DIODES

- The simplest and the most fundamental non-linear circuit element is the diode.

- Just like a resistor a diode is a two terminal device.

- But unlike the resistor which has a linear (straight line) characteristic between the current flowing through it and the voltage across it, the diode has a nonlinear I-V characteristics.

- Of the many applications of diodes, their use in the design of rectifier (which converts AC to DC) is the most common.

The Ideal Diode

Current Voltage Characteristic

- The ideal diode may be considered the most fundamental non-linear circuit element.
- It is a two terminal device having circuit symbol of Fig 3.1 (a) and the i-v characteristic shown in Fig. 3.1 (b). The terminal characteristic of the ideal diode can be interpreted as follows:
- If a negative voltage is applied to the diode, no current flows and the diode behaves as an open circuit (Fig. 3.1 (c)). Diodes operated in this mode are said to be **reverse biased**, or operated in the reverse direction. An ideal diode has zero current when operated in the reverse direction and is said to be **cut-off** or simply **off**.
- On the other hand, if a positive voltage is applied to then ideal diode, zero voltage drop appears across the diode. In other words, the ideal diode behaves as a short circuit in the forward direction (Fig. 3.1 (d)); it passes any current with zero voltage drop.
- A **forward-biased** diode is said to be **turned on**, or simply **on**.
- The positive terminal of the diode is called the **anode** and the negative terminal of diode is called the **cathode**.

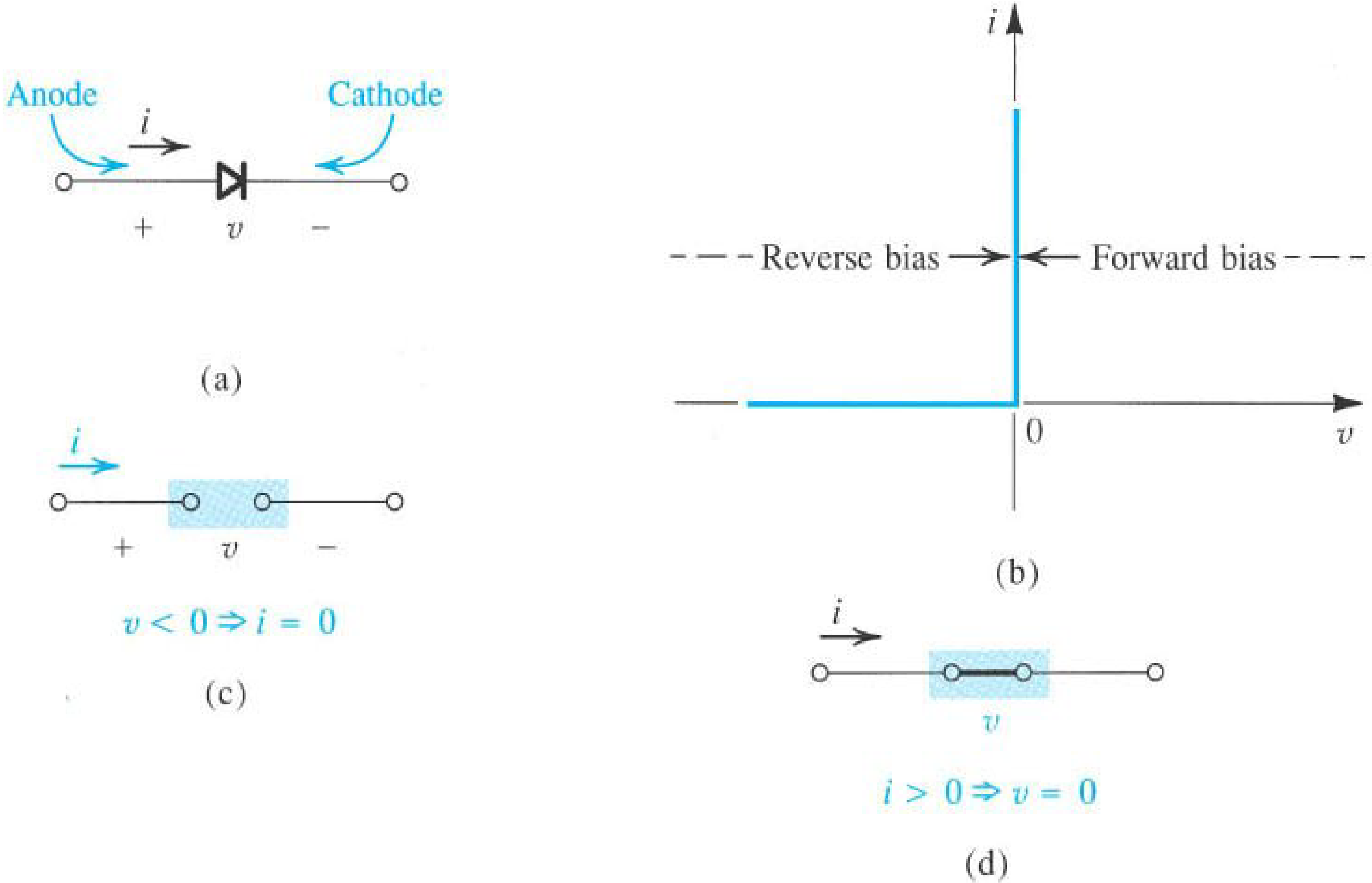


Figure 3.1 The ideal diode: **(a)** diode circuit symbol; **(b)** i–v characteristic; **(c)** equivalent circuit in the reverse direction; **(d)** equivalent circuit in the forward direction.

Terminal Characteristics of Junction Diodes

Figure 3.7 shows the i-v characteristic of a silicon junction diode.

The same characteristic is shown in Fig. 3.8 with some scales expanded and the others compressed to reveal details.

The characteristic curve consists of the three distinct regions:

1. The forward-bias region, determined by $v > 0$

2. The reverse-bias region, determined by $v < 0$

3. The breakdown region, determined by $v < -V_{ZK}$

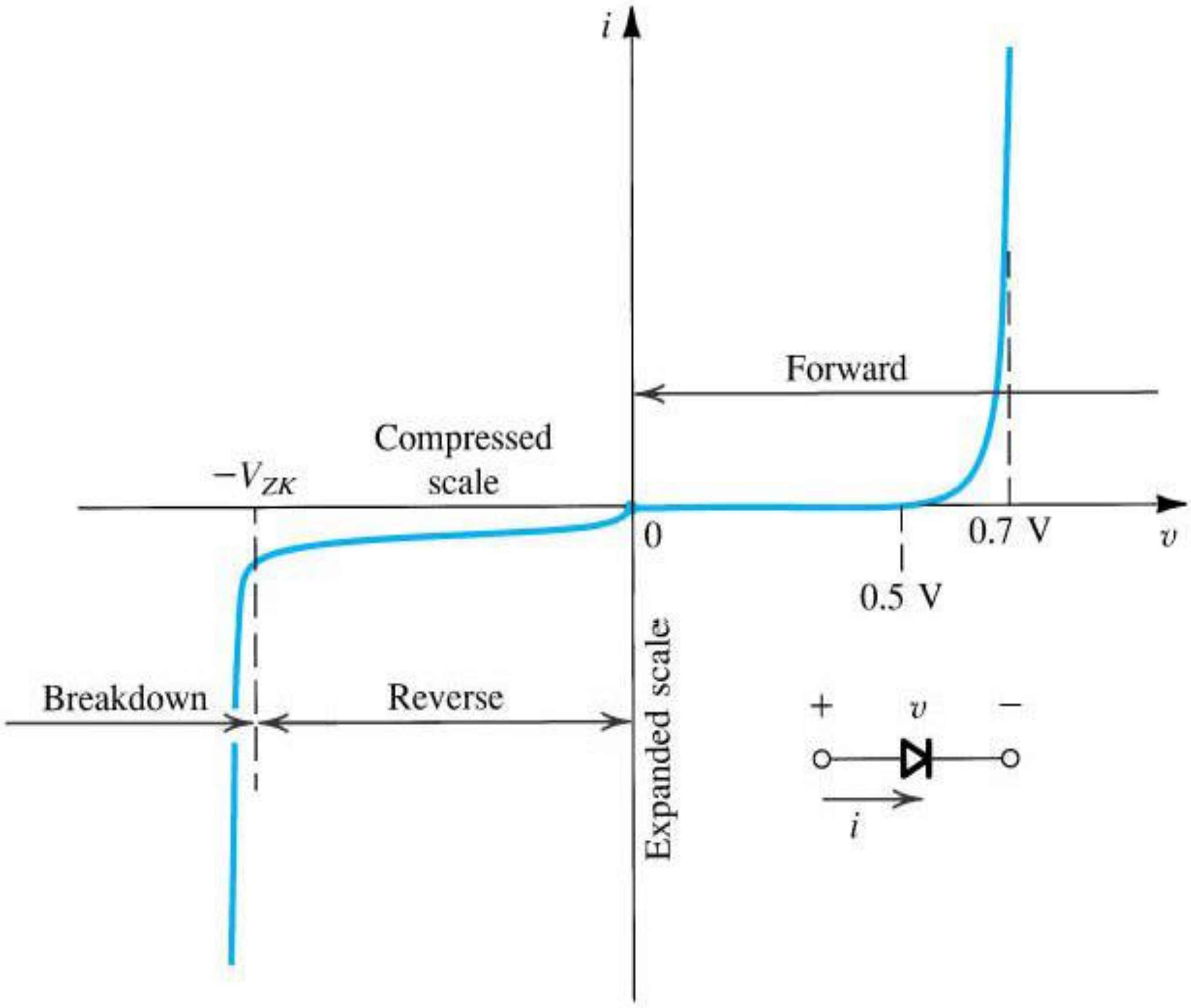


Figure 3.8 The diode i–v relationship with some scales expanded and others compressed in order to reveal details.

The Forward-Bias Region

- The forward bias or simply forward-region of operation is entered when the terminal voltage v is positive. In the forward region the i-v relationship is closely approximated by
- $i = I_S\left(e^{v/nV_T} - 1\right)$

- In this equation I_S is a constant for a given diode at a given temperature. The current I_S is usually called the saturation current.

- The value of I_S is however a very strong function of temperature.

- As a rule of the thumb, I_S doubles in value for every 5°C rise in temperature

.

- The voltage V_T is a constant called the thermal voltage and is given by

$$V_T = \frac{kT}{e}$$

Where
k = Boltzmann's constant = 1.38 x 10^{-23} joules / kelvin.
T = the absolute temperature in kelvins = 273 + temperature in ^{0}C.
e = the magnitude of electronic charge = 1.60 x 10^{-19} Coulomb.

- At the room temperature (20°C) the value of V_T is 25.2 mV. In rapid approximation we shall use V_T = 25 mV at room temperature.

- In the diode equation the constant n has a value between 1 and 2, depending upon the material and the physical structure of diode. Diodes made using standard integrated circuit fabrication process exhibit n = 1 when operated under normal conditions.

- Diodes available as discrete two-terminal components generally exhibit n = 2. In general we shall assume n = 1 unless otherwise specified.

- For appreciable current i in the forward direction, specifically for i >> IS the above diode equation can be approximated by the exponential relationship

$$i = I_S e^{v/nV_T}$$

This relationship can be expressed alternatively in the logarithmic form

$$v = nV_T In \frac{i}{I_S}$$

Let us consider the forward i-v relationship and evaluate the current I_1 corresponding to a diode voltage V_1

$$I_1 = I_S e^{V_1/nV_T}$$

Similarly, the current I_2 for a corresponding diode voltage V_2 is given as

$$I_2 = I_S e^{V_2/nV_T}$$

Dividing we get

$$\frac{I_2}{I_1} = e^{(V_2 - V_1)/nV_T}$$

Which can be rewritten as

$$V_2 - V_1 = nV_T \ ln \frac{I_2}{I_1}$$

Or

$$V_2 - V_1 = 2.3 \, nV_T \ log10 \frac{I_2}{I_1}$$

Modelling the Diode Forward Characteristic

The Exponential Model

The most accurate description of the diode operation in the forward region is provided by the exponential model. From Fig. 3.10, assuming V_{DD} is greater than 0.5 V or so, the diode current is much greater than I_S and we can represent the i-v characteristic by the exponential relationship resulting in

$$I_D = I_S e^{V_D/nV_T}$$

The other equation that governs the current operation by writing a Kirchhoff loop equation resulting in

$$I_D = \frac{V_{DD} - V_D}{R}$$

Assuming that the diode parameters I_S and n are known, the unknown quantities are V_D and I_D can be found out from the two equations given above.

