•Lecture 2

Semiconductor Diodes

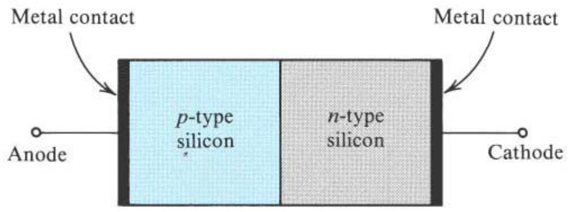
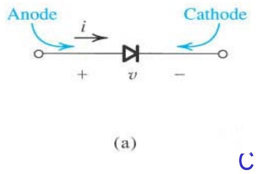
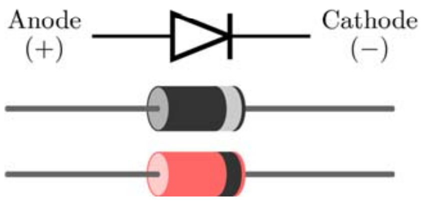


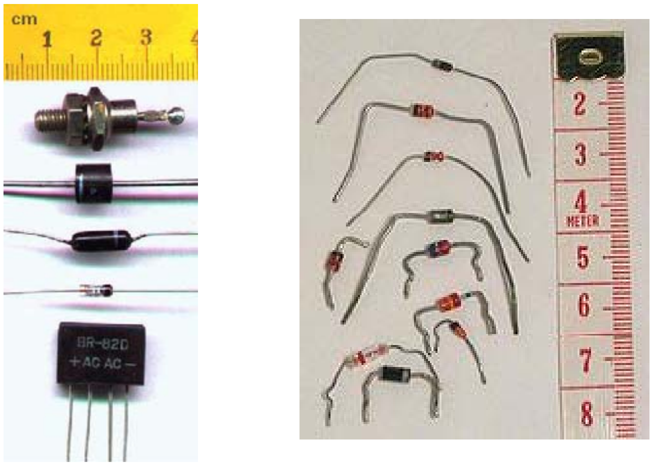
Figure 3.39 Simplified physical structure of the junction diode. (Actual geometries are given in Appendix A.)



Circuit symbol

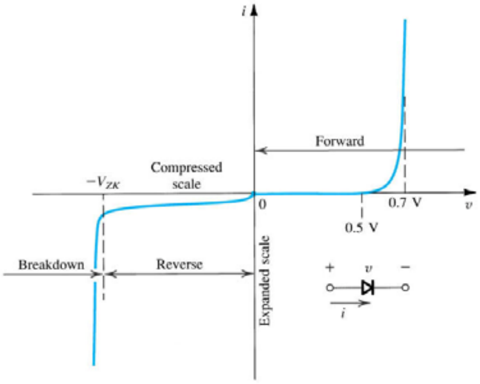


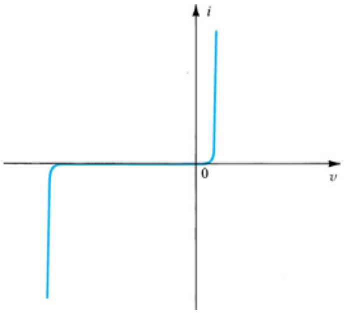
Diodes



Several types of diodes. The scale is centimeters

The *i–v* characteristic of a silicon diode.





ure 3.7 The *i*–*v* characteristic of a silicon junction diode.

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

The *i–v* characteristic of a silicon diode.

- **The Forward-Bias region:-**
- In the forward region the *i- v* relationship is closely approximated by…..

$$i = I_s(e^{kv/T_k} - 1)$$

- I_s …….the reverse saturation current (scale current)
  - K = Boltzmann`s constant = 1.38*10-23 joules / kelvin
  - T_k= the absolute temperature in kelvins = 273 + temperature in °C

The *i–v* characteristic of a silicon diode.

- **The Reverse-Bias region:-**
- The exponential term becomes negligibly small compared to unity, and the diode current becomes…..

$$i \approx -I_s$$

- That is, the current in the reverse direction is constant and equal to I*s* which tends to zero.
- **The Breakdown Region:-**
- The breakdown region is entered when the magnitude of the reverse voltage exceeds a threshold value that is specific to the particular diode, called the breakdown voltage.

