ENG2210
Electronic Circuits

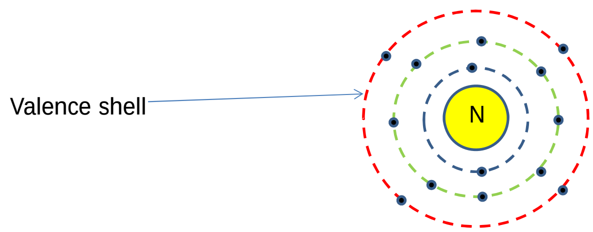
Mokhtar A. Aboelaze
York University

Chapter 3 Diodes

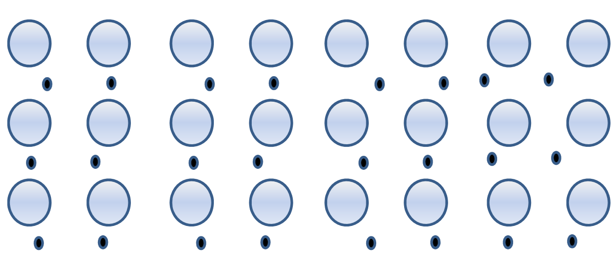
- **Objectives**
- Learn the characteristics of ideal diode and how to analyze and design circuits containing multiple diodes
- Learn the *i-v* characteristic of the junction diode
- Learn a simple model of the diode
- Learn the use of diodes operating in the forward and reverse bias region to provide constant dc voltage.
- Learn application of the diode in the design of rectifier circuits.

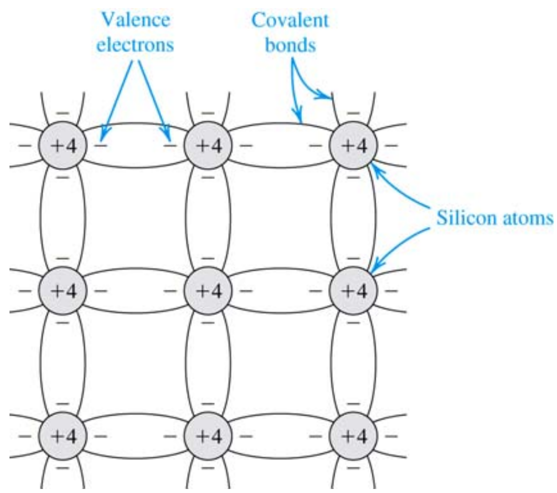
Atoms

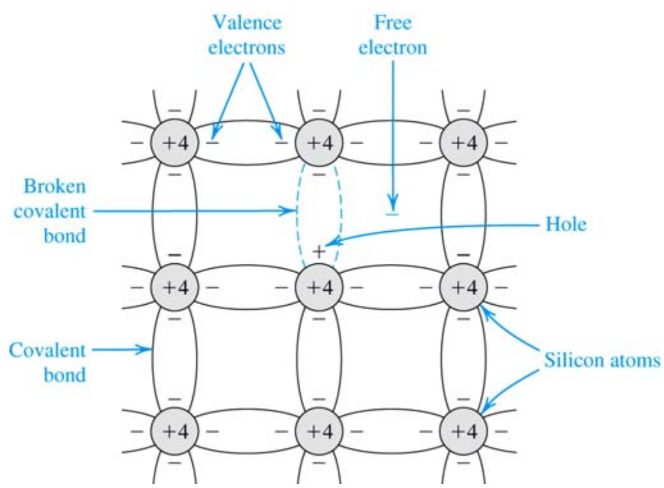
- Atoms consists of a positively charged nucleus and a number of negatively charged electrons rotating around the nucleus.
- Electrons are arranged in shells
- The electrons in the outer shell (<8) are called *valence electrons*.

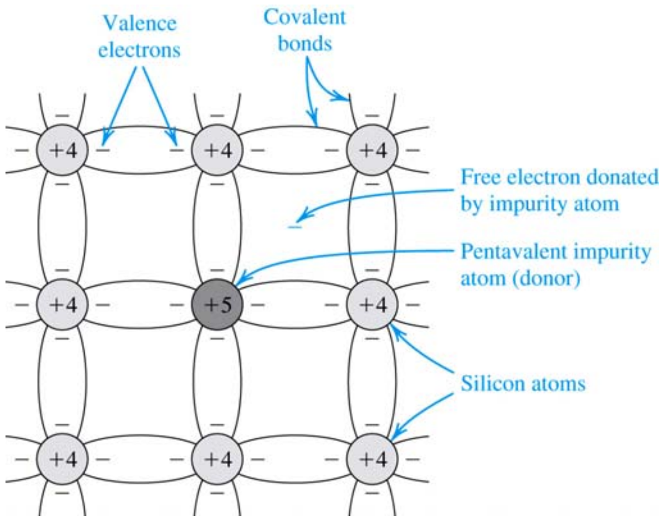


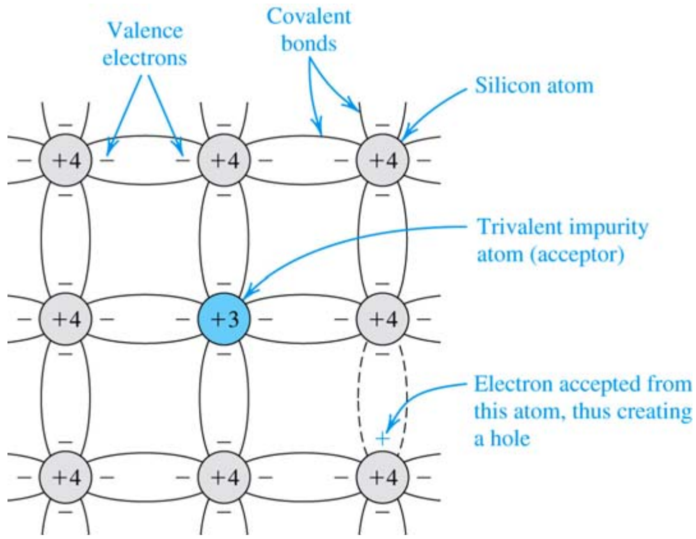
- Conductors: The valence electrons are free to move around.
- When applying an electric field, these electrons starts to move in the opposite direction of the filed (current).




