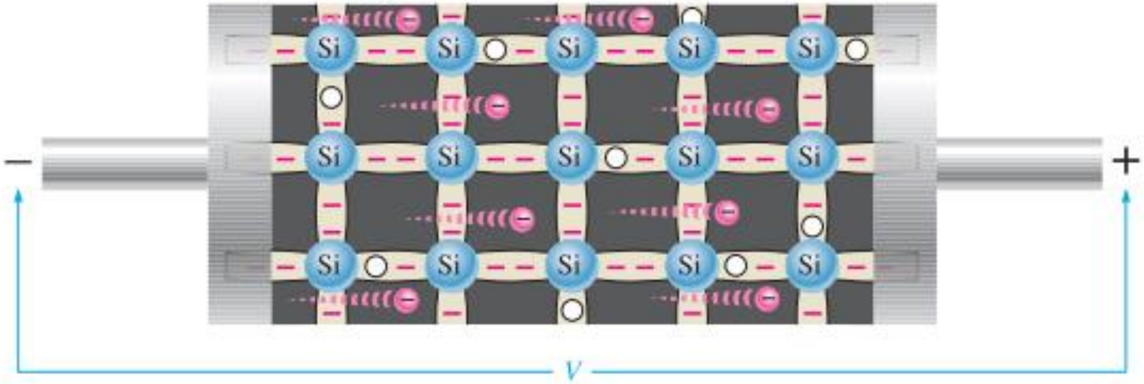
# SEMICONDUCTORS

# CURRENT IN SEMICONDUCTORS

- Creation of electron-hole pairs in a silicon crystal.
- Electrons in the conduction band are free electrons.

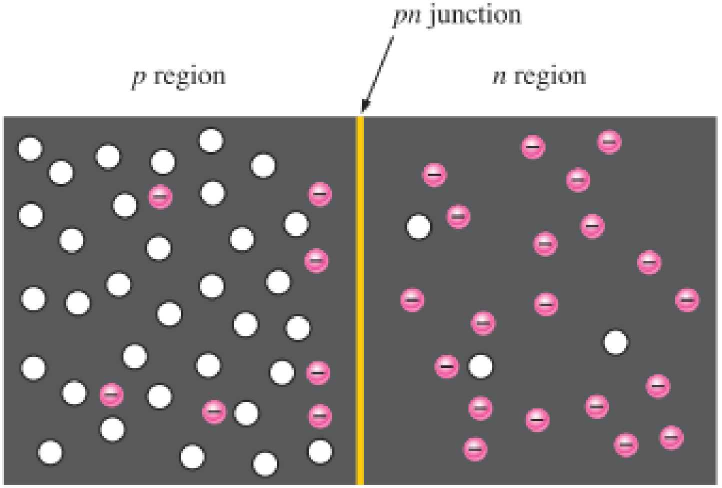


- Electron current in intrinsic silicon is produced by the movement of thermally generated free electrons.

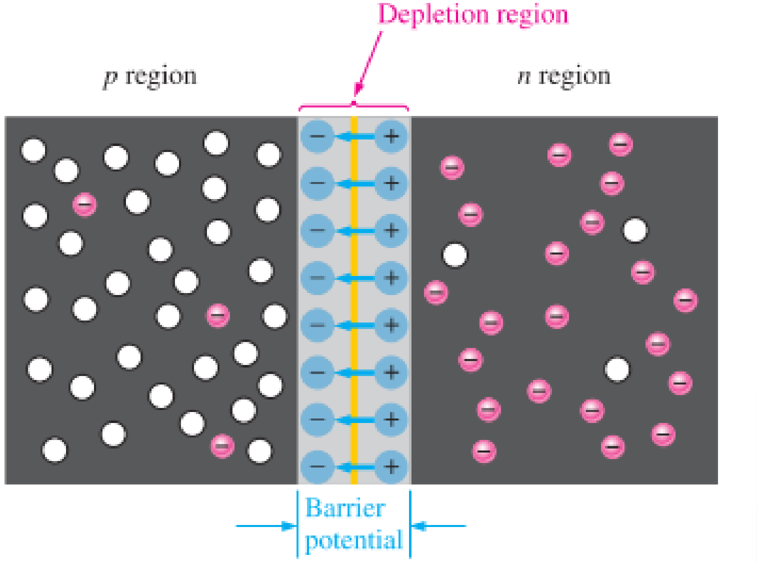


# PN Junction

- N-Type Semiconductor
  - The electrons are the majority carriers and the holes are the minority. This is done by doping process.
- P-Type Semiconductor
  - The holes are the majority carriers and the electrons are the minority.



- The basic silicon structure at the instant of junction formation showing only the majority and minority carriers.

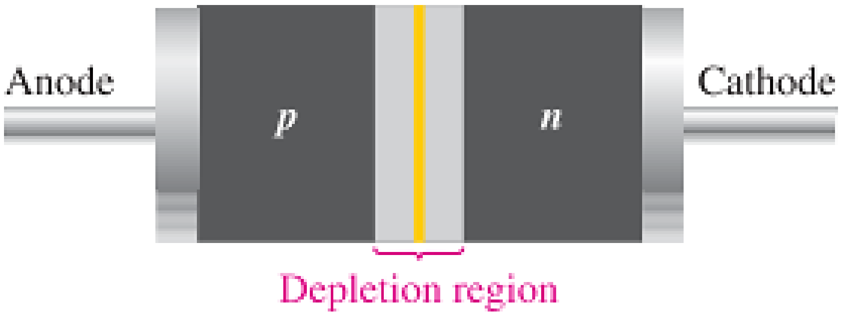


- electrons diffuse and a depletion region is formulated.

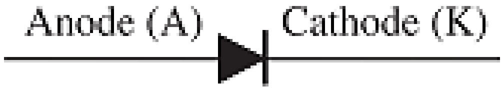
# DIODE BASICS

# Diodes

- A diode is made from a small piece of semiconductor material, usually silicon, in which half is doped as a ***p*** region and half is doped as an ***n*** region with a ***pn*** junction and depletion region in between.

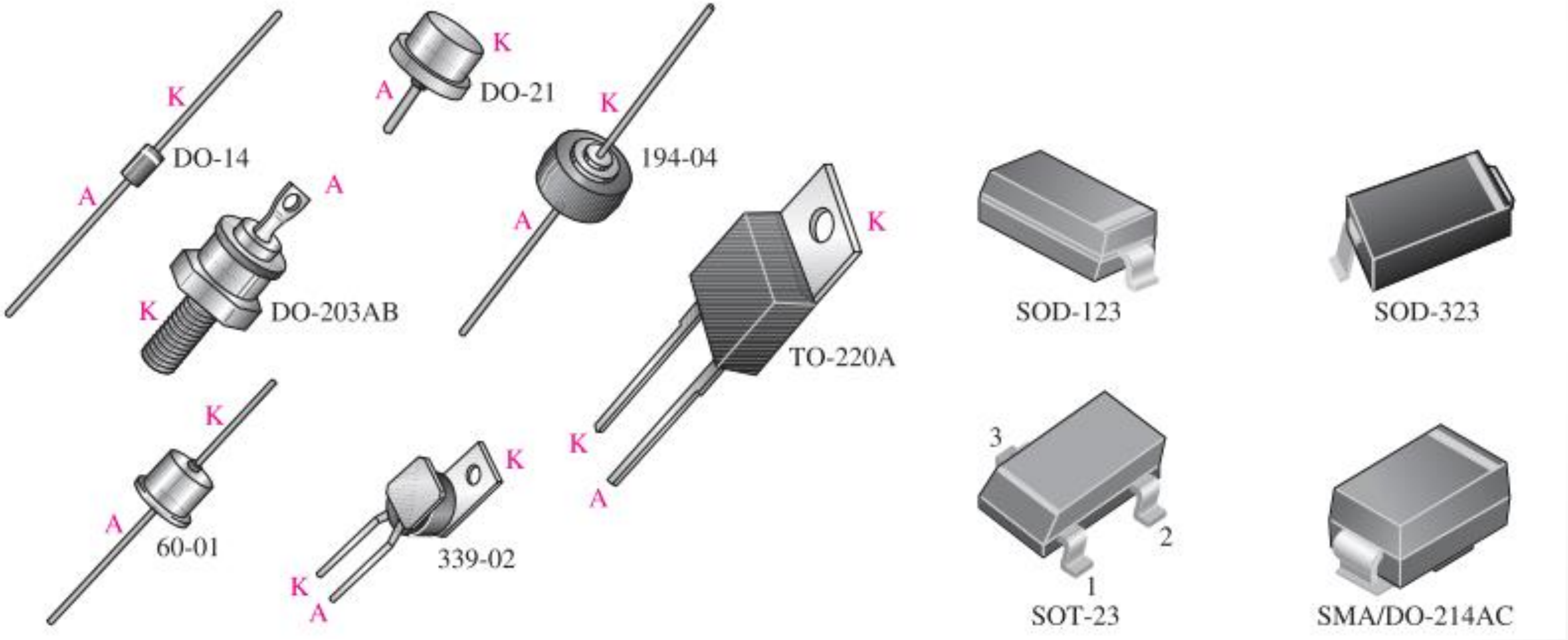


Basic structure



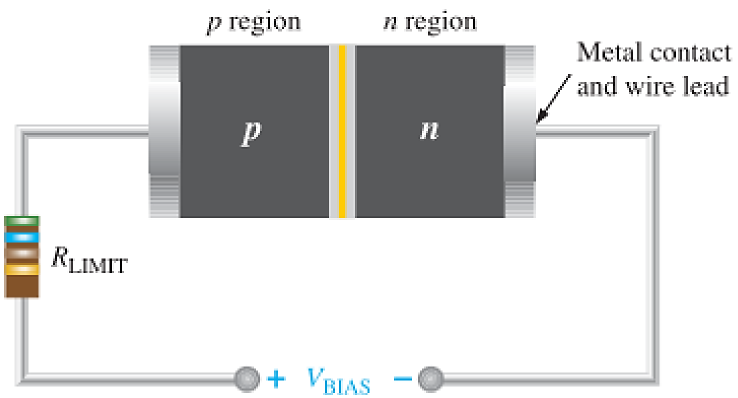
Symbol

# Diode Packages

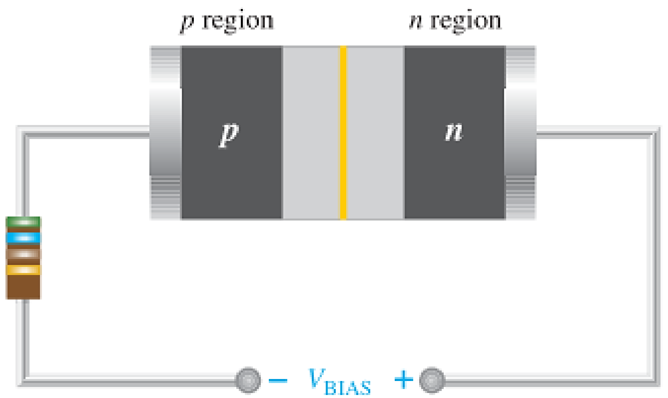


# Forward & Reverse Bias

- To **bias** a diode, you apply a dc voltage across it.
- **Forward bias** is the condition that **allows current** through the pn junction.
- **Reverse bias** is the condition that essentially **prevents current** through the diode.



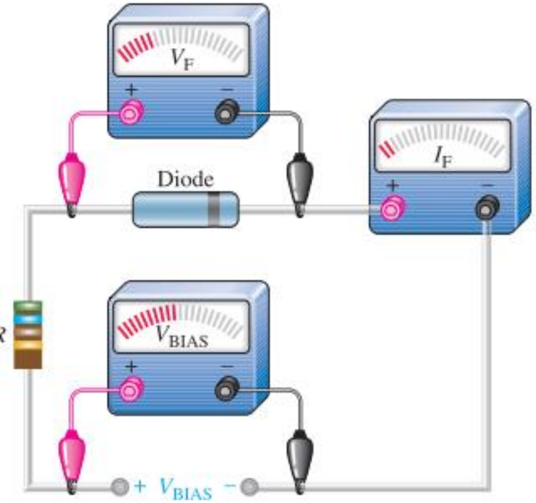
Forward bias



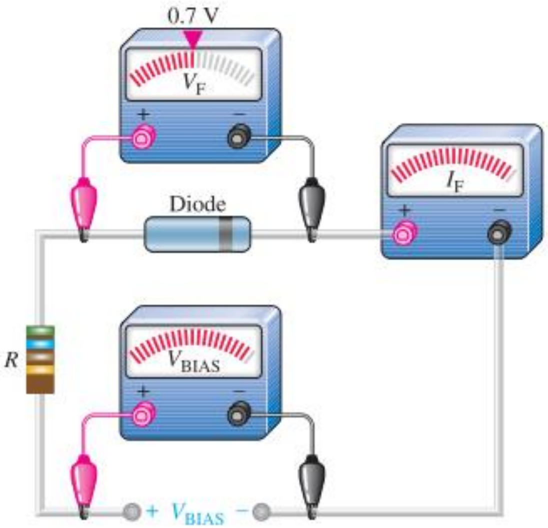
Reverse bias

# VOLTAGE-CURRENT CHARACTERISTIC OF A DIODE

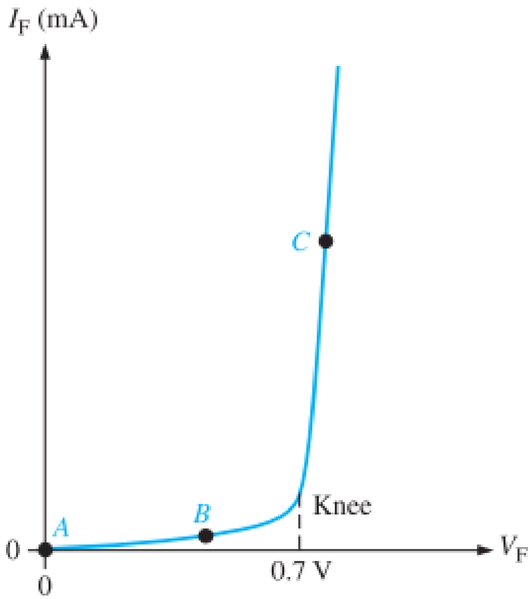
- **V-I Characteristic for Forward Bias**



(a) Small forward-bias voltage ($V_F < 0.7$ V), very small forward current.

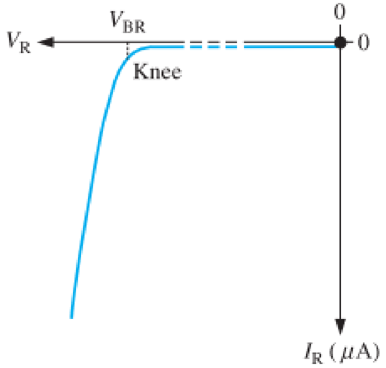


(b) Forward voltage reaches and remains nearly constant at approximately 0.7 V. Forward current continues to increase as the bias voltage is increased.

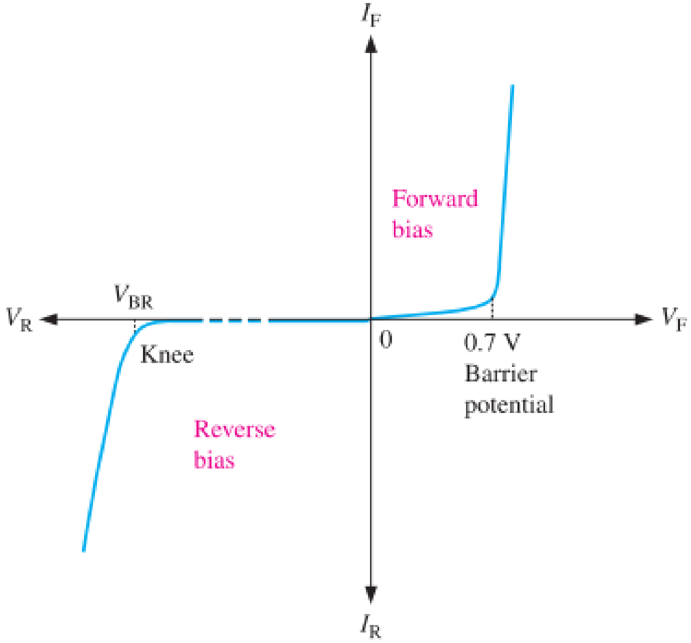


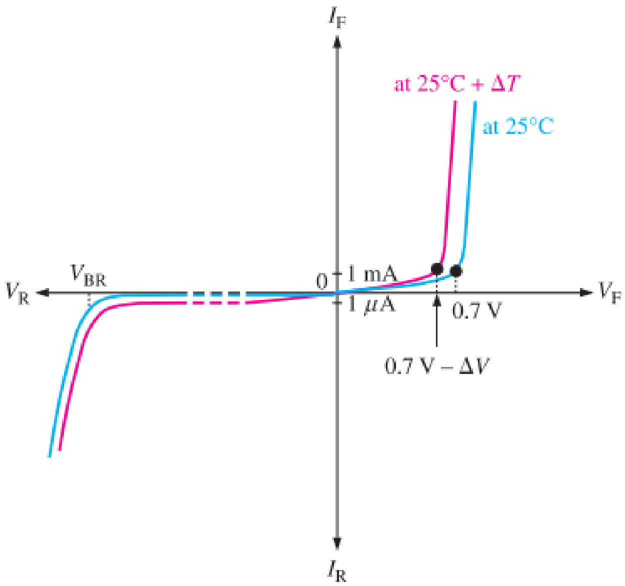
# V-I CHARACTERISTIC OF A DIODE ..

