Diode Wave Shaping Techniques, Clipping and Clamping Circuits, Voltage Regulation using Zener Diode

Text Books

1. Electronic Devices and Circuit Theory

by R Boylestad and L Nashelsky

2. **Op-Amps and Linear Integrated Circuits**

by Ramakant A. Gayakwad

3. Microelectronic Circuits Analysis and Design

by Muhammad H. Rashid

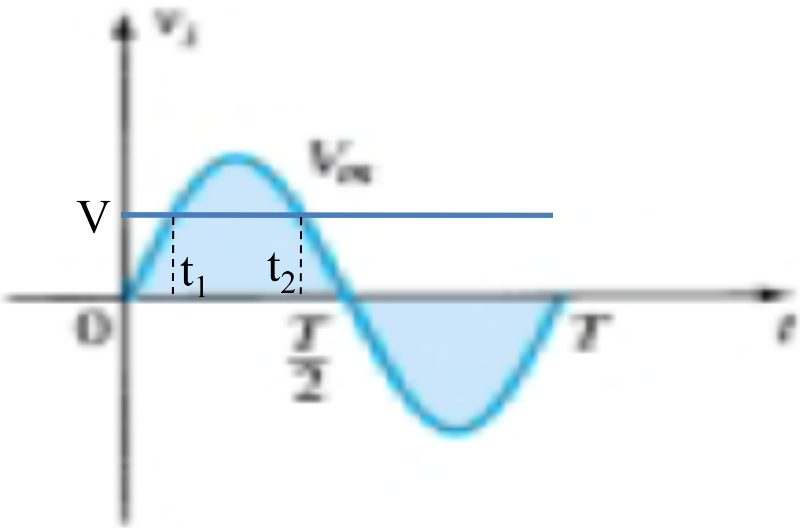
4. Electronic Principles 7th Edition

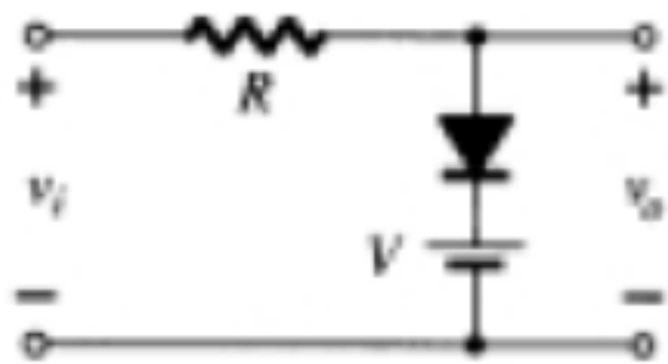
by Albert Malvino, David Bates

Clipper circuit

- Used to clip off a portion of the input signal.
- Needs diode, resistor and dc battery.
- Half wave rectifier is the simplest form of clipper which clips off the entire half cycle of the input.