Ideal Diode

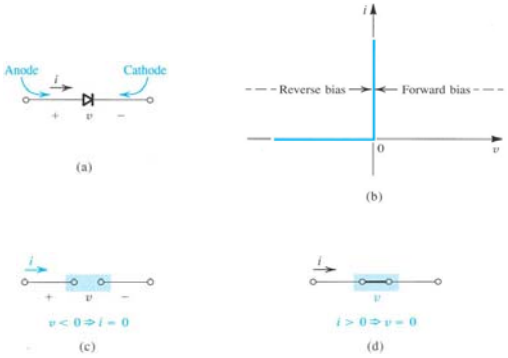


Figure 3.1 The ideal diode: **(a)** diode circuit symbol; **(b)** *i*–*v* characteristic; **(c)** equivalent circuit in the reverse direction; **(d)** equivalent circuit in the forward direction.

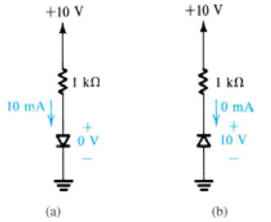


Figure 3.2 The two modes of operation of ideal diodes and the use of an external circuit to limit the forward current **(a)** and the reverse voltage **(b)**.

Modeling the diode forward characteristic

The Piecewise-linear Model

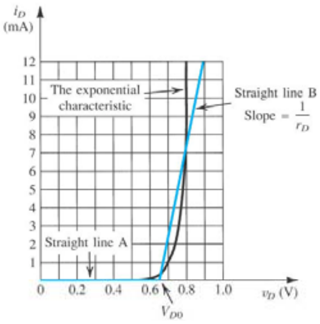


Figure 3.12 Approximating the diode forward characteristic with two straight lines: the piecewise-linear model.

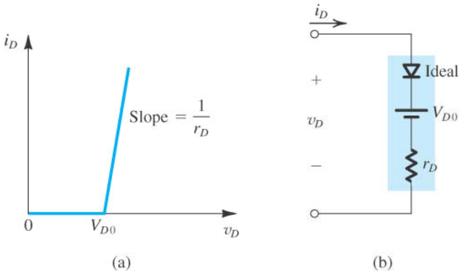


Figure 3.13 Piecewise-linear model of the diode forward characteristic and its equivalent circuit representation.

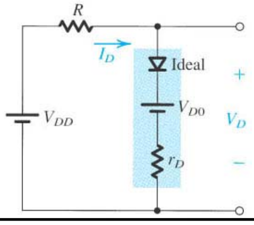
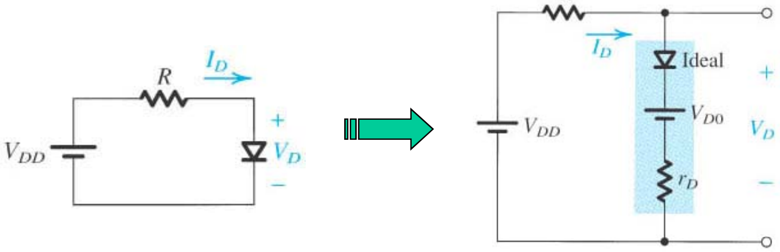


Figure 3.14 The circuit of Fig. 3.10 with the diode replaced with its piecewise-linear model of Fig. 3.13.

Modeling the diode forward characteristic

The Piecewise-linear Model

Example:



Given: V_{DD} = 5V, V_{DO}= 0.65, r_D = 20Ω ,R= 1KΩ

Thus

$$I_D = \frac{5-0.65}{1+0.02} = 4.26mA$$

$V_D = V_{DO}+I_Dr_D$

= 0.65+4.26x0.02=0.735V

Modeling the diode forward characteristic

The Constant-voltage-drop Model

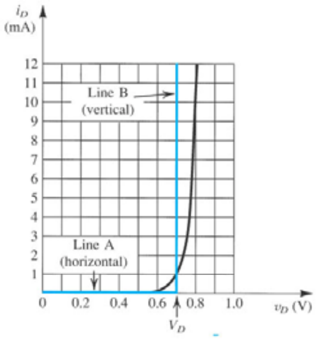


Figure 3.15 Development of the constant-voltage-drop model of the diode forward characteristics. A vertical straight line (B) is used to approximate the fast-rising exponential. Observe that this simple model predicts V_D to within ±0.1 V over the current range of 0.1 mA to 10 mA.