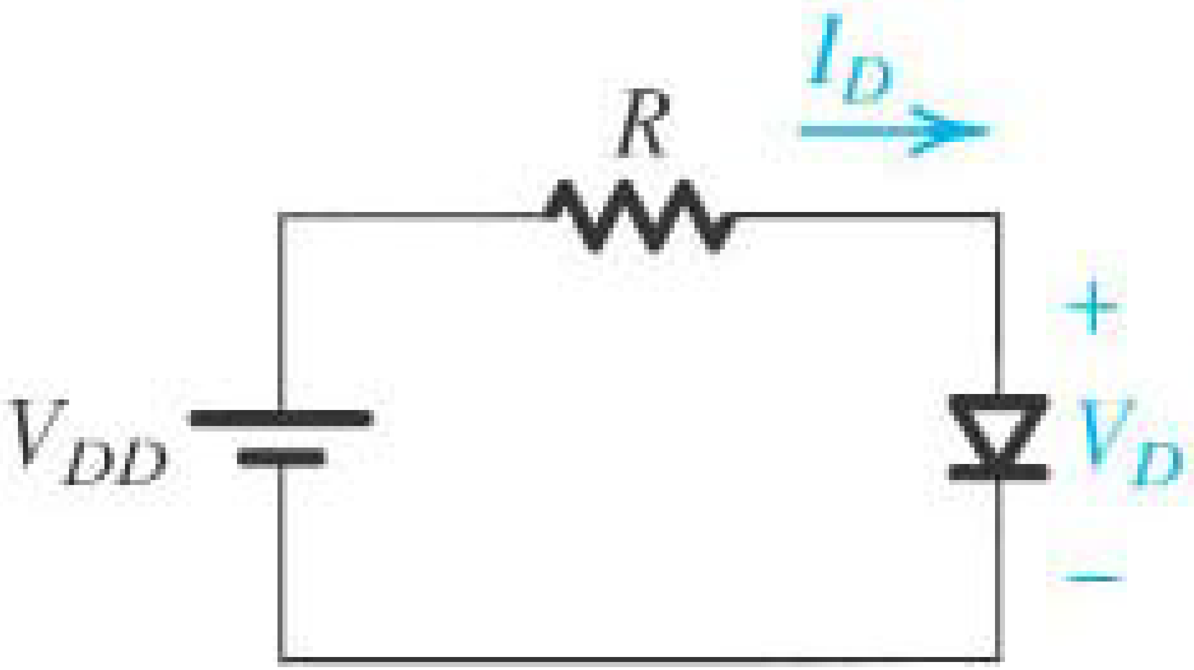


Figure 3.10 A simple circuit used to illustrate the analysis of circuits in which the diode is forward conducting.

Graphical Analysis Using the Exponential Model

- Graphical analysis is performed by plotting the relationships of the previous two equations on the i-v plane.

- The solution can then be obtained as the coordinates of the point of the intersection of the two graphs.

- A sketch of the construction is shown in Fig. 3.11.

- The curve represents the exponential diode equation and the straight line represents the second equation. Such straight line is known as load line.

- The load line intersects the diode curve at point Q, which represents the operating point of the circuit. Its coordinates give the values of I_D and V_D.

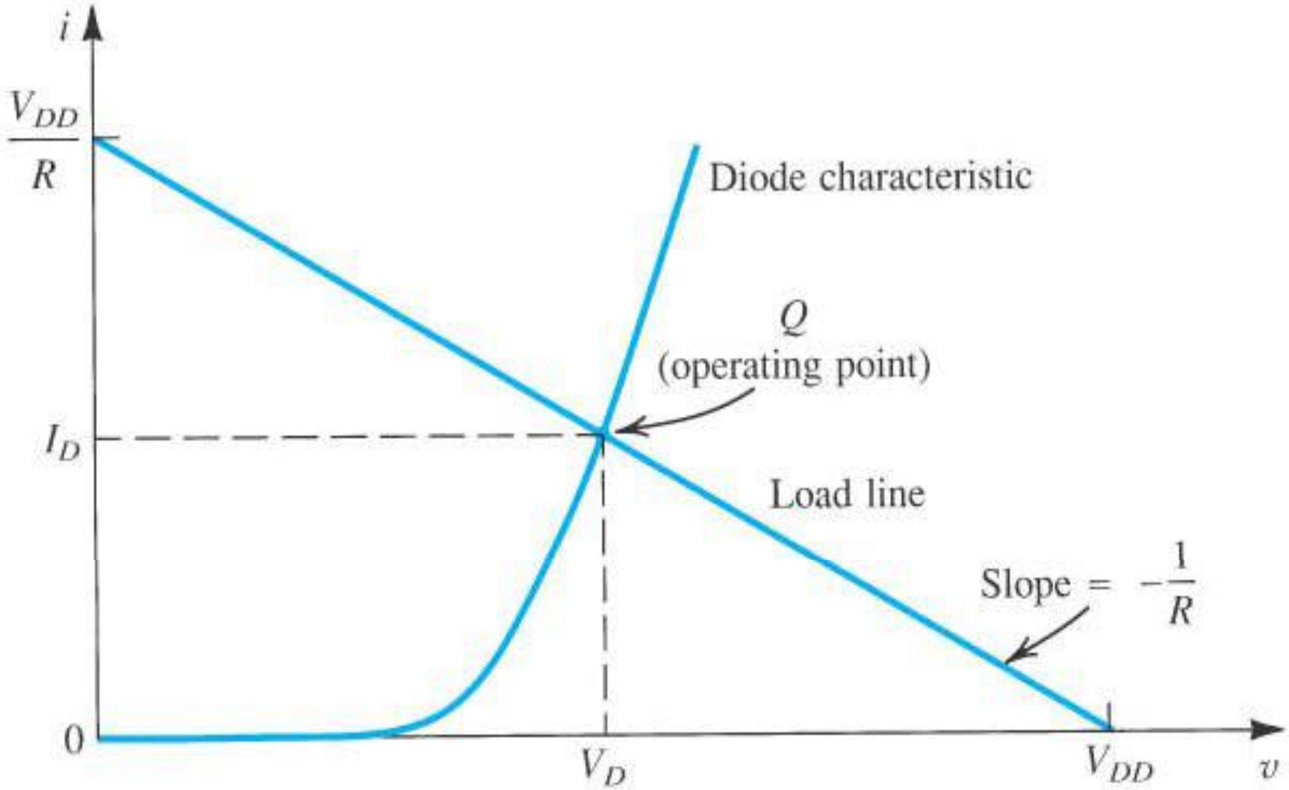


Figure 3.11 Graphical analysis of the circuit in Fig. 3.10 using the exponential diode model.

The Piecewise-Linear Model

- The analysis can be greatly simplified if we can find the linear relationships to describe the diode characteristics.

- An attempt is made in this direction illustrated in Fig. 3.12, where the exponential curve is approximated by two straight lines, line A with zero slope and line B with a slope of $1/r_D$.

- The straight-lines (or piecewise-linear) model of the Fig. 3.12 can be described by

$$i_D = 0, \quad v_D \leq V_{DO}$$

$$i_D = (v_D - V_{DO})/r_D, \quad v_D \geq V_{DO}$$

- Where V_{DO} is the intercept of line B on the voltage axis and r_D is the inverse of the slope of the line B. For the particular example shown, $V_{DO} = 0.65$ and $r_D = 20\ \Omega$.

- The piecewise-linear model described in the above equation can be represented by equivalent circuit shown in Fig. 3.13. Note that an ideal diode is included in this model to constrain i_D to flow in the forward direction only. This model is also known as **battery-plus resistance** model.

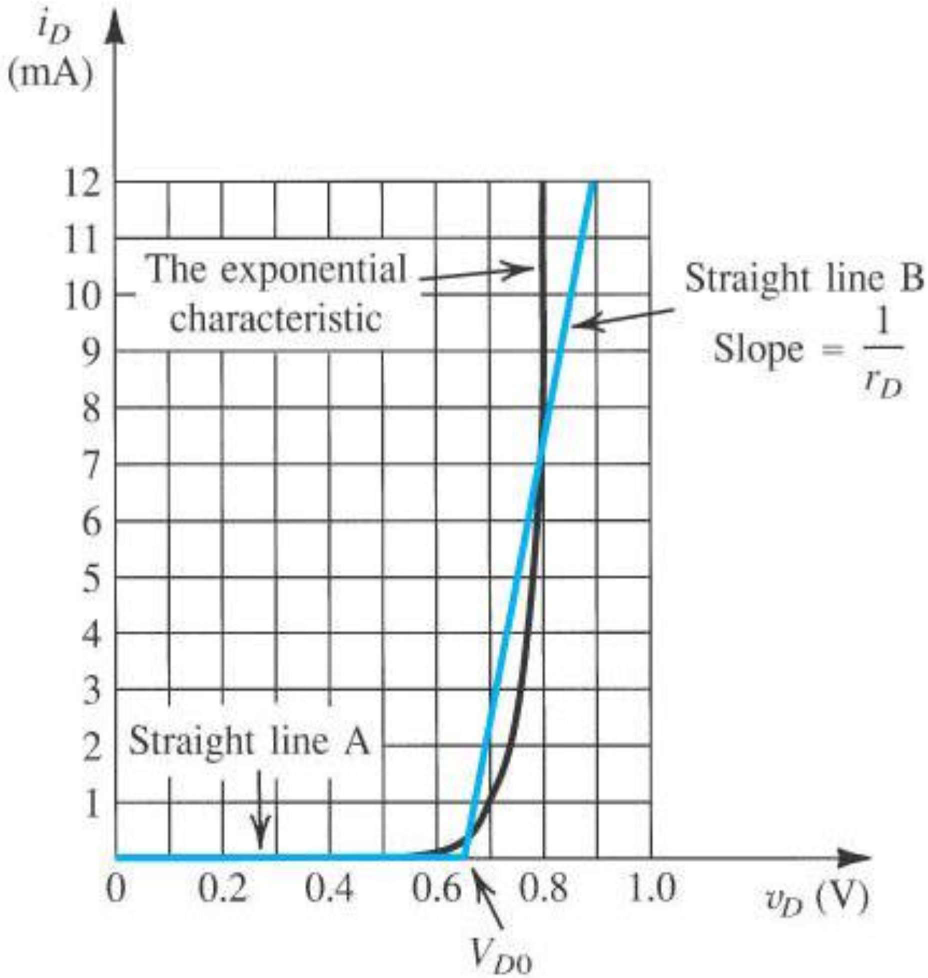
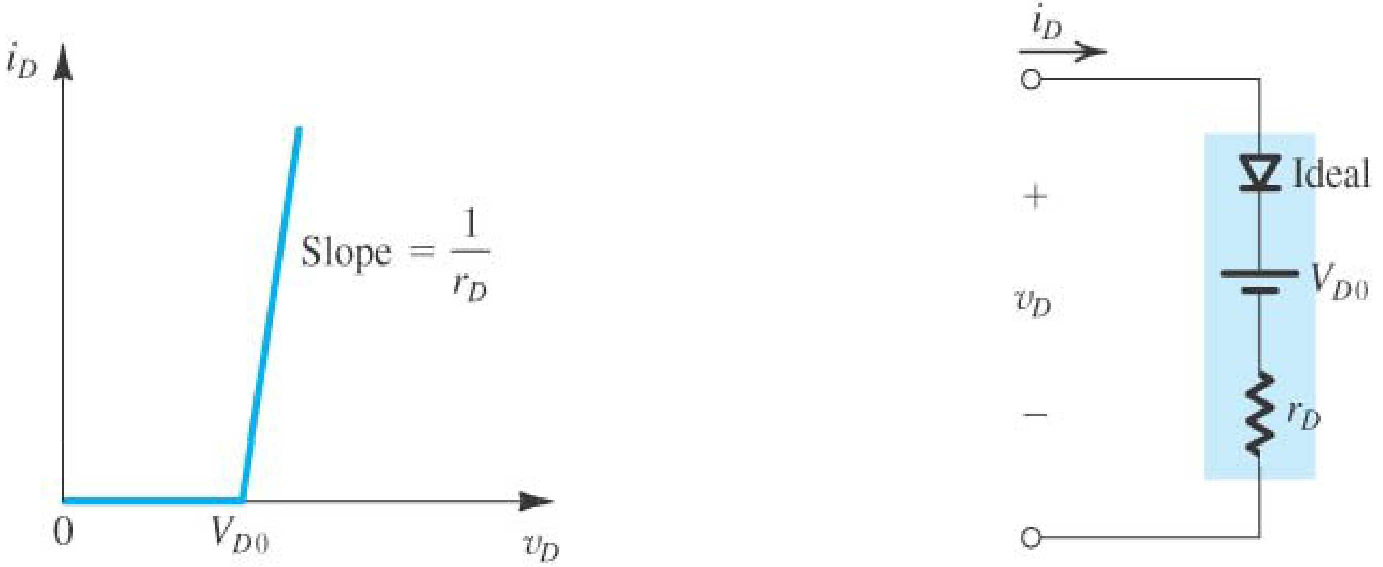


Figure 3.12 Approximating the diode forward characteristic with two straight lines: the piecewise-linear model.



(a) (b)

Figure 3.13 Piecewise-linear model of the diode forward characteristic and its equivalent circuit representation.

The Constant Voltage Drop Model

- An even simpler model of the diode forward characteristics can be obtained if we use a vertical straight line to approximate the fast-rising part of the exponential curve, as shown in Fig. 3.15.

- The resulting model simply says a forward-conducting diode exhibits a constant voltage drop V_D. The value of V_D is usually taken to be 0.7 V.