Valence
electrons
Covalent
bonds
+4
Silicon atoms


Valence
electrons
Free
electron
Broken
covalent
bond
Hole
+4
Covalent
bond
Silicon atoms


Valence
electrons
Covalent
bonds
Free electron donated
by impurity atom
Pentavalent impurity
atom (donor)
Silicon atoms
+4
+5


Valence
electrons
Covalent
bonds
Silicon atom
Trivalent impurity
atom (acceptor)
Electron accepted from
this atom, thus creating
a hole
+4
+3

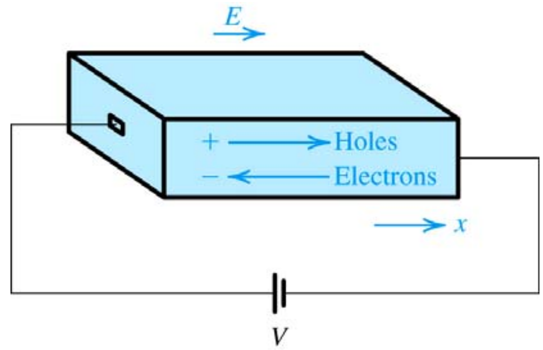
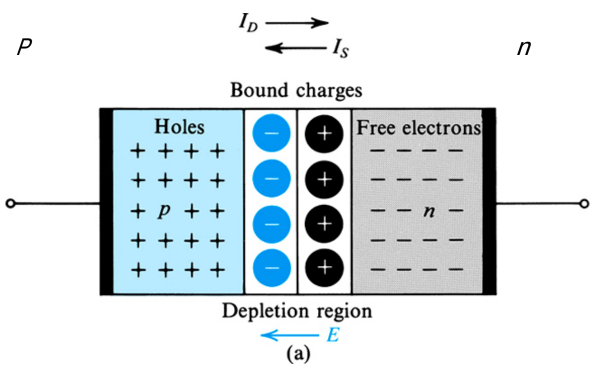
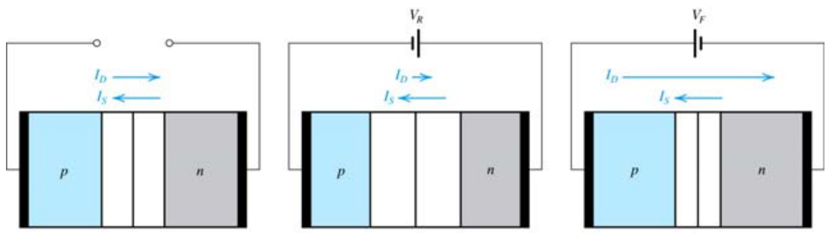


Figure 3.5 An electric field *E* established in a bar of silicon causes the holes to drift in the direction of *E* and the free electrons to drift in the opposite direction. Both the hole and electron drift currents are in the direction of *E*.

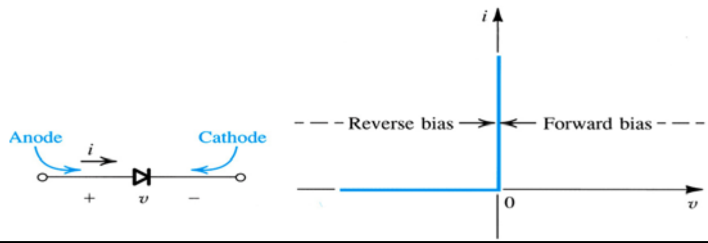
P *n*



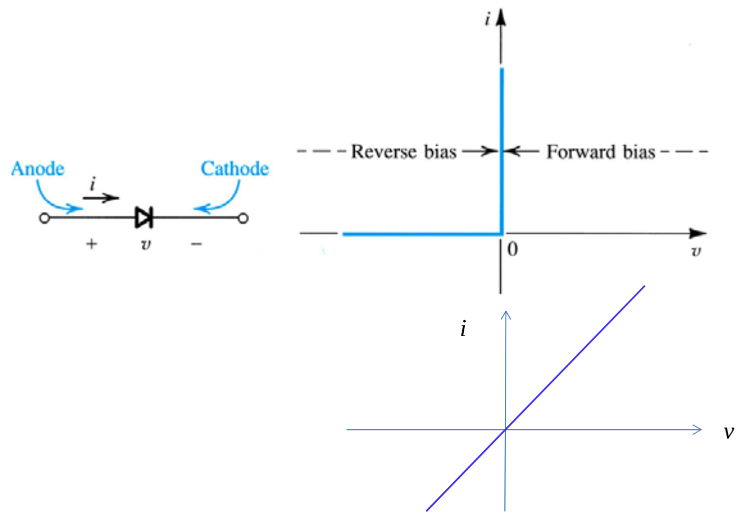


The Ideal Diode

- So far, we are dealing with linear elements.
- An ideal diode allows current to flow in only one direction, it has a resistance of ∞ in the other direction.
- Short circuit in one direction, and open circuit in the other direction

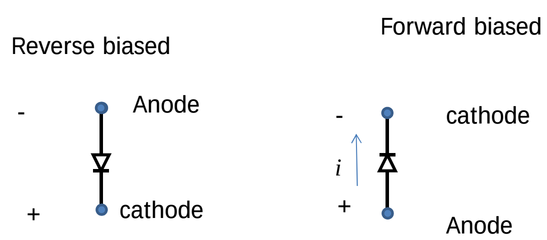


Ideal Diode



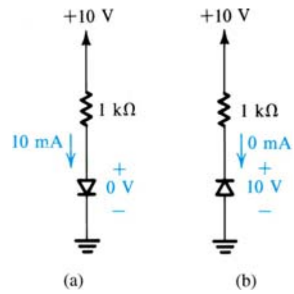
Diodes

- Conducts or not (ON or OFF) based on the relative polarity. Voltage drop across diode not voltage values.



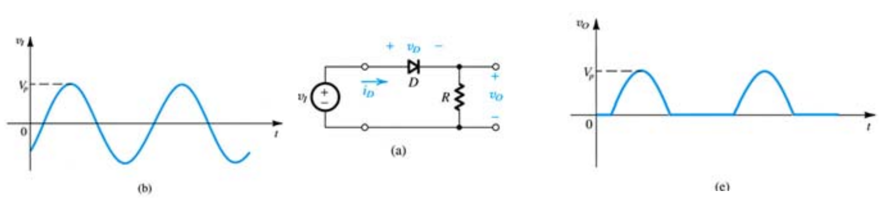
The Ideal Diode

- Forward biased R=0
- Reverse biased R=∞

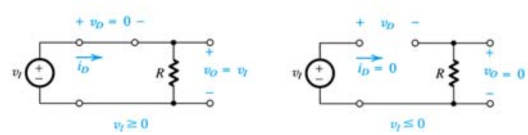


Rectifier

- A fundamental application of the diode is the rectifier.