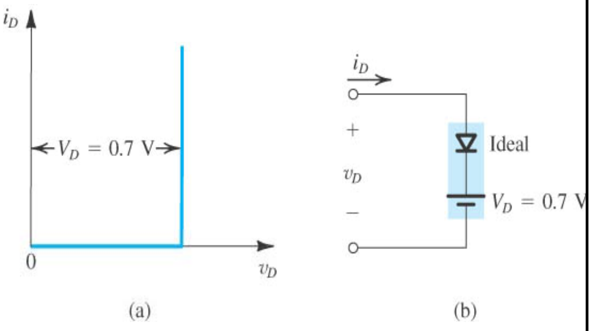


Figure 3.16 The constant-voltage-drop model of the diode forward characteristics and its equivalent-circuit representation.

Modeling the diode forward characteristic

The Ideal Diode Model

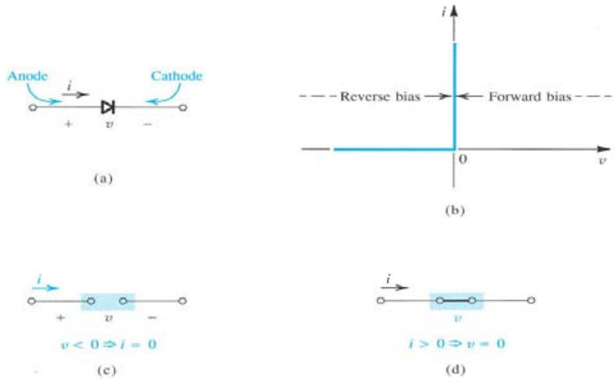


Figure 3.1 The ideal diode: **(a)** diode circuit symbol; **(b)** *i*–*v* characteristic; **(c)** equivalent circuit in the reverse direction; **(d)** equivalent circuit in the forward direction.

Operation in The reverse Breakdown Region- Zener Diodes

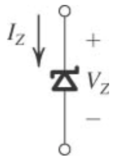


Figure 3.20 Circuit symbol for a zener diode.

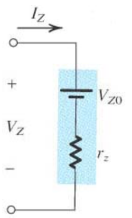


Figure 3.22 Model for the zener diode.

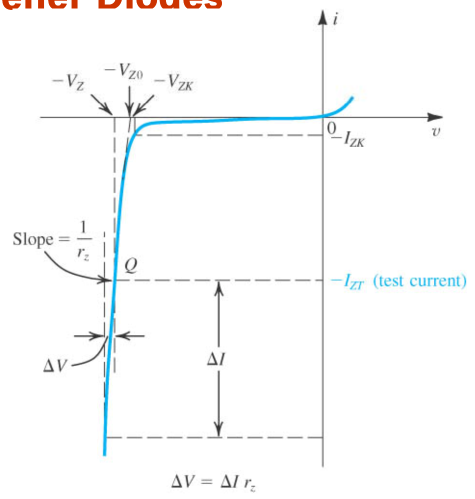


Figure 3.21 The diode *i*–*v* characteristic with the breakdown region shown in some detail.

Operation in The reverse Breakdown Region- Zener Diodes

Example: Find *I* ?

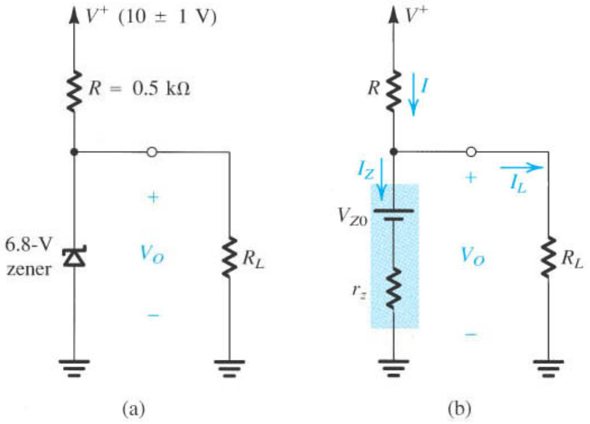
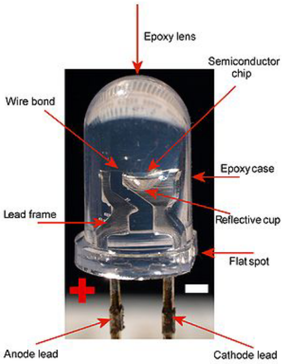
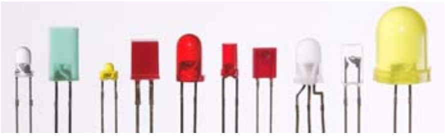


Figure 3.23 **(a)** Circuit for Example 3.8. **(b)** The circuit with the zener diode replaced with its equivalent circuit model.