$V_D = 0.7\ V \qquad I_D = \frac{V_{DD} - 0.7}{R}$

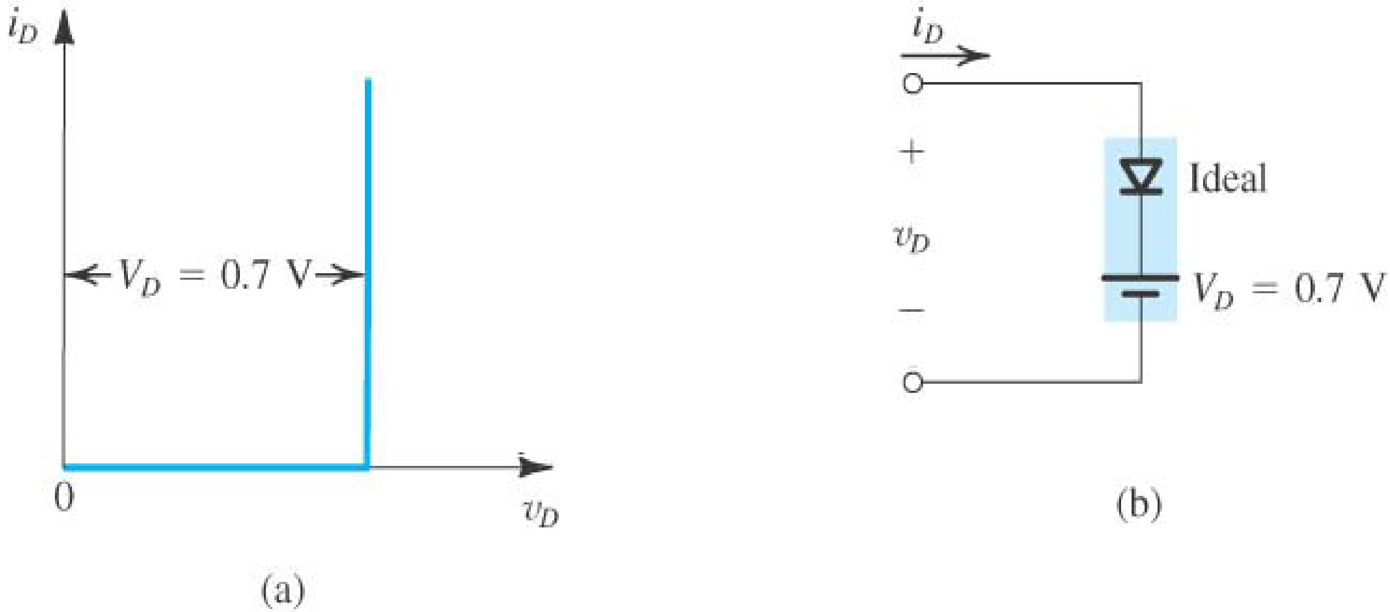


Figure 3.16 The constant-voltage-drop model of the diode forward characteristics and its equivalent-circuit representation.

Rectifier Circuits

- One of the most important applications of diodes is in the design of rectifier circuits.
- A diode rectifier forms an essential building block of the dc power supplies required to power electronic equipment. A block diagram of such a power supply is shown in Fig. 3.24.
- The dc voltage V_O is required to be as constant as possible in spite of variations in the ac line voltage and in the current drawn by the load.

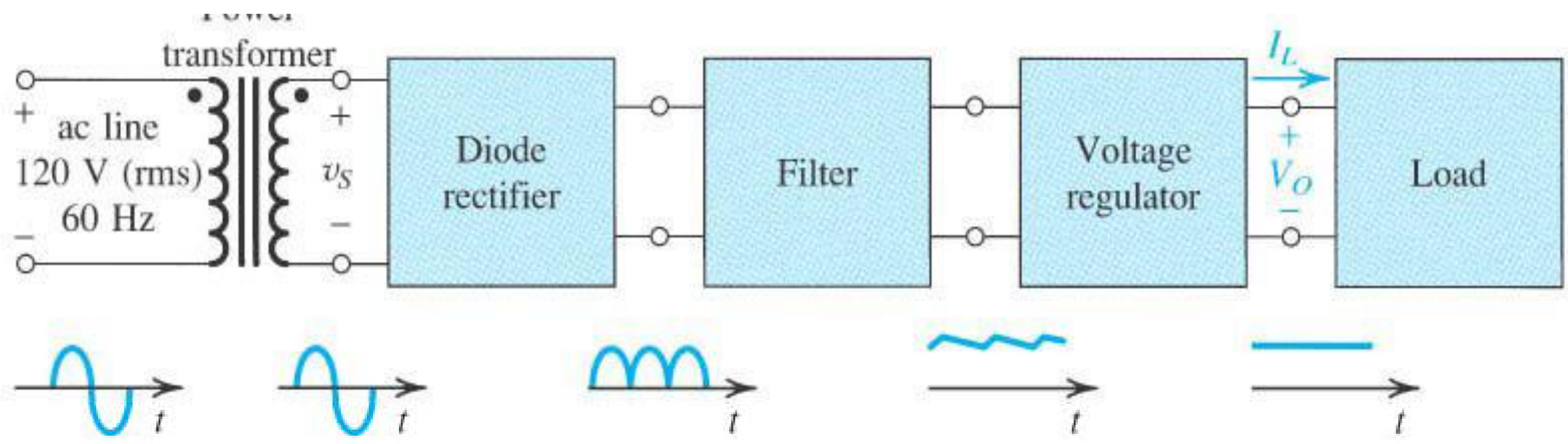


Figure 3.24 Block diagram of a dc power supply.

- The first block in a dc power supply is **power transformer**. It consists of two separate coils wound around an iron core that magnetically couples the two windings.

- The primary winding, having N_1 turns, is connected to the 120 V ac supply and the secondary winding, having N_2 turns is connected to the circuit of the dc power supply.

- Thus an ac voltage v_s of $120(N_2/N_1)$ V rms develops between the two terminals of the secondary winding.

- For example a secondary voltage of 8 V rms may be appropriate for a dc output of 5 V. This can be achieved with a 15:1 turns ratio.

- The output of the rectifier filter, though much more constant than without the filter, still contains a time-dependent component known as **ripple**. To reduce the ripple and to stabilize the magnitude of the dc output voltage of the supply against variations caused by changes in the load current, a voltage regulator is employed.

- Such a regulator can be implemented using the zener diode.

The Half Wave Rectifier

- The half wave rectifier utilizes alternate half-cycles of the input sinusoid. Fig. 3.25 (a) shows the circuit of a half wave rectifier.
- Using the more realistic battery plus resistance diode model, we obtain the circuit shown in Fig. 3.25 (b), from which we can write

- $v_o = 0, \quad v_S < V_{DO}$

- $v_o = \frac{R}{R+r_D} v_S - V_{DO} \frac{R}{R+r_D}$

- The transfer characteristic represented by these equations is sketched in Fig. 3.25 (c). In many applications, $r_D \ll R$ and the second equation can be simplified to

- $v_o = v_S - V_{DO}$

- Where V_{DO} = 0.7 V or 0.8 V. Fig. 3.25 (d) shows the output voltage obtained when the input v_S is a sinusoid.

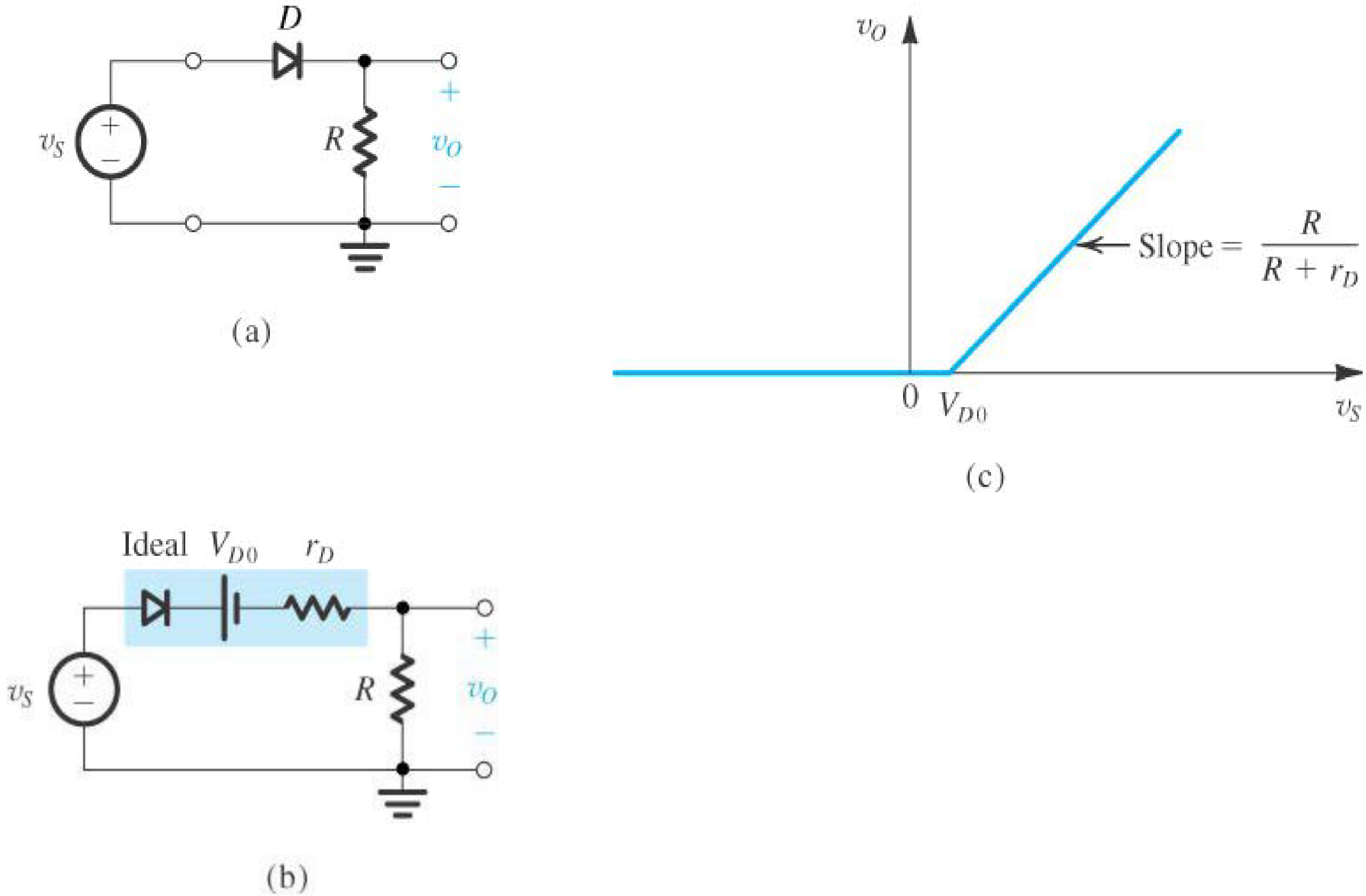


Figure 3.25 (a) Half-wave rectifier. **(b)** Equivalent circuit of the half-wave rectifier with the diode replaced with its battery-plus-resistance model. **(c)** Transfer characteristic of the rectifier circuit.

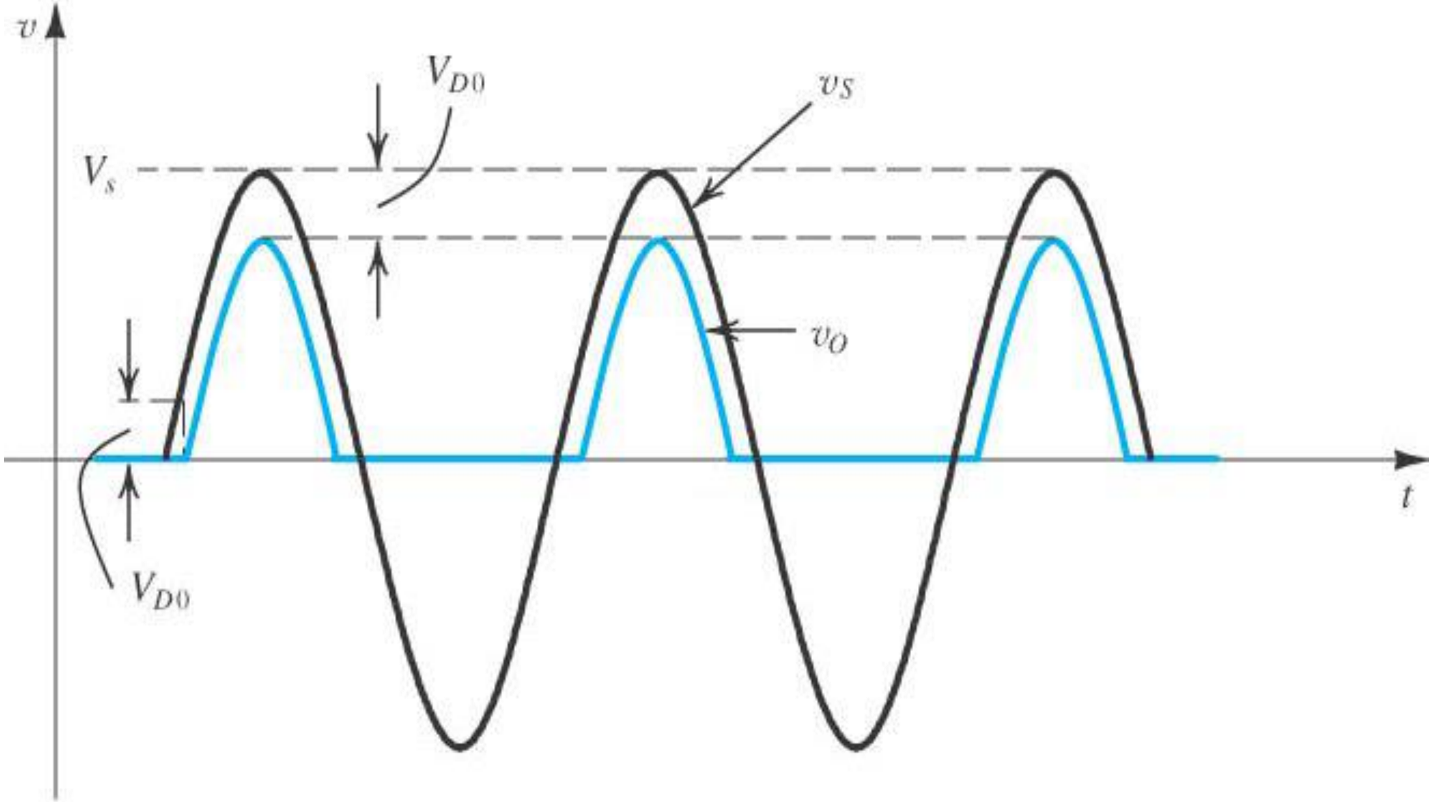


Figure 3.25 (d) Input and output waveforms, assuming that $r_D << R$.