- **V-I Characteristic for Reverse Bias**



- **Complete V-I Characteristic**

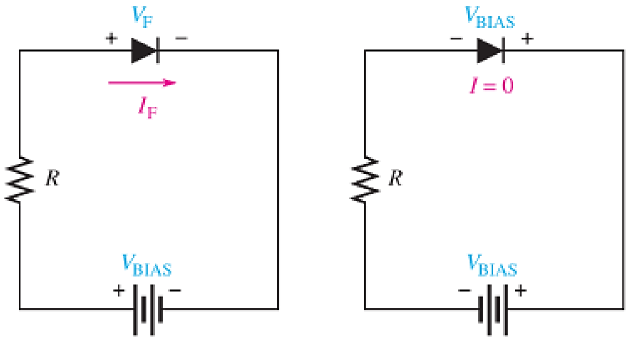




Temperature Effect

# DIODE MODELS

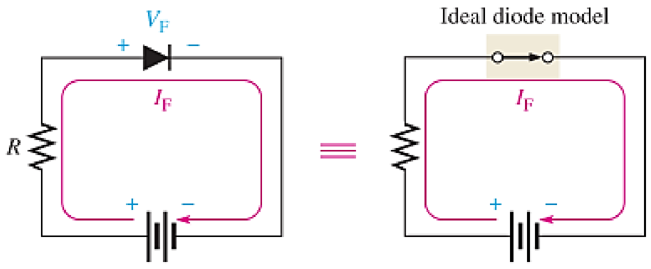
- **Bias Connections**



(a) Forward bias (b) Reverse bias

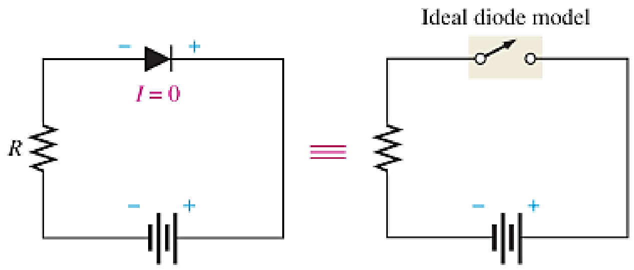
## 1. The Ideal Diode Model

$$V_F = 0\text{ V} \qquad I_F = \frac{V_{BIAS}}{R_{LIMIT}}$$

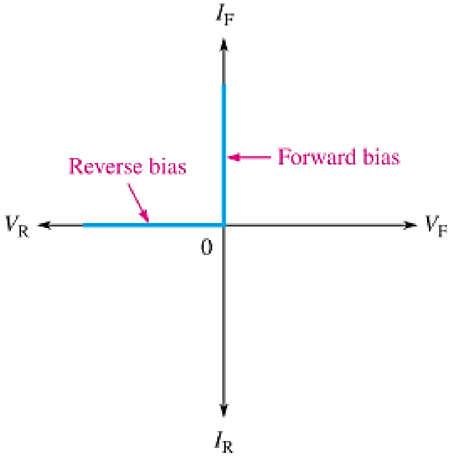


(a) Forward bias

$$I_R = 0\text{ A} \qquad V_R = V_{BIAS}$$



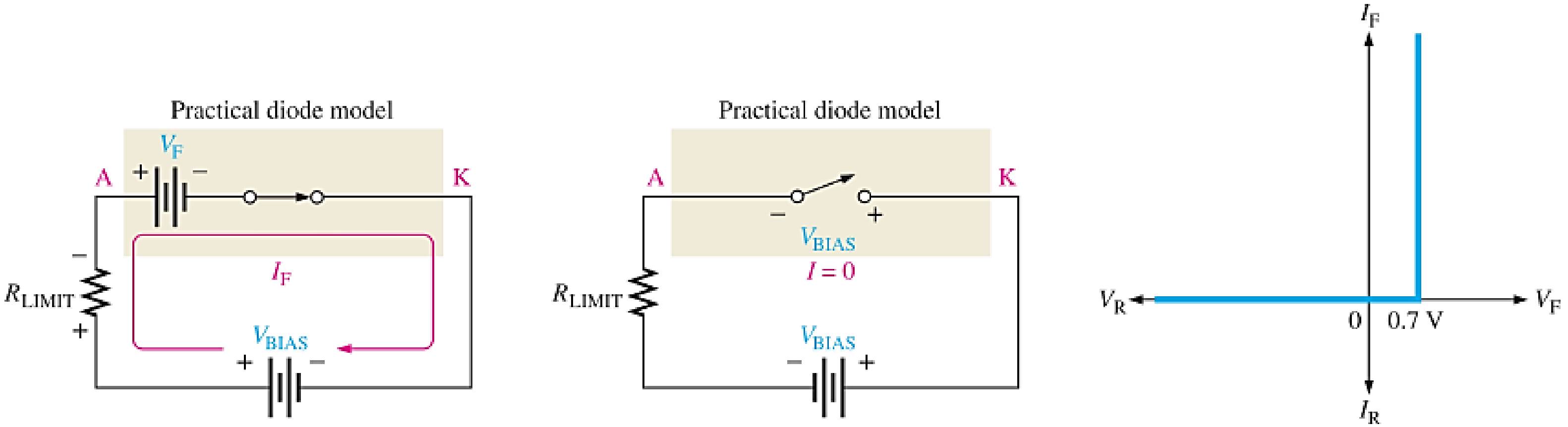
(b) Reverse bias



(c) Ideal *V-I* characteristic curve (blue)

# DIODE MODELS..

**2. The Practical Diode Model**



(a) Forward bias (b) Reverse bias (c) Characteristic curve (silicon)

$$\boxed{V_F = 0.7\text{ V}}$$

$$V_{BIAS} - V_F - V_{R_{LIMIT}} = 0$$

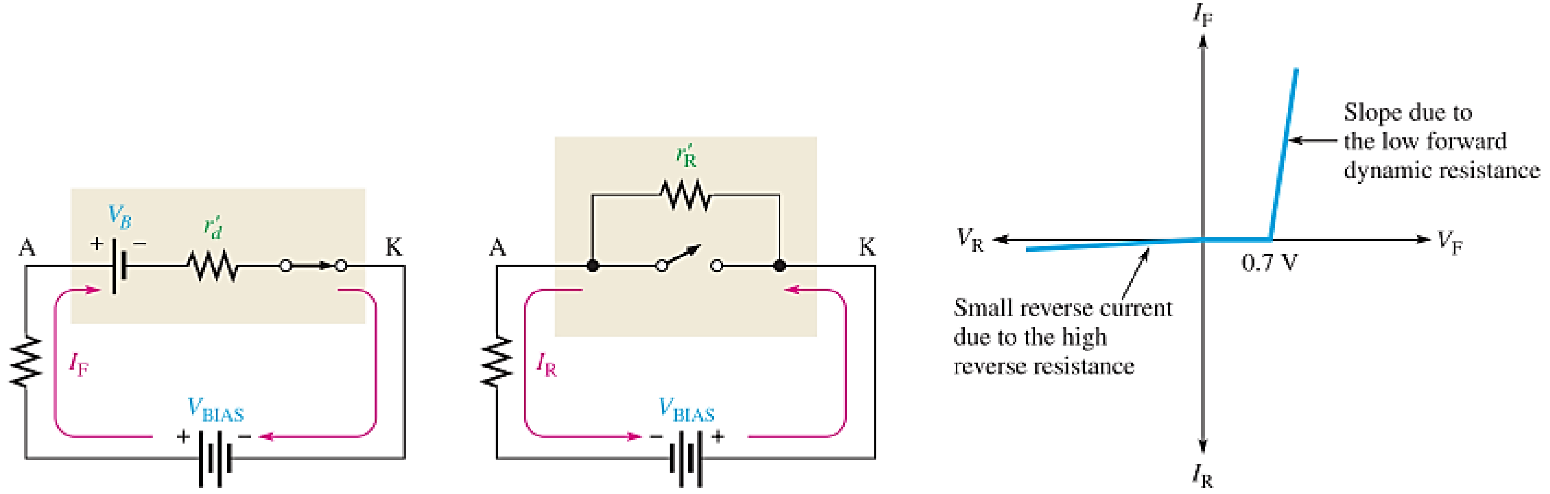
$$V_{R_{LIMIT}} = I_F R_{LIMIT}$$

$$\boxed{I_F = \frac{V_{BIAS} - V_F}{R_{LIMIT}}}$$

$$\boxed{\begin{aligned} I_R &= 0\text{ A} \\ V_R &= V_{BIAS} \end{aligned}}$$

# DIODE MODELS..

## 3. The Complete Diode Model



(a) Forward bias

(b) Reverse bias

(c) V-I characteristic curve

$$V_F = 0.7\text{ V} + I_F r'_d$$

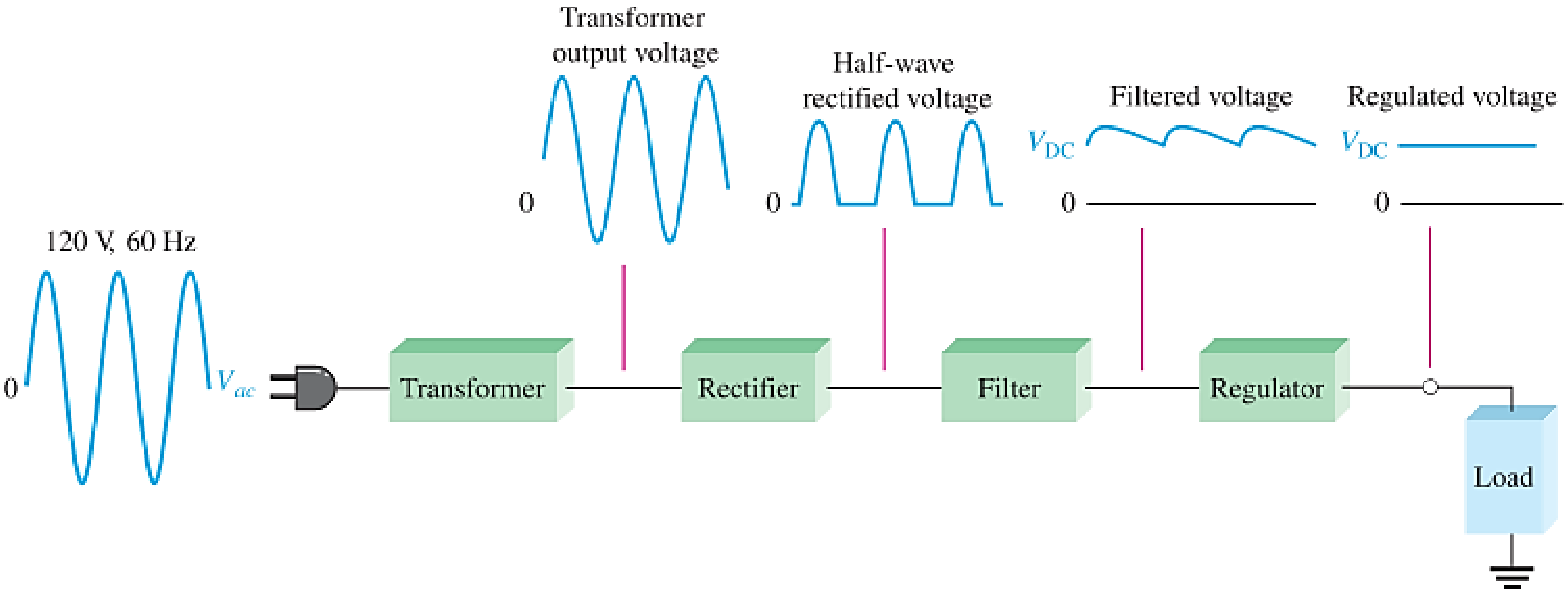
$$I_F = \frac{V_{BIAS} - 0.7\text{ V}}{R_{LIMIT} + r'_d}$$

$I_R$ : Reverse (leakage) current → diode datasheet

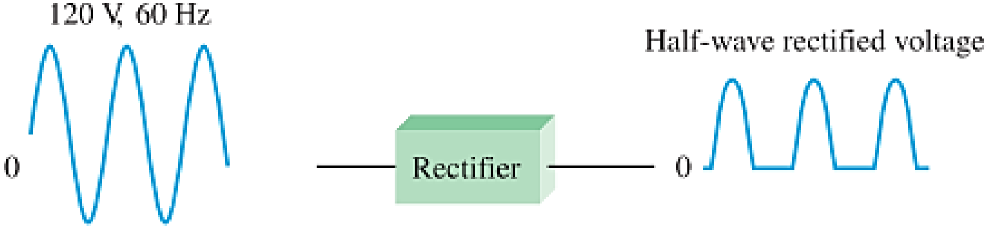
$V_R = I_R r'_R$

# DIODE APPLICATIONS

# Rectifiers
# Half-wave Rectifiers

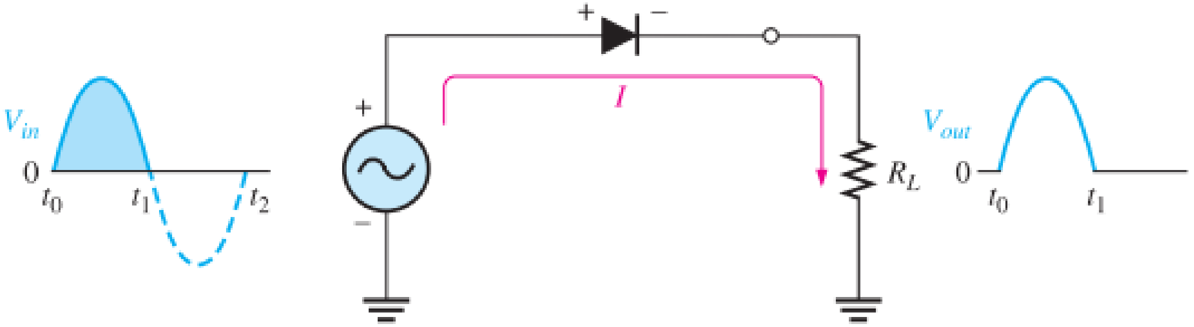


(a) Complete power supply with transformer, rectifier, filter, and regulator

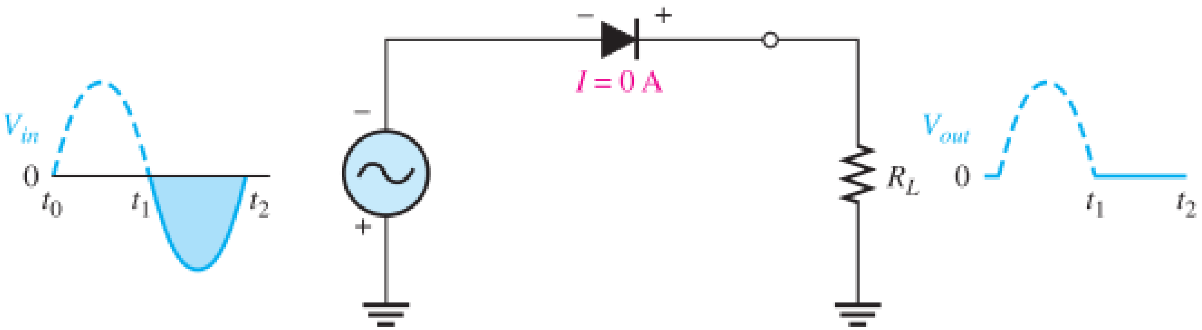


(b) Half-wave rectifier

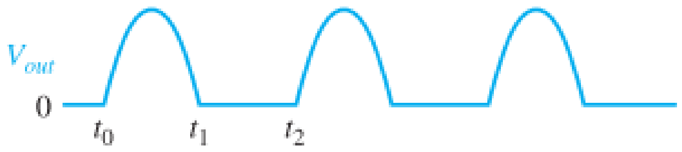
# Half-wave Rectifier Operation



(a) During the positive alternation of the 60 Hz input voltage, the output voltage looks like the positive half of the input voltage. The current path is through ground back to the source.



(b) During the negative alternation of the input voltage, the current is 0, so the output voltage is also 0.

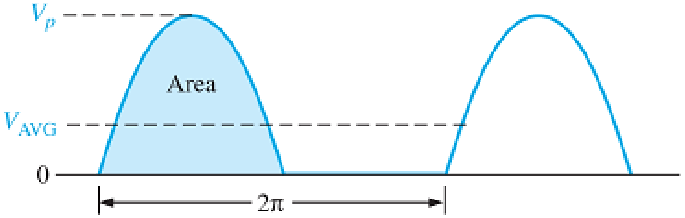


(c) 60 Hz half-wave output voltage for three input cycles

# Average Voltage & PIV

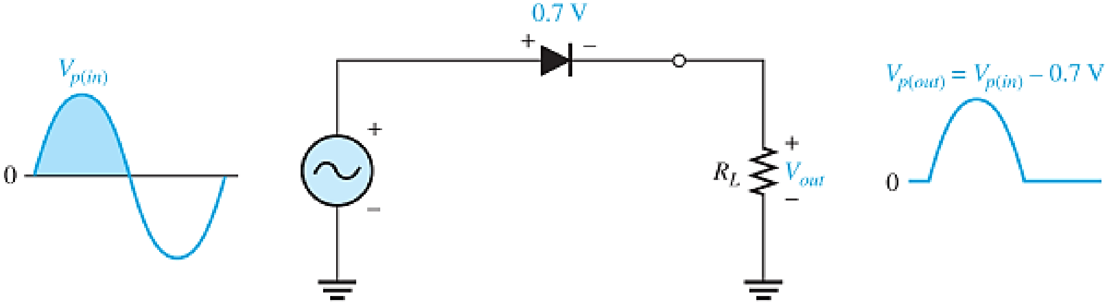
- Average Value of the Half-Wave Output Voltage

$$\boxed{V_{\mathrm{AVG}} = \frac{V_p}{\pi}}$$



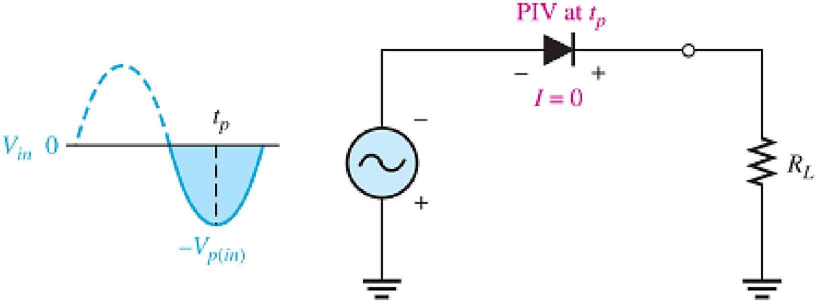
- Effect of the Barrier Potential

$$\boxed{V_{p(out)} = V_{p(in)} - 0.7\ \mathrm{V}}$$



- The peak inverse voltage (**PIV**) equals the peak value of the input voltage

$$\boxed{\mathrm{PIV} = V_{p(in)}}$$

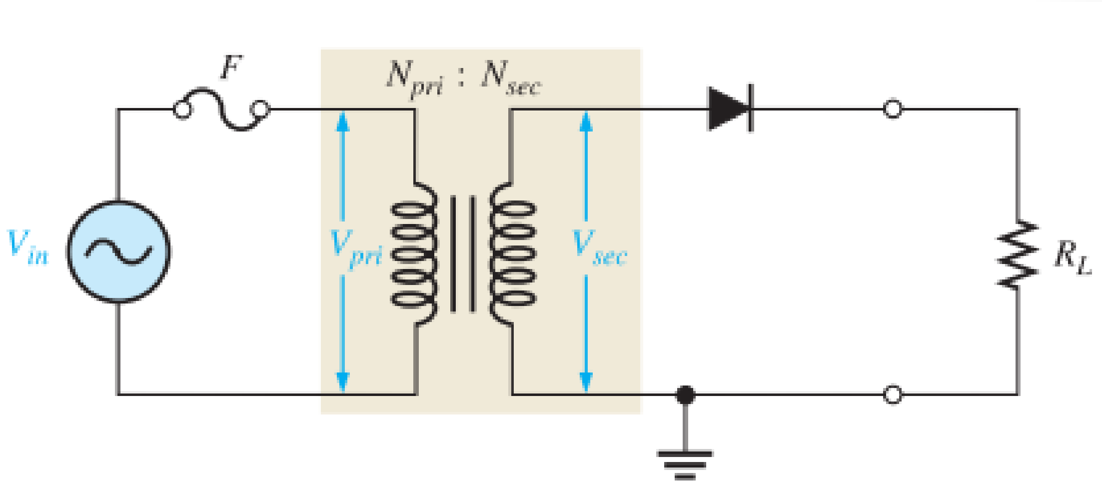


The diode must be capable of withstanding this amount of repetitive reverse voltage.

