Microelectronics
Circuit Analysis and Design

Donald A. Neamen

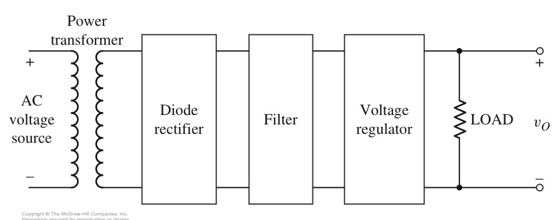
Chapter 2

Diode Circuits

In this chapter, we will:

- Determine the operation and characteristics of diode rectifier circuits, which is the first stage of the process of converting an ac signal into a dc signal in the electronic power supply.
- Apply the characteristics of the Zener diode to a Zener diode voltage regulator circuit.
- Apply the nonlinear characteristics of diodes to create waveshaping circuits known as clippers and clampers.
- Examine the techniques used to analyze circuits that contain more than one diode.

Block Diagram for ac to dc Converter

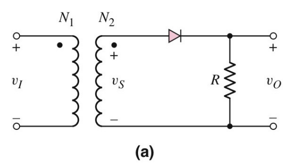


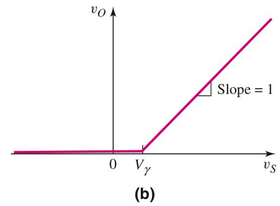
The diode rectifier, filter, and voltage regulator are diode circuits.

Problem-Solving Technique: Diode Circuits

1. Determine the input voltage condition such that the diode is conducting (on).
   a. Find the output signal for this condition.
2. Determine the input voltage such that the diode is not conducting (off).
   a. Find the output signal for this condition.

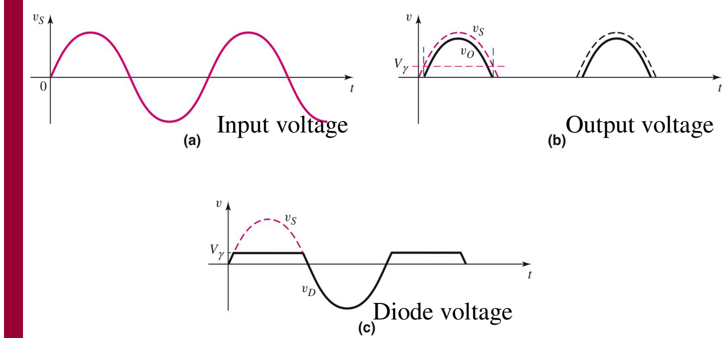
Half-Wave Rectifier



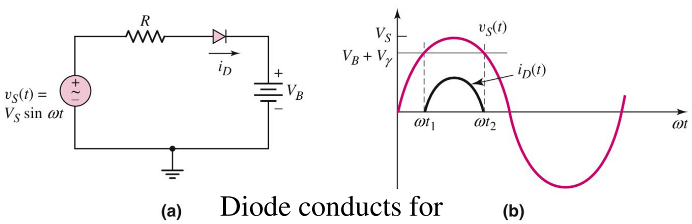


Voltage Transfer Characteristics

Signals of Half Wave Rectifier



Half-Wave Rectifier as Battery Charger

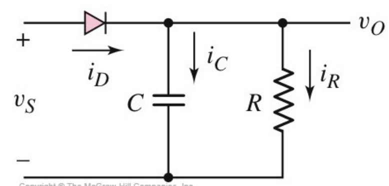


Diode conducts for
$v_s - V_B > V_\gamma$

$$\omega t_1 = sin^{-1}\left(\frac{V_B + V_\gamma}{V_S}\right) \quad \& \quad \omega t_2 = 180^\circ - \omega t_1$$

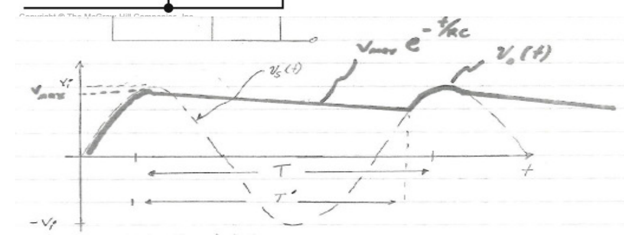
$$Percent\ time = \frac{\omega t_2 - \omega t_1}{360°}$$