- In selecting diodes for rectifier, two important parameters must be specified:

- the current handling capability of the diode, determined by the largest current the diode is expected to conduct,

- and the peak inverse voltage (PIV) that the diode must be able to withstand without breakdown, determined by the largest reverse voltage that is expected to appear across the diode.

- From Fig. 3.25 (a) we observe that when v_S is negative the diode will cut off and v_O will be zero.

- It follows that the PIV is equal to the peak of v_S

- $PIV = V_S$

- It is usually obvious that to select a diode that has a reverse that has a reverse breakdown voltage at least 50 % greater than the expected PIV.

The Full Wave Rectifier

- The full wave rectifier utilizes both halves of the input sinusoid. To provide a unipolar output, it inverts the negative half of the sine wave.
- One possible implementation is shown in Fig. 3.26 (a).
- Here the transformer secondary winding is center tapped to provide two equal voltages v_S across the two halves of the secondary winding with the polarities indicated.
- When the input line voltage (feeding the primary) is positive, both the signals labelled v_S will be positive. In this case D_1 will conduct and D_2 will be reverse biased. The current through D_1 will flow through R and back to the center tap of the secondary.
- Now during the negative half cycle of the ac line voltage, both the voltages are labelled v_S will be negative. Thus D_1 will be cut off while D_2 will conduct.
- The important point here is that the current through R always flows in the same direction, and thus v_O will be unipolar, as indicated in the Fig. 3.26 (c).
- The output waveform shown is obtained by assuming that a conducting diode has a constant voltage drop V_D.

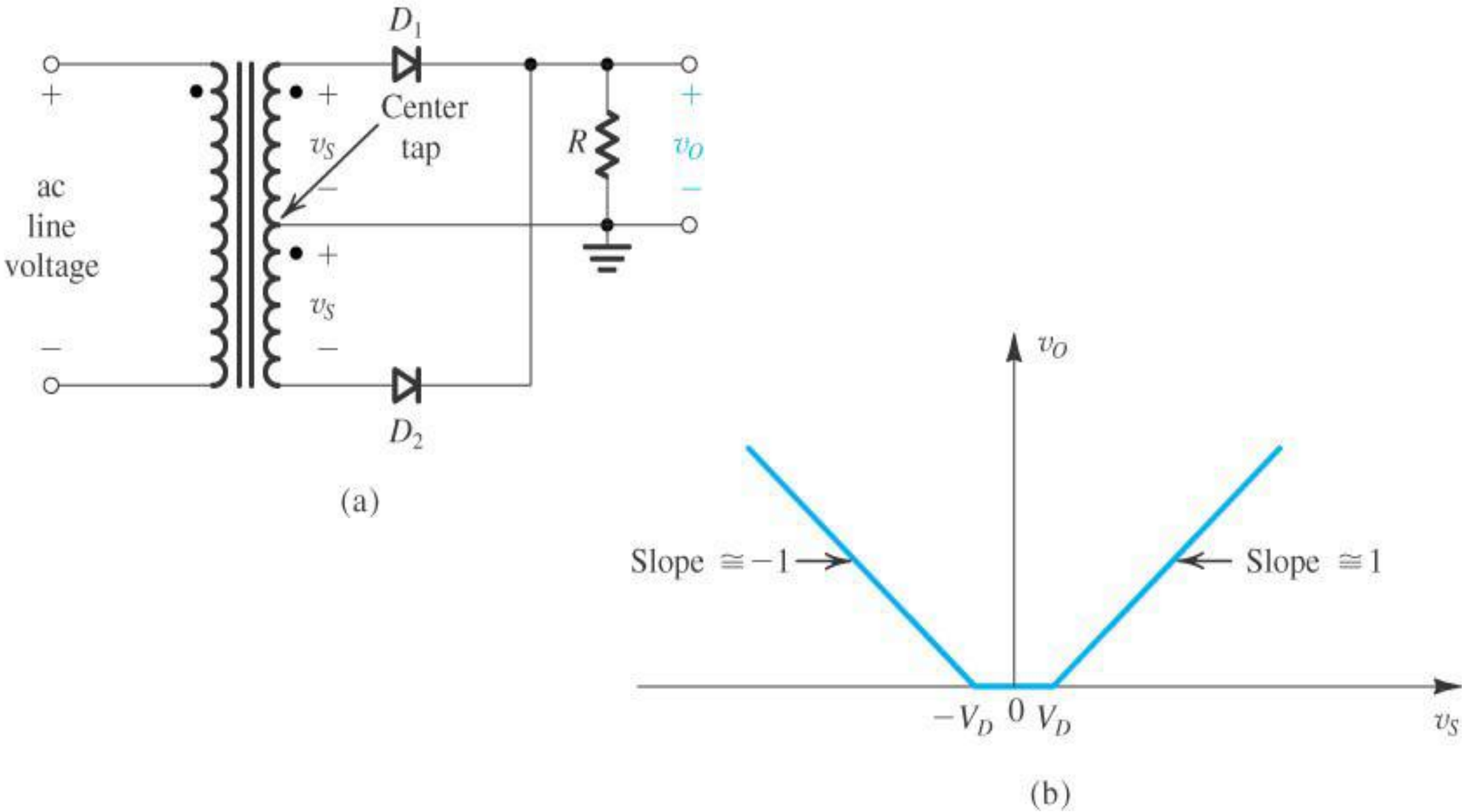
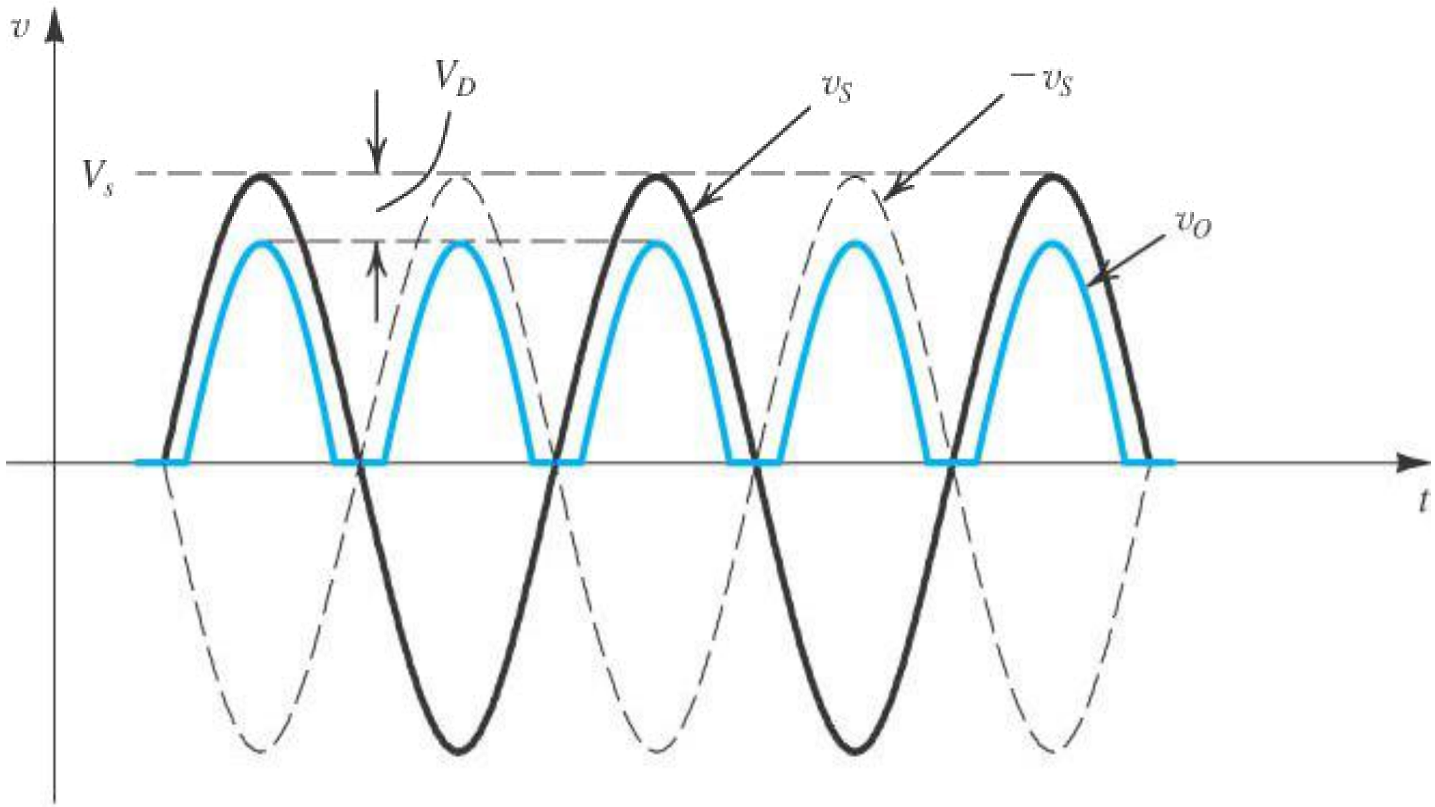


Figure 3.26 Full-wave rectifier utilizing a transformer with a center-tapped secondary winding: **(a)** circuit; **(b)** transfer characteristic assuming a constant-voltage-drop model for the diodes;



(c)

Figure 3.26 Full-wave rectifier utilizing a transformer with a center-tapped secondary winding: **(c)** input and output waveforms.

- To find the PIV of the diodes in full wave rectifier circuit, consider the situation during the positive half cycles.

- Diode D_1 is conducting and D_2 is cut off. The voltage at the cathode of D_2 is v_o and that at its anode is $-v_s$.

- Thus the reverse voltage across D_2 will be $(v_o + v_s)$, which will reach the maximum when v_o is at its peak value of $(V_S - V_D)$, and v_s is at its peak value of V_S ; thus

- $PIV = 2V_S - V_D$

- Which is approximately twice that of the half wave rectifier.

The Bridge Rectifier

- An alternative implementation of the full wave rectifier is shown in Fig. 3.27 (a).

- The circuit known as Bridge Rectifier because of the similarity with the Wheatstone Bridge.

- The bridge rectifier, however, requires four diodes as compared to two in the previous circuit.

- The bridge rectifier circuit operates as follows: During the positive half cycles of the input voltage, v_S is positive and thus current is conducted through diode D_1 resistor R and diode D_2. Meanwhile diodes D_3 and D_4 will be reverse biased.

- v_o will be lower than v_s by two diode drops (compared with one drop in circuit previously discussed). This is somewhat of a disadvantage of the bridge rectifier.

- Next consider the situation during the negative half cycles of the input voltage. The secondary voltage v_s will be negative and thus $-v_s$ will be positive forcing current through D_3 R and D_4. Meanwhile diodes D_1 and D_2 will be reverse biased. v_o will always be positive as indicated in Fig. 3.27 (b).