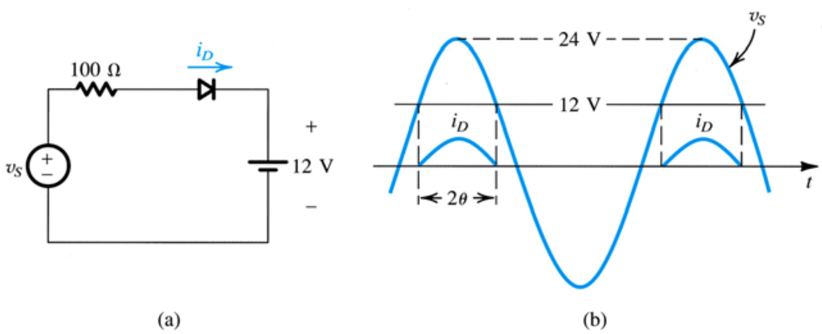


Plot v_D



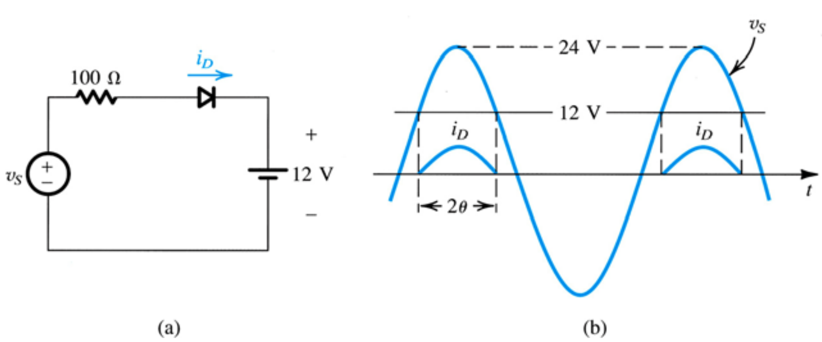
Charger

- When the diode is ON
- When the diode is OFF

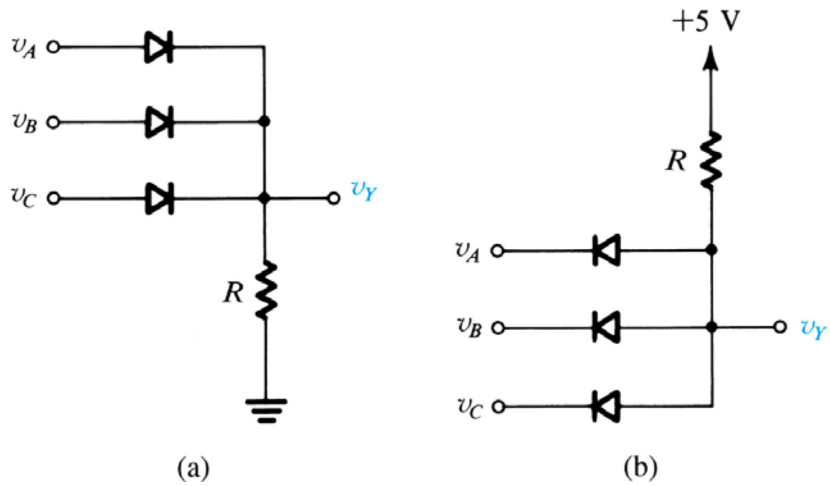


Example

- Find the peak diode current, maximum reverse-bias diode voltage, and the fraction of the cycle over which the diode is conducting

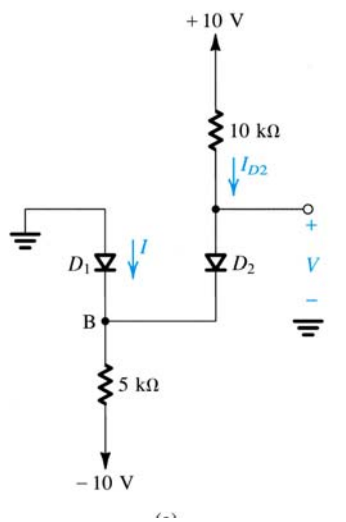


Logic Gates



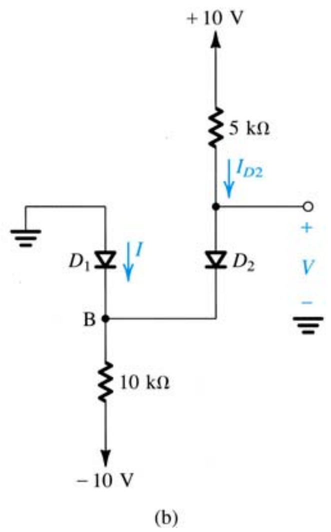
Example

- Make an assumption, then validate your assumption
- Both are ON
- VB=0 =V
- ID2=(10-0)/10K = 1mA
- 1mA+I=(0-(10))/5k
- I=1 mA
- Assumption is O.K.



Example

- Assume both ON
- VB=0=V
- ID2=(10-0)/5k =2mA
- ID2+I=(0- -10)/5=2 mA
- 2+I=10/10K=1mA
- I=-1 mA
- D1 is not ON, invalid assumption
- Try it for D1 OFF