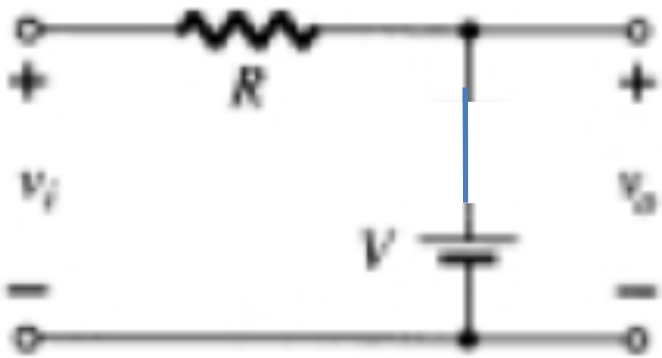
Example-1

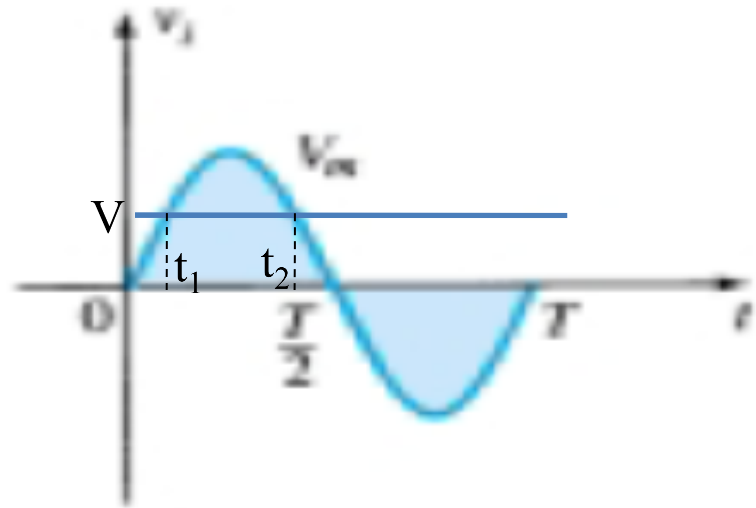


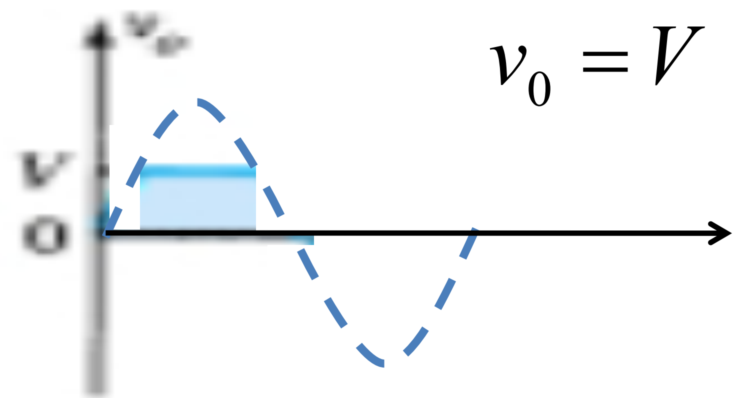


$$v_0 = V$$

Example-1



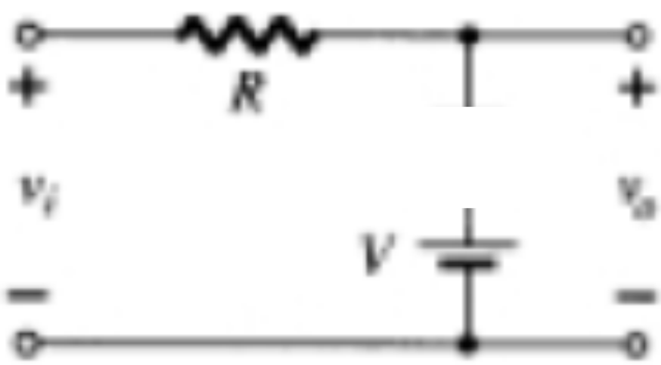


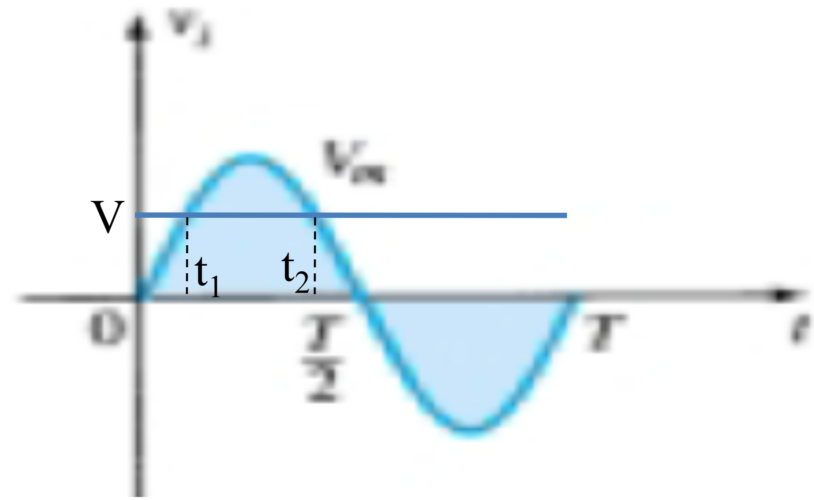


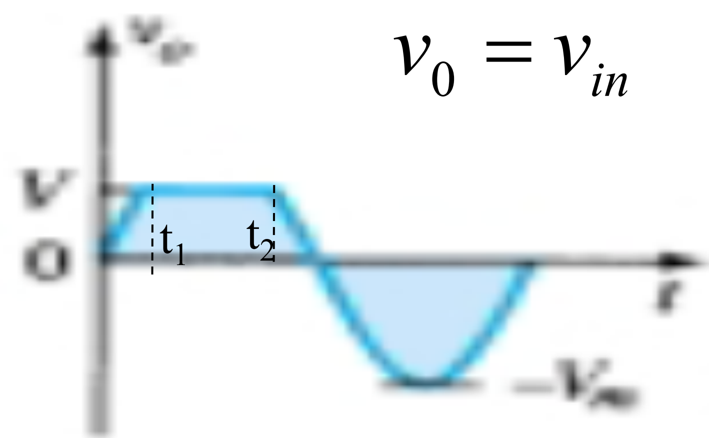
$$v_0 = V$$

The diode will turn on during the positive half cycle only when $v_i \geq$V, the output is then $v_0 =$ V.