Half-Wave Rectifier with Filter



$$V_{max} = V_{s(max)} - V_\gamma$$

$$V_{min} = V_{max} e^{-T'/RC}$$



Half-Wave Rectifier with Filter

For $RC >> T'$ *and if* $T' \cong T = {}^{1}/_{f}$

Then

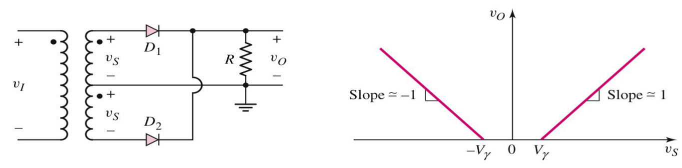
$$V_{min} = V_{max} e^{-T'/RC} \cong V_{max}\left(1 - \frac{1}{fRC}\right)$$

$$V_r = V_{max} - V_{min} = V_{max}\left(\frac{1}{fRC}\right)$$

$$\%\ Ripple = \frac{V_{max} - V_{min}}{V_{max}}\ x\ 100\%$$

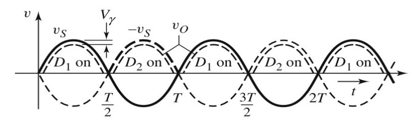
$$\%\ Ripple = \frac{1}{fRC}\ x\ 100\%$$

Full-Wave Rectifier



(a) (b)

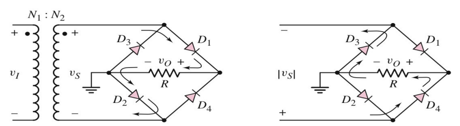
Voltage transfer characteristics



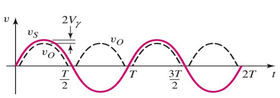
(c)

Input and output waveforms

Full-Wave Bridge Rectifier



(a) (b)

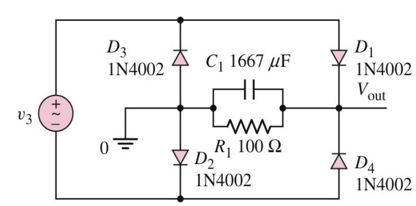


(c)

When v_S is positive, D_1 and D_2 are turned on (a). When v_S is negative, D_3 and D_4 are turned on (b).

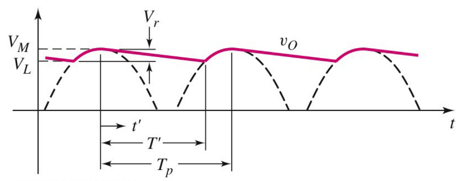
In either case, current flows through R in the same direction, resulting in an output voltage, v_O, shown in (c).

Output Voltage of Full-Wave Rectifier with RC Filter



(a)

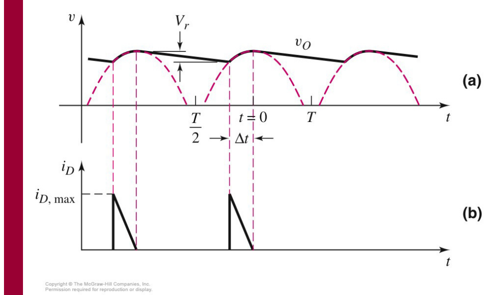
Output Voltage of Full-Wave Rectifier with RC Filter



The ripple on the 'dc' output is $V_r = \frac{V_M}{2fRC}$ where $f = \frac{1}{2T_P}$

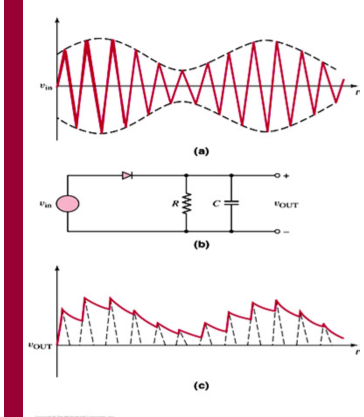
The average 'dc' output is $V_{avg} = \frac{1}{T'/2}\int_0^{T'/2} V_M sinwt\, dt \cong \frac{2}{\pi}V_M$

Output Voltage of Full-Wave Rectifier with RC Filter



Diode conducts current for only a small portion of the period.

Demodulation of AM Signal

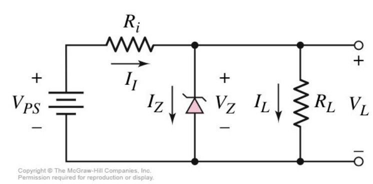


Modulated input signal

Detector circuit

Demodulated output signal

Voltage Regulator



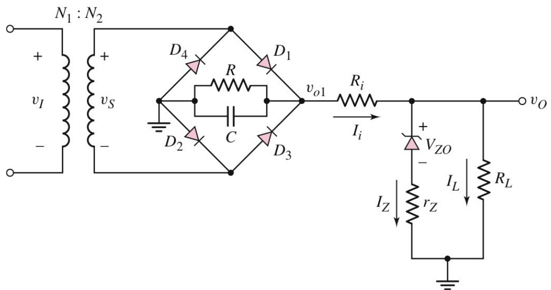
$$I_L = \frac{V_Z}{R_L}$$

$$I_I = \frac{V_{PS} - V_Z}{R_i}$$

$$I_Z = I_I - I_L$$

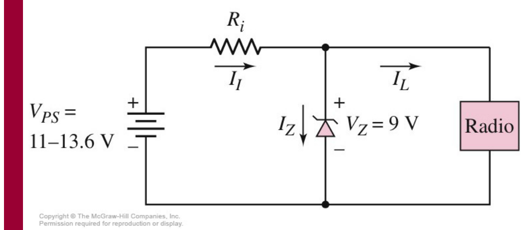
The characteristics of the Zener diode determines V_L.