Terminal Characteristics

Changes with temp

Sometimes v/nV_T

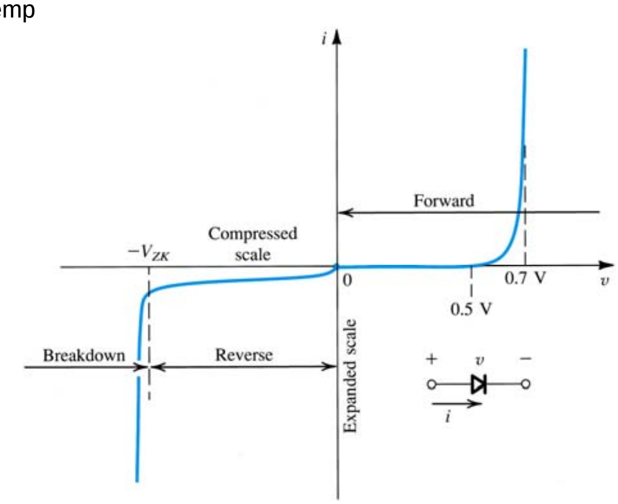
$$i = I_s\left(e^{v/V_T} - 1\right)$$

I_s Saturation current

$$V_T = \frac{KT}{q} \text{ Thermal voltage}$$

$$\text{if } v >> V_T, \quad i = I_s e^{v/V_T}$$

$$v = V_T \ln\frac{i}{I_s}$$



At room temperature, $V_T = 25.3$ mV

Compare this to an
ideal diode

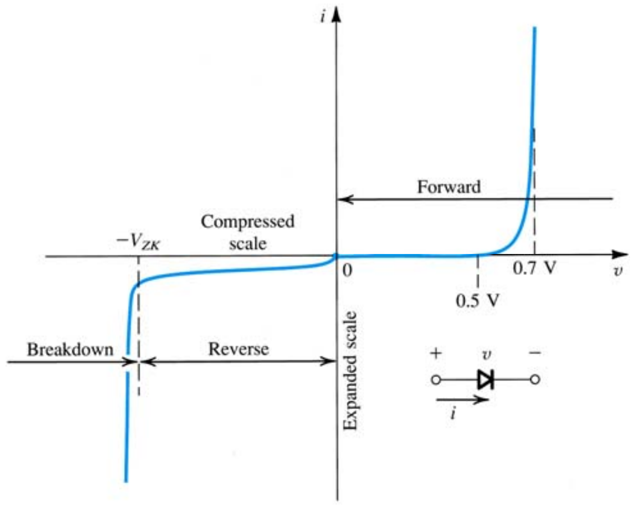


Figure 4.8 The diode i–v relationship with some scales expanded and others compressed in order to reveal details.

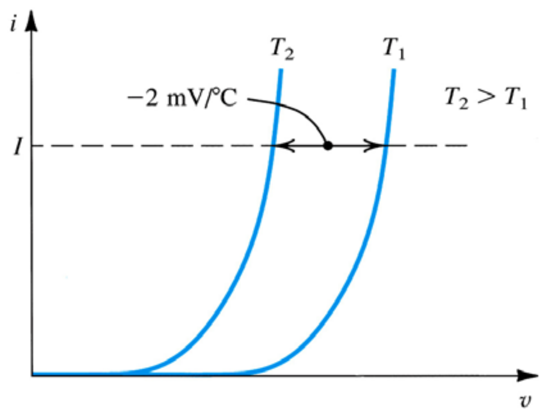


Figure 4.9 Temperature dependence of the diode forward characteristic. At a constant current, the voltage drop decreases by approximately 2 mV for every 1°C increase in temperature.

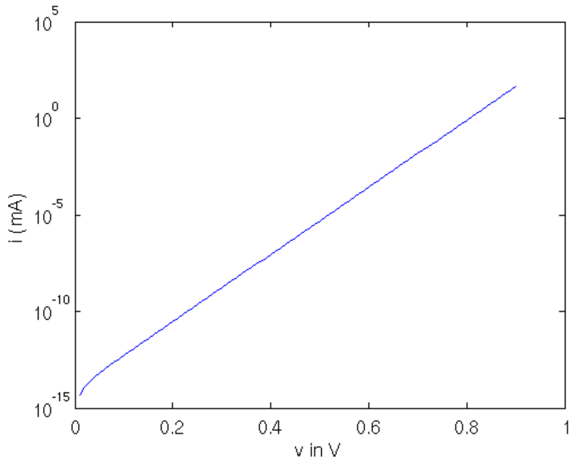
$$i_1 = I_s e^{v_1/V_T}$$

$$i_2 = I_s e^{v_1/V_T}$$

$$\frac{i_2}{i_1} = \frac{e^{v_2/V_T}}{e^{v_1/V_T}} = e^{\frac{v_2 - v_1}{V_T}}$$

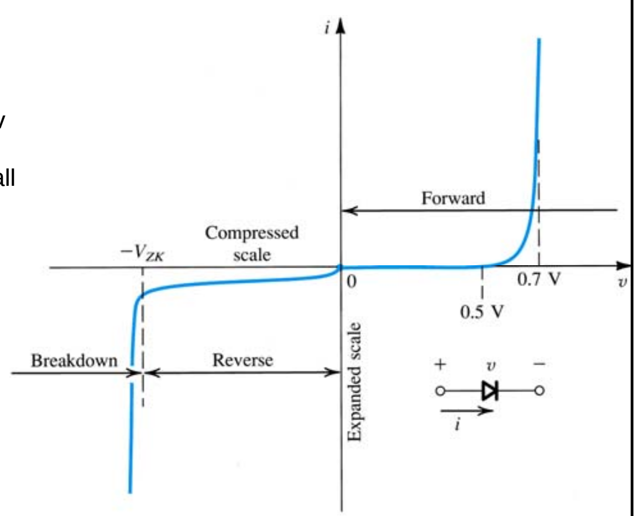
$$\ln\left(\frac{i_2}{i_1}\right) = \frac{v_2 - v_1}{V_T}$$

$$v_2 - v_1 = V_T \ln\left(\frac{i_2}{i_1}\right)$$



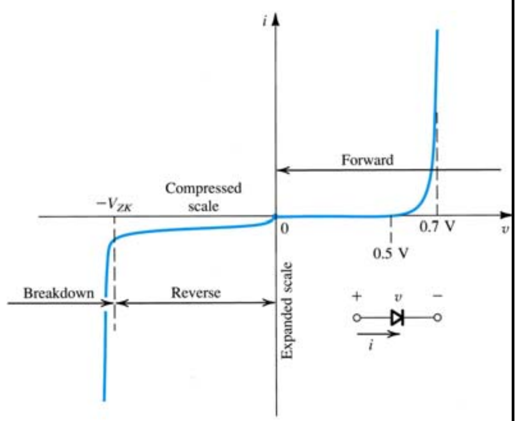
Reverse Bias Region

- In the reverse bias region, v << -v_T, the current is I_s
- In reality, the current is small but much bigger than I_S $I_{reverse}$ (1 nA), $I_s = 10^{-14}$
- The current also increases (slightly) with decreasing v
- Increases with temperature (doubles every 10 rise)



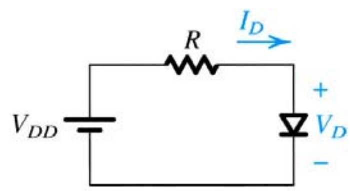
The Breakdown Region

- The current I increases rapidly with almost no change in voltage drop
- It is normally not destructive if the power dissipation is limited
- This is useful for voltage regulation



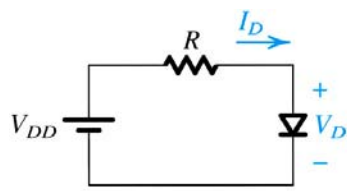
Diode Models

- Diode can be modeled in different ways depends on the application (and the required accuracy).
  - Exponential model
  - Constant voltage drop model
  - Ideal diode model
  - Piecewise Linear Model
  - Small signal model



The exponential Model

- Most accurate, but highly nonlinear
- Assume diode voltage greater than 0.5V
- The diode current is $I_D = I_s e^{V_D/V_T}$
- Also, the diode current is $I_D = \frac{V_{DD} - V_D}{R}$
- Solve these 2 equations