Example-1



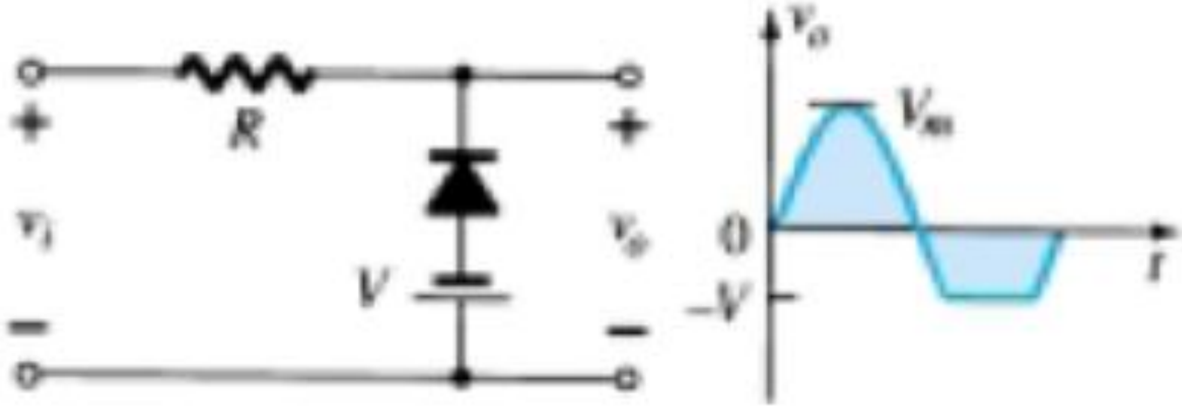




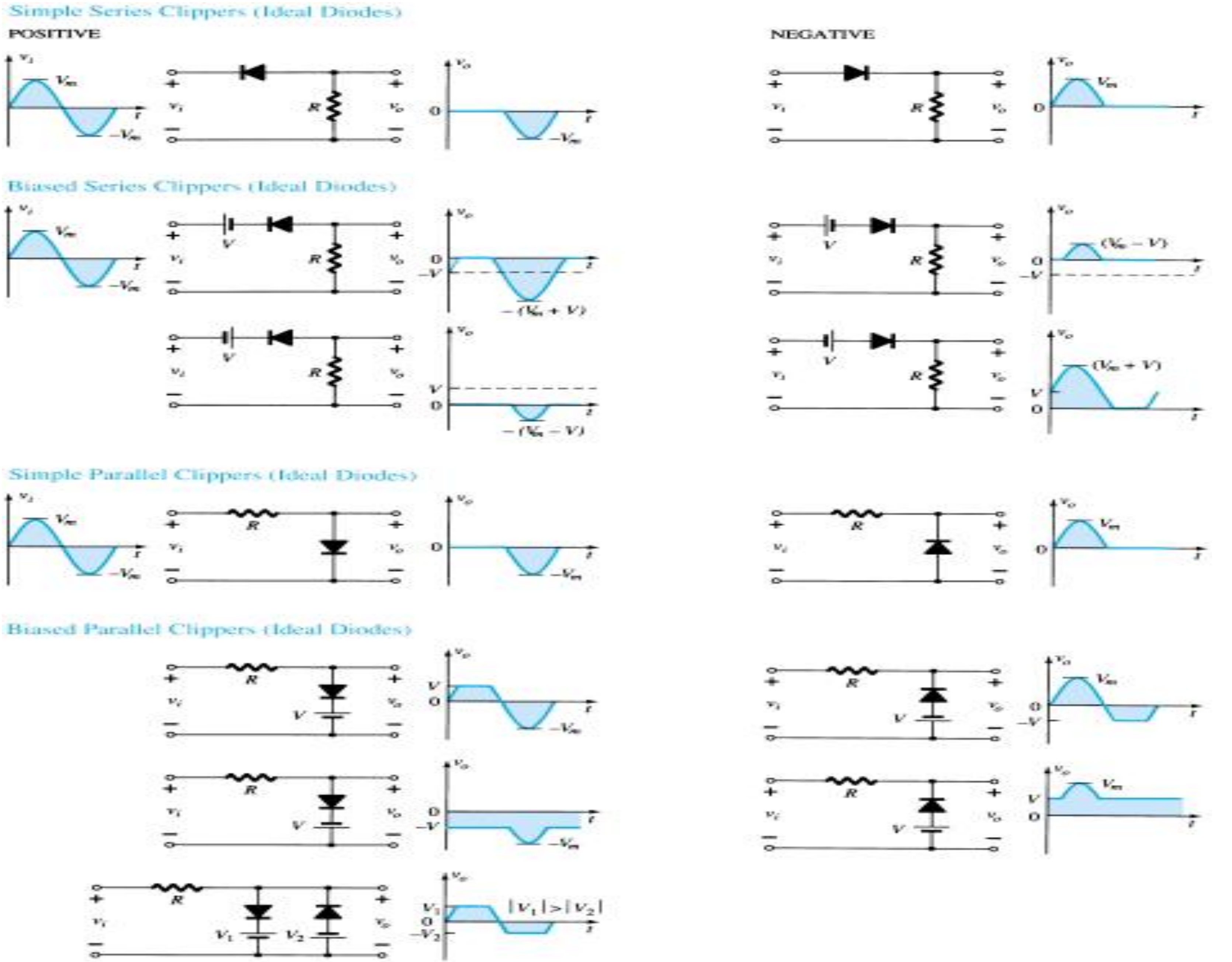
$$v_0 = v_{in}$$

- For v_i<V, the diode is off, the diode will also be off during entire negative half cycle of the input signal.
- When the diode is off, $v_0 = v_i$.

Example-2



- The diode is off during entire positive half cycle of the input signal. Therefore, $v_0 = v_i$.
- In negative half cycle the diode will be also off for $v_i < -V$, output will be also, $v_0 = v_i$.
- The will turn on when $v_i \geq -V$, the output is then $v_0 = -V$.