Special Diode Types

Light-Emitting Diodes (LEDs)





Series Diode Configurations with DC Inputs

- For the series diode configurations that will be considered, the first thing to do is to determine the state of the diode " ON" or "OFF"
- In the "ON" state, the diode may be replaced with a constant voltage drop (0.3, or 0.7) or a short circuit based on the model of approximation.
- In the OFF state, diode is replaced with an open circuit.
- Example 2.8, and Example 2.9

Parallel and Series Parallel Configurations

- The method applied before can be extended to the analysis of parallel and series-parallel configurations where more than one diode is contained in the circuit, simply match the sequential series steps applied to series diode configurations
  - Example 2.12 and Example 2.15

Diode Applications

Diodes Applications: Rectifier Circuits

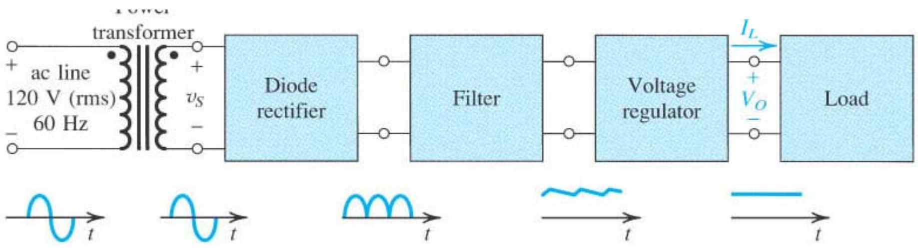


Figure 3.24 Block diagram of a dc power supply.

The Half-Wave Rectifier

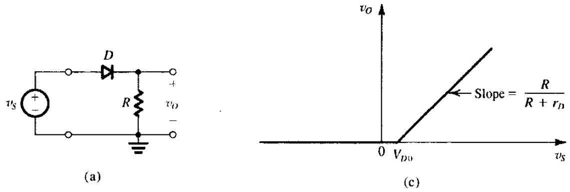


Figure 3.25 **(a)** Half-wave rectifier. **(b)** Equivalent circuit of the half-wave rectifier with the diode replaced with its battery-plus-resistance model.

$$v_O = 0, \qquad v_S < V_{D0}$$

$$v_O = \frac{R}{R+r_D} v_S - V_{D0}\frac{R}{R+r_D}, \qquad v_S \geq V_{D0}$$

$$v_O \simeq v_S - V_{D0}$$

The Half-Wave Rectifier

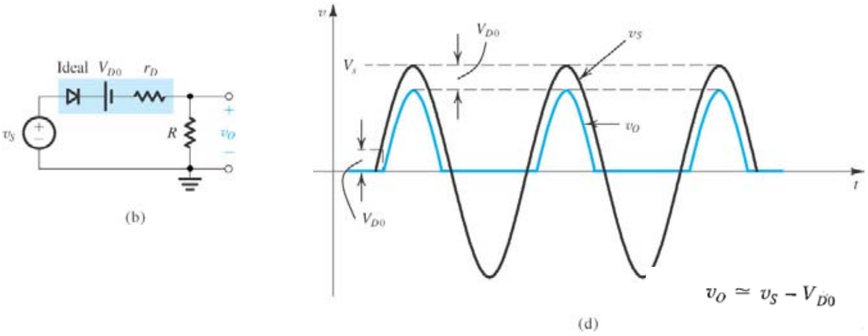
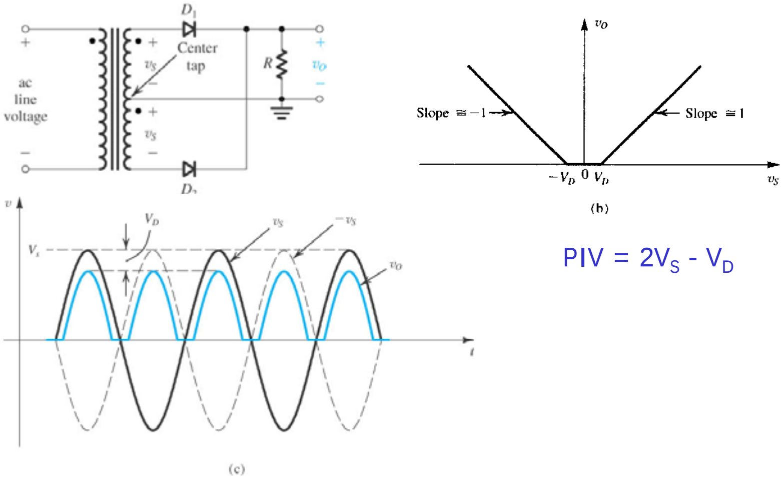


Figure 3.25. **(c)** Transfer characteristic of the rectifier circuit. **(d)** Input and output waveforms, assuming that r_D / R.