Design DC Power Supply Circuit



Example

Select a diode and resistor to supply a steady 9 V to a radio which draws 0 to 0.1 A. The source is an unsteady 12V supply.



$0 < I_L < 0.1\ A$

Zener diode voltages range from 2.0 to 25 volts, at power rating from 0.3 to 5 watts.

Example

1. **Choose a zener diode voltage:**
 Select **9V** zener for this example.

2. **Determine max. circuit current:**
The load requires 100mA, plus we need at least 10 mA for the zener diode. Since the supply is unstable, we can add 20-50% margin to obtain a safe value. Let's choose **Imax = 200mA**.

3. **Select zener diode power rating:**
 Pz = Vz*Imax = 9*0.2 = **1.8W**
 => select 1.8W or higher rated zener

Example

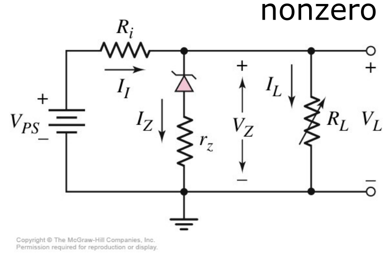
4. **Select the resistor:**

$$\boldsymbol{R_i = \frac{V_{PSmax} - V_z}{I_{max}} = \frac{13.6 - 9}{0.2} = 23\Omega}$$

5. **Select the resistor power rating:**
 Pr = Vr * Imax = 3.6 * 0.2 = **0.72W**
 => select 0.72W or higher rated resistor.

Would the circuit be adequate if the source voltage varied up to 15.5V?

Voltage Rectifier with nonzero Zener resistance



The Zener diode begins to conduct when $V_{PS} = V_Z$.

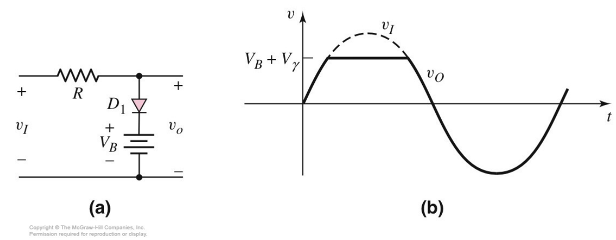
When $V_{PS} \geq V_Z$: $V_L = V_Z$

$I_L = V_Z/R_L$, but $V_Z \neq$ constant

$I_1 = (V_{PS} - V_Z)/R_i$

$I_Z = I_1 - I_L$

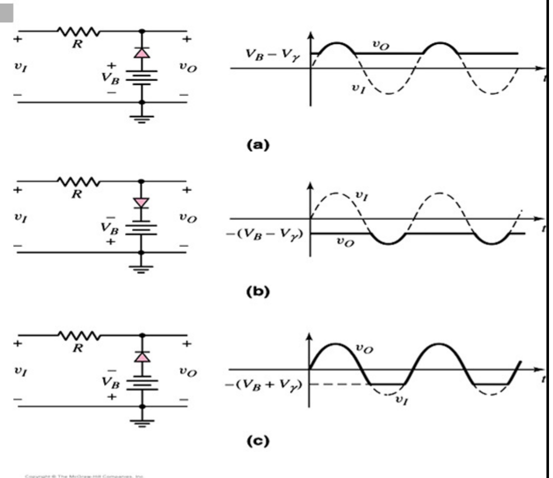
Single Diode Clipper



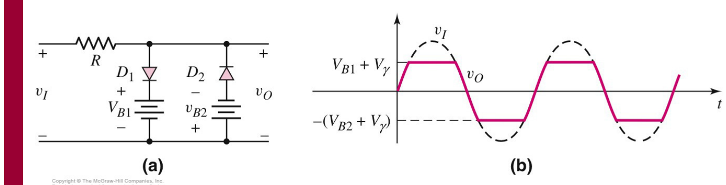
For $v_I < V_B + V_\gamma$ the diode is open and $v_0 = v_I$