Simple Series Clippers (Ideal Diodes)
POSITIVE
NEGATIVE
Biased Series Clippers (Ideal Diodes)
Simple Parallel Clippers (Ideal Diodes)
Biased Parallel Clippers (Ideal Diodes)
$|V_1| > |V_2|$

Clamper circuit

- Clamper adds a dc level to an ac signal. It shifts the ac signal to a certain dc level.
- Needs diode, resistor, capacitor.
- Sometimes it needs a dc battery too.

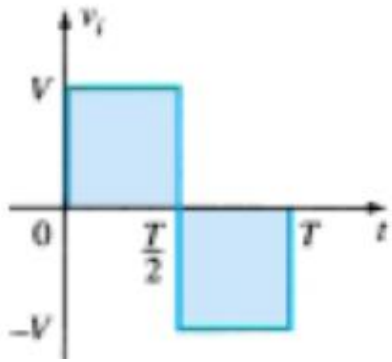
Steps to analyze

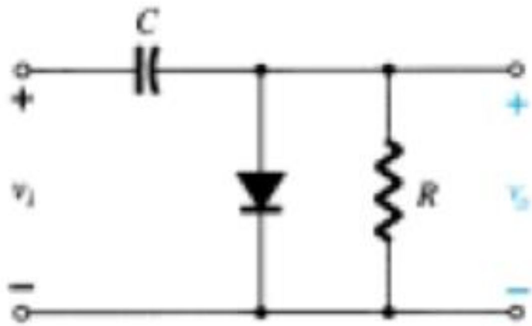
- Analyze the circuit for the portion of the input signal first for which the diode conducts.