# Transformer Coupling

$$\boxed{V_{sec} = nV_{pri}}$$

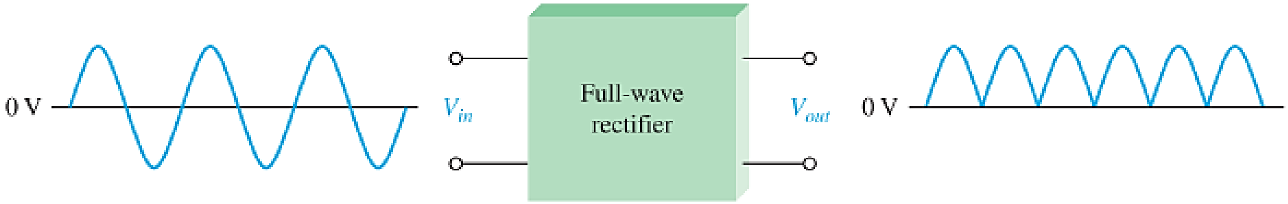
$n$ : turns ratio
$V_{sec}$: secondary voltage
$V_{pri}$ : primary voltage



$$\boxed{V_{p(out)} = V_{p(sec)} - 0.7\text{ V}}$$

$$\boxed{\text{PIV} = V_{p(sec)}}$$

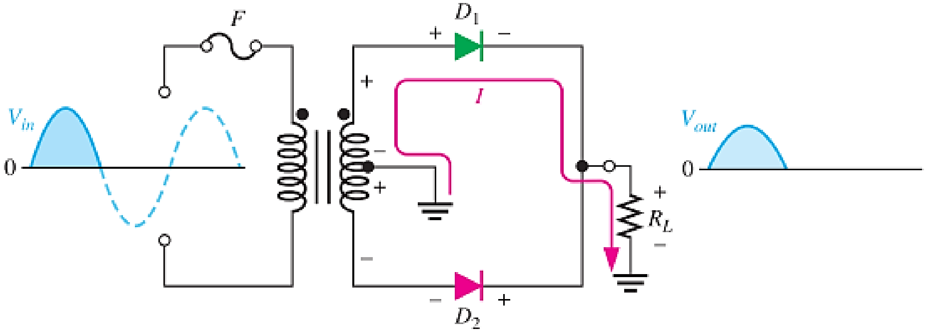
# Rectifiers
# Full-wave Rectifiers



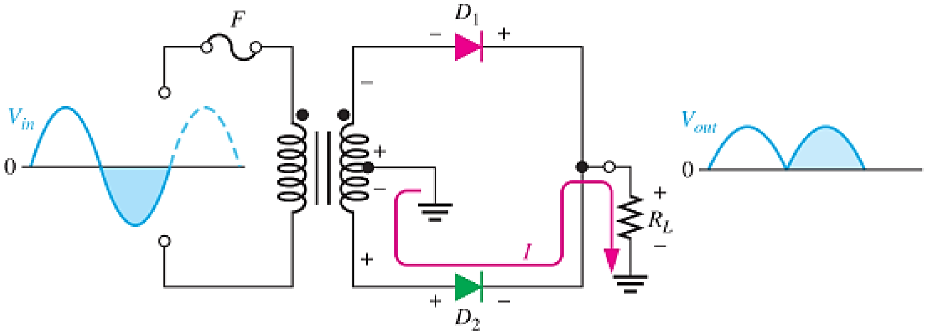
$$\boxed{V_{AVG} = \frac{2V_p}{\pi}}$$

- **Center-tapped Full-wave Rectifier**

$$\boxed{V_{out} = \frac{V_{sec}}{2} - 0.7\ \text{V}}$$

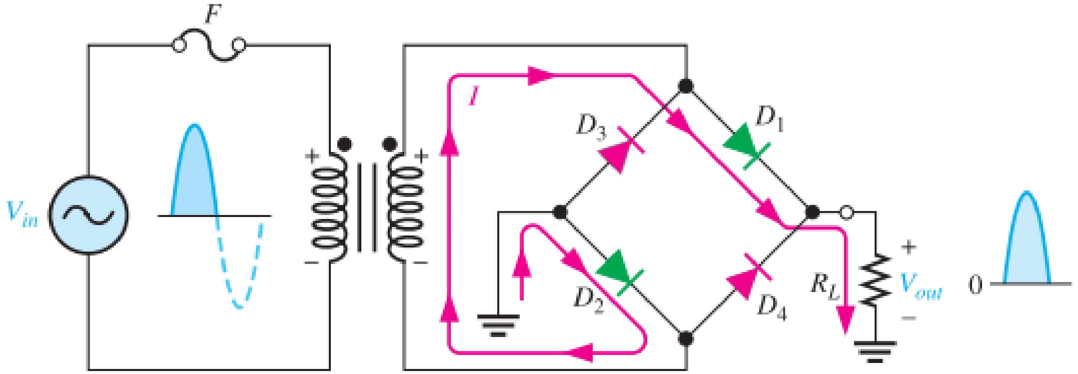


(a) During positive half-cycles, $D_1$ is forward-biased and $D_2$ is reverse-biased.



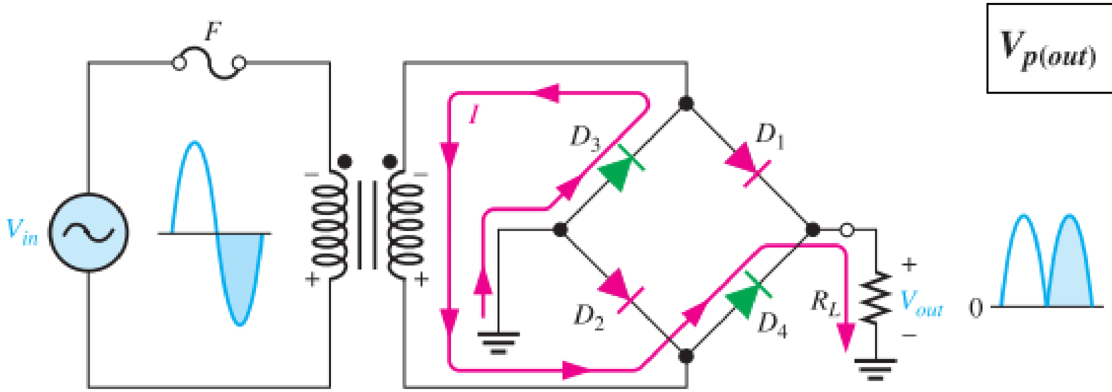
(b) During negative half-cycles, $D_2$ is forward-biased and $D_1$ is reverse-biased.

# Bridge Full-Wave Rectifier Operation



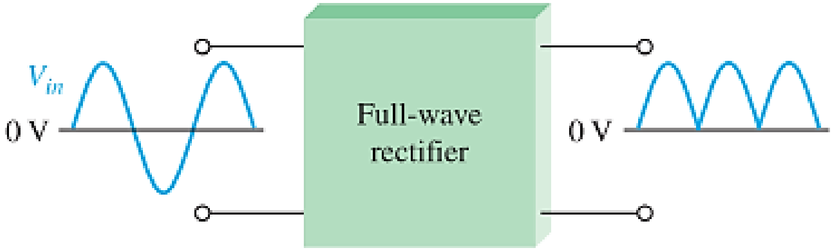
(a) During the positive half-cycle of the input, $D_1$ and $D_2$ are forward-biased and conduct current. $D_3$ and $D_4$ are reverse-biased.

$$\boxed{V_{p(out)} = V_{p(sec)} - 1.4\text{ V}}$$

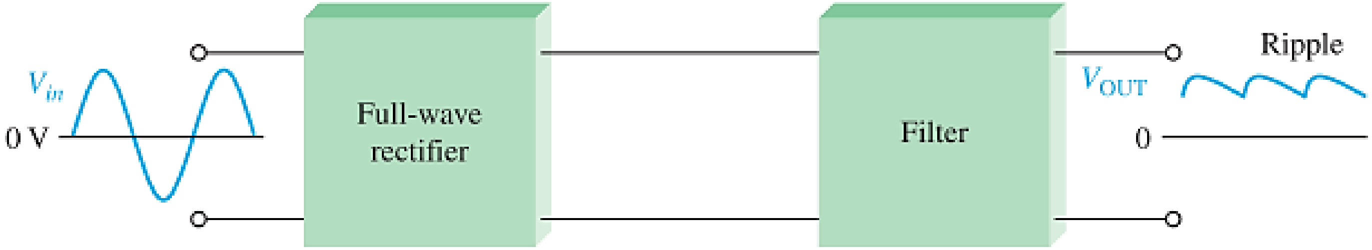


(b) During the negative half-cycle of the input, $D_3$ and $D_4$ are forward-biased and conduct current. $D_1$ and $D_2$ are reverse-biased.

# POWER SUPPLY FILTERS

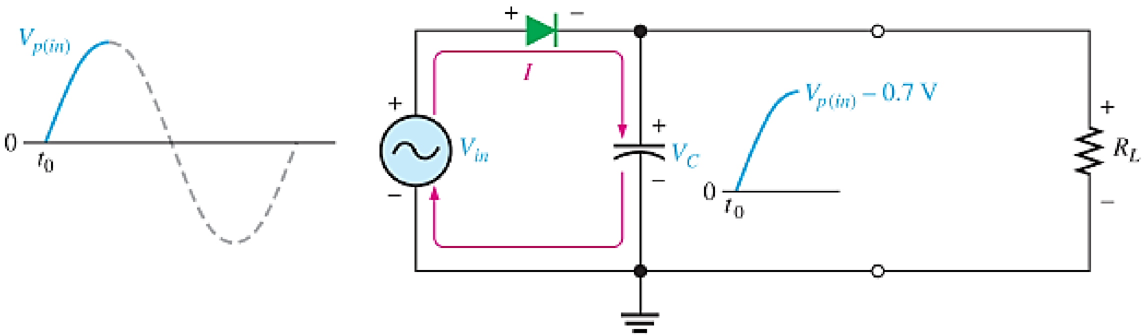


(a) Rectifier without a filter

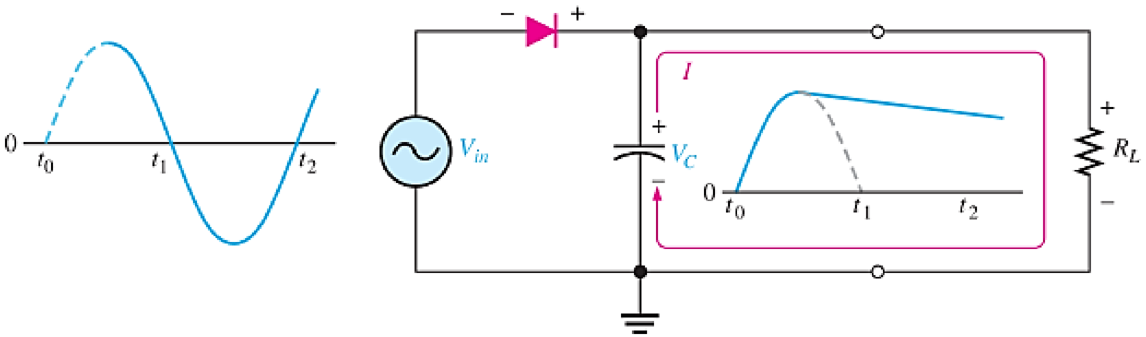


(b) Rectifier with a filter (output ripple is exaggerated)

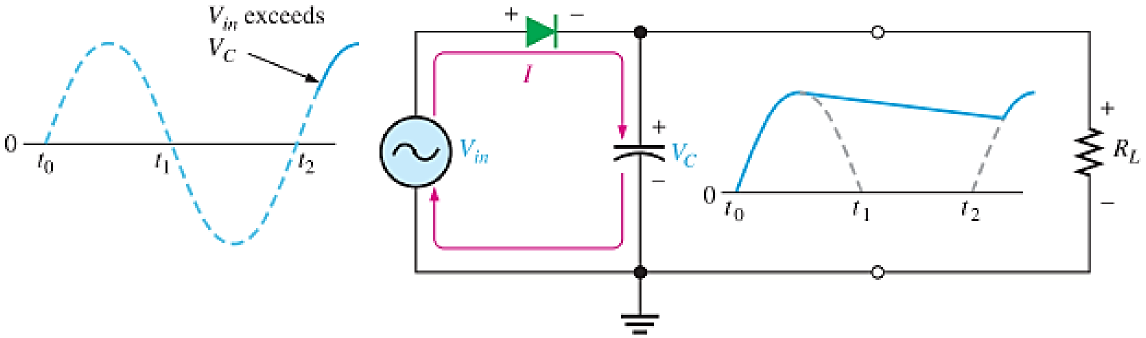
# Capacitor-Input Filter



(a) Initial charging of the capacitor (diode is forward-biased) happens only once when power is turned on.



(b) The capacitor discharges through $R_L$ after peak of positive alternation when the diode is reverse-biased. This discharging occurs during the portion of the input voltage indicated by the solid dark blue curve.

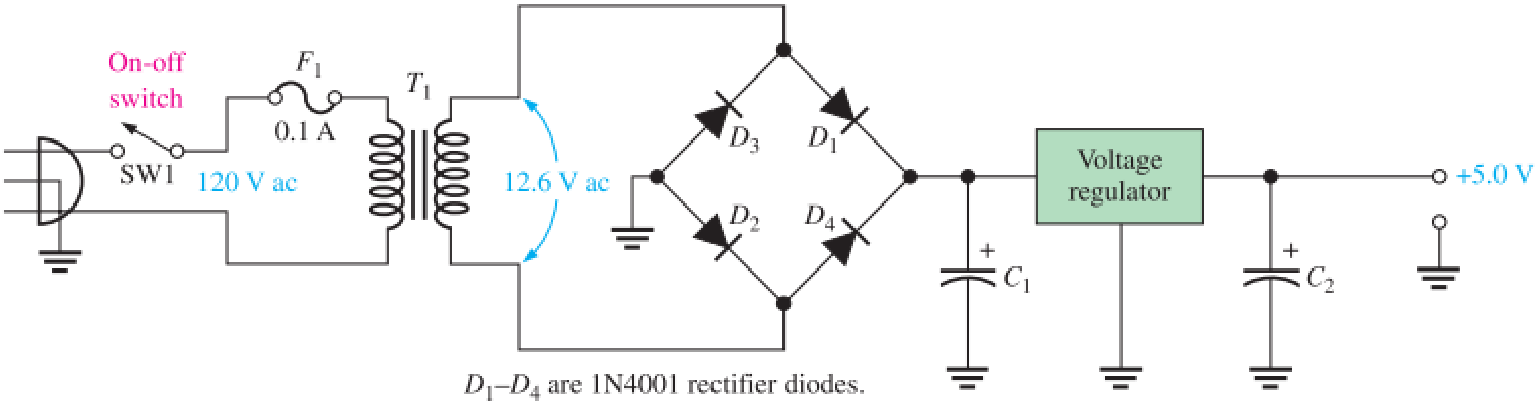


(c) The capacitor charges back to peak of input when the diode becomes forward-biased. This charging occurs during the portion of the input voltage indicated by the solid dark blue curve.

# POWER SUPPLY REGULATORS

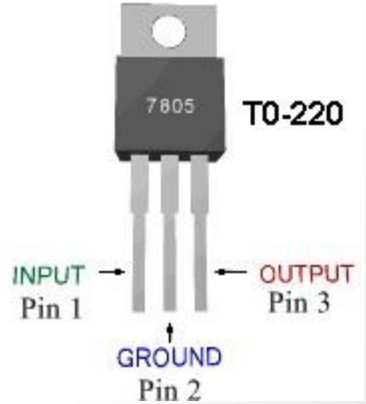
- While filters can reduce the ripple from power supplies to a low value, the most effective approach is a combination of a capacitor-input filter used with a voltage regulator.

**A basic +5.0 V regulated power supply**

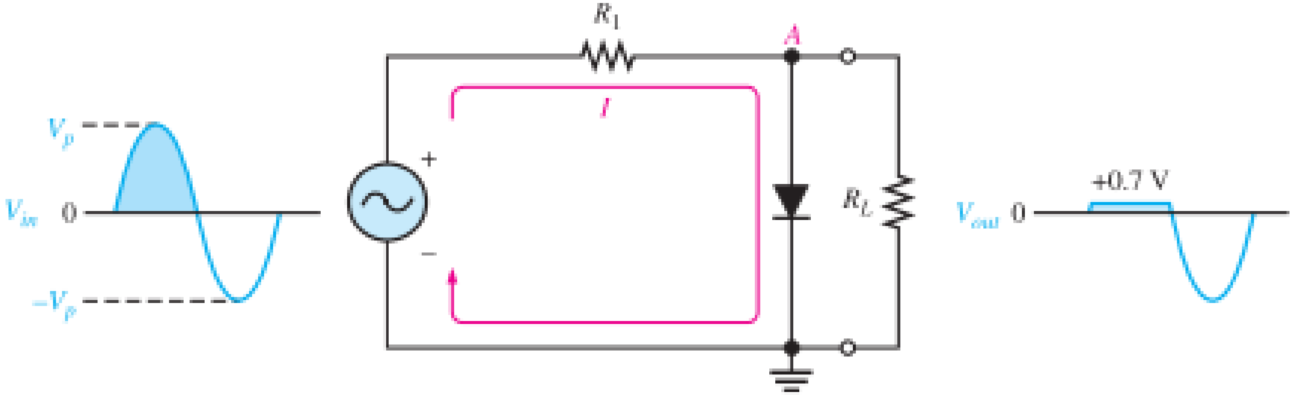


$D_1$–$D_4$ are 1N4001 rectifier diodes.

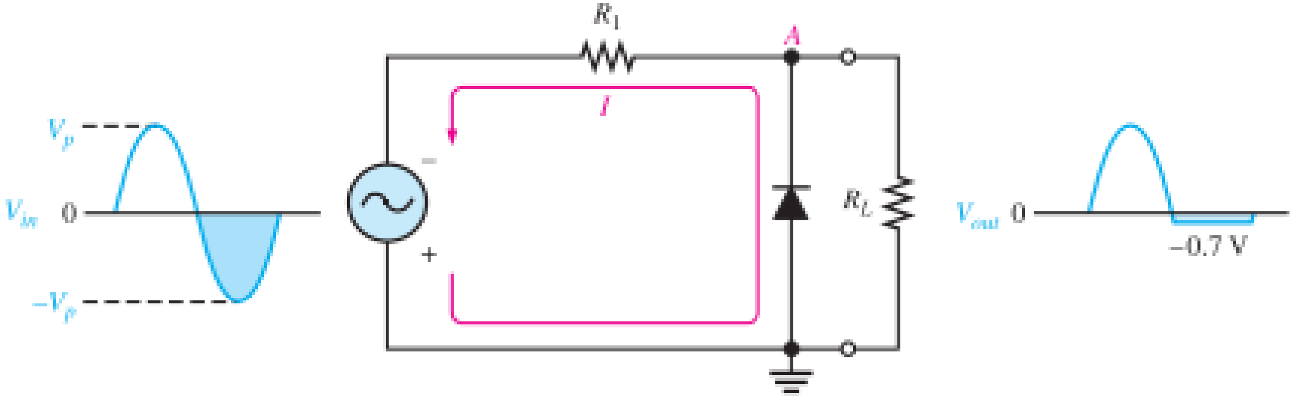
7805 Voltage Regulator IC →



# Diode Limiters (Clippers)



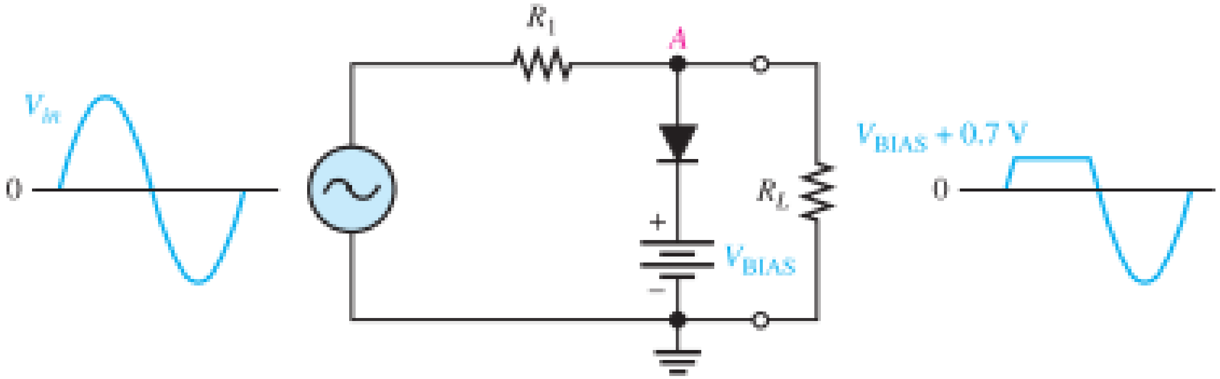
(a) Limiting of the positive alternation. The diode is forward-biased during the positive alternation (above 0.7 V) and reverse-biased during the negative alternation.