The Peak Inverse Voltage PIV = Vs

The Full Wave Rectifier



PIV = $2V_S$ - V_D

Figure 3.26 Full-wave rectifier utilizing a transformer with a center tapped secondary winding: (a) circuit; (b) transfer characteristics assuming a constant-voltage-drop model for the diodes; © input and output wave forms.

The Bridge Rectifier

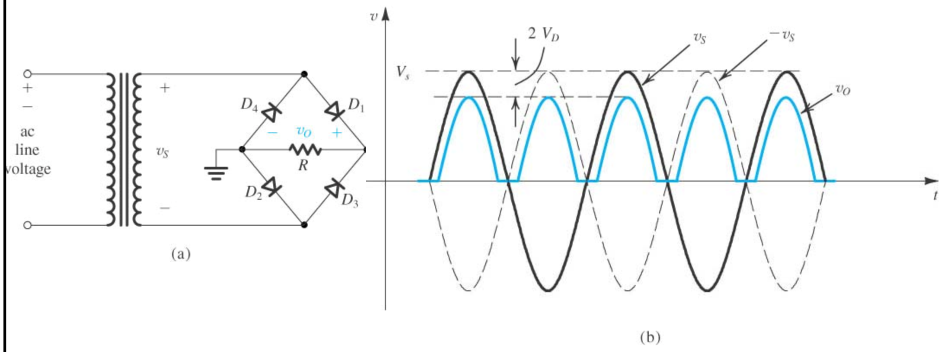


Figure 3.27 The bridge rectifier: **(a)** circuit; **(b)** input and output waveforms.

PIV = $V_S – 2V_D + V_D = V_S - V_D$

The rectifier with a filter capacitor

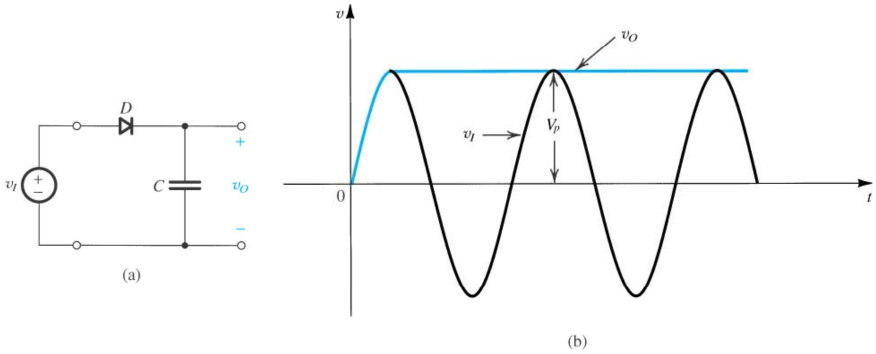


Figure 3.28 **(a)** A simple circuit used to illustrate the effect of a filter capacitor. **(b)** Input and output waveforms assuming an ideal diode. Note that the circuit provides a dc voltage equal to the peak of the input sine wave. The circuit is therefore known as a peak rectifier or a peak detector.