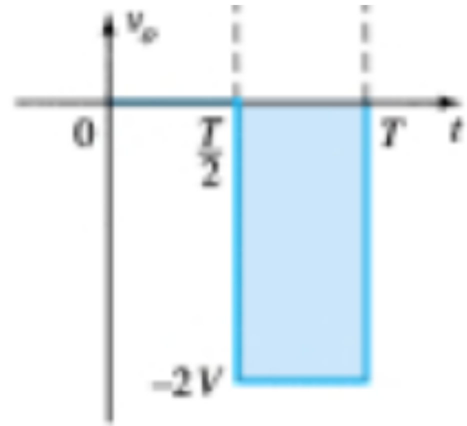
- Find the voltage across the capacitor and indicate the polarity. Find the corresponding output voltage.

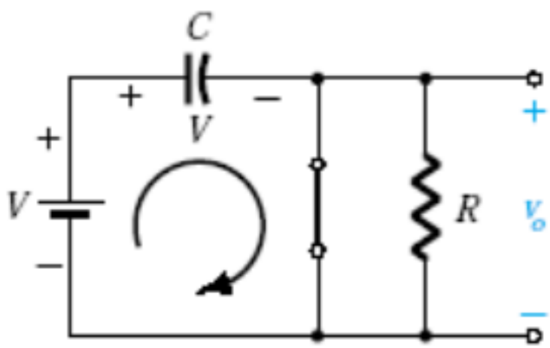
- Then, determine the output voltage due to the rest portion of the input signal.