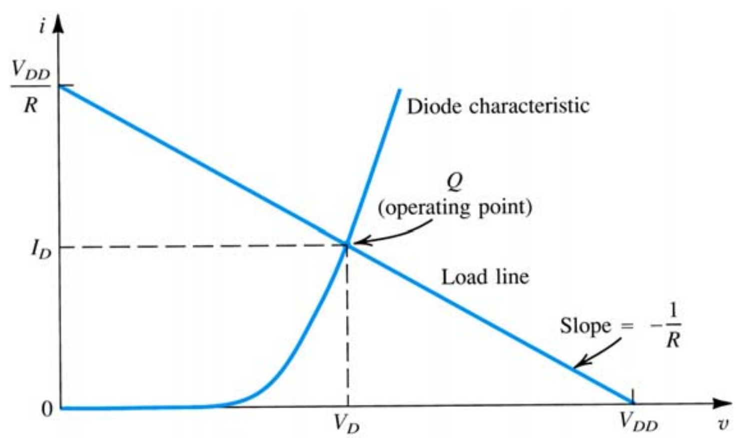
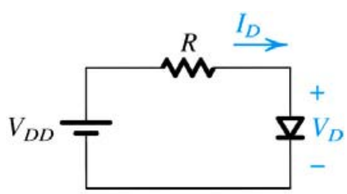
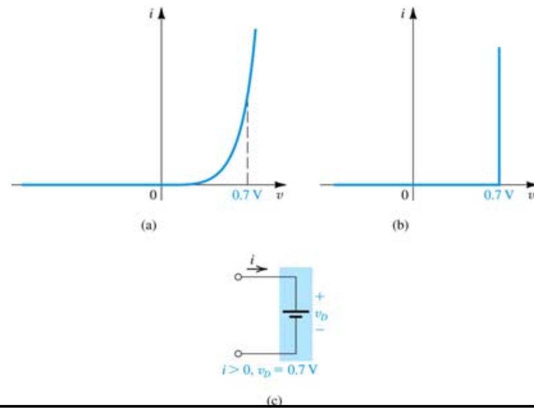


Figure 4.11 Graphical analysis of the circuit in Fig. 4.10 using the exponential diode model.

Constant Voltage Drop Model

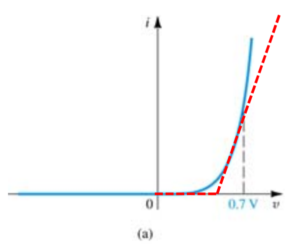
- Assume that if the diode is ON, it has a constant voltage drop (0.7V)





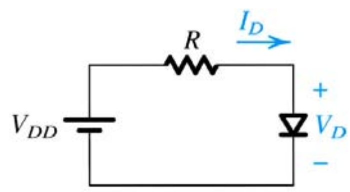
Piecewise Linear Model

- Constant voltage up to ~0.5V then resistor

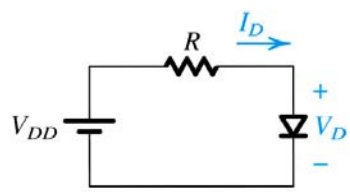


Ideal Diode Model

- Similar to constant voltage drop, but the voltage drop is 0 V



Find ID and VD for VDD = 5V, R=1KΩ
Assume 0.7 V at 1-mA Use iteration



Design a circuit to provide output voltage of 2.4V
(0.7 V at 1 mA)

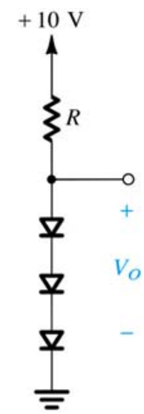
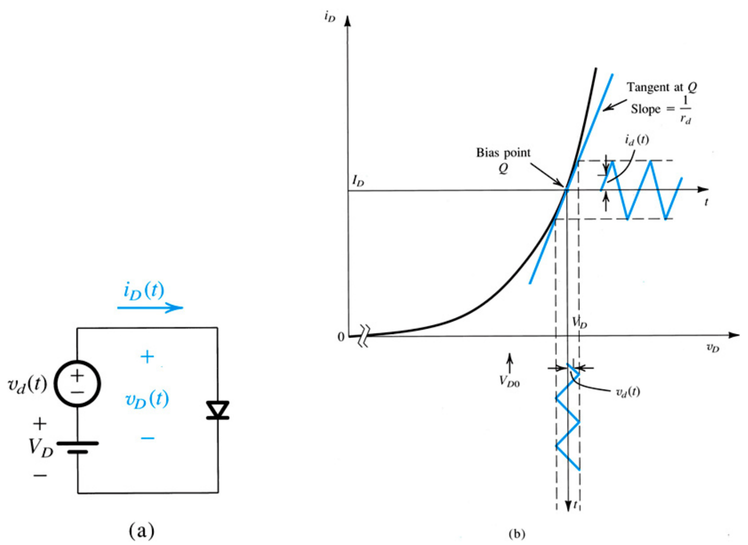


Figure E4.11

Small Signal Model



Solve

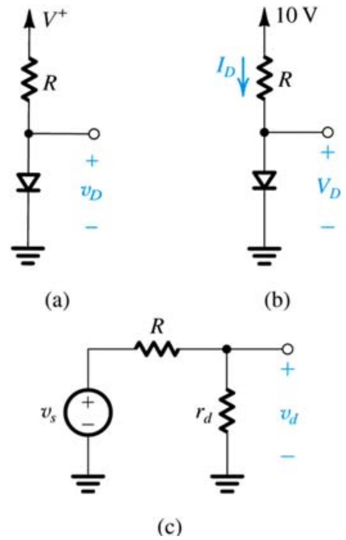


Figure 4.14 (a) Circuit for Example 4.5. (b) Circuit for calculating the dc operating point. (c) Small-signal equivalent circuit.

Voltage Regulator (forward bias)

- A voltage regulator is a circuit that provides a constant DC voltage even with the changes of the load resistance or the source resistance.
- Since the diode in the forward bias region have a constant voltage with relatively large changes in current, it could be used as a voltage regulator

Solve

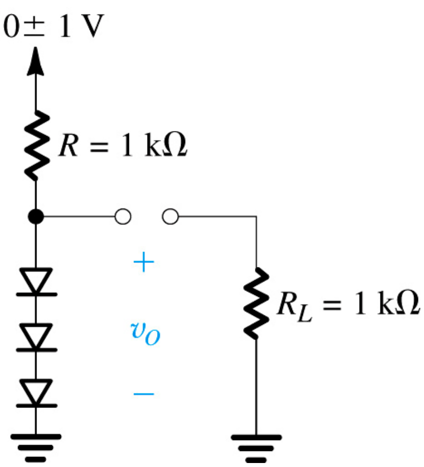


Figure 4.15 Circuit for Example 4.6.