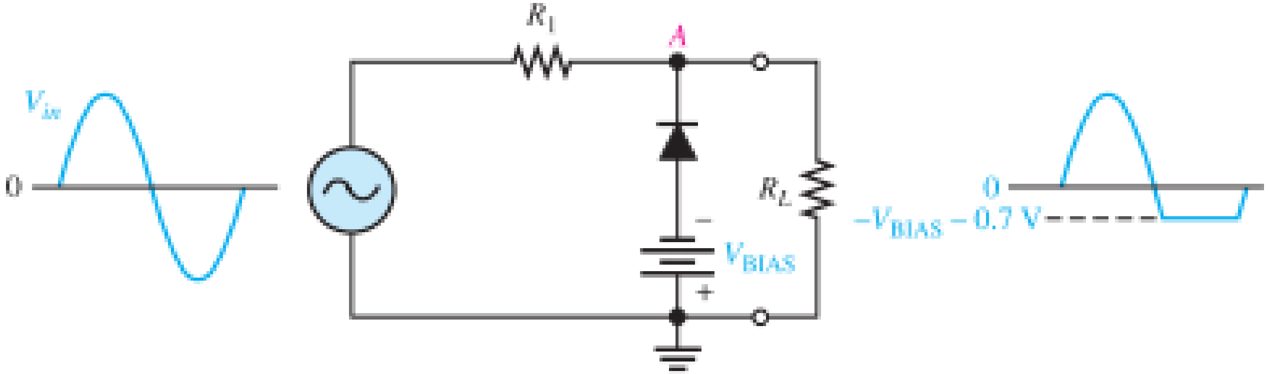


$$V_{out} = \left(\frac{R_L}{R_1 + R_L}\right)V_{in}$$

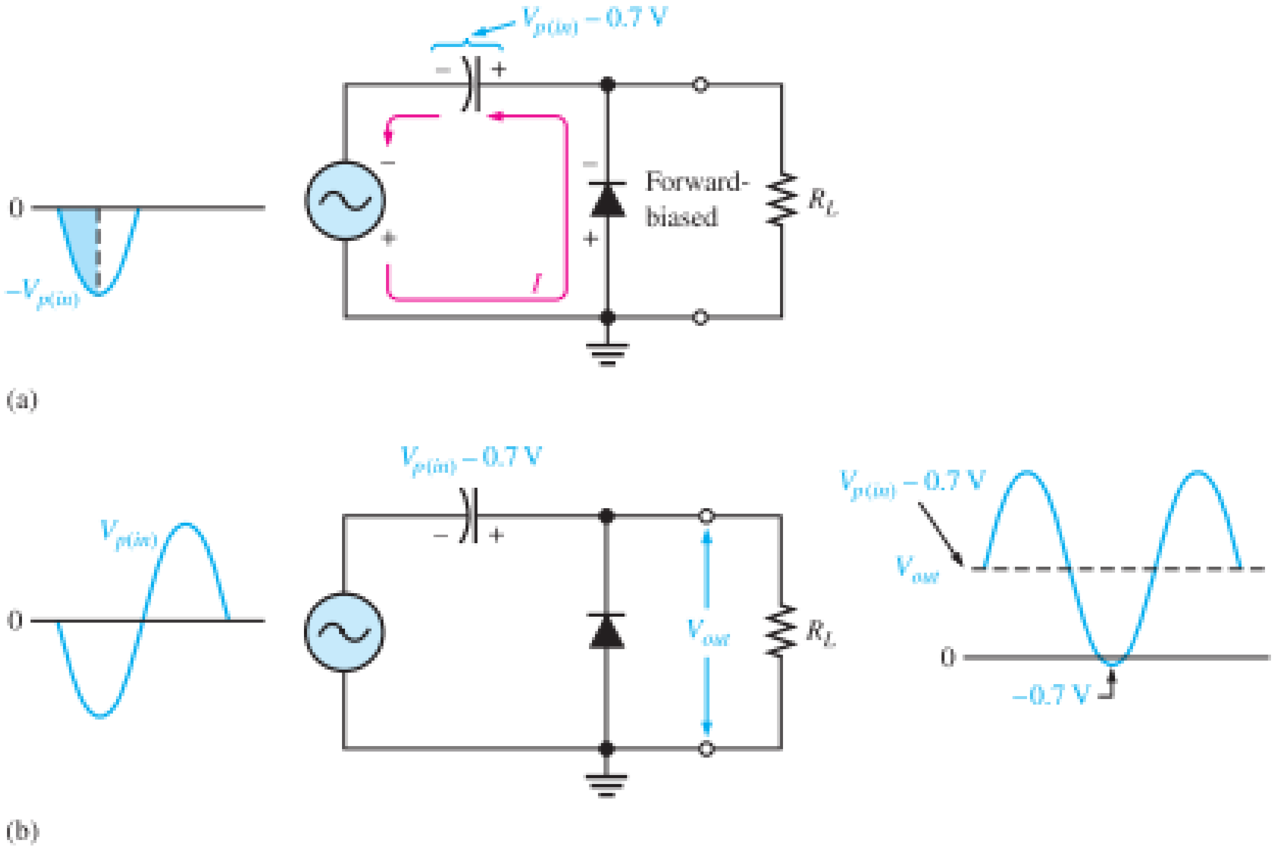
(b) Limiting of the negative alternation. The diode is forward-biased during the negative alternation (below −0.7 V) and reverse-biased during the positive alternation.

# +ve & -ve Limiter

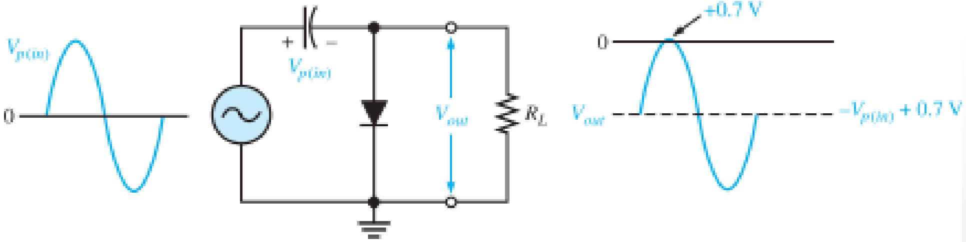




# Clampers



-ve Clamper →



# Voltage Multipliers

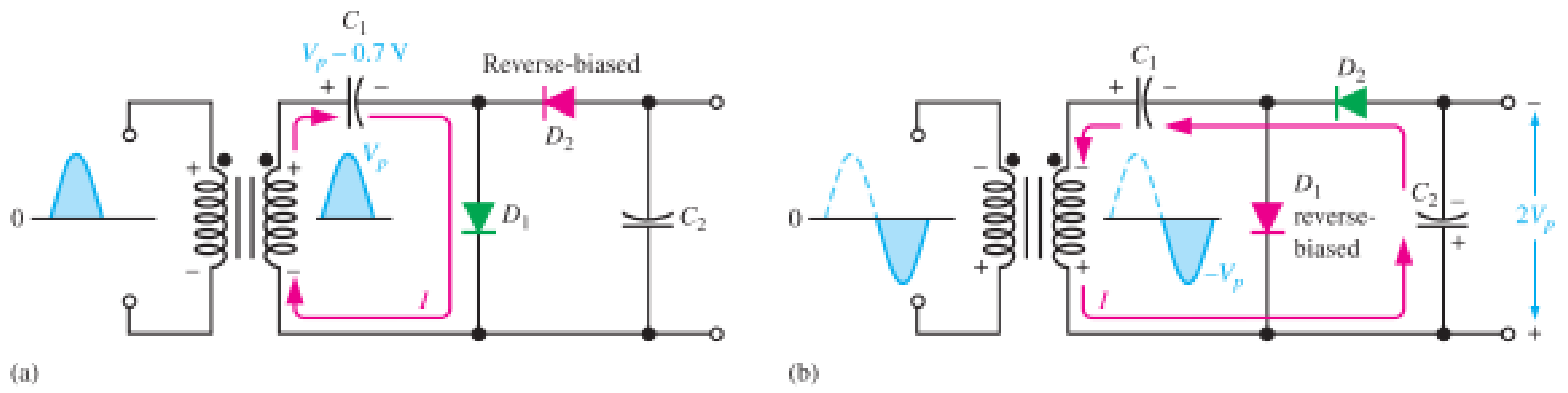


FIGURE 2–67

Half-wave voltage doubler operation. $V_p$ is the peak secondary voltage.

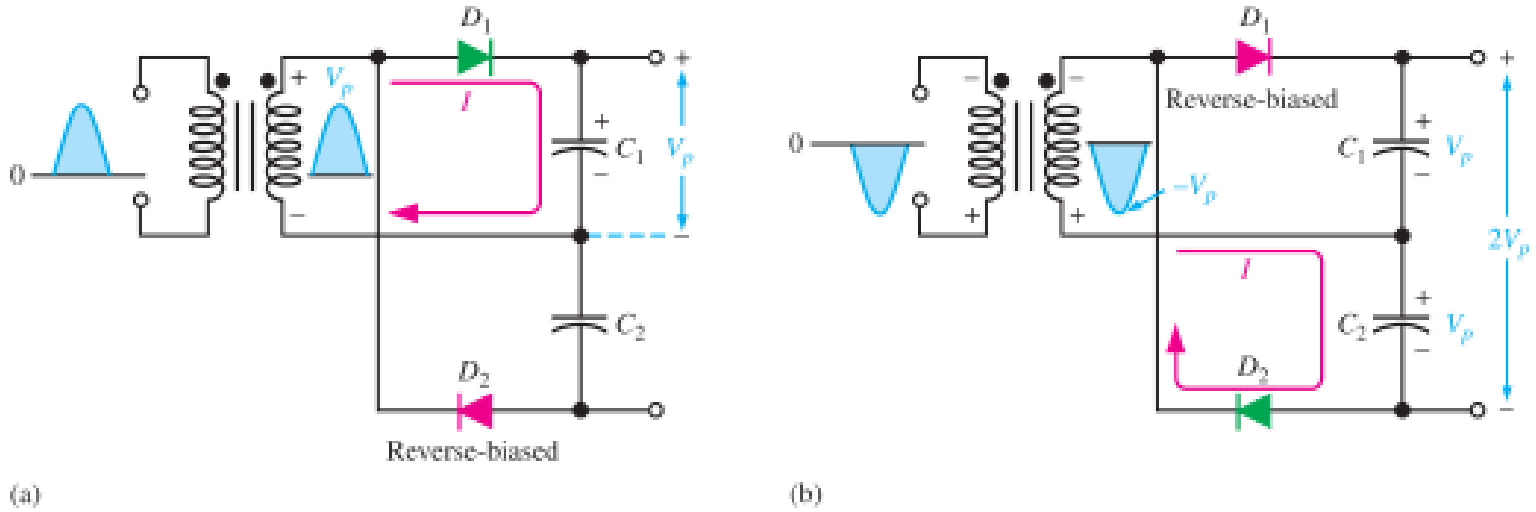


FIGURE 2–68

Full-wave voltage doubler operation.

# Voltage Tripler & Quadrupler

**FIGURE 2–69**

Voltage tripler.

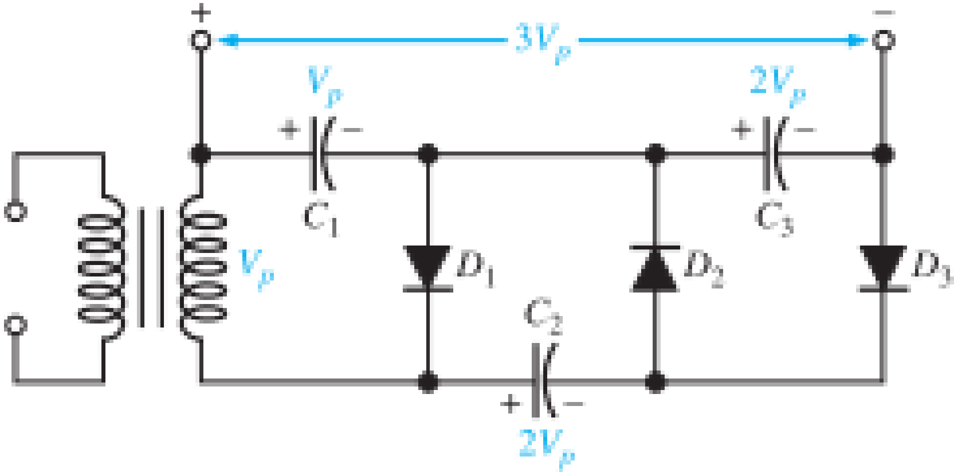
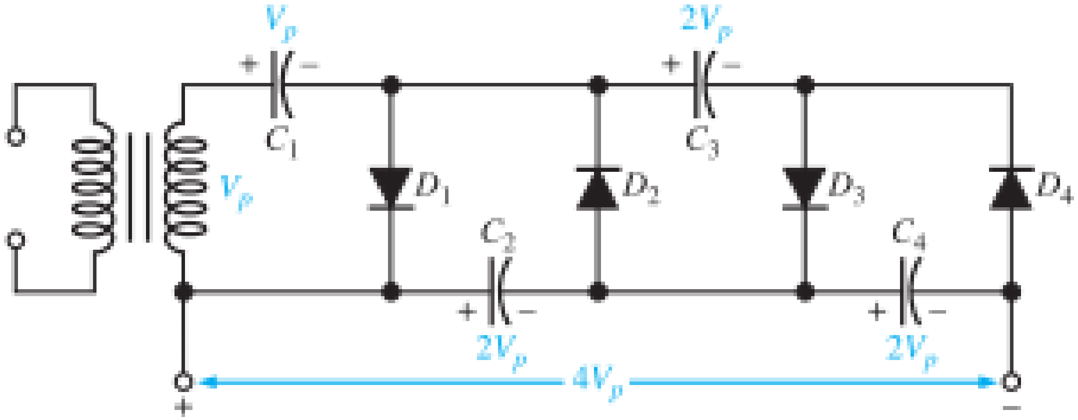
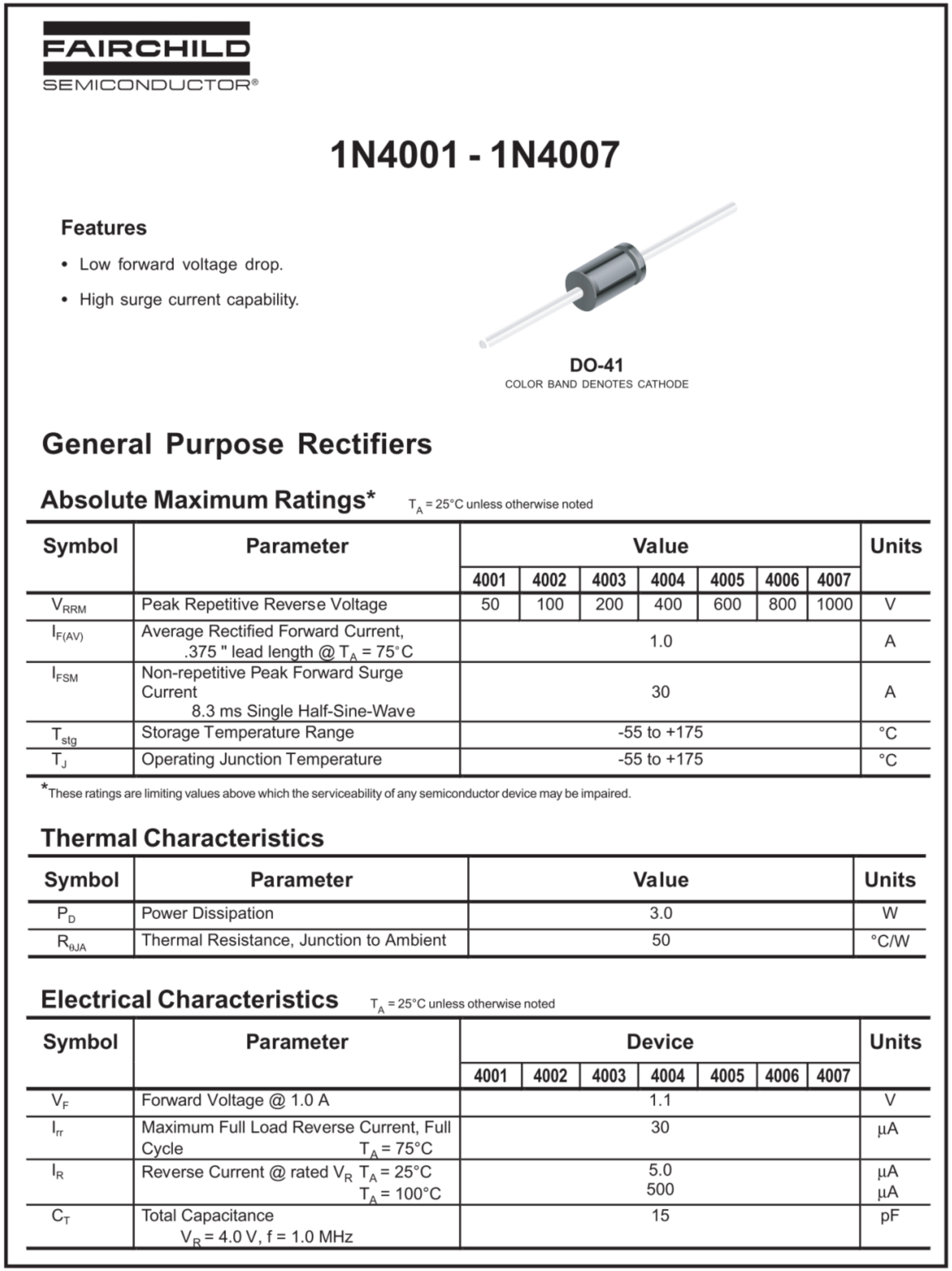


**FIGURE 2–70**

Voltage quadrupler.



# Diode Datasheet



FAIRCHILD SEMICONDUCTOR®

## 1N4001 - 1N4007

**Features**

- Low forward voltage drop.
- High surge current capability.

**DO-41**
COLOR BAND DENOTES CATHODE

## General Purpose Rectifiers

### Absolute Maximum Ratings*

$T_A$ = 25°C unless otherwise noted

| Symbol | Parameter | Value |  |  |  |  |  |  | Units |
|---|---|---|---|---|---|---|---|---|---|
|  |  | 4001 | 4002 | 4003 | 4004 | 4005 | 4006 | 4007 |  |
| $V_{RRM}$ | Peak Repetitive Reverse Voltage | 50 | 100 | 200 | 400 | 600 | 800 | 1000 | V |
| $I_{F(AV)}$ | Average Rectified Forward Current, .375 " lead length @ $T_A$ = 75°C | 1.0 |  |  |  |  |  |  | A |
| $I_{FSM}$ | Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave | 30 |  |  |  |  |  |  | A |
| $T_{stg}$ | Storage Temperature Range | -55 to +175 |  |  |  |  |  |  | °C |
| $T_J$ | Operating Junction Temperature | -55 to +175 |  |  |  |  |  |  | °C |

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

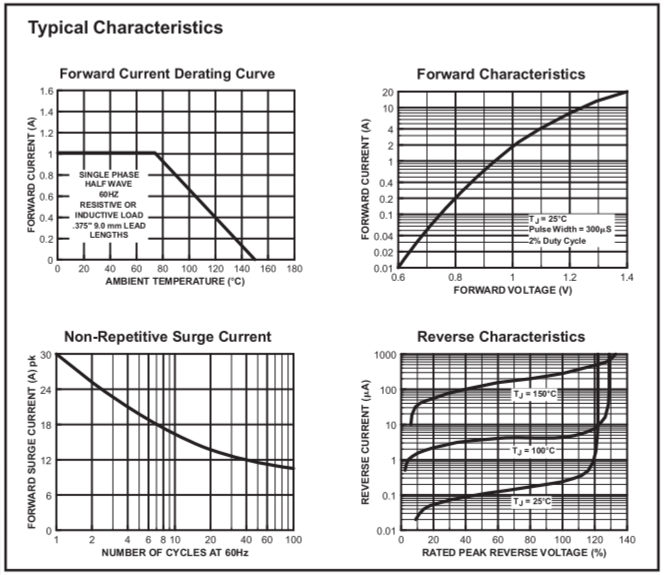
### Thermal Characteristics

| Symbol | Parameter | Value | Units |
|---|---|---|---|
| $P_D$ | Power Dissipation | 3.0 | W |
| $R_{\theta JA}$ | Thermal Resistance, Junction to Ambient | 50 | °C/W |

### Electrical Characteristics

$T_A$ = 25°C unless otherwise noted

| Symbol | Parameter | Device |  |  |  |  |  |  | Units |
|---|---|---|---|---|---|---|---|---|---|
|  |  | 4001 | 4002 | 4003 | 4004 | 4005 | 4006 | 4007 |  |
| $V_F$ | Forward Voltage @ 1.0 A | 1.1 |  |  |  |  |  |  | V |
| $I_{rr}$ | Maximum Full Load Reverse Current, Full Cycle $T_A$ = 75°C | 30 |  |  |  |  |  |  | µA |
| $I_R$ | Reverse Current @ rated $V_R$ $T_A$ = 25°C<br>$T_A$ = 100°C | 5.0<br>500 |  |  |  |  |  |  | µA<br>µA |
| $C_T$ | Total Capacitance $V_R$ = 4.0 V, f = 1.0 MHz | 15 |  |  |  |  |  |  | pF |