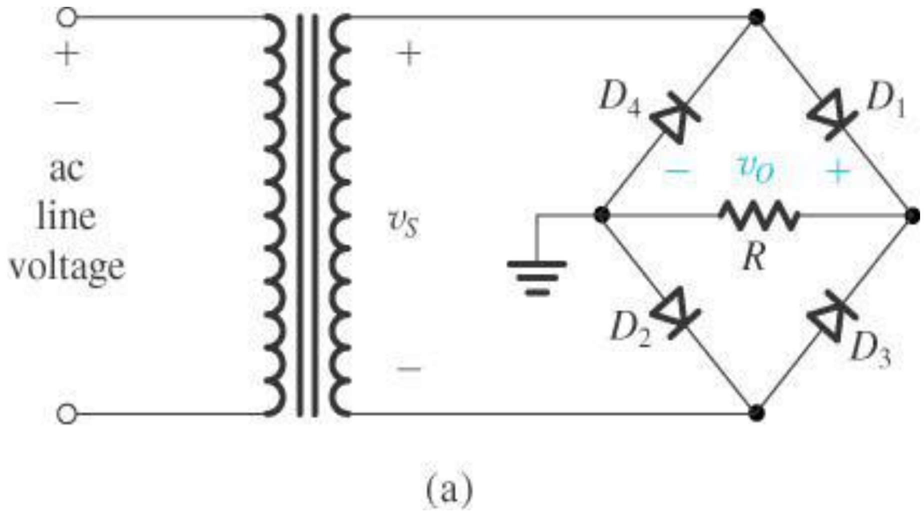
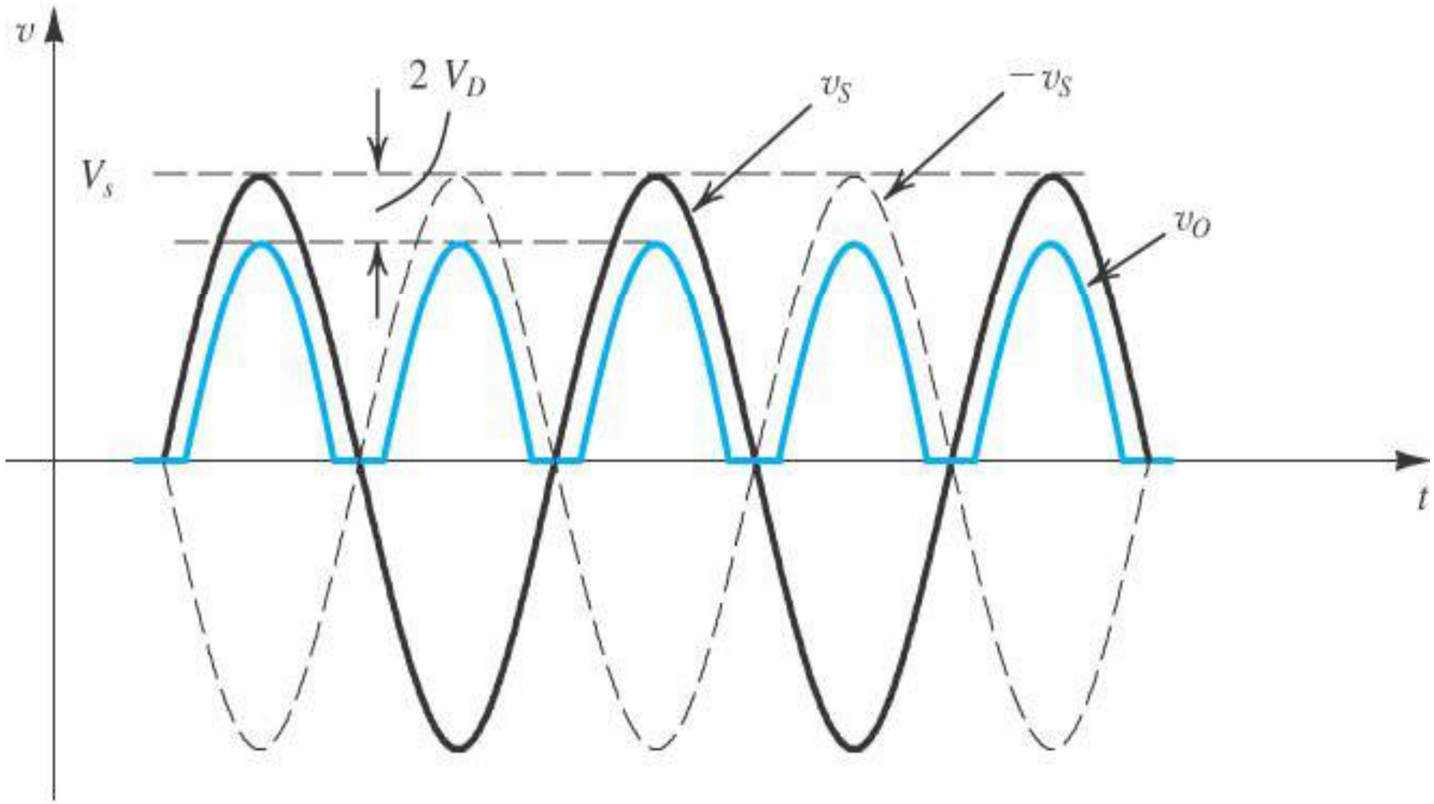


Figure 3.27 The bridge rectifier: **(a)** circuit



(b)

Figure 3.27 The bridge rectifier: **(b)** input and output waveforms.

- To determine the peak inverse voltage (PIV) of each diode, consider the circuit during the positive half cycles.

- The reverse voltage across D_3 can be determined form the loop formed by D_3, R and D_2 as

- $v_{D3}(reverse) = v_o + v_{D2}(forward)$

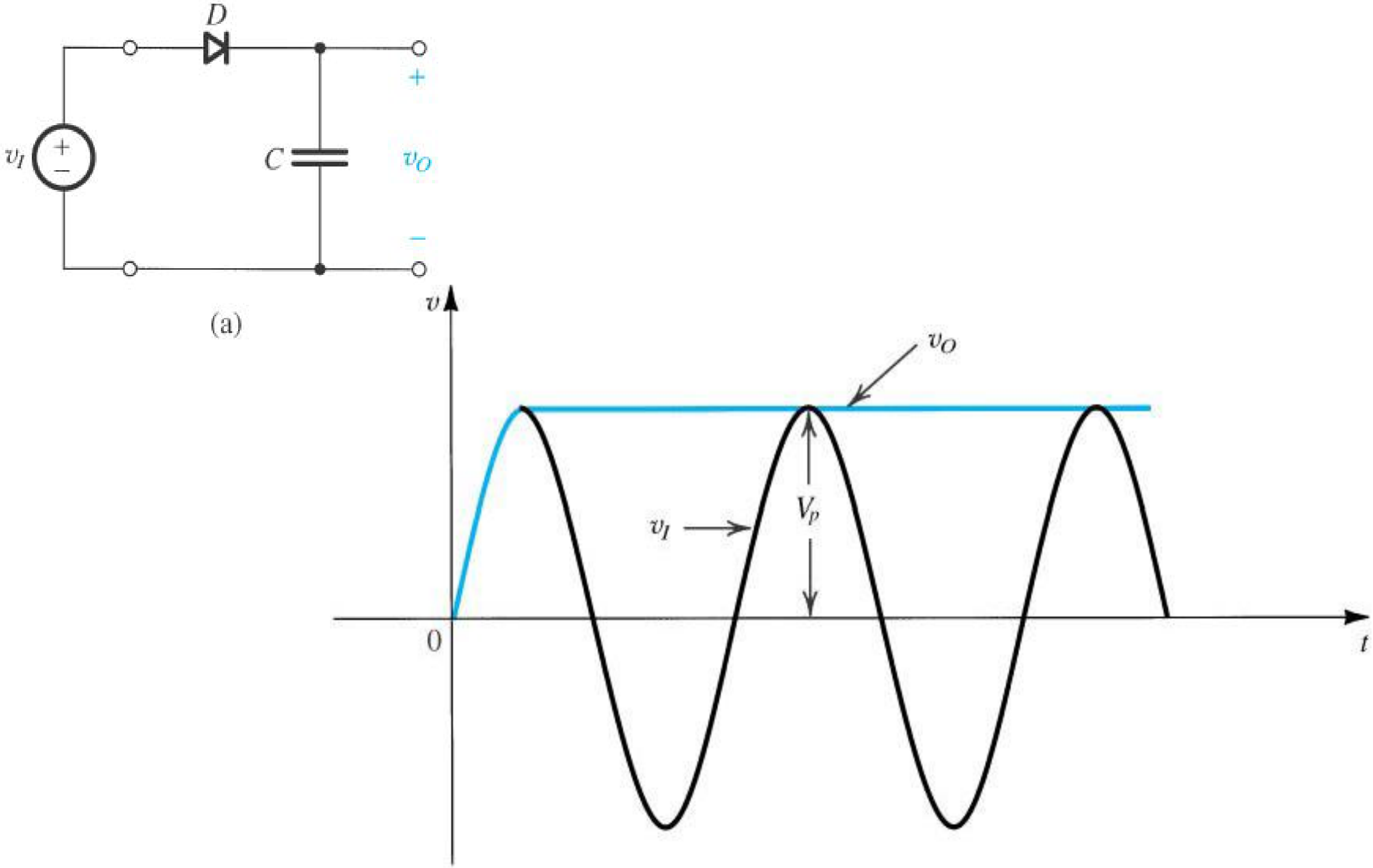
- Thus the maximum value of v_{D3} occurs at the peak of v_o and is given by

- $PIV = V_s - 2V_D + V_D = V_s - V_D$

- Observe that here PIV is about half of the value for the full-wave rectifier with a center tapped transformer. This is another advantage of the bridge rectifier.

The Rectifier with a Filter Capacitor – The Peak Rectifier

- A simple way to reduce the variation of the output voltage is to place a capacitor across the load resistor. The filter capacitor serves to reduce substantially the variations in the output voltage.
- To see how the rectifier circuit with a filter capacitor works, consider first the simple circuit shown in Fig. 3.28.
- Let the input v_I be a sinusoid with a peak value V_P , and assume the diode to be ideal. As v_I goes positive, the diode conducts and the capacitor is charged so that $v_o = v_I$. This situation continues until v_I reaches its peak value V_P. Beyond the peal value, as v_I decreases the diode becomes reverse biased and the output voltage remains constant at the value V_P.
- In fact theoretically speaking the capacitor will retain its charge and hence its voltage indefinitely, because there is no way for the capacitor to discharge.
- Thus the circuit provides a dc voltage output equal to the peak of the input sine wave.



(b)

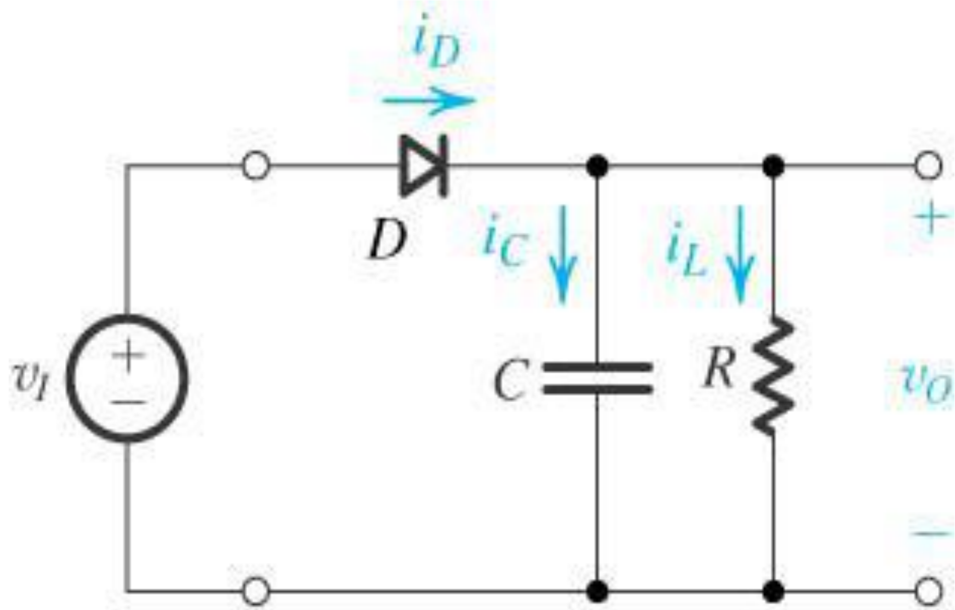
Figure 3.28 (a) A simple circuit used to illustrate the effect of a filter capacitor. **(b)** Input and output waveforms assuming an ideal diode. Note that the circuit provides a dc voltage equal to the peak of the input sine wave. The circuit is therefore known as a peak rectifier or a peak detector.

- Next, we consider the more practical situation where a load resistance R is connected across the capacitor C, as depicted in Fig. 3.29 (a). However, we will continue to assume the diode to be ideal.

- As before, for a sinusoidal input, the capacitor charges to the peak of the input V_P. Then the diode cuts off and the capacitor discharges through the load resistor R.

- The capacitor discharge will continue for almost the entire cycle, until the time at which v_I exceeds the capacitor voltage.

- Then the diode turns on again and charges the capacitor up to the peak of v_I, and the process repeats itself. Observe that to keep the output voltage from decreasing too much during capacitor discharge, one selects a value of C so that the time constant CR is much greater than the discharge interval.



(a)

Figure 3.29 (a) Circuit Diagram with Filter Capacitor. The diode is assumed ideal.