Solve

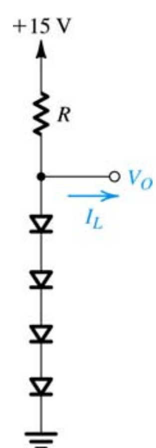
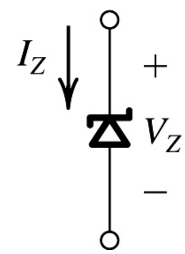


Figure E4.15

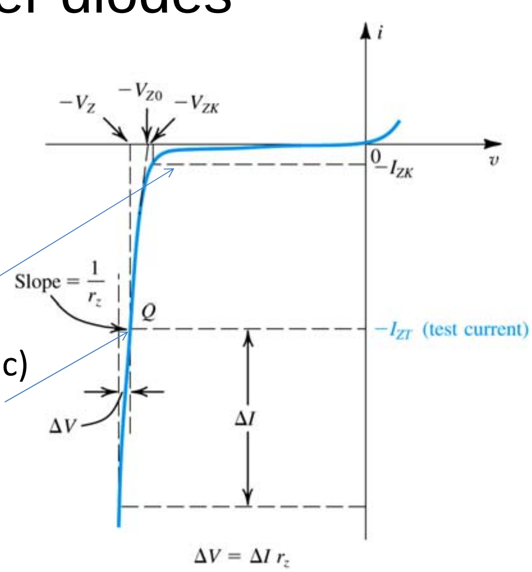
Zener Diode

- Diodes that are designed to operate in the reverse breakdown region.
- Used for low current regulators (although regulators chips are widely used now).



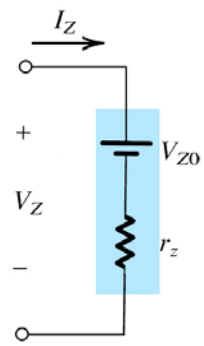
Zener diodes

- Characterized by
  - V_z at a specified test current I_{ZT}
  - Maximum power
  - Knee current I_{KZ}
  - Incremental (dynamic) resistance $r_z = \Delta V/\Delta I$



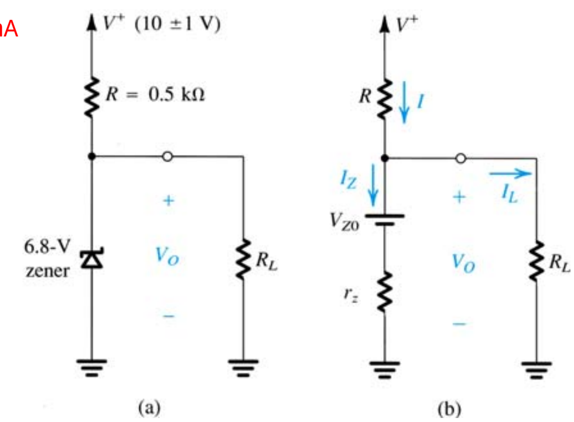
Zener Diodes

- Equivalent circuit
- VZ0 in practice is the same as the knee voltage



Assume a 6.8-V Zener diode with V_Z=6.8 at I_z=5mA, r_z=20 Ω, I_{ZK} = 0.2 mA, V^+ =10V± 1V

- Find VO and the line regulation at no load
- Find the load regulation when the load current is 1mA
- Find VO for R=2 KΩ, 0.5KΩ
- Find the minimum load for the diode to operate in the breakdown region



Changing amplitude and ***Electrical isolation***

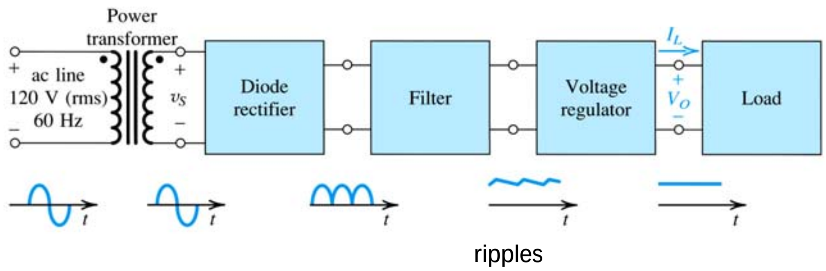
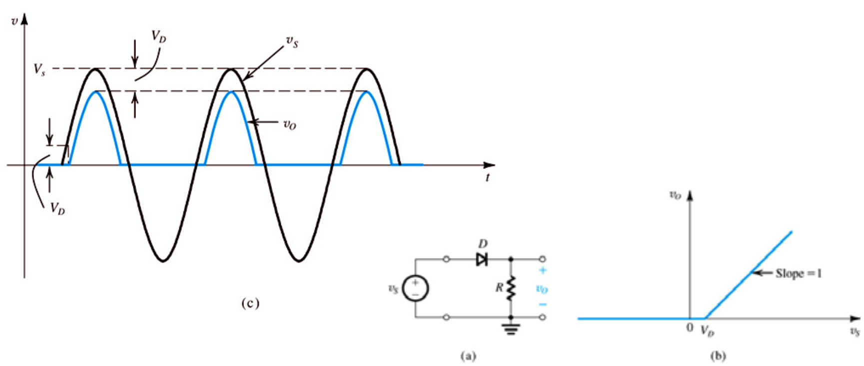


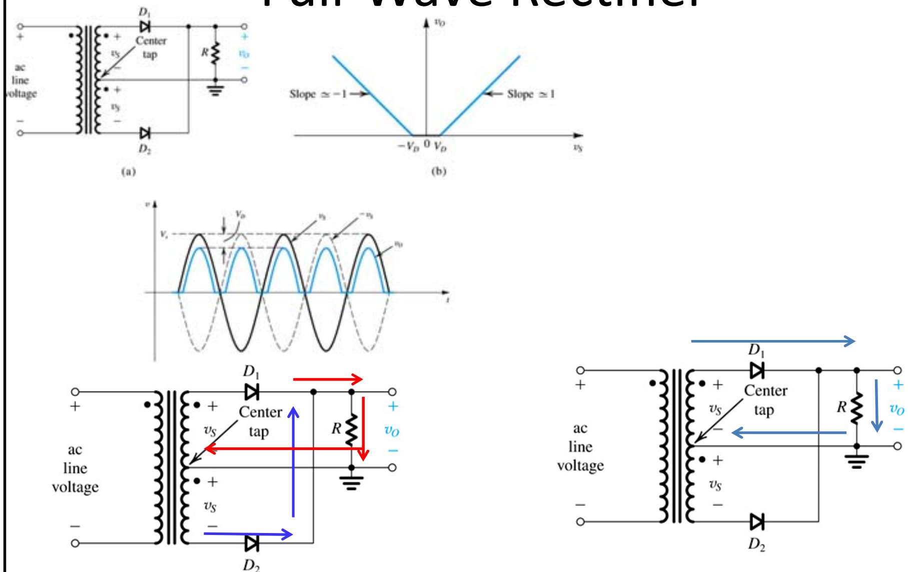
Figure 4.20 Block diagram of a dc power supply.