The rectifier with a filter capacitor

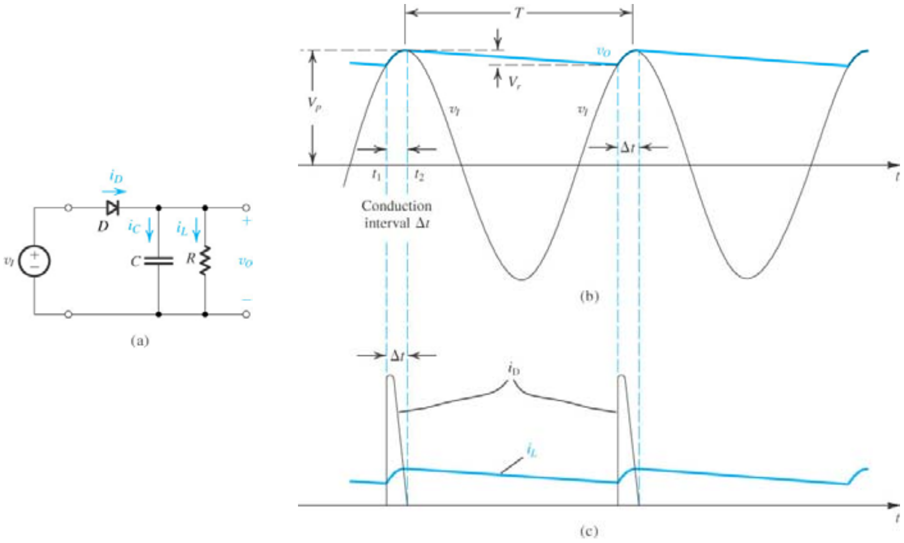


Figure 3.29 Voltage and current waveforms in the peak rectifier circuit with *CR* @ *T*. The diode is assumed ideal.

The rectifier with a filter capacitor

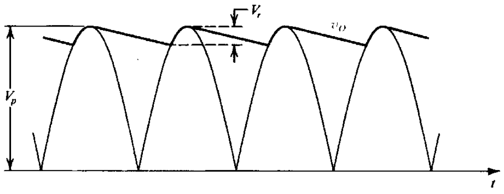
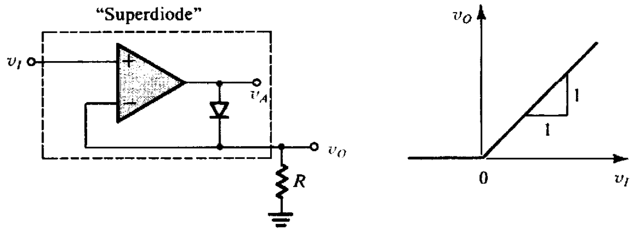


Figure 3.30 Waveforms in the full-wave peak rectifier.

Precision Half-Wave Rectifier- The Super Diode



(a)

(b)

Figure 3.31 The "superdiode" precision half-wave rectifier and its almost-ideal transfer characteristic. Note that when $v_I > 0$ and the diode conducts, the op amp supplies the load current, and the source is conveniently buffered, an added advantage. Not shown are the op-amp power supplies.

Limiter Circuits

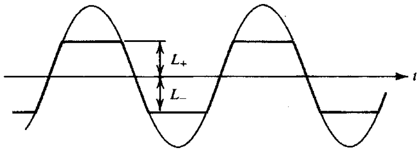


Figure 3.33 Applying a sine wave to a limiter can result in clipping off its two peaks.

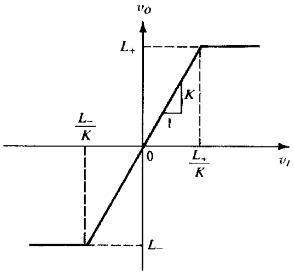


Figure 3.32 General transfer characteristic for a limiter circuit.

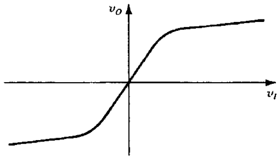


Figure 3.34 Soft limiting.

Limiter Circuits

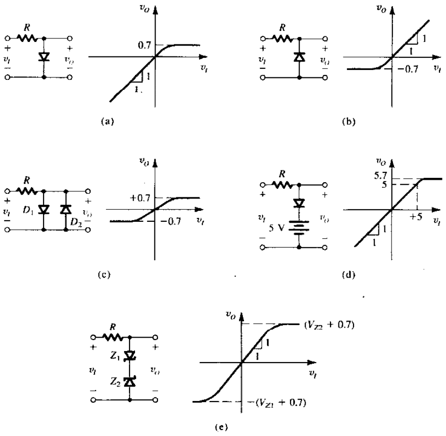
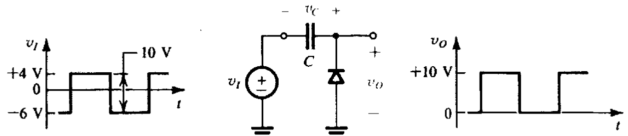


Figure 3.35 A variety of basic limiting circuits.