**Typical Characteristics**

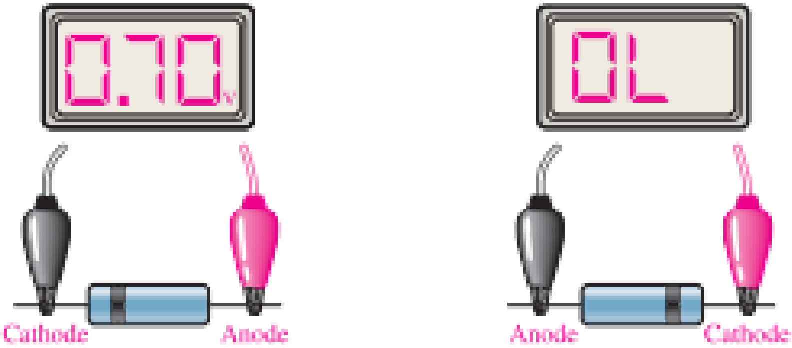
Forward Current Derating Curve

Forward Characteristics

Non-Repetitive Surge Current

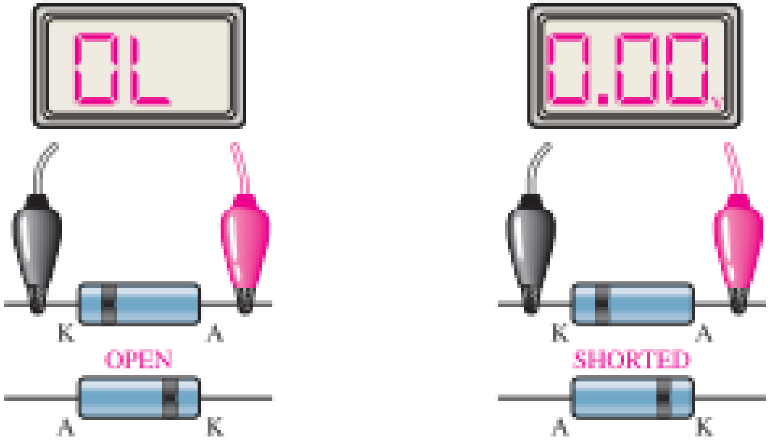
Reverse Characteristics

# Diode Testing



(a) Forward-bias test

(b) Reverse-bias test



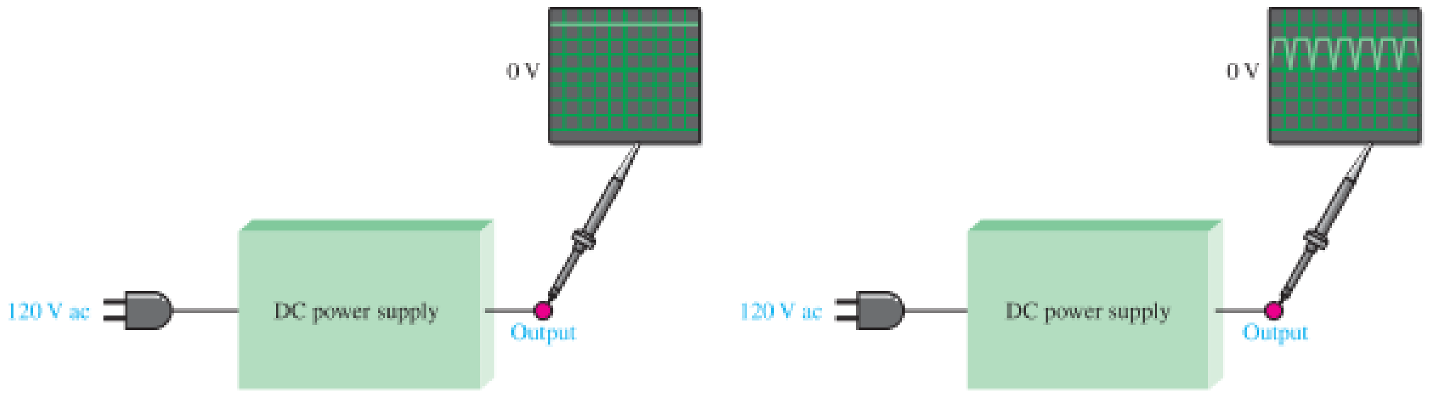
(c) Forward- and reverse-bias tests for an open diode give the same indication.

(d) Forward- and reverse-bias tests for a shorted diode give the same 0 V reading.

▲ FIGURE 2–76

Testing a diode out-of-circuit with a DMM.

# Troubleshooting

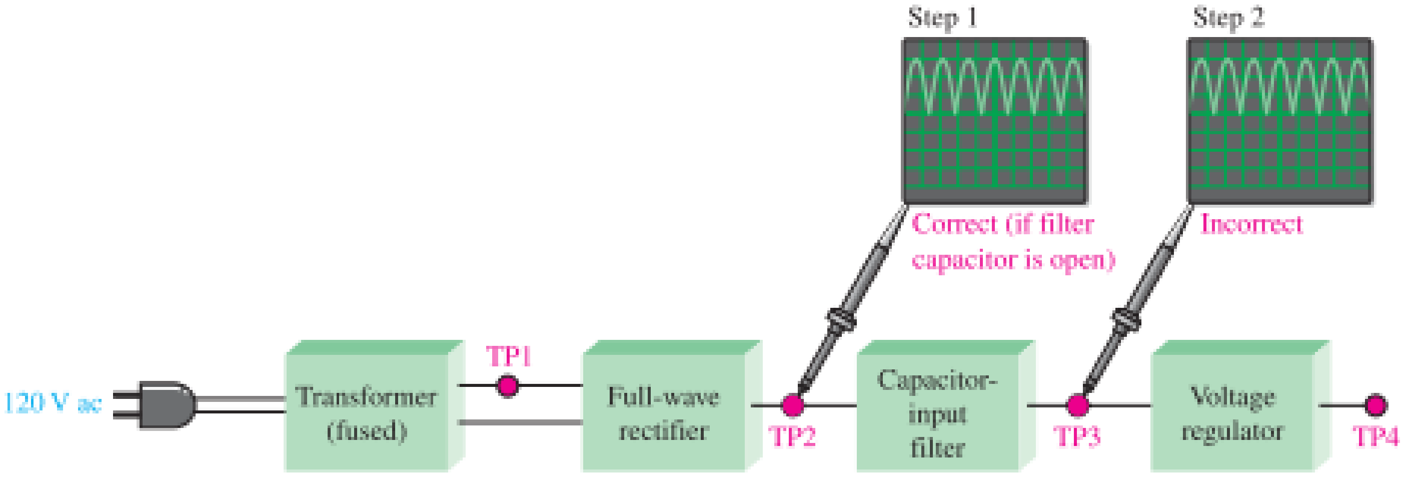


(a) The correct dc output voltage is measured with oscilloscope.

(b) An incorrect voltage is measured at the output with oscilloscope.

▲ FIGURE 2–77

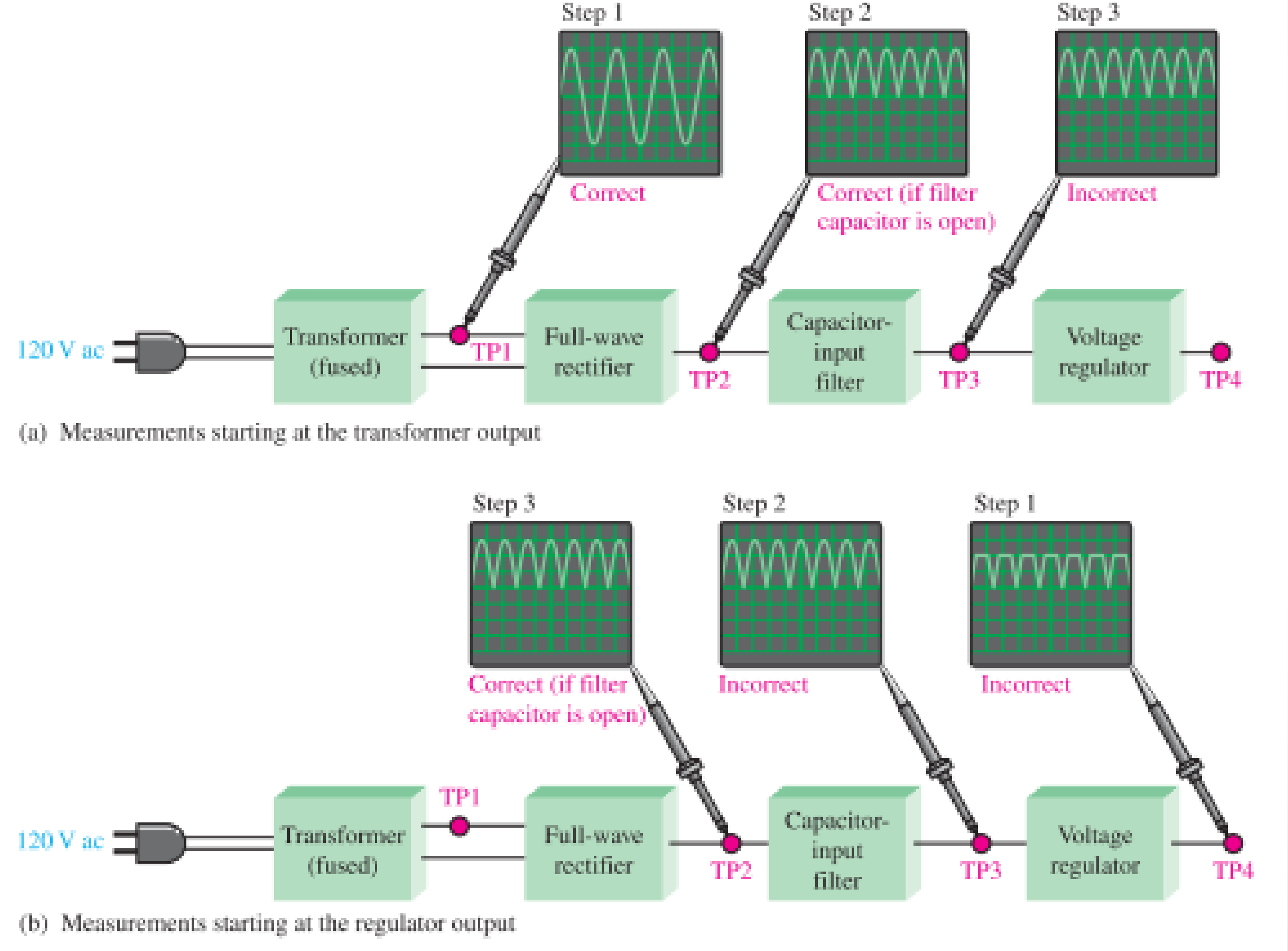
Block representations of functioning and nonfunctioning power supplies.



▲ FIGURE 2–78

Example of the half-splitting approach. An open filter capacitor is indicated.

# Troubleshooting ..

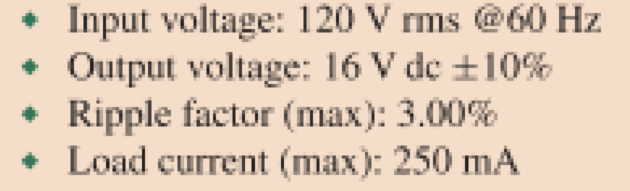


(a) Measurements starting at the transformer output

(b) Measurements starting at the regulator output

# Application: DC Power Supply

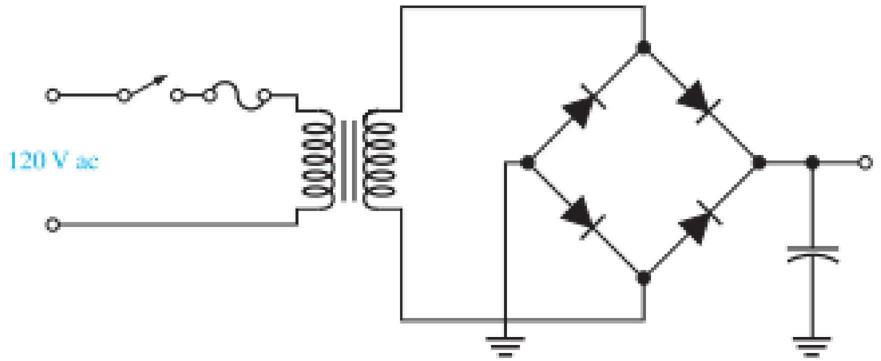
Specs:



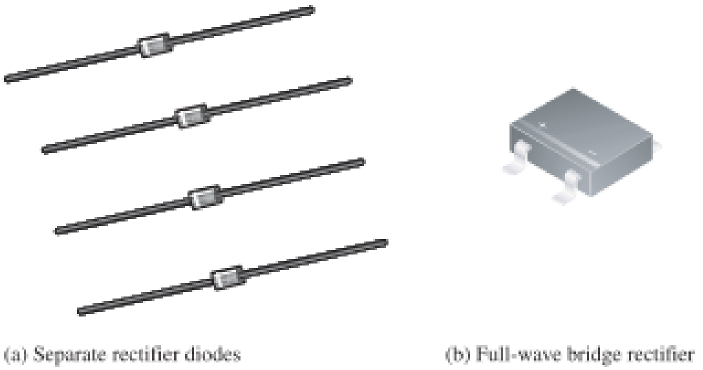
- Input voltage: 120 V rms @60 Hz
- Output voltage: 16 V dc ±10%
- Ripple factor (max): 3.00%
- Load current (max): 250 mA

# Design

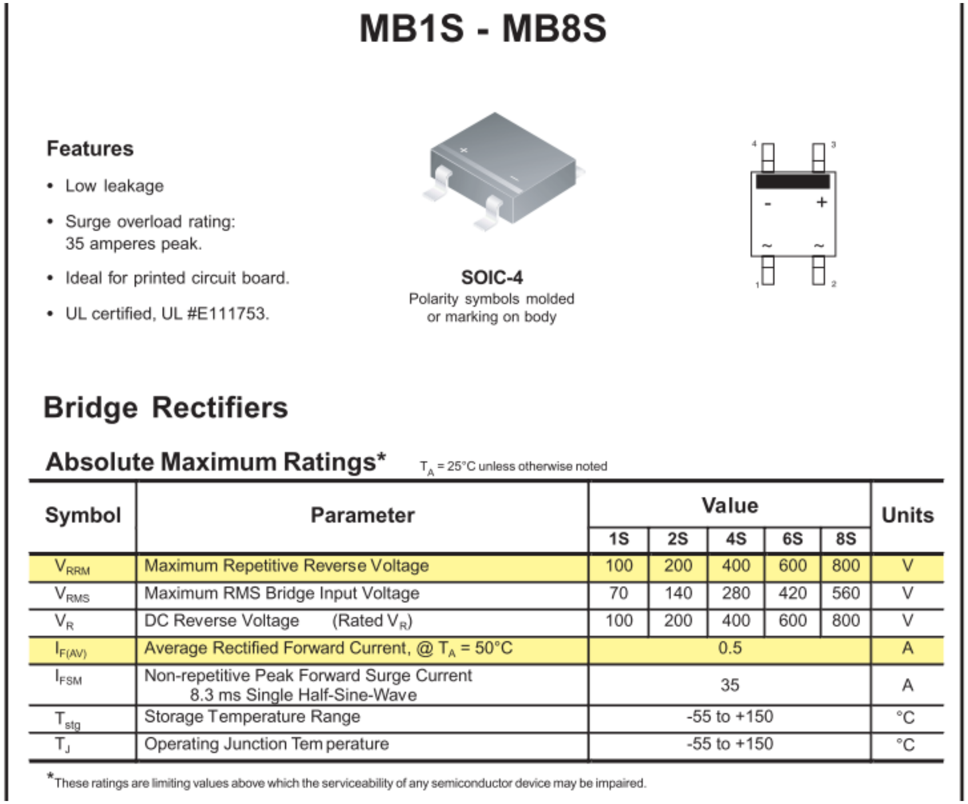
Rectifier Circuit



Rectifier Diodes



- Forward current rating must be equal or greater than 250 mA (maximum load current).
- PIV must be greater than the minimum calculated value of 16.7 V (PIV $= V_{p(out)} + 0.7$ V).



## MB1S - MB8S

**Features**

- Low leakage
- Surge overload rating: 35 amperes peak.
- Ideal for printed circuit board.
- UL certified, UL #E111753.

**SOIC-4**
Polarity symbols molded or marking on body

### Bridge Rectifiers

**Absolute Maximum Ratings*** $T_A = 25°C$ unless otherwise noted

| Symbol | Parameter | Value | | | | | Units |
|---|---|---|---|---|---|---|---|
| | | 1S | 2S | 4S | 6S | 8S | |
| $V_{RRM}$ | Maximum Repetitive Reverse Voltage | 100 | 200 | 400 | 600 | 800 | V |
| $V_{RMS}$ | Maximum RMS Bridge Input Voltage | 70 | 140 | 280 | 420 | 560 | V |
| $V_R$ | DC Reverse Voltage (Rated $V_R$) | 100 | 200 | 400 | 600 | 800 | V |
| $I_{F(AV)}$ | Average Rectified Forward Current, @ $T_A = 50°C$ | 0.5 | | | | | A |
| $I_{FSM}$ | Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave | 35 | | | | | A |
| $T_{stg}$ | Storage Temperature Range | -55 to +150 | | | | | °C |
| $T_J$ | Operating Junction Temperature | -55 to +150 | | | | | °C |

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

**Equation 2–11**
$$r = \frac{V_{r(pp)}}{V_{DC}}$$

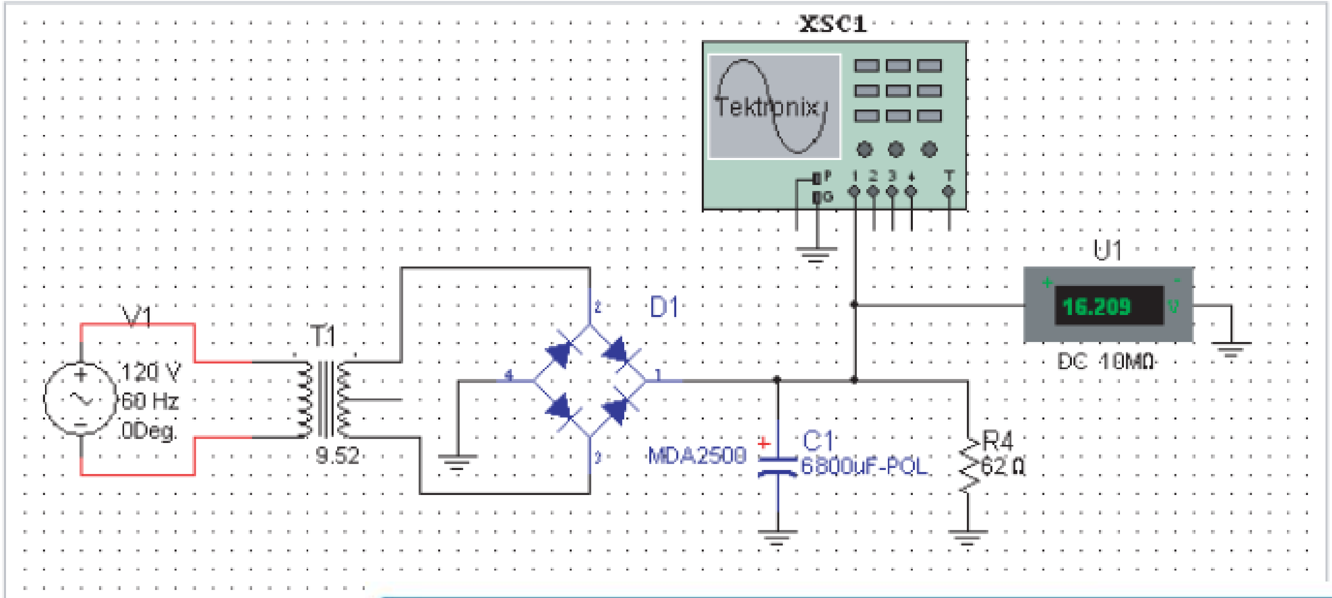
**Equation 2–12**
$$V_{r(pp)} \cong \left(\frac{1}{fR_LC}\right)V_{p(rect)}$$

**Equation 2–13**
$$V_{DC} \cong \left(1 - \frac{1}{2fR_LC}\right)V_{p(rect)}$$

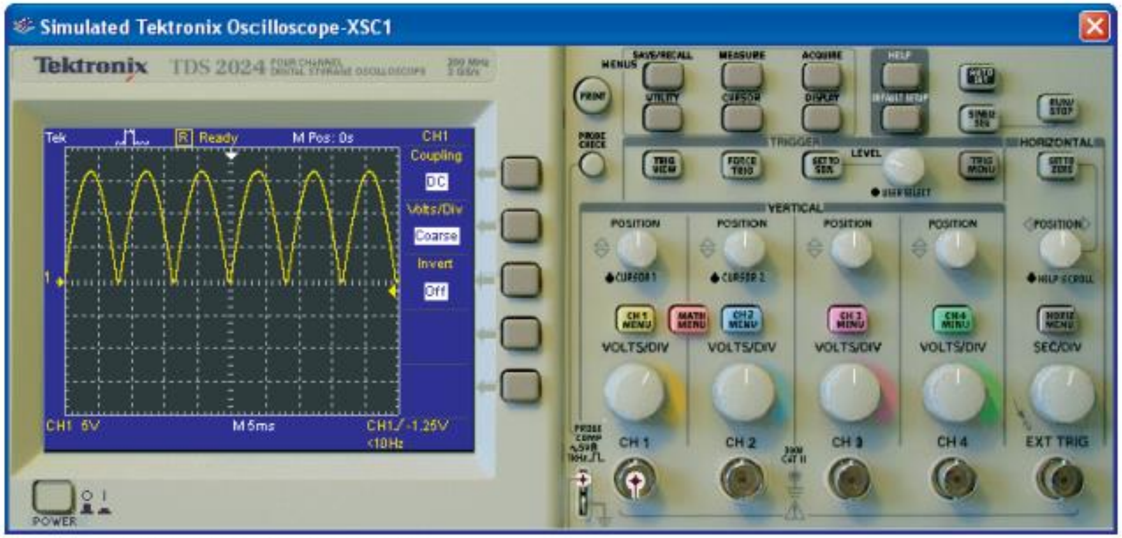
***The Filter Capacitor*** The capacitance of the filter capacitor must be sufficiently large to provide the specified ripple.