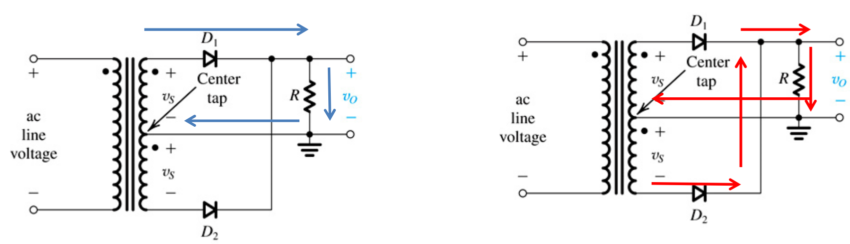
Half-Wave Rectifier

- Removes the negative voltage half cycle
- Peak inverse voltage < breakdown voltage

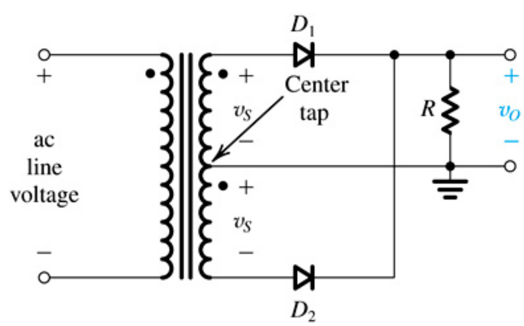


Full-Wave Rectifier





PIV ?



Bridge Rectifier

PIV ?

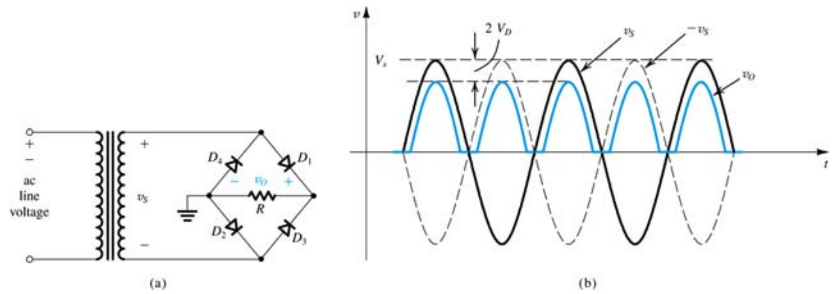


Figure 4.23 The bridge rectifier: (a) circuit; (b) input and output waveforms.

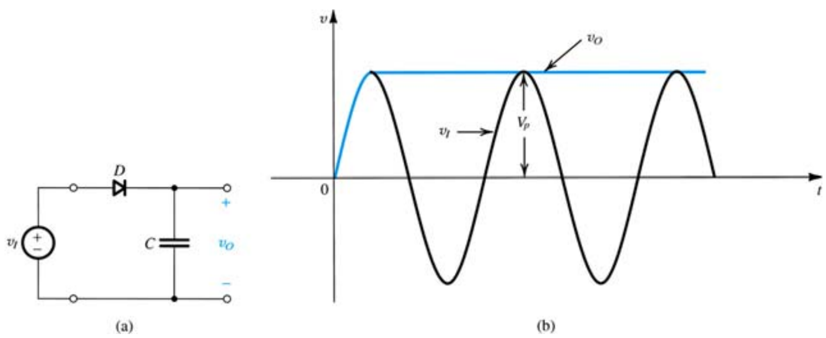


Figure 4.24 (a) A simple circuit used to illustrate the effect of a filter capacitor. (b) Input and output waveforms assuming an ideal diode. Note that the circuit provides a dc voltage equal to the peak of the input sine wave. The circuit is therefore known as a *peak rectifier* or a *peak detector*.

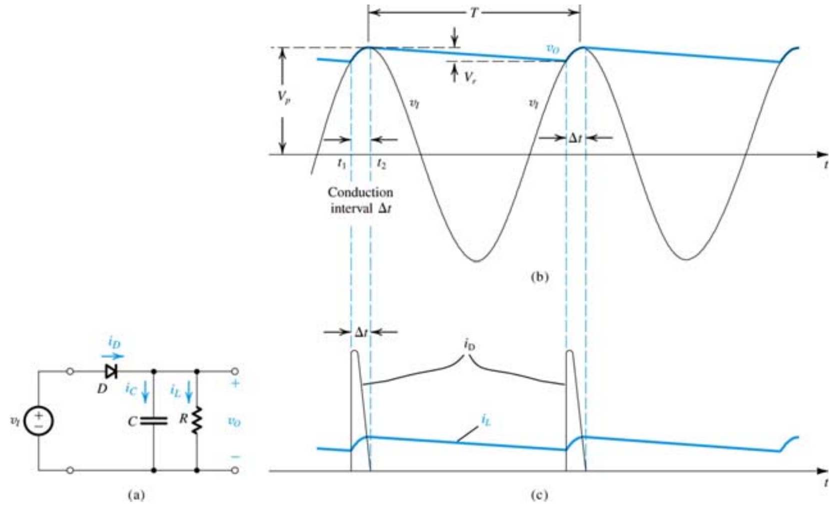


Figure 4.25 Voltage and current waveforms in the peak rectifier circuit with $CR \gg T$. The diode is assumed ideal.

Microelectronic Circuits, Sixth Edition Sedra/Smith

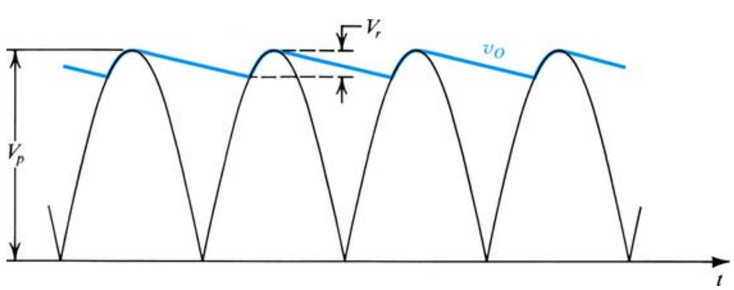


Figure 4.26 Waveforms in the full-wave peak rectifier.