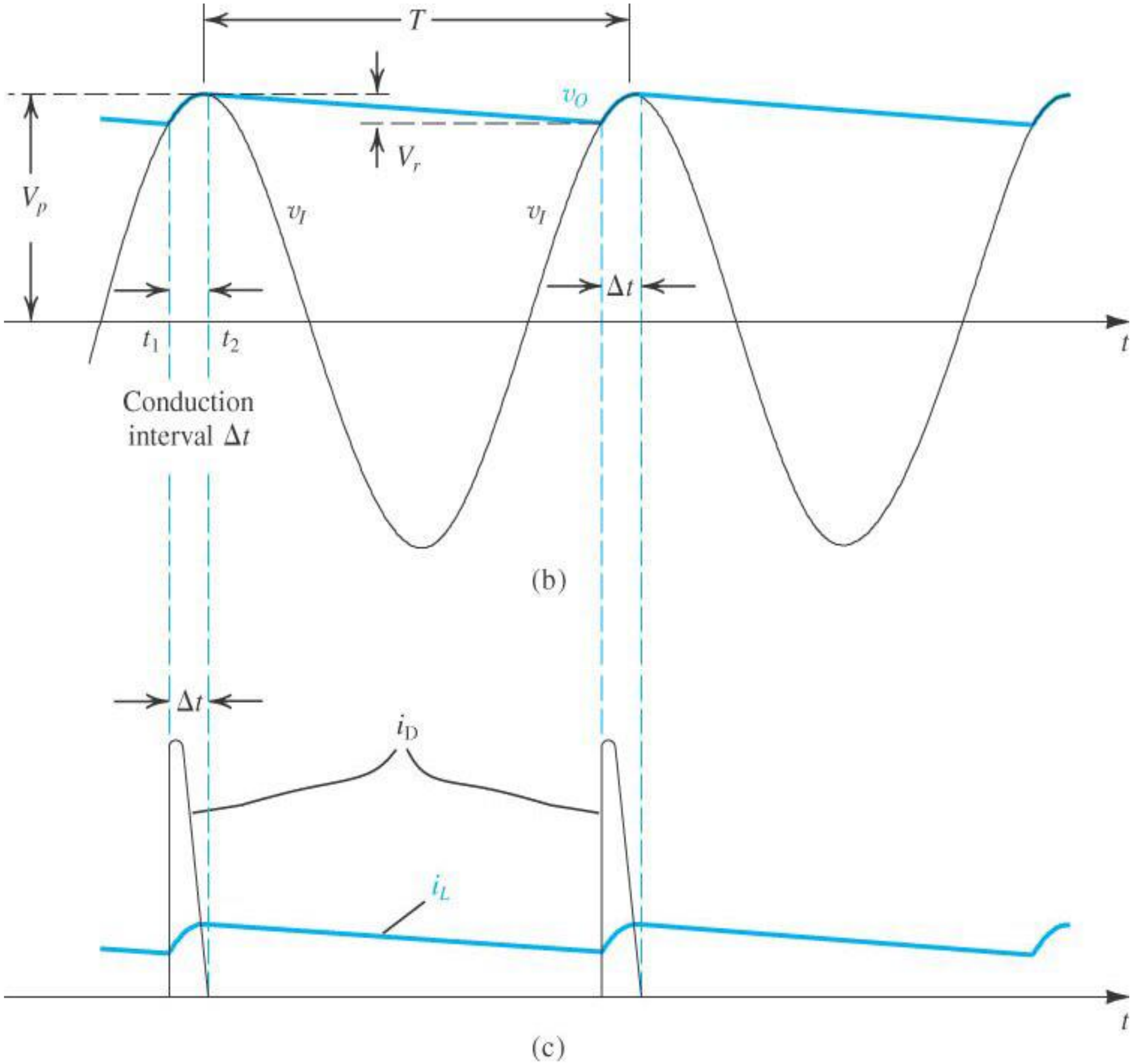


Figure 3.29 (b) & (c) Voltage and current waveforms in the peak rectifier circuit with CR @T. The diode is assumed ideal.

- We are now ready to analyse the circuit in detail. Figure 3.29 (b) shows the steady-state input and output voltage waveforms under the assumption that CR >> T, where T is the period of the sinusoid. The waveforms of the load current

- $i_L = v_o/R$

- and the diode current (when it is conducting)

- $i_D = i_C + i_L = \mathrm{C}\dfrac{dv_I}{dt} + i_L$

- Are shown in Fig. 3.29 (c). The following observations are in order:

1. The diode conducts for a brief interval $\Delta t,$ near the peak of the input sinusoid and supplies the capacitor with the charge equal to that lost during the much longer discharge interval.
2. Assuming an ideal diode, the diode conduction begins at time t_1, at which the input v_I equals the exponential decaying output v_o. Conduction stops at t_2 shortly after the peak of v_I; the exact value of t_2 can be determined by setting $i_D = 0$ in the above equation.

3. During the diode off interval, the capacitor C discharges through R and thus v_o decays exponentially with a time constant CR. The discharge interval begins just past the peak of v_I. At the end of discharge interval, which lasts for almost the entire period T, $v_o = V_p – V_r$, where V_r is the peak to peak ripple voltage. When CR >> T, the value of V_r is small.

4. When V_r is small, v_o is almost constant and equal to the peak value of v_I. Thus the dc output voltage is approximately equal to V_p. Similarly, the current i_L is almost constant, and its dc component I_L is given by

- $I_L = \frac{V_P}{R}$

- If desired a more accurate expression for the output dc voltage can be obtained by taking the average of the extreme value of v_o,

- $V_o = V_P - \frac{1}{2}V_r$

- With these observations in hand, we derive the expression for V_r and for the average and peak to peak values of the diode current. During the diode off interval, vo can be expressed as
- $v_o = V_p e^{-t/CR}$

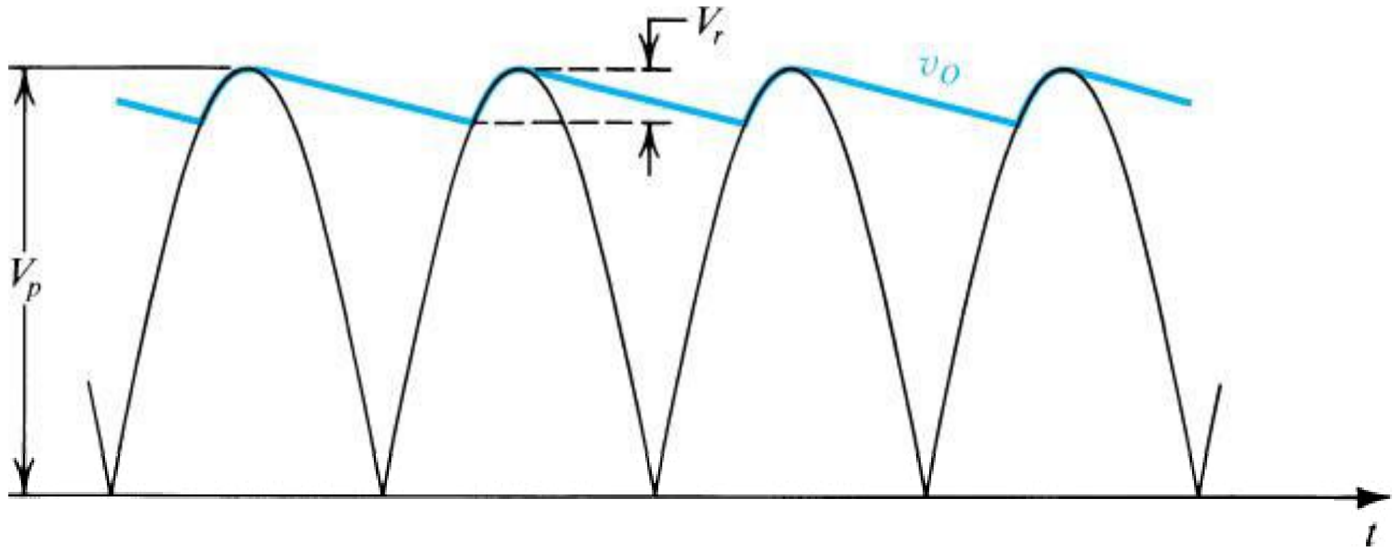
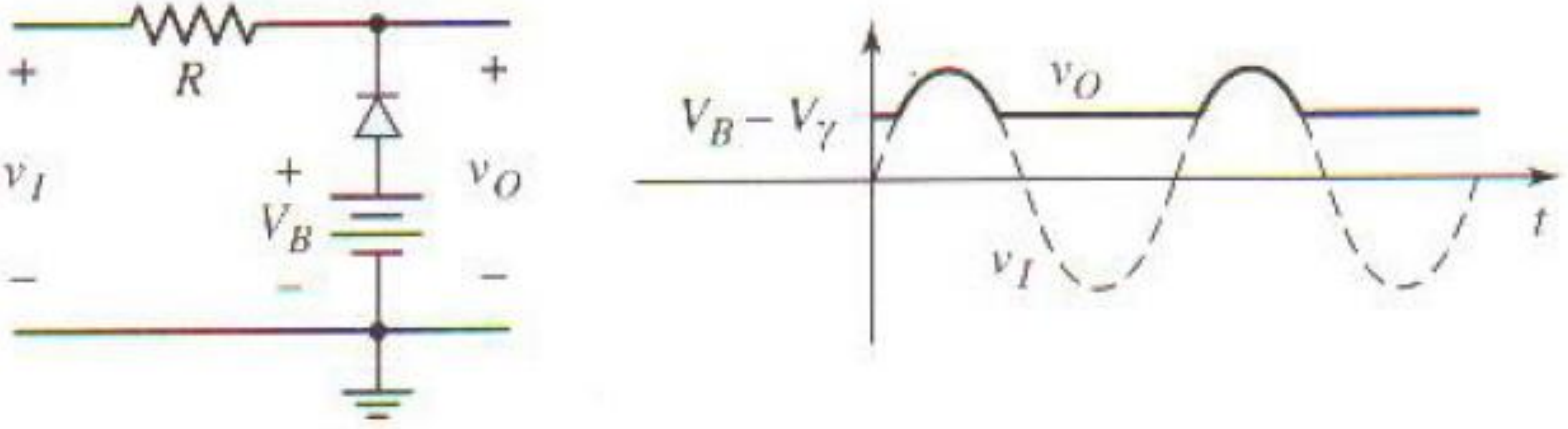


Figure 3.30 Waveforms in the full-wave peak rectifier.

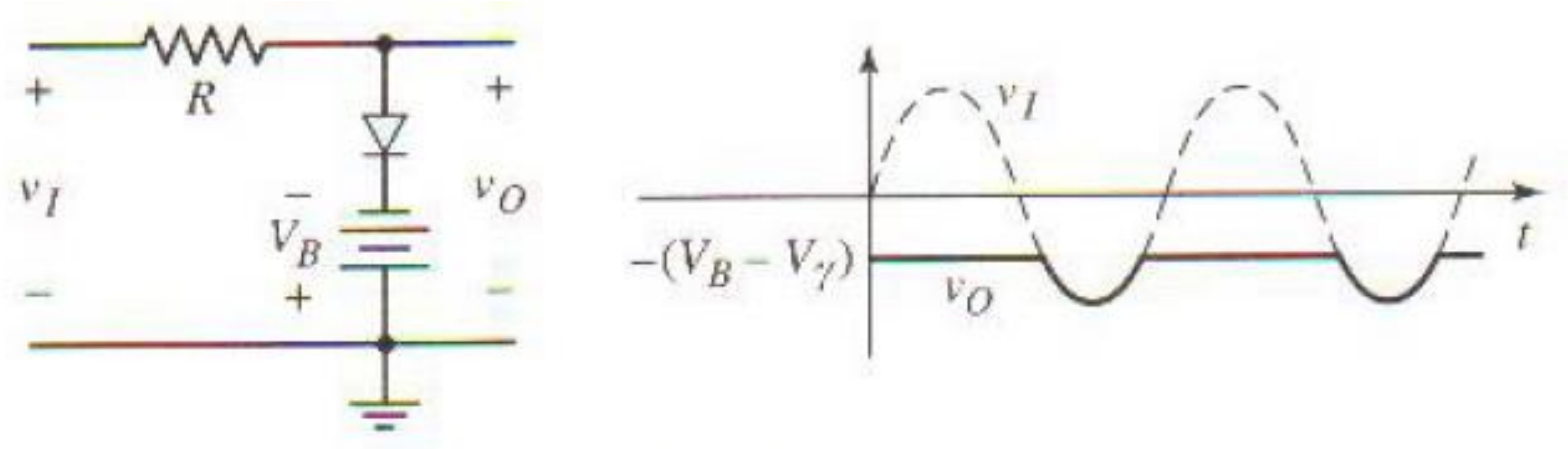
Clipper and Clamper Circuits

Clippers



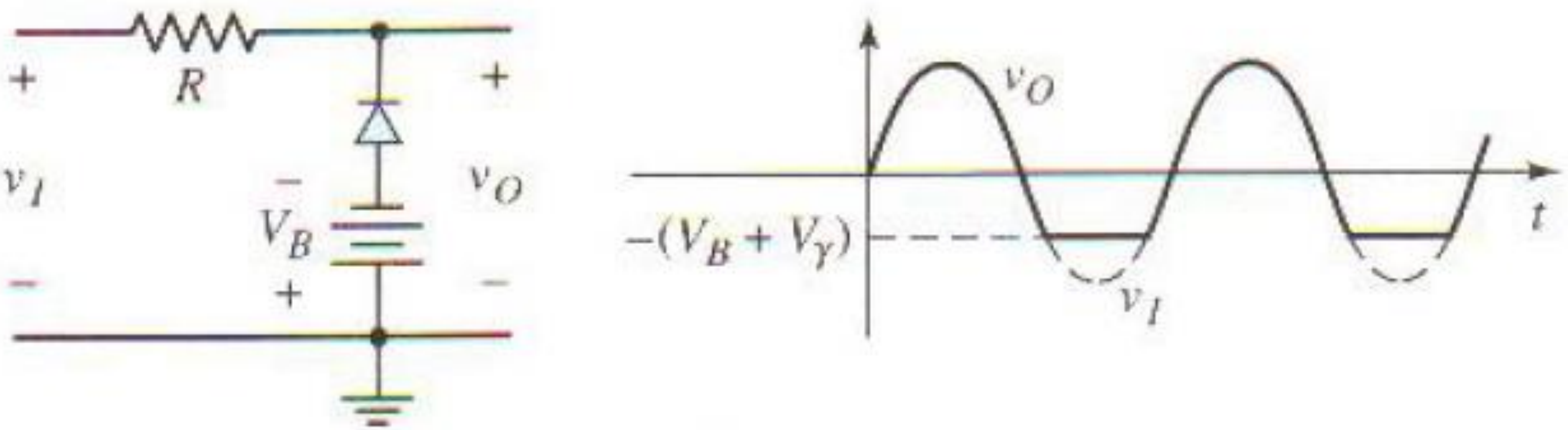
(a)