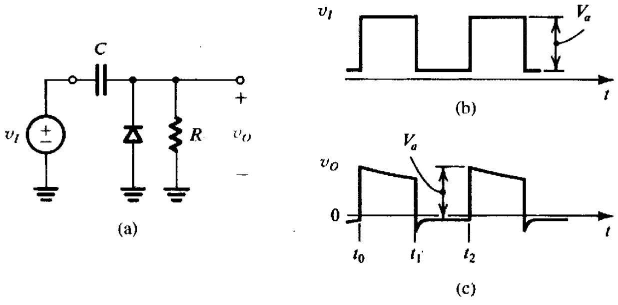
The Clamped Capacitor or DC Restorer



(a) (b) (c)

Figure 3.36 The clamped capacitor or dc restorer with a square-wave input and no load.

The Clamped Capacitor or DC Restorer



(a) (b) (c)

Figure 3.37 The clamped capacitor with a load resistance *R*.

The Voltage Doublers

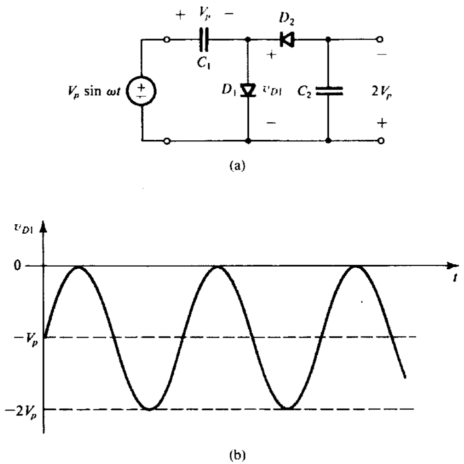
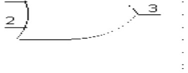


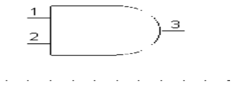
Figure 3.38 Voltage doubler: **(a)** circuit; **(b)** waveform of the voltage across D_1.

Diode Applications

AND/OR Gates

- AND and OR gates represent basic components of computers that are used to implement Boolean algebra.





OR-Gate

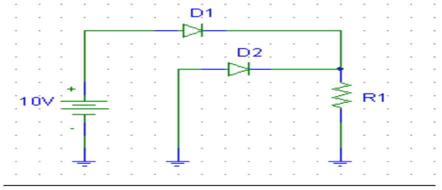
1	2	3
0	0	0
0	1	1
1	0	1
1	1	1

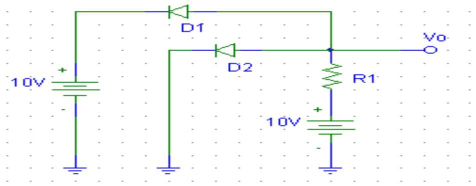
AND-Gate

1	2	3
0	0	0
0	1	0
1	0	0
1	1	1

If logic “1” is represented by +10 (+5) V and logic “0” is represented by 0 V, the OR and the AND gates can be represented by the following diode combinations;

AND/OR Gates

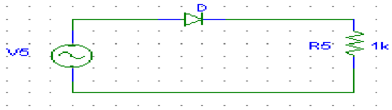


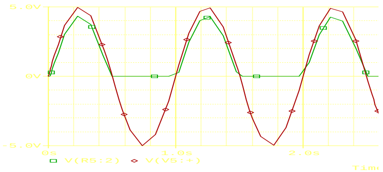


- For the OR gate;
  - D1⇒ON
  - D2 ⇒OFF
  - V_0=10V (logic 1)
- For the AND gate;
  - D1 ⇒OFF
  - D2 ⇒ON
  - V_0=0V (logic 0)

Sinusoidal Inputs; Half-wave Rectification (Ideal diode Model)

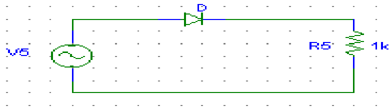
- So far, we have considered time invariant signals only (DC).
- Now, diode circuit analysis will be extended to include circuits containing time varying signals (AC).
- The simplest diode application that uses AC signals is the HWR signal shown.
- To simplify the analysis, we'll assume that the diodes used are ideal.
- Note that, the DC content of the input waveform is zero, Why?
- During time interval t=0 ⇒T/2, diode is ON.
- Since we are using an ideal diode model, $v_0=v_i$.
- *During the time interval t=T/2* ⇒T, diode is OFF; $v_0=0$.
- Now, what is the value of the DC level in the output waveform? ($V_{dc}=0.318V_m$)