6. Use Equation 2–11 to calculate the peak-to-peak ripple voltage, assuming $V_{DC} = 16$ V.
7. Use Equation 2–12 to calculate the minimum capacitance value. Use $R_L = 64\ \Omega$, calculated on page 89.

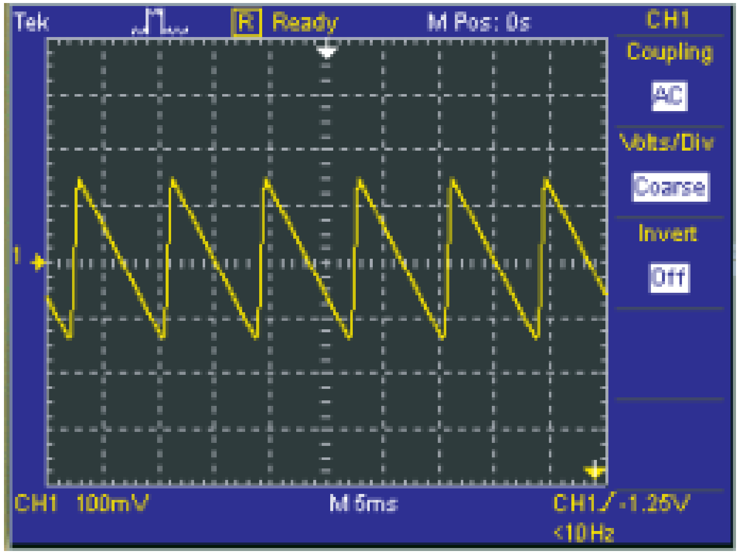
# Simulation



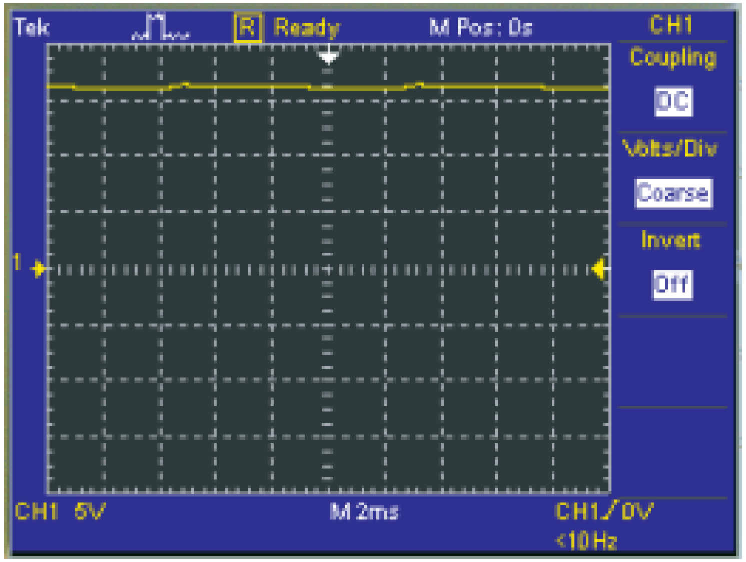
(a) Multisim circuit screen


Simulated Tektronix Oscilloscope-XSC1

(b) Output voltage without the filter capacitor

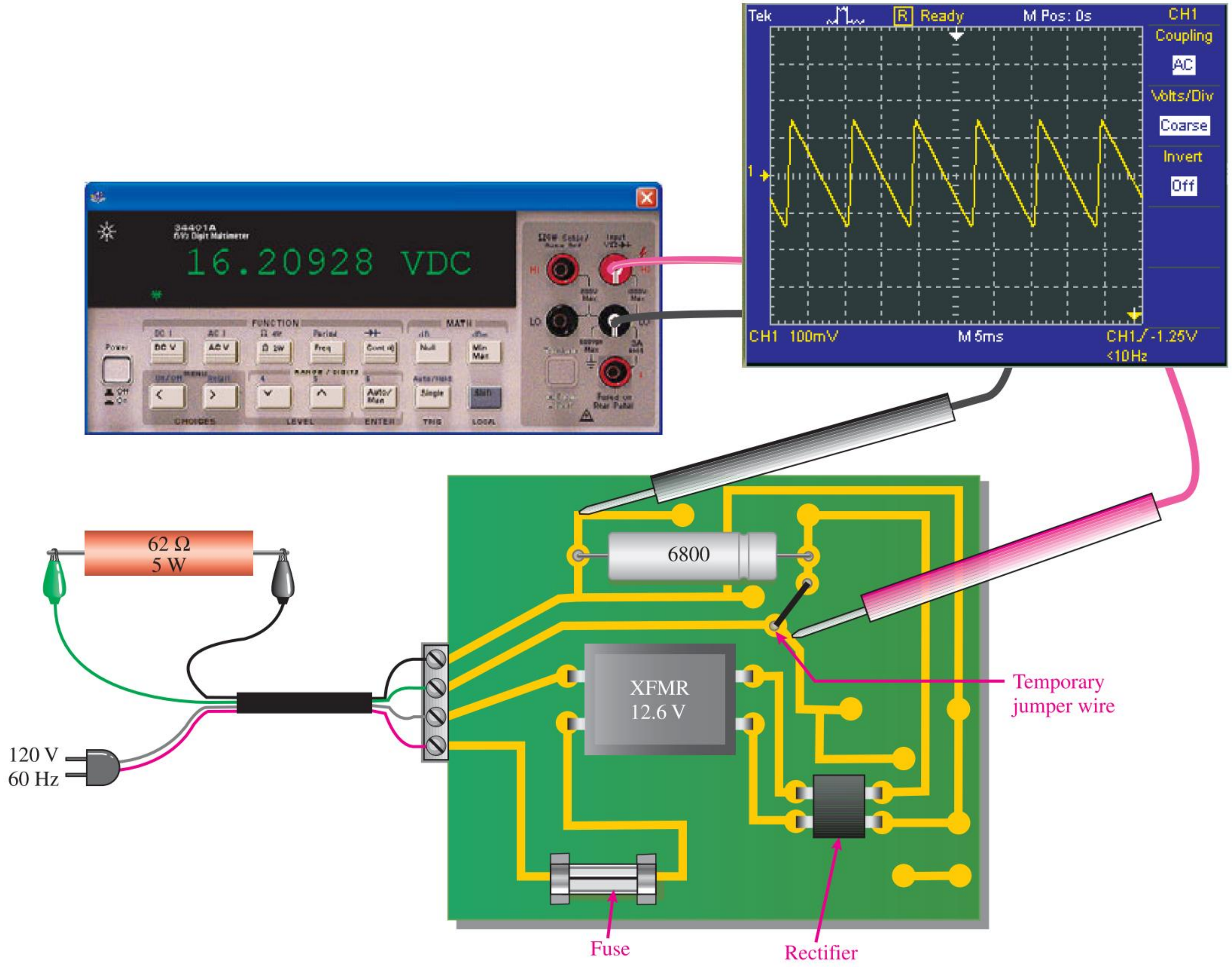


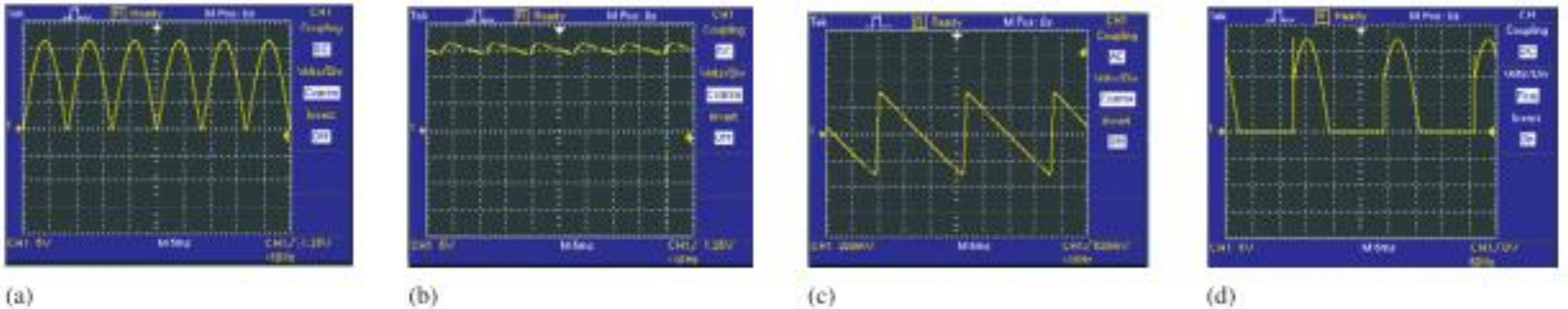
(c) Ripple voltage is less than 300 mV pp



(d) DC output voltage with filter capacitor (near top of screen)

# PCB

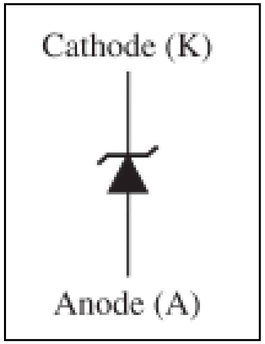

34401A
6½ Digit Multimeter
16.20928 VDC
Tek
Ready
M Pos: 0s
CH1
Coupling
AC
Volts/Div
Coarse
Invert
Off
CH1 100mV
M 5ms
CH1 ∕ -1.25V
<10Hz
62 Ω
5 W
120 V
60 Hz
6800
XFMR
12.6 V
Temporary
jumper wire
Fuse
Rectifier

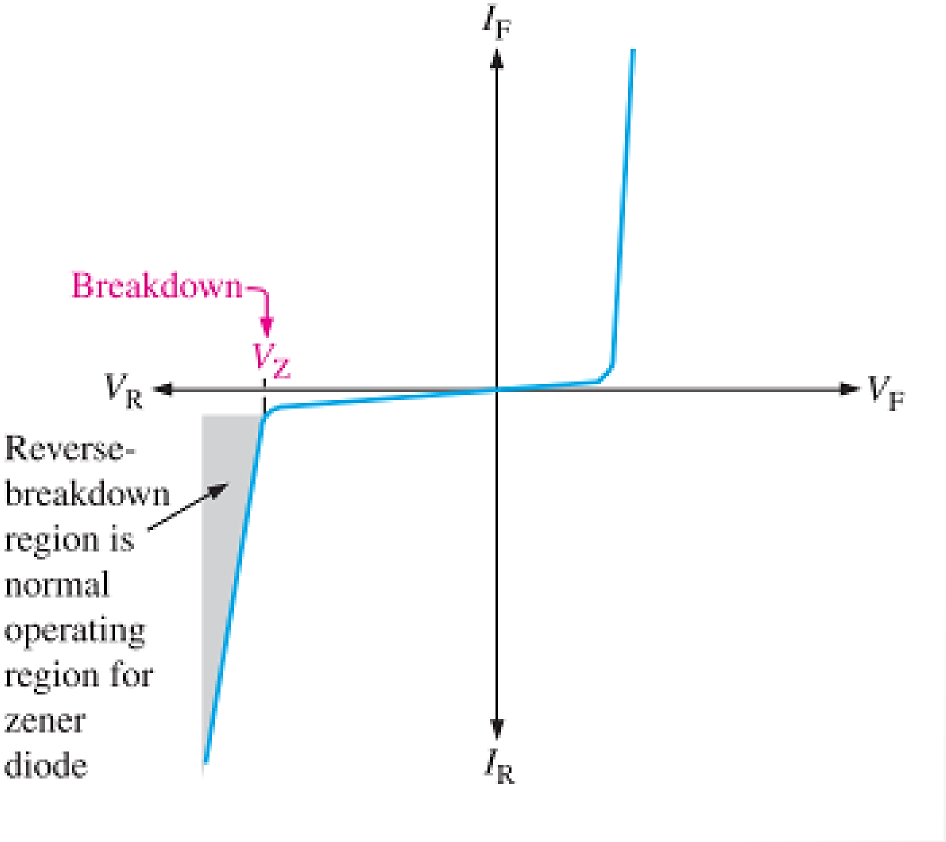

(a)
(b)
(c)
(d)

# SPECIAL PURPOSE DIODES

# The Zener Diode

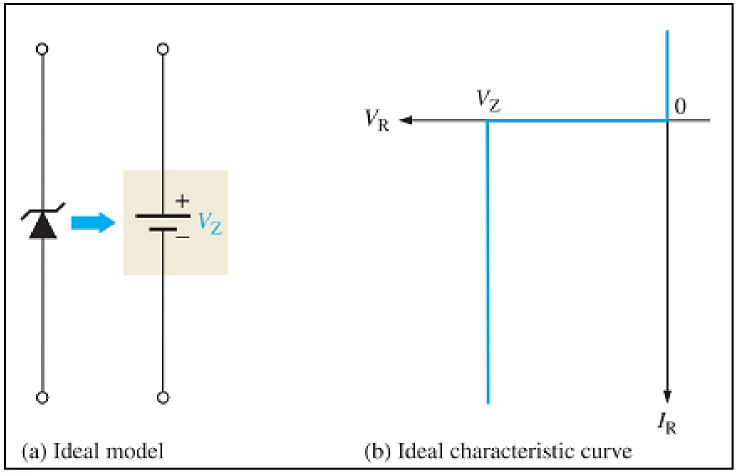
- A zener diode is a silicon pn junction device that is designed for operation in the reverse-breakdown region.
- The breakdown voltage of a zener diode is set by carefully controlling the doping level during manufacture.



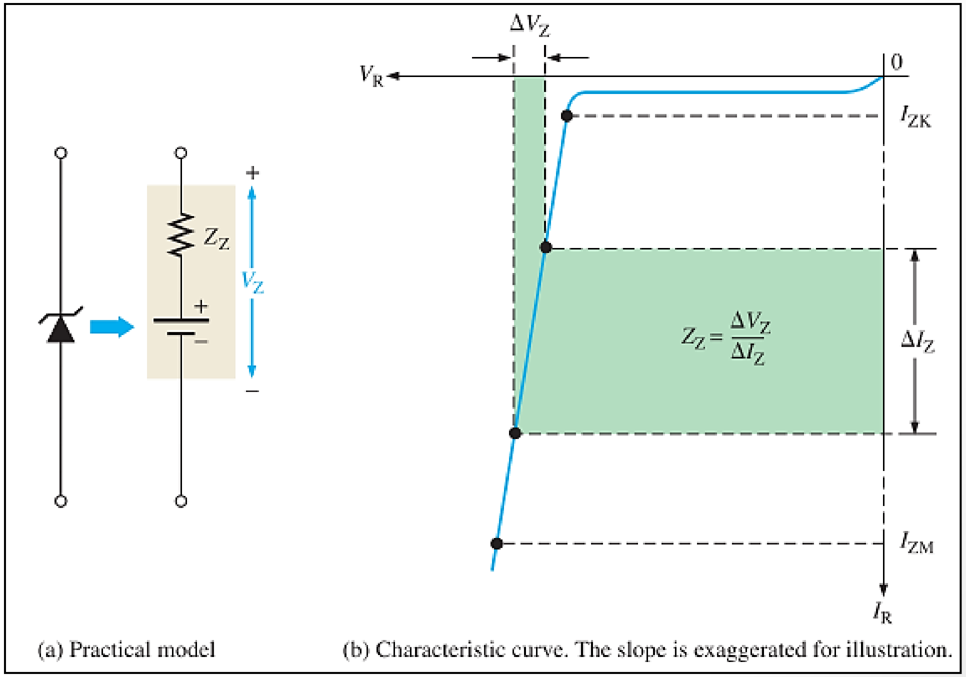


# Zener Equivalent Circuits

- Zener is used as Regulator
- Two Models
  - Ideal Model
  - Practical Model



(a) Ideal model (b) Ideal characteristic curve

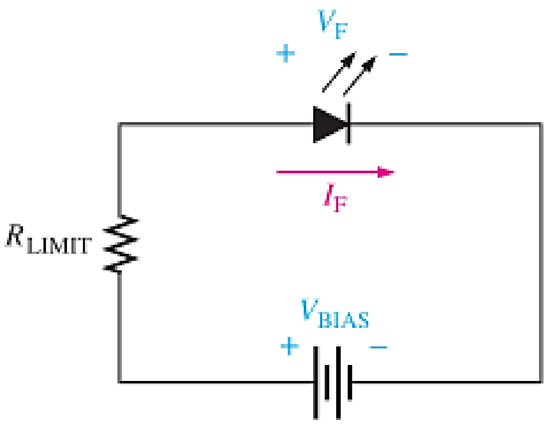


(a) Practical model (b) Characteristic curve. The slope is exaggerated for illustration.

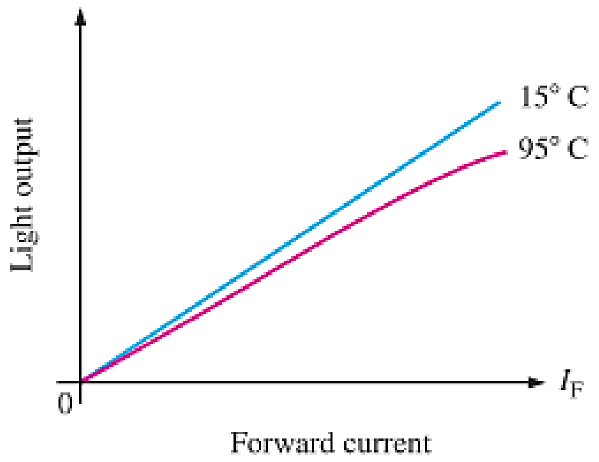
# Optical Diodes
# The Light-Emitting Diode (LED)

Basic operation :

- When the device is forward-biased, electrons cross the pn junction from the n-type material and recombine with holes in the p-type material.
- The difference in energy between the electrons and the holes corresponds to the energy of visible light.
- When recombination takes place, the recombining electrons release energy in the form of ***photons***.