Clippers



(b)

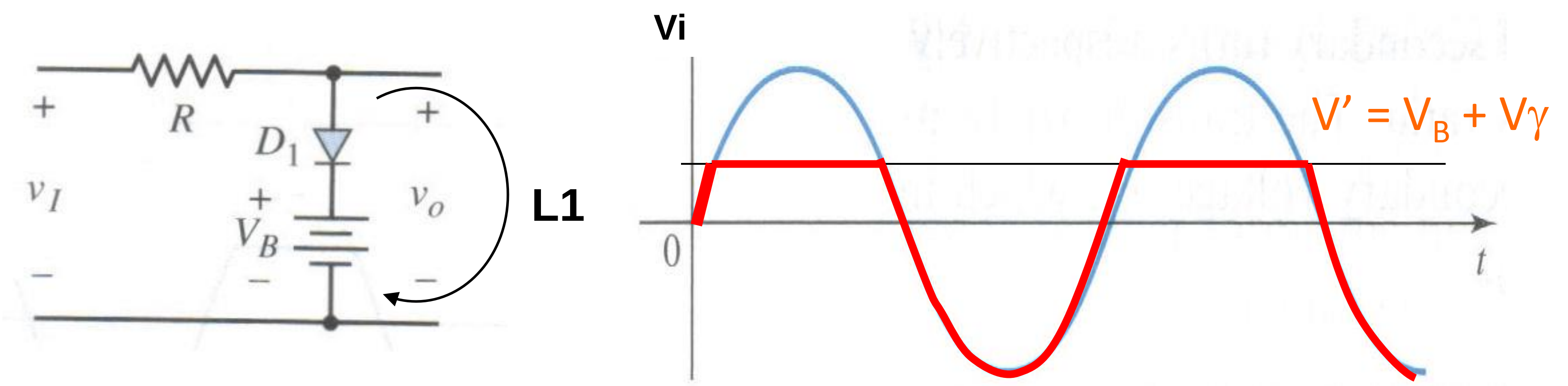
Clippers



(c)

Clippers

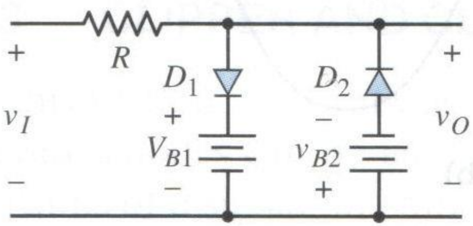
- Clipper circuits, also called **limiter circuits**, are used to eliminate portion of a signal that are above or below a specified level – clip value.
- The purpose of the diode is that when it is turn on, it provides the clip value
- Clip value = V'. To find V', use KVL at L1
- The equation is : $V' – V_B - V\gamma = 0 \rightarrow V' = V_B + V\gamma$

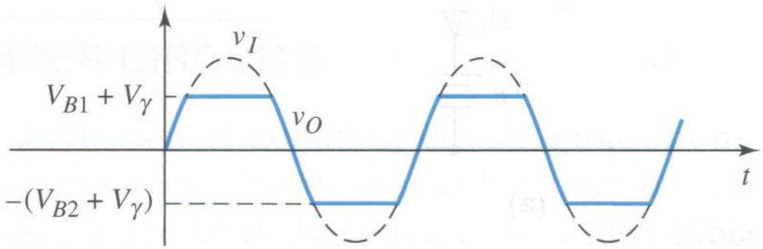


- Then, set the conditions
  - If **Vi > V'**, what happens? → diode conducts, hence Vo = V'
  - If **Vi < V'**, what happens? → diode off, open circuit, no current flow, Vo = Vi

Parallel Based Clippers

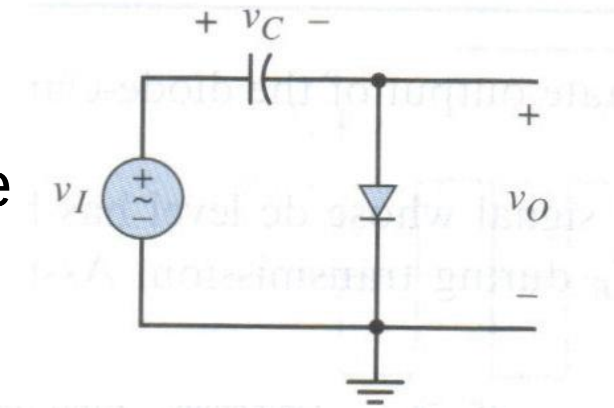
- Positive and negative clipping can be performed simultaneously by using a double limiter or a **parallel-based clipper**.





- The parallel-based clipper is designed with two diodes and two voltage sources oriented in opposite directions.
- This circuit is to allow clipping to occur during both cycles; negative and positive

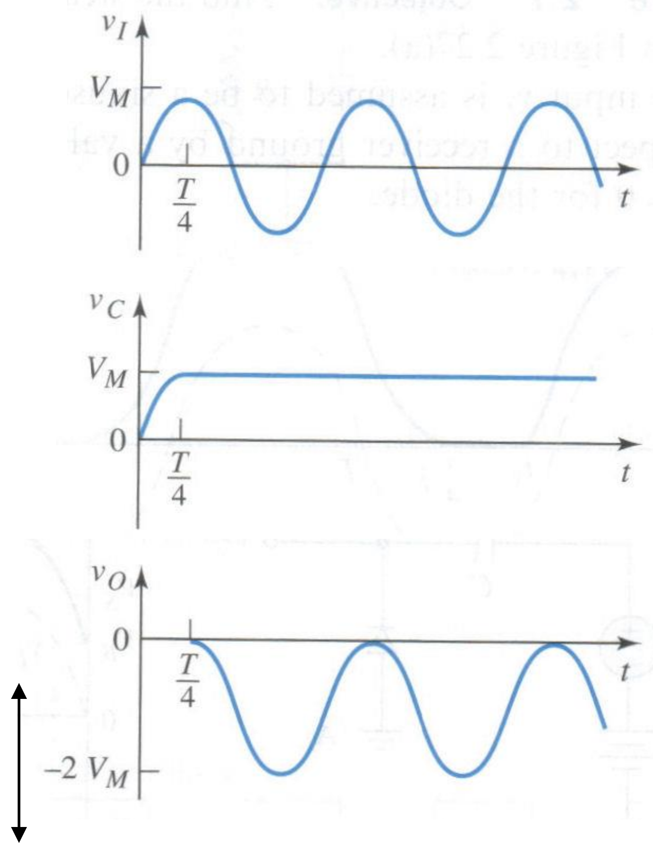
Clampers



- Clamping shifts the entire signal voltage by a DC level.
  - Consider, the sinusoidal input voltage signal, v_I.
  - 1st 90^0, the capacitor is charged up to the peak value of **Vi which is V_M.**
  - Then, as Vi moves towards the –ve cycle,
    - the diode is reverse biased.
    - Ideally, capacitor cannot discharge, hence Vc = V_M
  - By KVL, we get

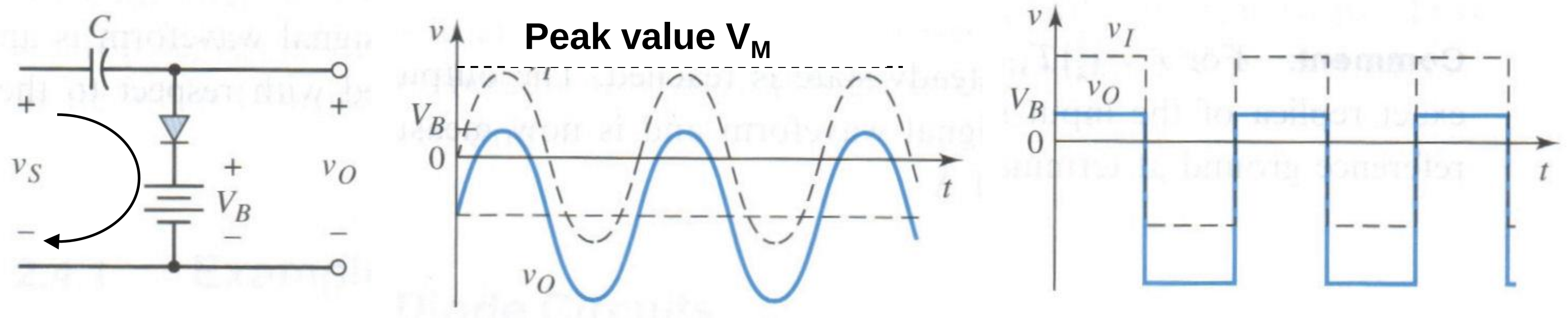
$$\boxed{v_O = -v_C + v_I = -V_M + V_M \sin \omega t}$$

NOTE: The input signal is shifted by a dc level; and that the peak-to-peak value is the same



Clampers

- A clamping circuit that includes an independent voltage source V_B.



$$v_o = -V_M + V_M sin\omega t + V_B$$

Operation in Reverse Breakdown Region – Zener Diodes

- The very steep i-v curve that the diode exhibits in the breakdown region (Fig. 3.8) and the almost constant voltage drop that this indicates suggest that diodes operating in the breakdown region can be used in the design of voltage regulators.
- This in fact turns out to be an important application of the diodes operating in the reverse breakdown region.
- Special diodes are manufactured to operate specifically in the breakdown region.
- Such diodes are called **breakdown diodes** or more commonly, Zener Diodes.
- Fig. 3.20 shows the circuit symbol of the zener diode.
- In normal applications of zener diodes, current flows into the cathode, and the cathode is positive with respect to the anode. Thus, I_Z and V_Z in Fig. 3.20 have positive values.

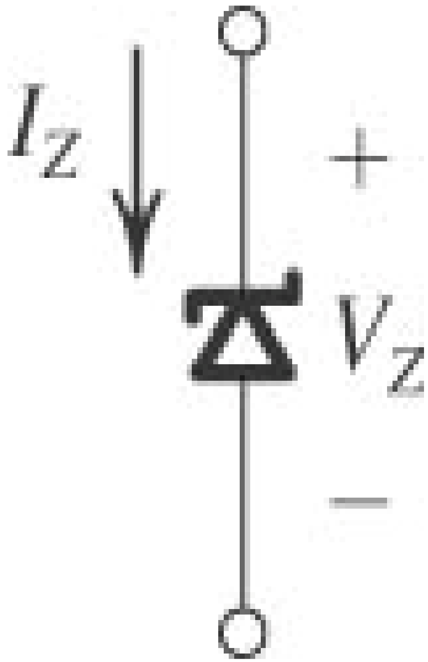


Figure 3.20 Circuit symbol for a zener diode.

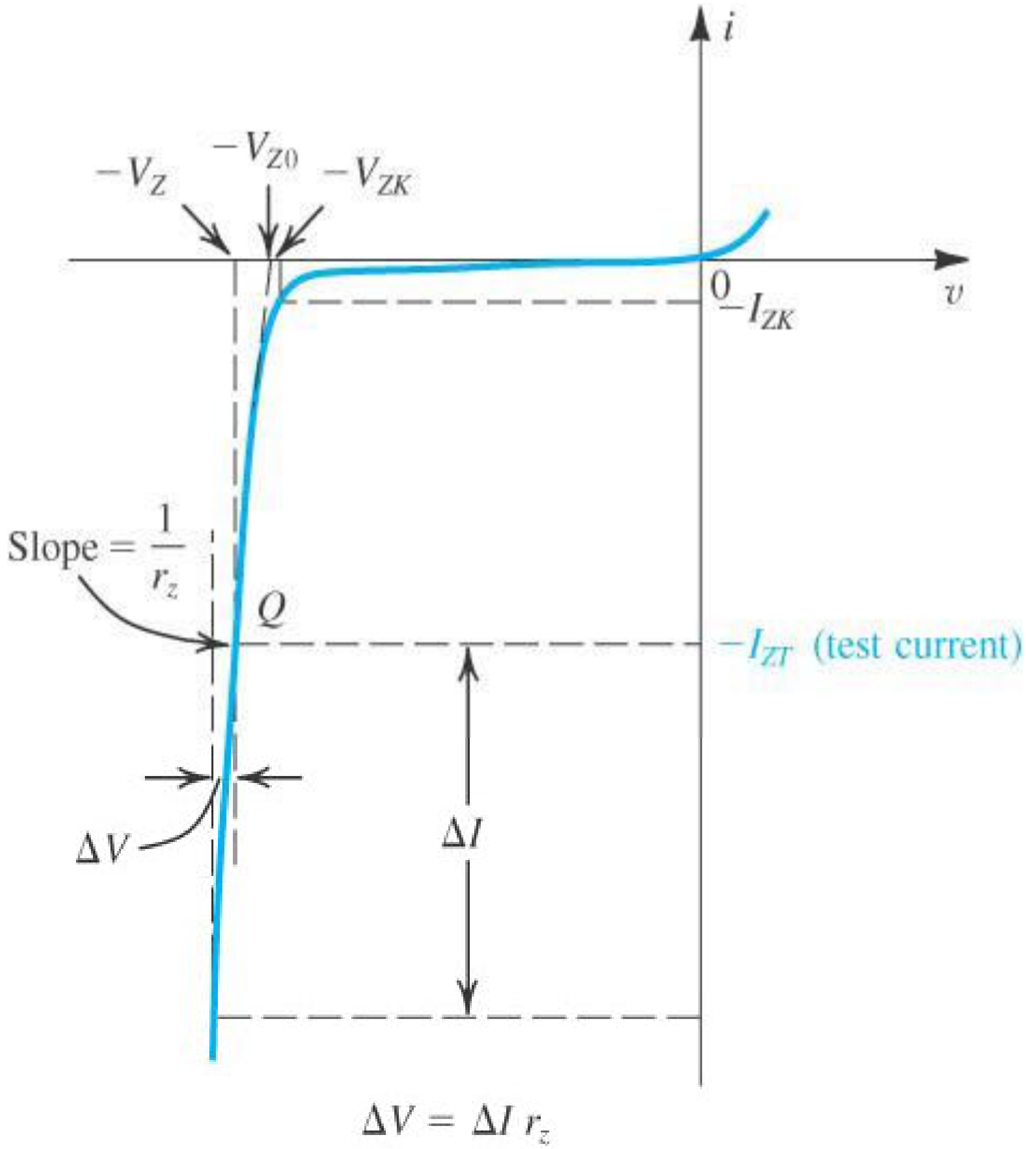


Figure 3.21 The diode i–v characteristic with the breakdown region shown in some detail.