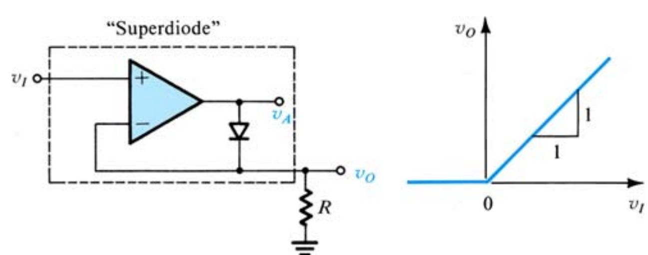
Microelectronic Circuits, Sixth Edition Sedra/Smith

Superdiode

- There is one or 2 diode voltage drops in the rectifier circuits we studied.
- That is O.K. when we are designing a DC power supply.
- Can not be used to rectify a small voltage signal (100 mV).

Superdiode

- When v_I is positive, v_A is positive, the diode conducts providing the –ve feed back and $v_O = v_I$
- When v_I is –ve v_A is negative diode is reverse biased, no current in R no drop on R, $v_o = 0$



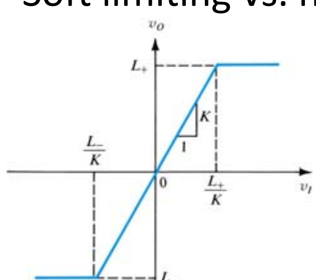
(a) (b)

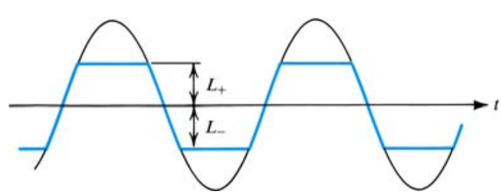
Diode Circuits

- Limiter circuits
- Clamped capacitor or DC restorer
- Voltage doubler

Limiter Circuits

- K could be > 1, but we concentrate of k<=1 (passive limiter)
- Also known as clippers
- Soft limiting vs. hard limiting





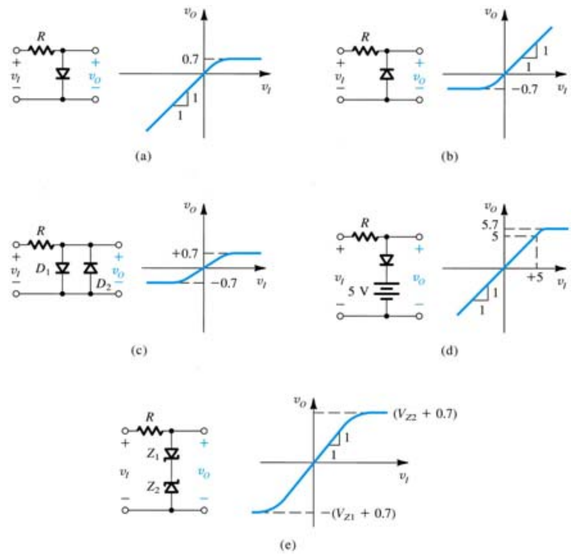


Figure 4.31 A variety of basic limiting circuits.

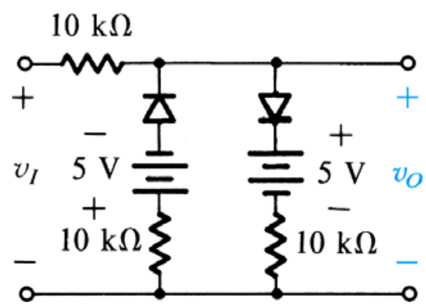
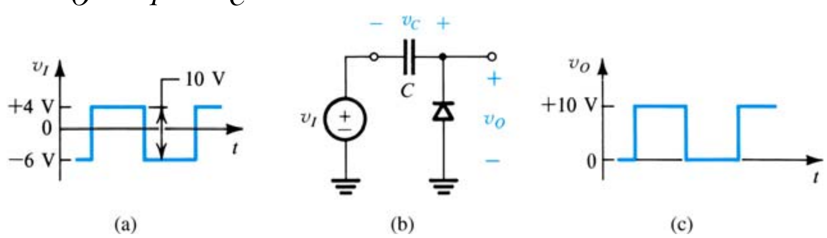


Figure E4.26

Clamped Capacitor (DC restorer)

- Shifts the input signal by a specific amount
- When v_I is -6, v_C = 6 V as shown
- When v_I is +4, diode is off and capacitor does not discharge
- $v_O = v_I + v_C$



Clamped Capacitor with a Load

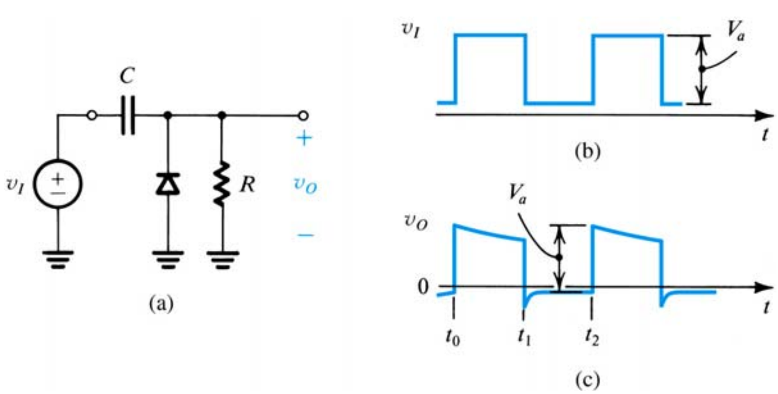


Figure 4.33 The clamped capacitor with a load resistance *R*.

Voltage Doubler

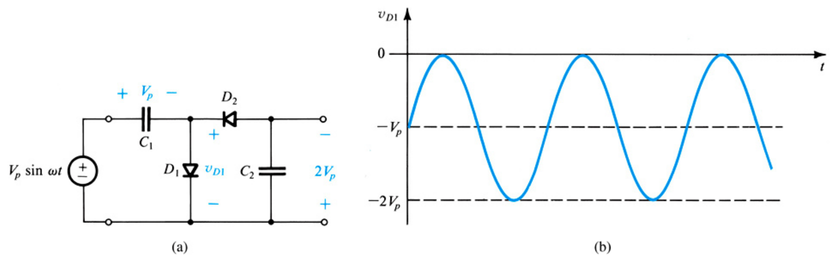


Figure 4.34 Voltage doubler: (a) circuit; (b) waveform of the voltage across D_1.