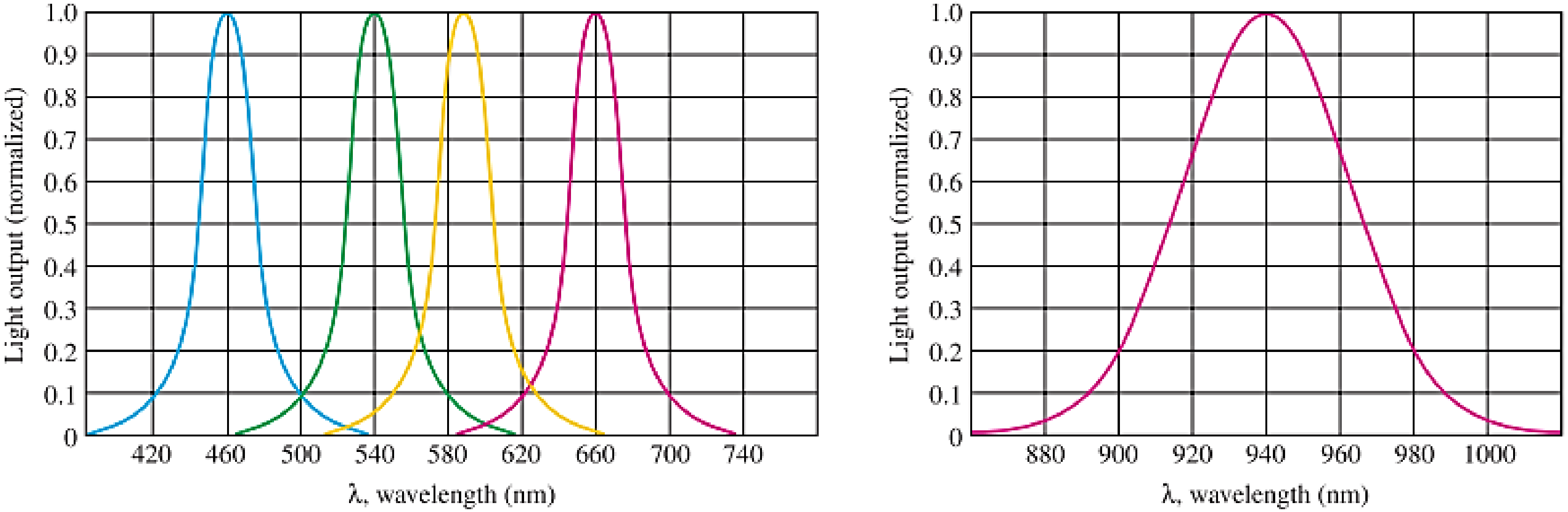
(a) Forward-biased operation



(b) General light output versus forward current for two temperatures

# Light Emission

- An LED emits light over a specified range of wavelengths.
- Examples of typical spectral output curves for LEDs:



(a) Visible light

(b) Infrared (IR)

# Typical LEDs

(a) Typical small LEDs for indicators

Helion 12 V overhead light with socket and module

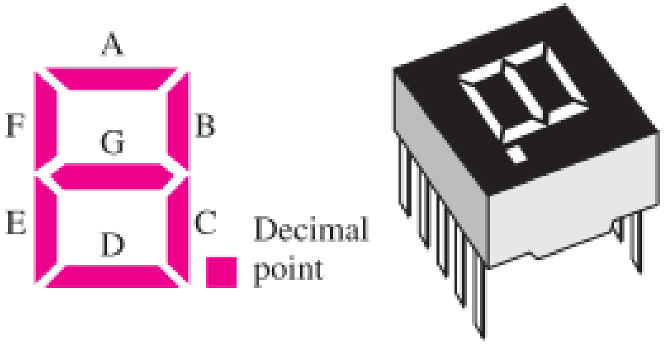
120 V, 3.5 W screw base for low-level illumination

120 V, 1 W small screw base candelabra style

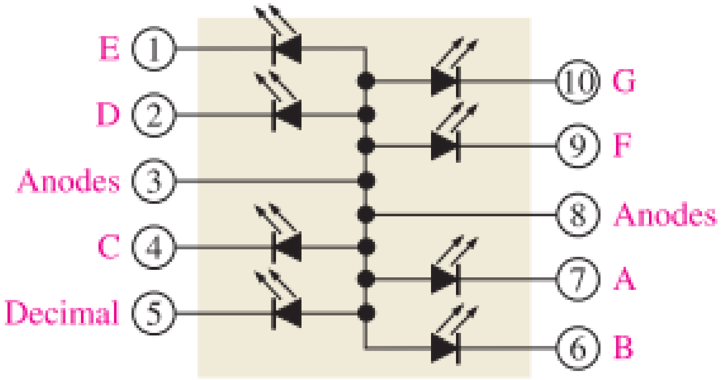
6 V, bayonet base for flashlights, etc.

(b) Typical LEDs for lighting applications

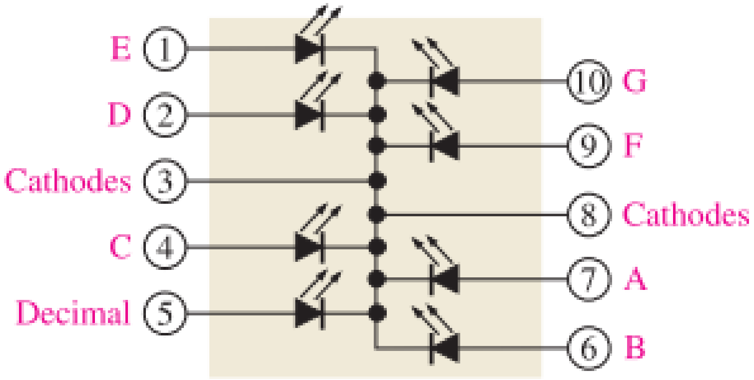
# LED Application
# 7-Segment Display



(a) LED segment arrangement and typical device



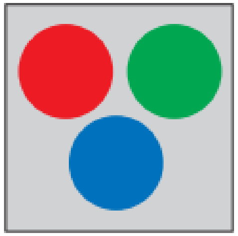
(b) Common anode



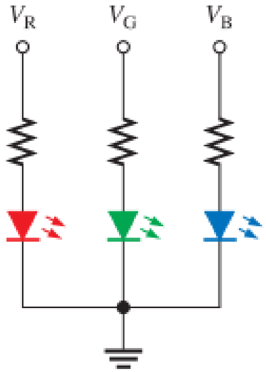
(c) Common cathode

# LED Application
# LED Displays

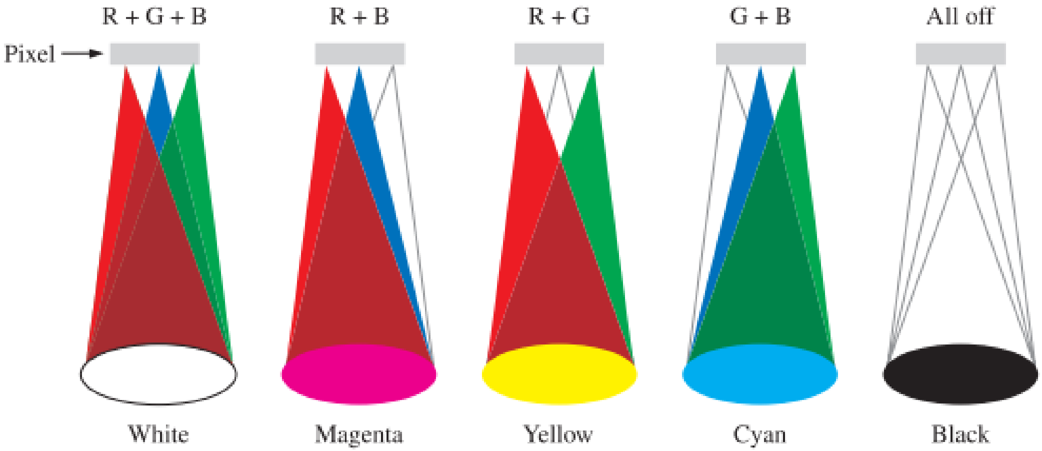
- The concept of an RGB pixel used in LED display screens.



(a) Basic pixel



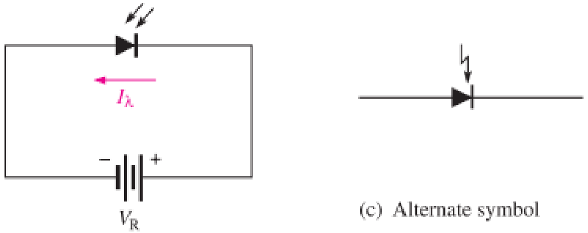
(b) Pixel circuit



(c) Examples of different combinations of equal amounts of primary colors

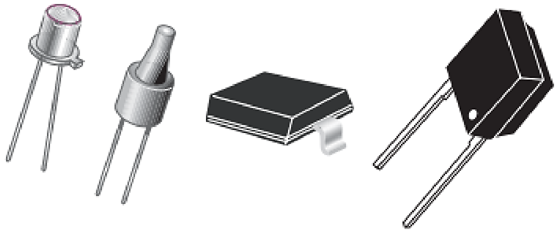
# Optical Diodes
# The Photodiode

- The photodiode is a device that operates in reverse bias where I is the reverse light current.
- The photodiode has a small transparent window that allows light to strike the pn junction.
- Internal Resistance changes by the amount of light.

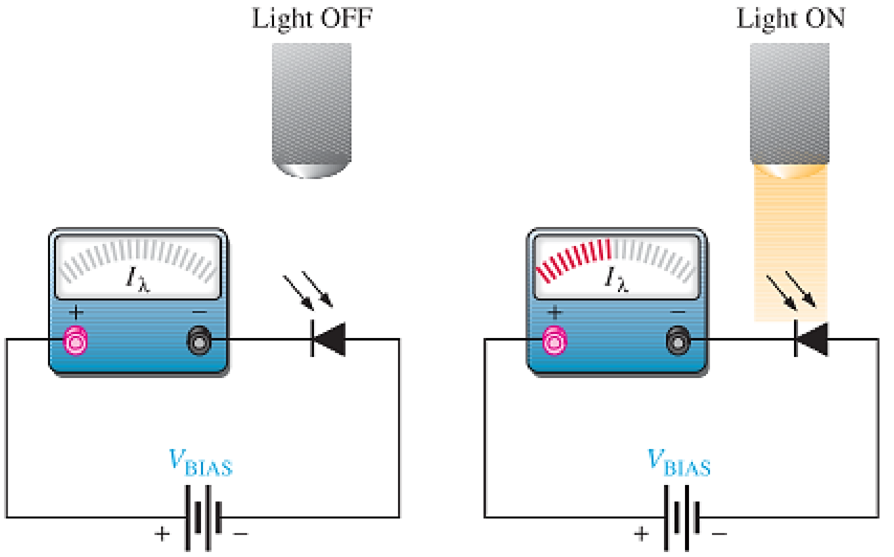


(a) Reverse-bias operation using standard symbol

(c) Alternate symbol



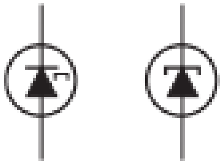
(b) Typical devices



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

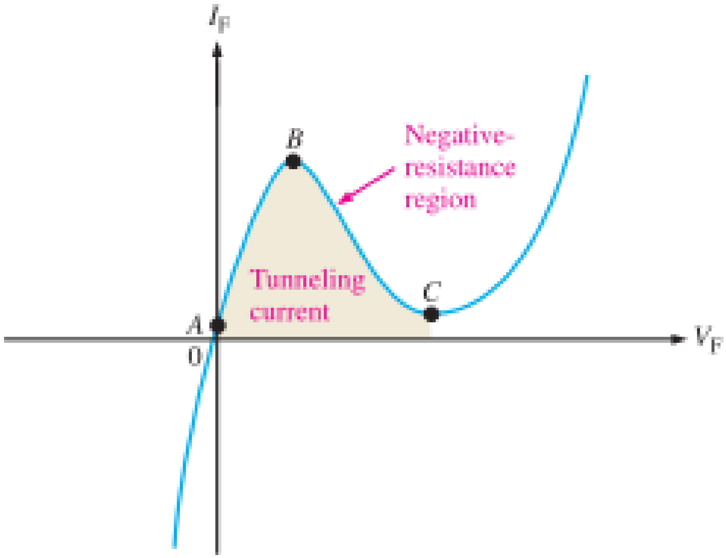
(b) Where there is incident light, resistance decreases and there is reverse current.

# Tunnel Diodes



▲ FIGURE 3–53

Tunnel diode symbols.



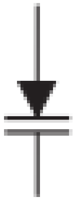
◀ FIGURE 3–54

Tunnel diode characteristic curve.

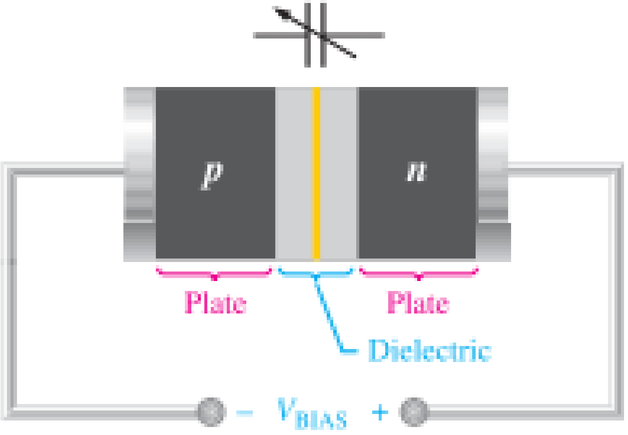
# Varactor Diode

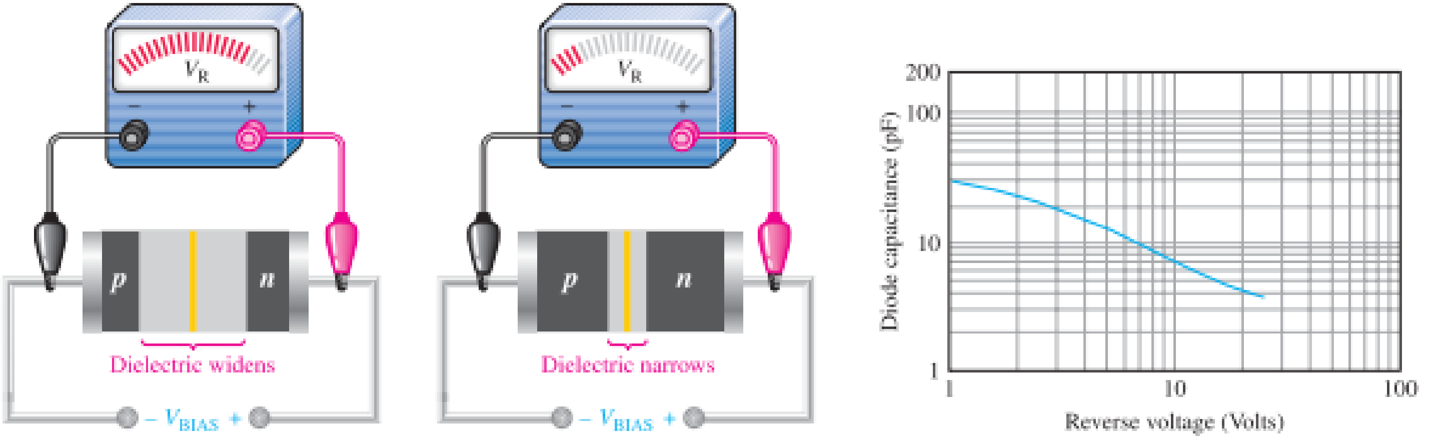
**FIGURE 3–21**

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



$$C = \frac{A\epsilon}{d}$$





(a) Greater reverse bias, less capacitance

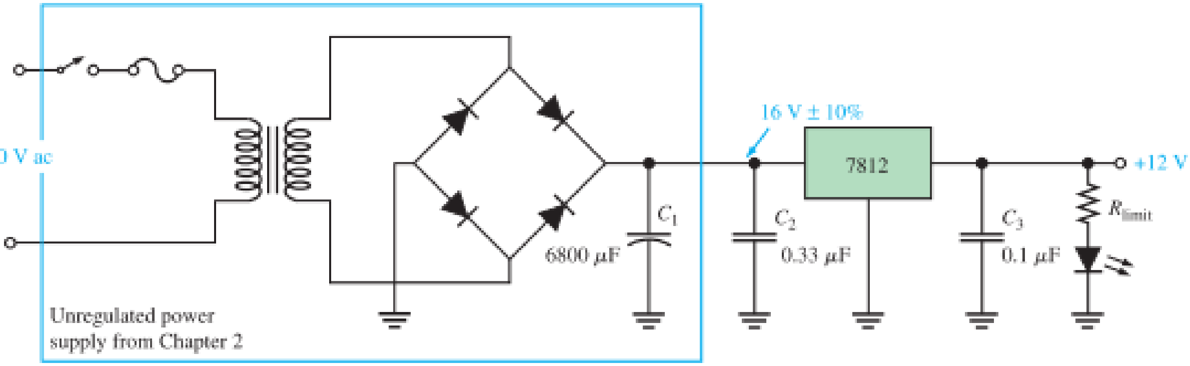
(b) Less reverse bias, greater capacitance

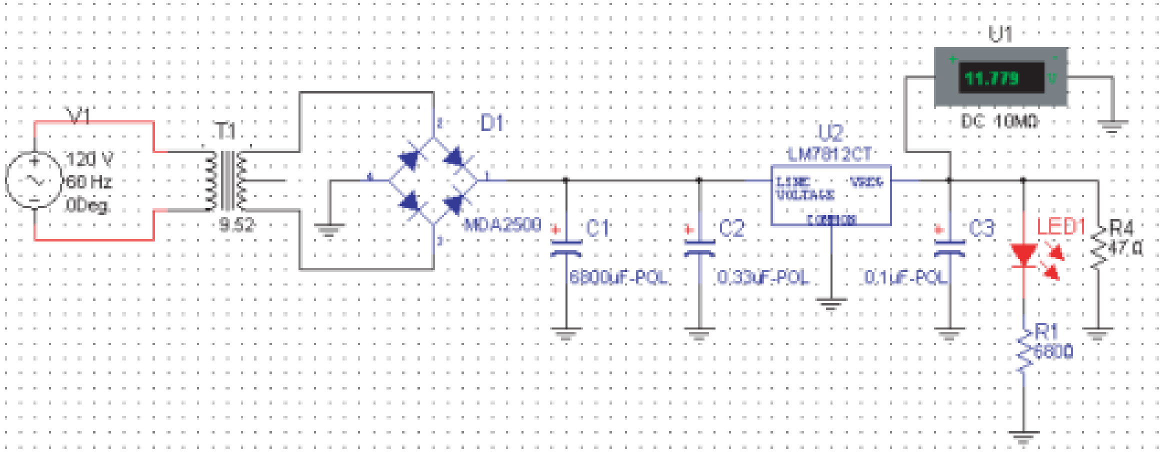
(c) Example of a diode capacitance versus reverse voltage graph

**FIGURE 3–22**

Varactor diode capacitance varies with reverse voltage.