For $v_I \geq V_B + V_\gamma$ the diode conducts and $v_0 = V_B + V_\gamma$

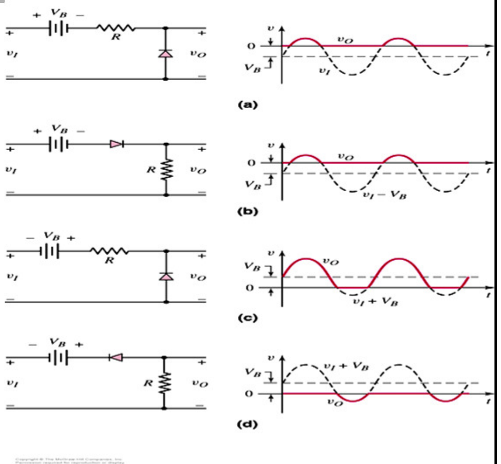
Additional Diode Clipper Circuits



Parallel-Based Diode Clipper Circuit

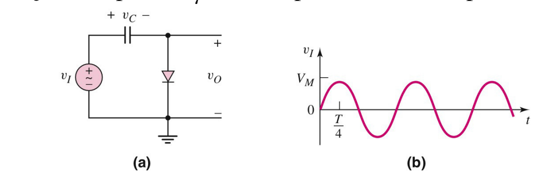


Series-Based Diode Clipper Circuits



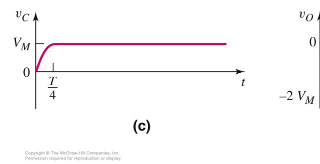
Diode Clamper Circuit

The clamper circuit shifts the entire signal voltage by a DC level. $v_o$is clamped to V_γ. The output is a shifted replica of input.



$v_o = v_I - v_c = V_M(sinwt\ - 1)$

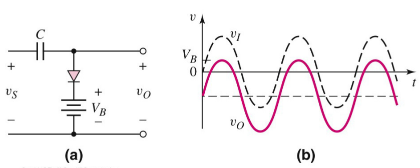
assume ideal diode



v_o clamped to 0V.

Diode Clamper Circuit with Voltage Source

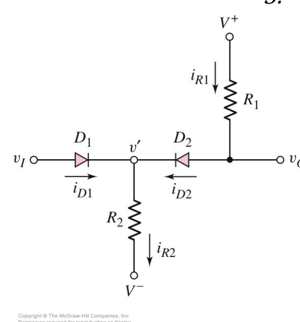
The clamper circuit shifts the entire signal voltage by a DC level. $v_o$is clamped to $V_\gamma + V_B$ ($V_\gamma = 0$ $shown$).

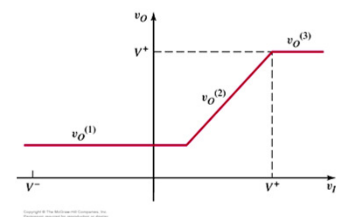


v_c $charges$ to $V_M - V_B$. $\Rightarrow v_o = v_s - v_c$

2 Diode Circuit

1. D_1 off & D_2 $on \Rightarrow$ $v_o = V^+ - IR_1$
2. D_1 on & D_2 on $\Rightarrow$ $v_o = v_I$
3. D_1 on & D_2 $off \Rightarrow$ $v_o = V^+$



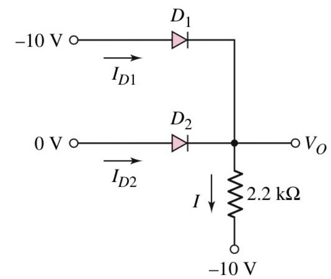


Voltage transfer characteristics

Problem-Solving Technique: Multiple Diode Circuits

1. Assume the state of the diode.
   a. If assumed on, $V_D = V_\gamma$
   b. If assumed off, $I_D = 0$.
2. Analyze the 'linear' circuit with assumed diode states.
3. Evaluate the resulting state of each diode.
4. If any initial assumptions are proven incorrect, make new assumption and return to Step 2.

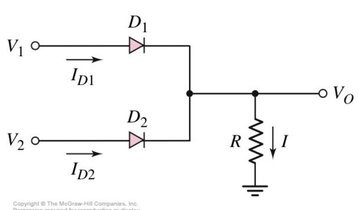
Exercise problem



D_1 is not on.

D_2 is on.
This pins V_O to -0.6V

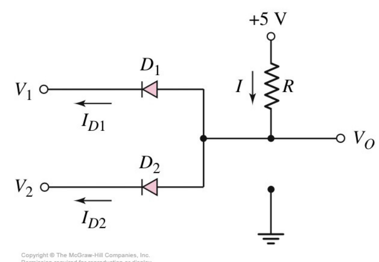
Diode Logic Circuits: 2-Input OR Gate



V_1 (V)	V_2 (V)	V_O (V)
0	0	0
5	0	4.3
0	5	4.3
5	5	4.3

$V_\gamma = 0.7V$

Diode Logic Circuits: 2-Input AND Gate



V_1 (V)	V_2 (V)	V_O (V)
0	0	0.7
5	0	0.7
0	5	0.7
5	5	5.0

$V_\gamma = 0.7V$