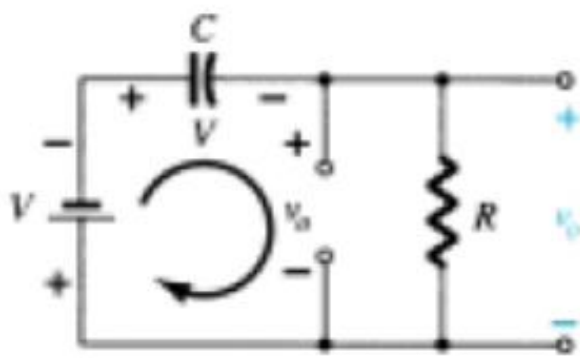
Example-1





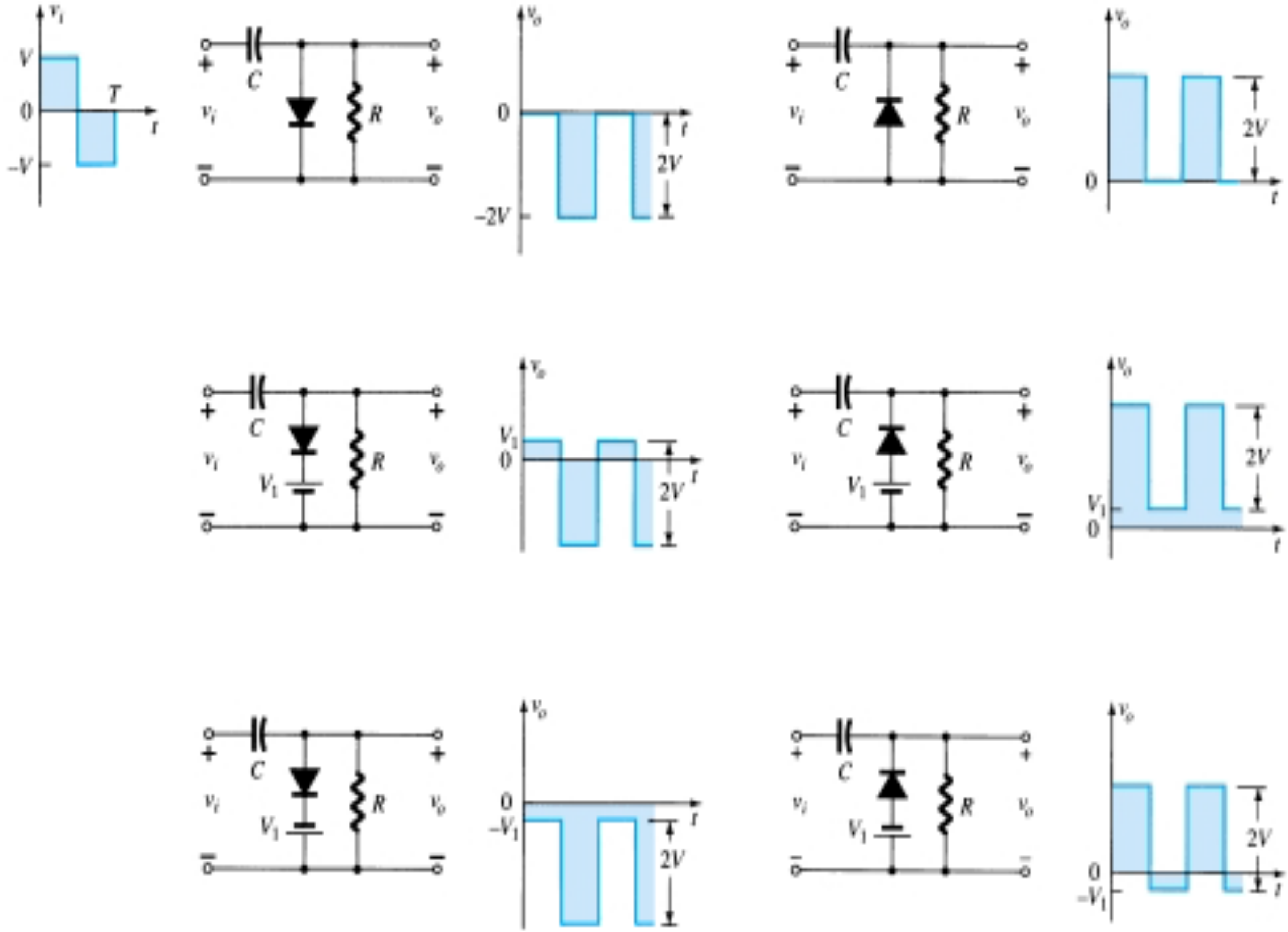






Applying KVL, $-V - V - v_o = 0$

$$v_o = -2V$$



v_i
V
0
T
t
–V
C
R
v_o
0
–2V
2V
V_1
2V
V_1
0
$-V_1$

Clamping network with a sinusoidal input

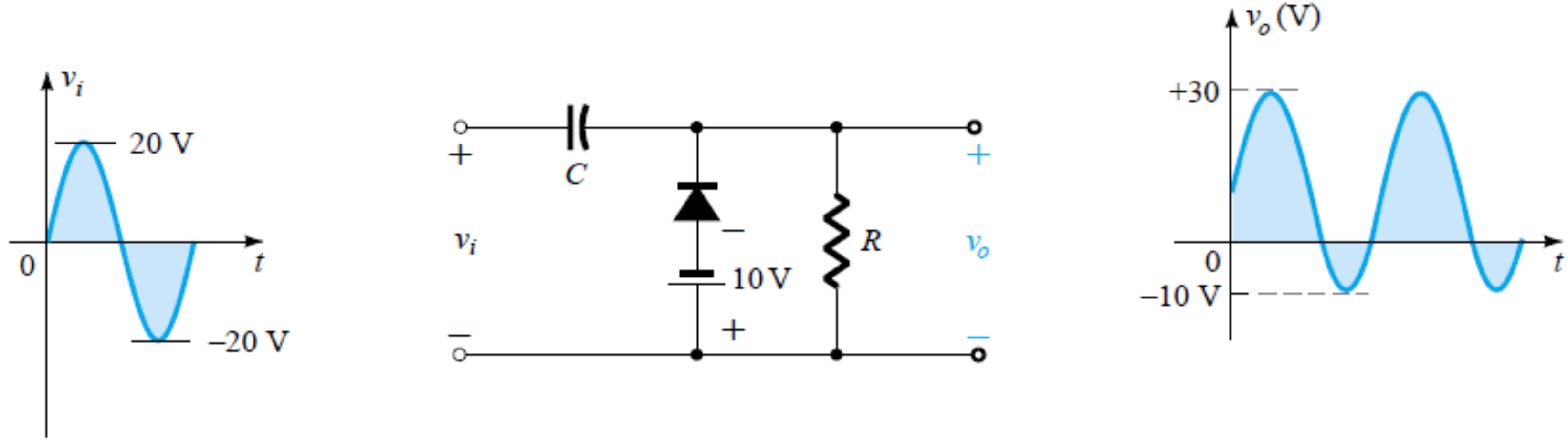


Figure 2.104 Clamping network with a sinusoidal input.

Network with a DC and AC source

The response of any network with both an ac and a dc source can be found by finding the response to each source independently and then combining them.