Specifying and Modelling the Zener Diode

- Figure 3.21 shows the details of the diode i-v characteristics in the breakdown region.
- We observe that for the currents greater than the knee current I_Z (which is specified in the data sheet of the zener diode), the i-v characteristic is always a straight line.
- The manufacturer usually specifies the voltage across the zener diode V_Z at the specified test current I_{ZT}.
- Thus 6.8 V zener diode will exhibit at 6.8 V drop at a specified test current, of say, 10 mA.
- As the current through the zener diode deviates from I_{ZT} , the voltage across it will change.
- Figure 3.21 shows that corresponding to current ΔI the zener voltage changes by ΔV, which is related to ΔI by
- $\Delta V = r_Z \Delta I$
- Where r_Z is the inverse of the slope of the almost linear i-v curve at point Q.
- Resistance r_Z is the **incremental resistance** of the zener diode at operating point Q.
- It is also known as the **dynamic resistance of the zener,** and its value is specified on the device data sheet. Typically r_Z is in the range of a few ohms to few tens of ohms.
- Zener diodes are fabricated with voltage V_Z in the range of a few volts to a few hundred volts.

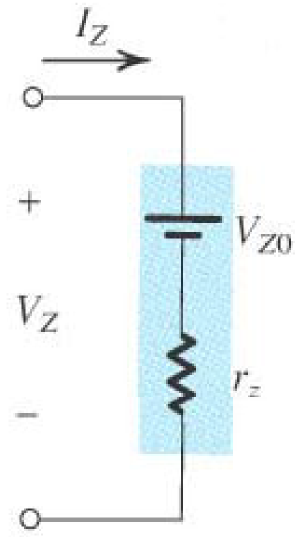


Figure 3.22 Model for the zener diode.

- The almost linear i-v characteristic of the zener diode suggests that the device can be modelled as indicated in the Fig 3.22.

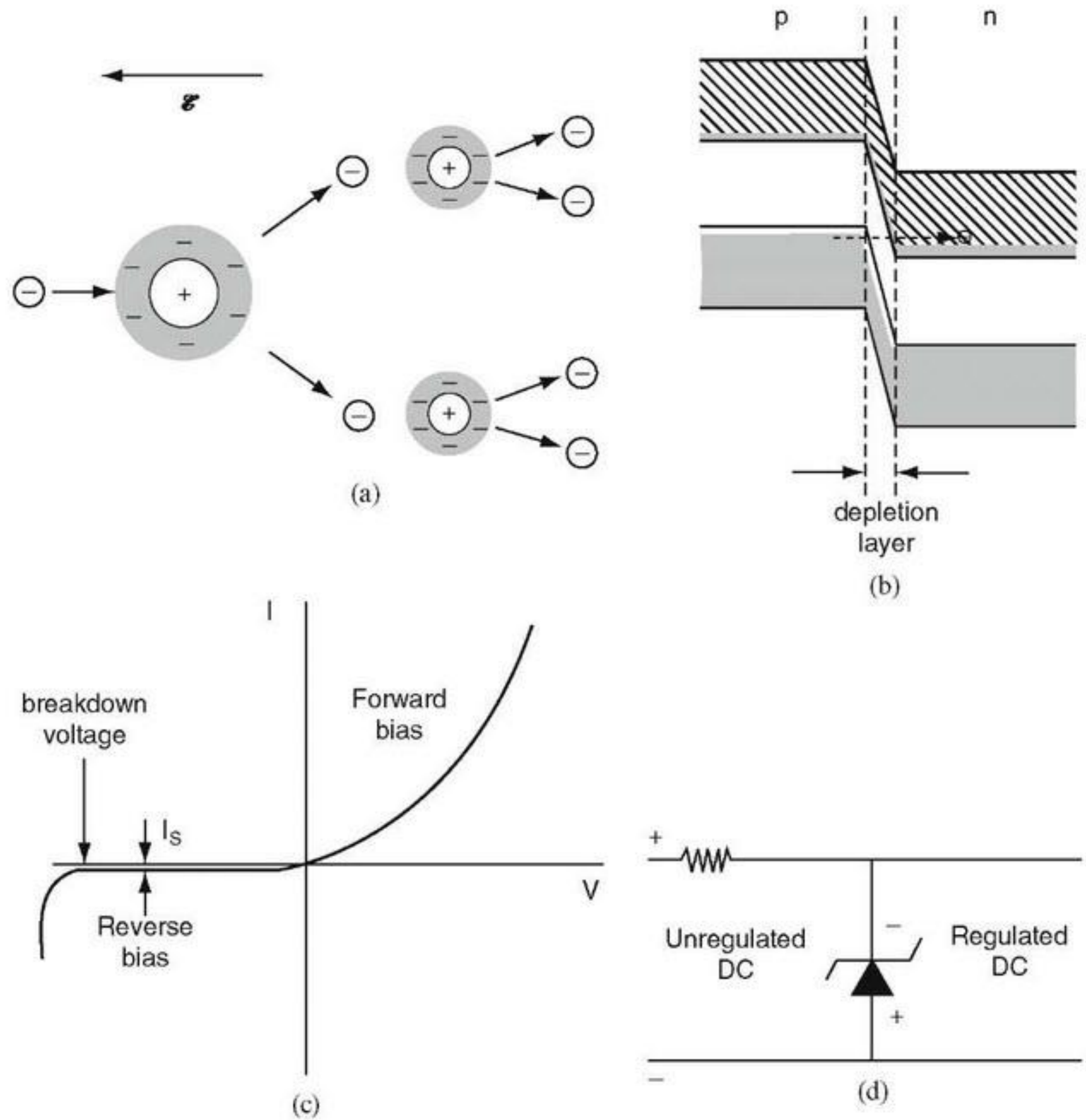
- Here V_{Z0} denotes the point at which the straight line of the slope $1/r_Z$ intersects the voltage axis (Refer to Fig. 3.21).

- Although V_{Z0} is shown to be slightly different from the knee voltage V_{ZK} , in practice their values are almost equal.

- The equivalent circuit model of the Fig. 3.22 can be analytically described by

- $V_Z = V_{Z0} + r_Z I_Z$

- And it applies for $I_Z > I_{ZK}$ and obviously, $V_Z > V_{Z0}$



ℰ
(a)
p
n
depletion
layer
(b)
I
breakdown
voltage
Forward
bias
I_S
V
Reverse
bias
(c)
+
Unregulated
DC
Regulated
DC
−
+
−
(d)

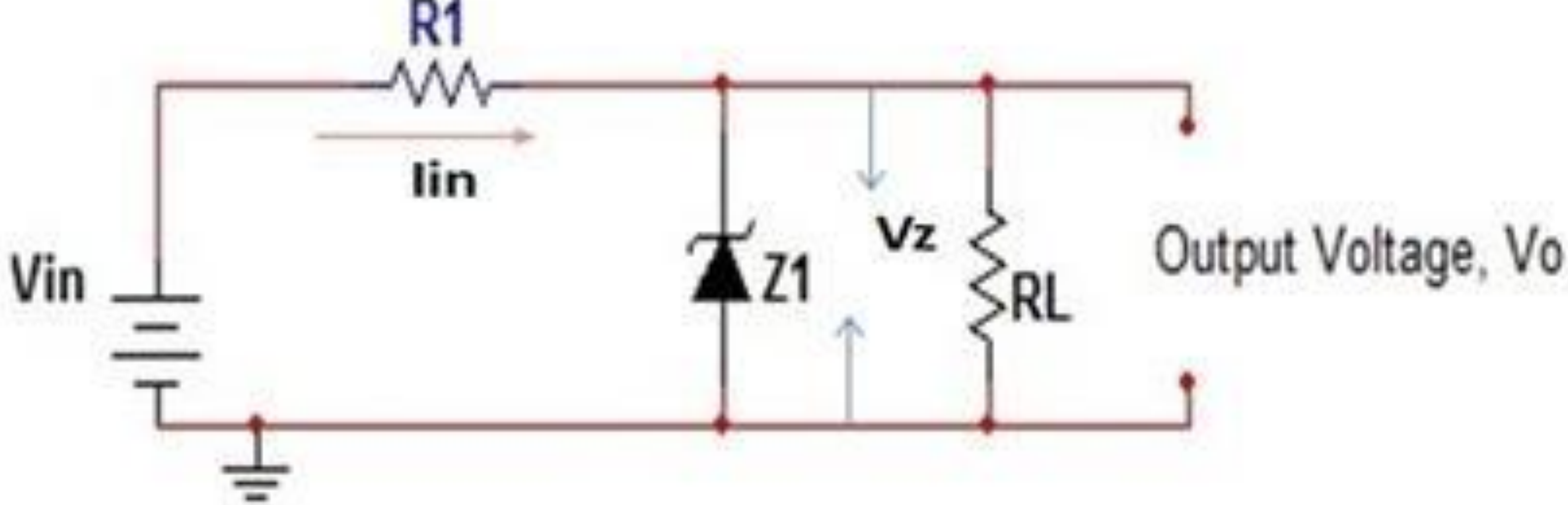
Zener Breakdown

- This type of breakdown occurs for a reverse bias voltage between 2 to 8V.
- Even at this low voltage, the electric field intensity is strong enough to exert a force on the valence electrons of the atom such that they are separated from the nuclei.
- This results in formation of mobile electron hole pairs, increasing the flow of current across the device. Approximate value of this field is about 2*10^7 V/m.
- This type of break down occurs normally for highly doped diode with low breakdown voltage and larger electric field.
- As temperature increases, the valence electrons gain more energy to disrupt from the covalent bond and less amount of external voltage is required.
- Thus zener breakdown voltage decreases with temperature.

Zener diode applications

Zener Diode as a voltage

- In a DC circuit, Zener diode can be used as a voltage regulator or to provide voltage reference. The main use of zener diode lies in the fact that the voltage across a Zener diode remains constant for a larger change in current.
- This makes it possible to use a Zener diode as a constant voltage device or a voltage regulator.
- In any power supply circuit, a regulator is used to provide a constant output (load) voltage irrespective of variation in input voltage or variation in load current.
- The variation in input voltage is called line regulation, whereas the variation in load current is called load regulation.



- A simple circuit involving Zener diode as a regulator requires a resistor of low value connected in series with the input voltage source.

- The low value is required so as to allow the maximum flow of current through the diode, connected in parallel.

- However, the only constraint being, the current through zener diode should not be less than minimum zener diode current.

- Simply put, for a minimum input voltage and a maximum load current, the Zener diode current should always be $I_{zmin.}$

- While designing a voltage regulator using zener diode, the latter is chosen with respect to its maximum power rating.

- In other words, the maximum current through the device should be:-

- I_{max} = Power/Zener Voltage

- Since the input voltage and the required output voltage is known, it is easier to choose a zener diode with a voltage approximately equal to the load voltage, i.e. $V_z \sim= V_o$.

- The value of the series resistor is chosen to be

- $R = (V_{in} – V_z)/(I_{zmin} + I_L)$,

- where I_L = Load Voltage/Load resistance.

- Zener diode is a junction formed by combining highly doped PN semiconductors.

- It works on the principle of Zener breakdown and is operated in reverse breakdown region.

- In reverse breakdown region high current flow through the diode leading to high power dissipation.

- Hence the Zener diodes are provided with adequate power dissipation capabilities to operate in reverse breakdown region.

- When a reverse bias is applied across the diode electric field is generated by uncovered charges at the depletion region. The electric field intensity across a PN junction diode increases as doping level are increased.