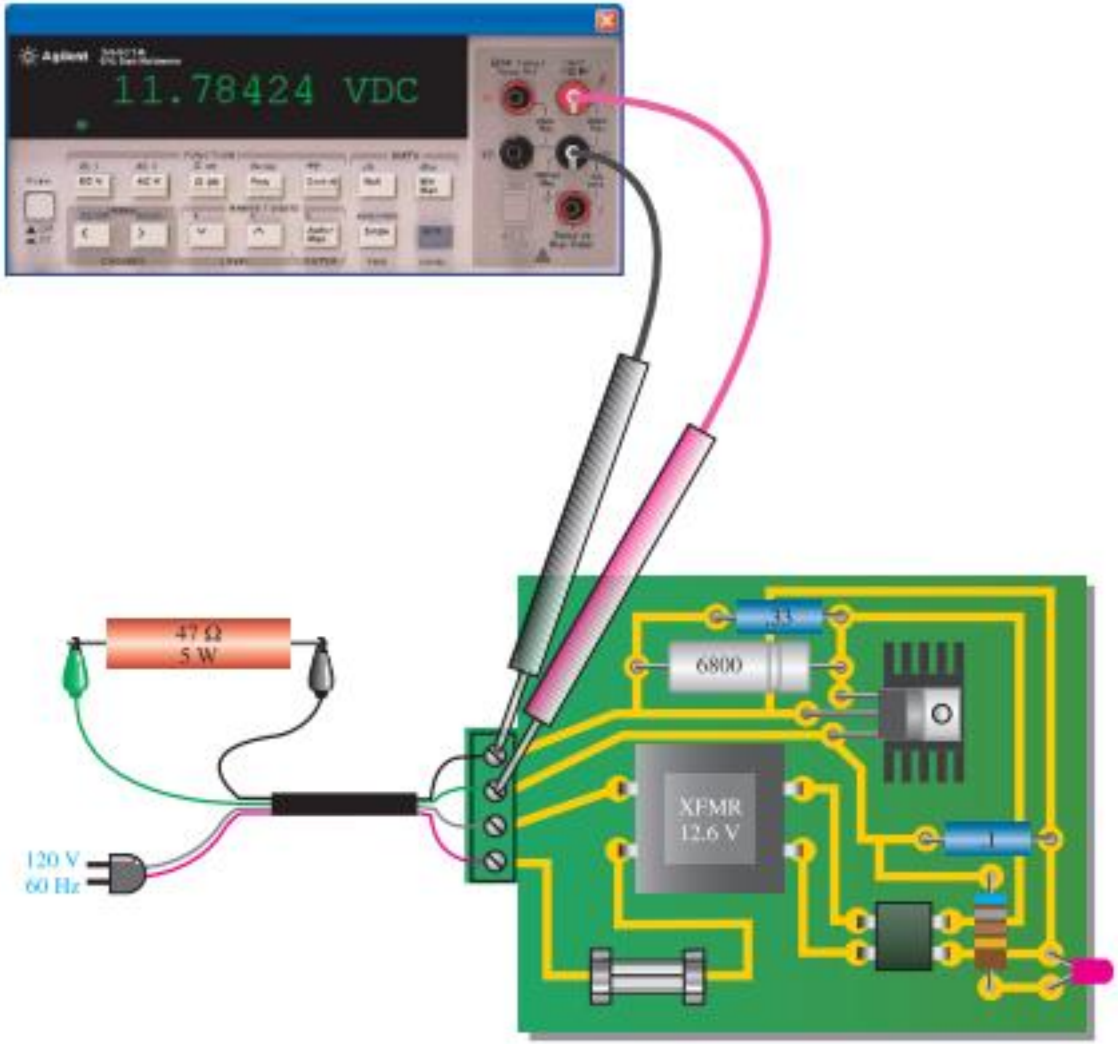
# Practical Applications
## 12v regulated Power Supply





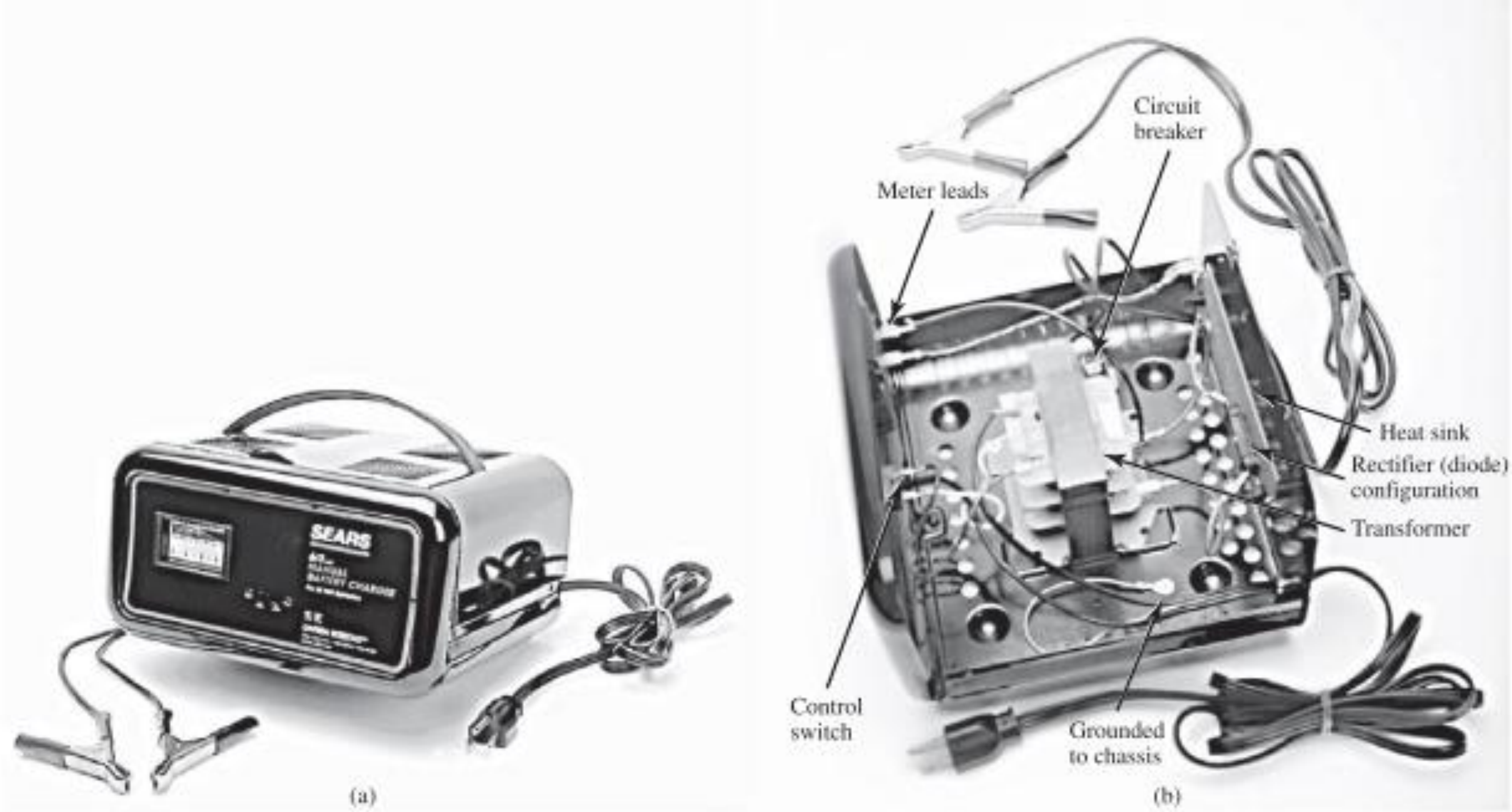
# Practical Applications

## 12v regulated Power Supply..



# Practical Applications

## Battery Charger



(a)

(b)

**FIG. 2.128**

*Battery charger: (a) external appearance; (b) internal construction.*

# Practical Applications

# Battery Charger..

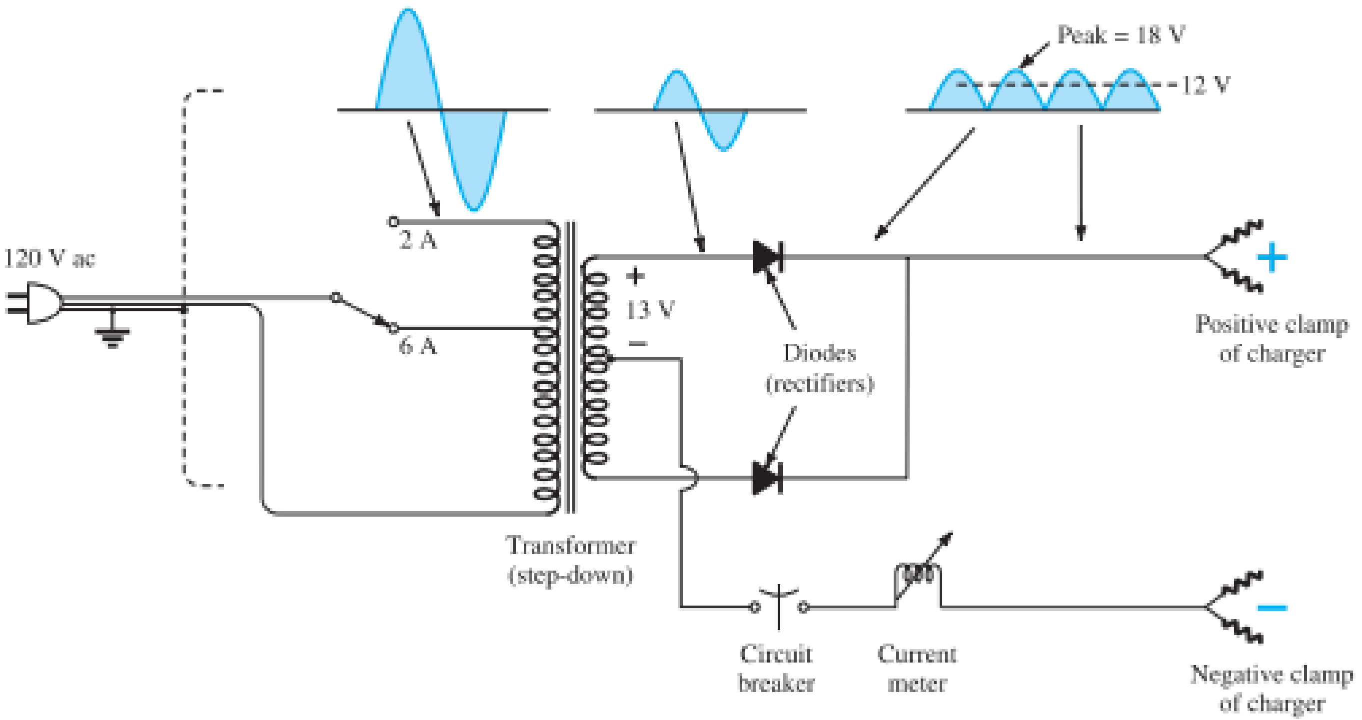


**FIG. 2.129**

*Electrical schematic for the battery charger of Fig. 2.128.*

# Practical Applications

# Diode Protection

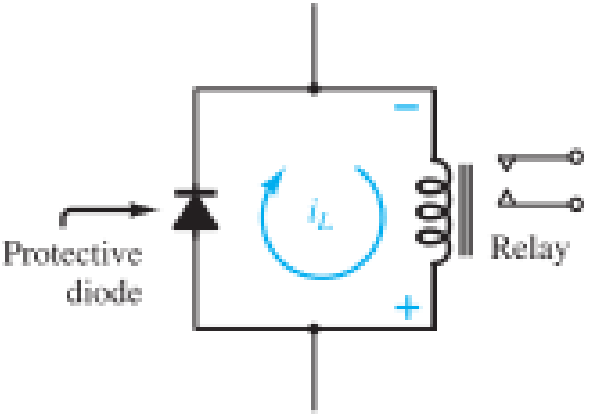


**FIG. 2.133**

*Diode protection for an RL circuit.*

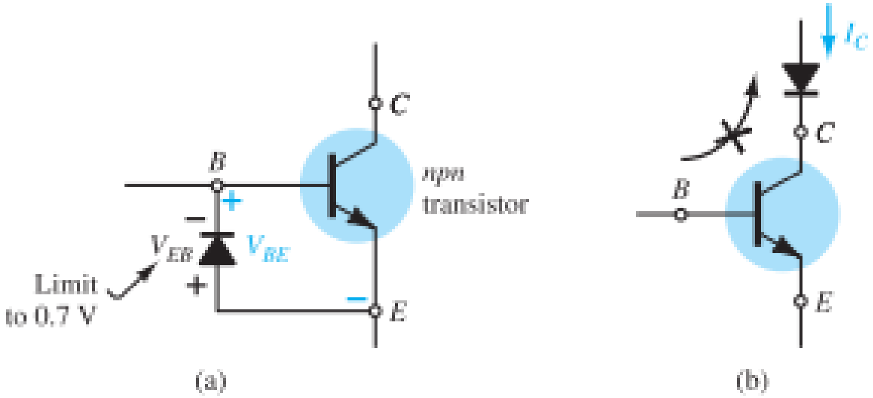
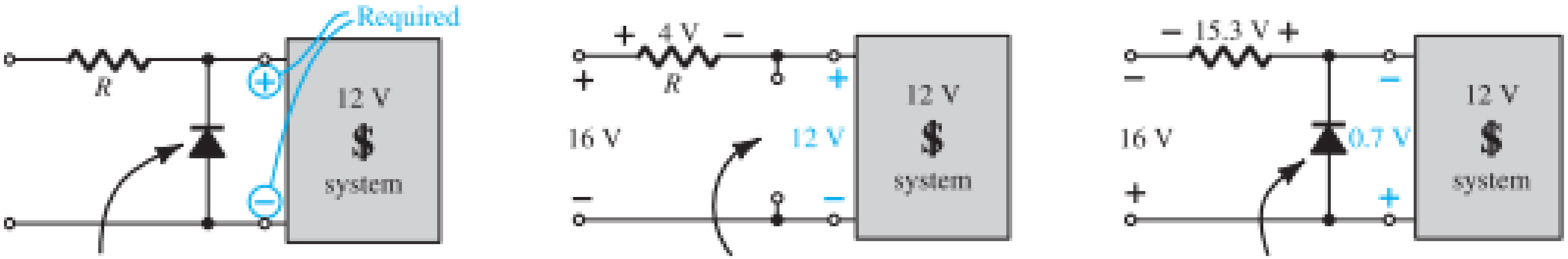


**FIG. 2.134**

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

# Practical Applications

# Polarity Insurance



Diode polarity protection

(a)

Diode open

(b)

Diode conducting

(c)

**FIG. 2.137**

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

# Practical Applications
## Controlled battery-powered backup

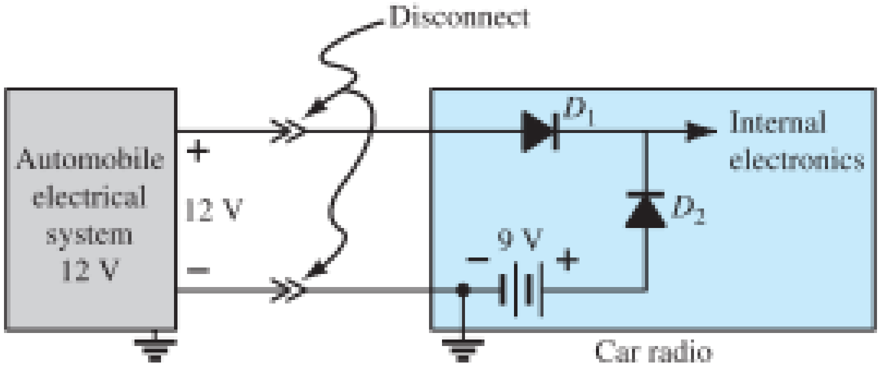


**FIG. 2.139**

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

# Practical Applications
# Polarity Detector

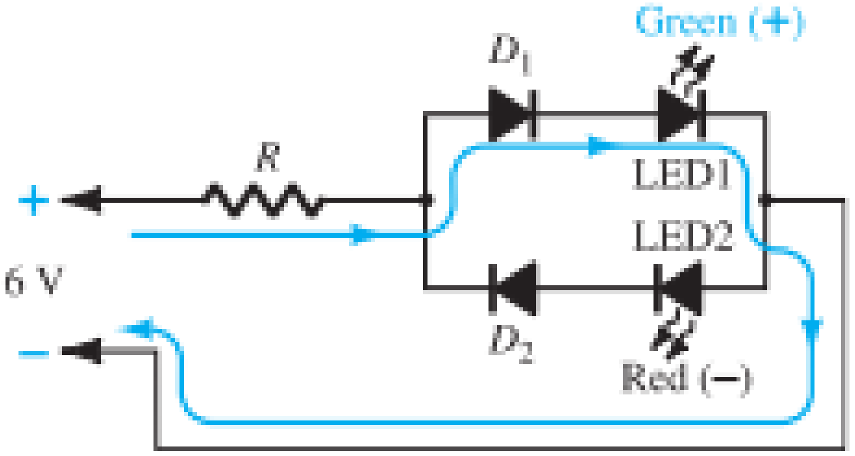


**FIG. 2.140**

*Polarity detector using diodes and LEDs.*

# Practical Applications

## Display

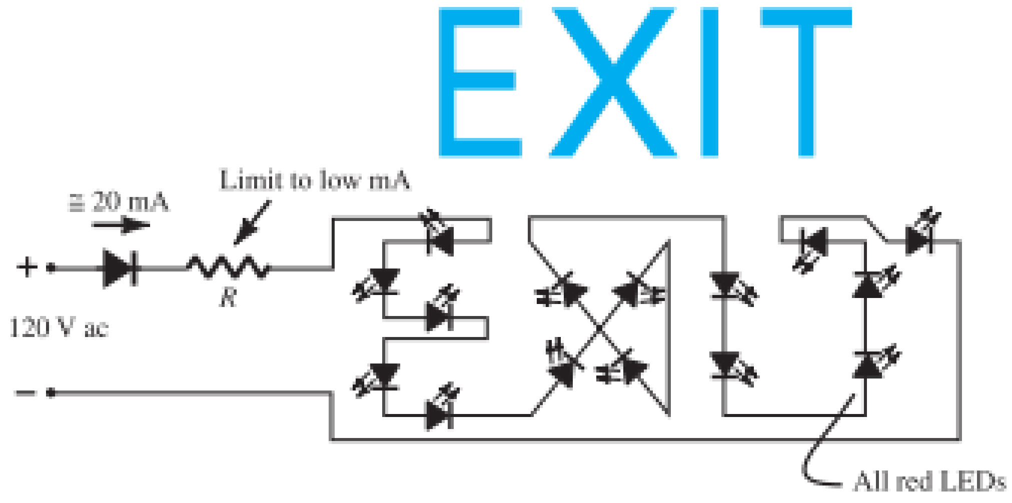


**FIG. 2.141**
*EXIT sign using LEDs.*

# Practical Applications

# Setting Voltage Reference Voltage

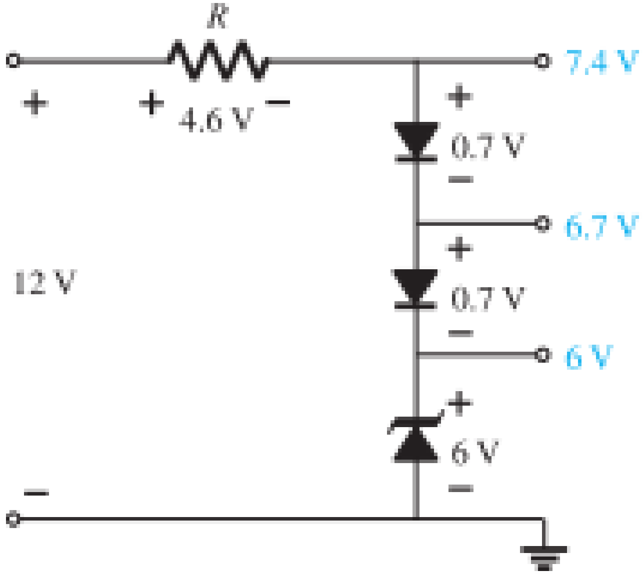


**FIG. 2.142**

*Providing different reference levels using diodes.*

# Practical Applications

# Square Wave Generator

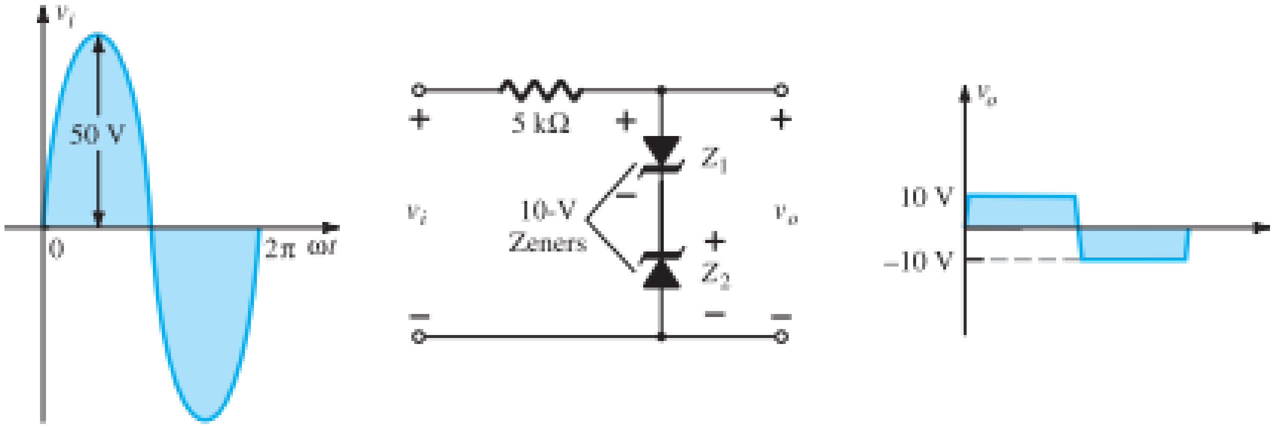


**FIG. 2.145**
*Simple square-wave generator.*

# References

- Floyd, chapters:1-3
- Boylestad, chapters: 1-2

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