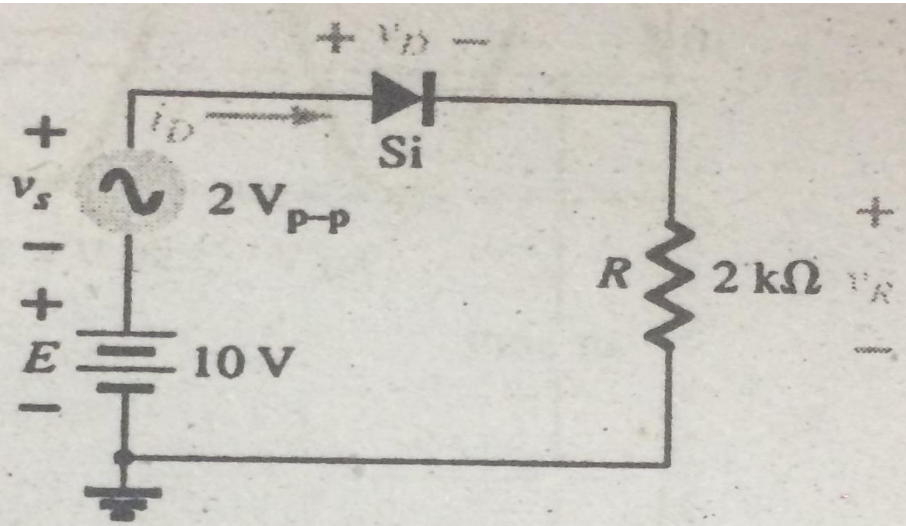


FIG. 2.102
Network with a dc and ac supply.

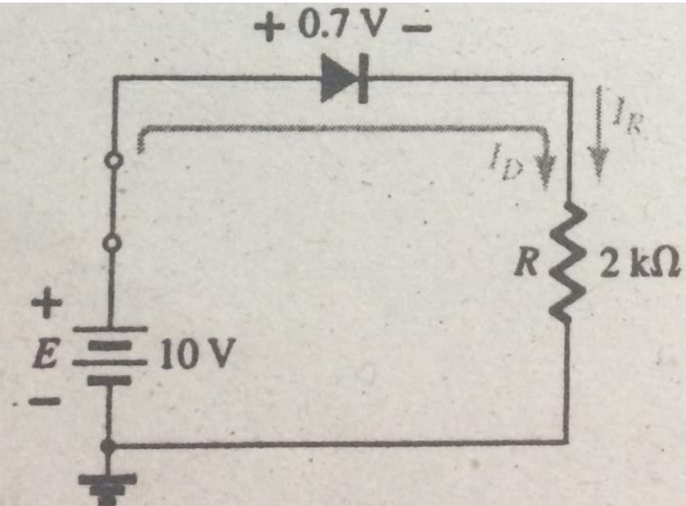


FIG. 2.103
Applying superposition to determine effects of the dc source.

$$V_R = E - V_D = 10\text{ V} - 0.7\text{ V} = 9.3\text{ V}$$

$$I_D = I_R = \frac{9.3\text{ V}}{2\text{ k}\Omega} = 4.65\text{ mA}$$

Network with a DC and AC source

$$r_d = \frac{26\text{ mV}}{I_D} = \frac{26\text{ mV}}{4.65\text{ mA}} = 5.59\ \Omega$$