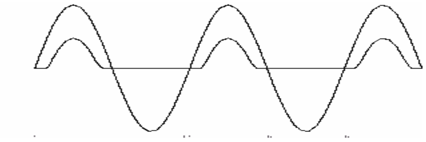




M Hassan

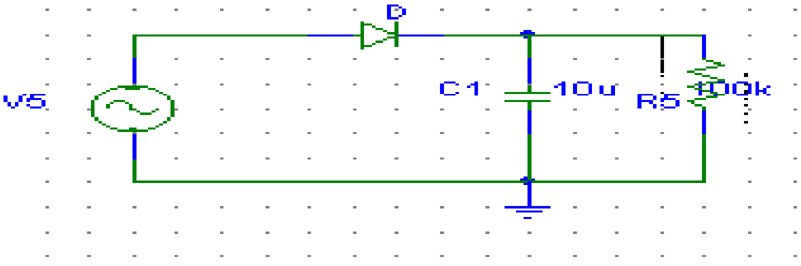
HWR with Const Voltage Drop Diode Model

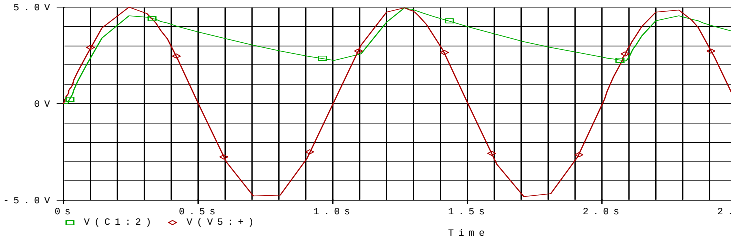




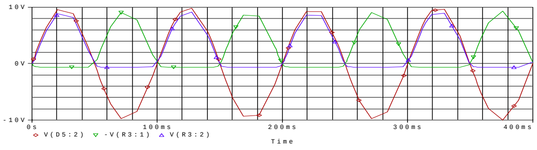
- In case of using the constant voltage drop diode model, during the conduction period diode will be replaced with a constant voltage source V_T.
- Thus, the peak of the output waveform will decrease from V_m by V_T.
- In addition, the conduction period of the diode will be slightly less than T/2.
- In this case, the DC content of the output waveform becomes;
- $V_{dc} \approx 0.318(V_m-V_T)$ (Note: $0.318V_m = V_m/\pi$)
- ***Peak Inverse Voltage* (PIV)**
- **Definition:** PIV is the value of the maximum reverse voltage that is expected to apply to the diode in during its operation.
- PIV: Peak Inverse Voltage in this case = V_m, Thus, $PIV_{rating} > V_m$

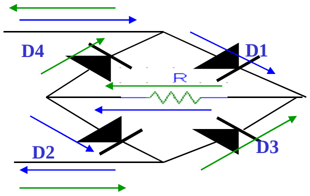
HWR Circuit With Smoothing Capacitor





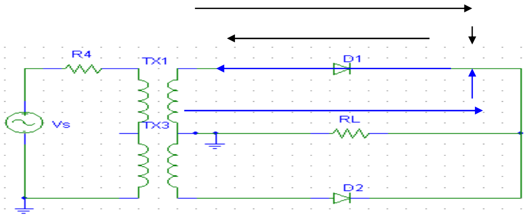
Full-wave Rectifier

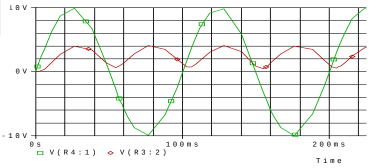




- As seen in the HWR circuit, the DC level obtained is small relative to the maximum value of the a/c signal.
- The reason for that low level DC is the removal of negative half-wave.
- DC level can be improved to 100% of that obtained in HWR, by using the ***full-wave rectifier*** configuration shown.
- For t=0→T/2, D1 and D2 ON while D3, and D4 OFF.
- For t=T/2→T, D3, D4 ON, while D1 and D2 OFF.
- As seen form the waveform generated, the DC level for that configuration is twice that of the HWR.
- $V_{dc(FWR)}$=2× $V_{dc(HWR)}$= 2× 0.318V_m , ideal diode model.
- =2× 0.318(V_m-2V_T) simplified
- PIV$|_{rating}$>V_m

Center Tapped Transformer FWR





- For t=0→T/2, D1 ON while D2, OFF.
- For t=T/2→T, D2 ON, while D1, OFF
- PIV$|_{rating}$>2V_m
- Example 2.19