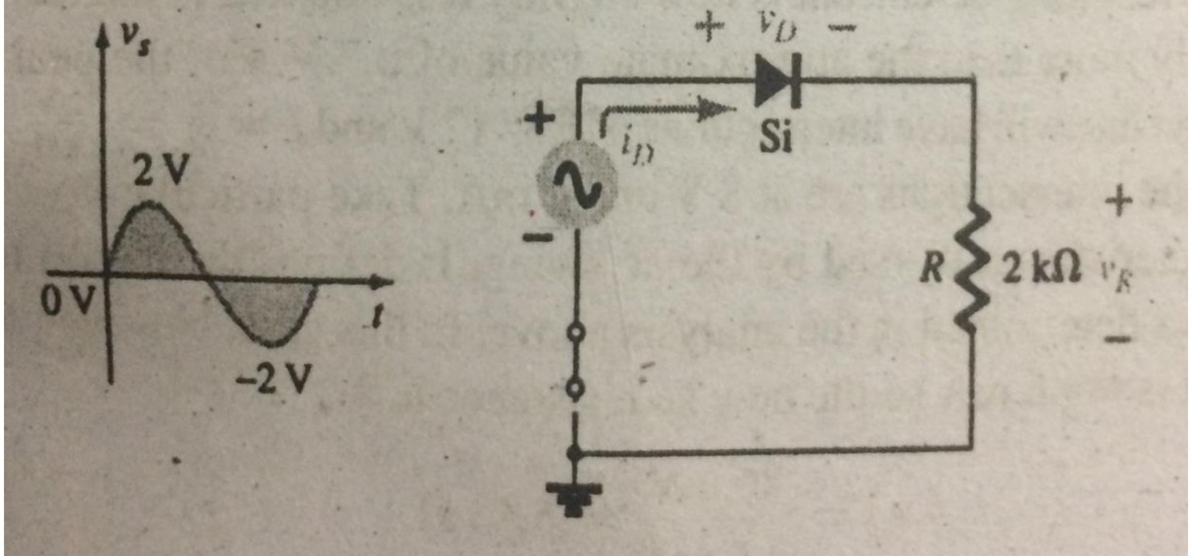


FIG. 2.104
Determing the response of v_R to the applied ac source.

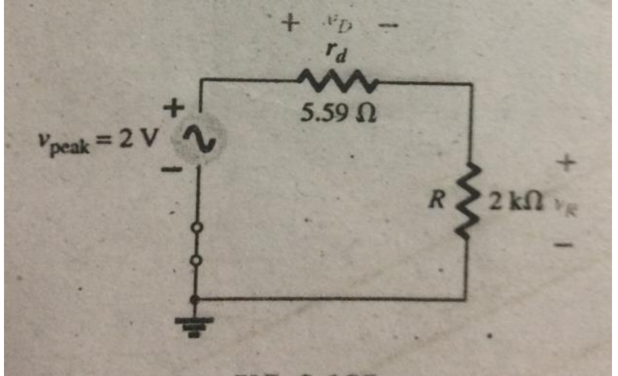
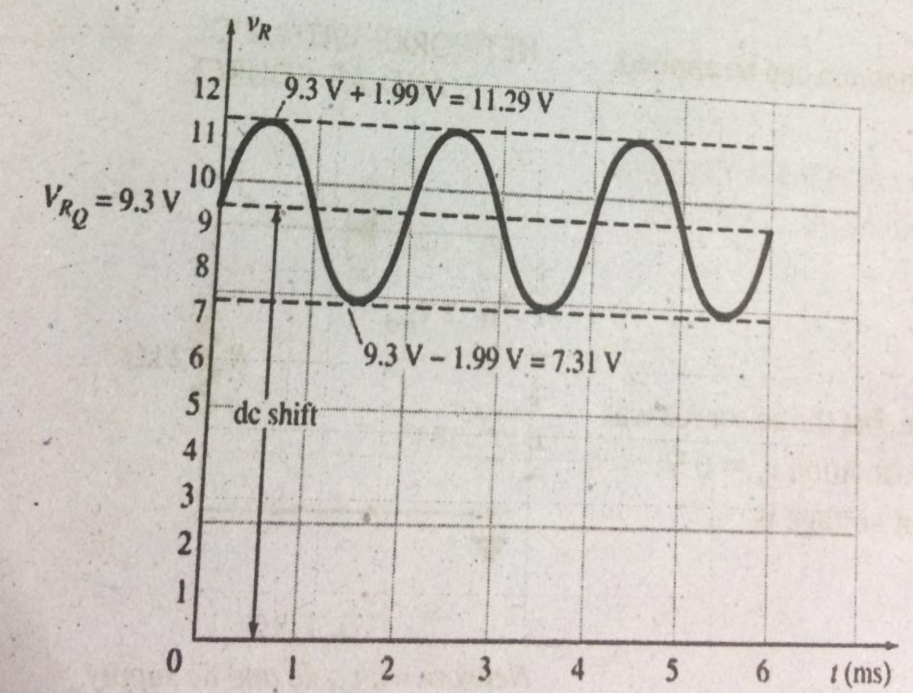


FIG. 2.105
Replacing the diode of Fig. 2.104 by its equivalent ac resistance.

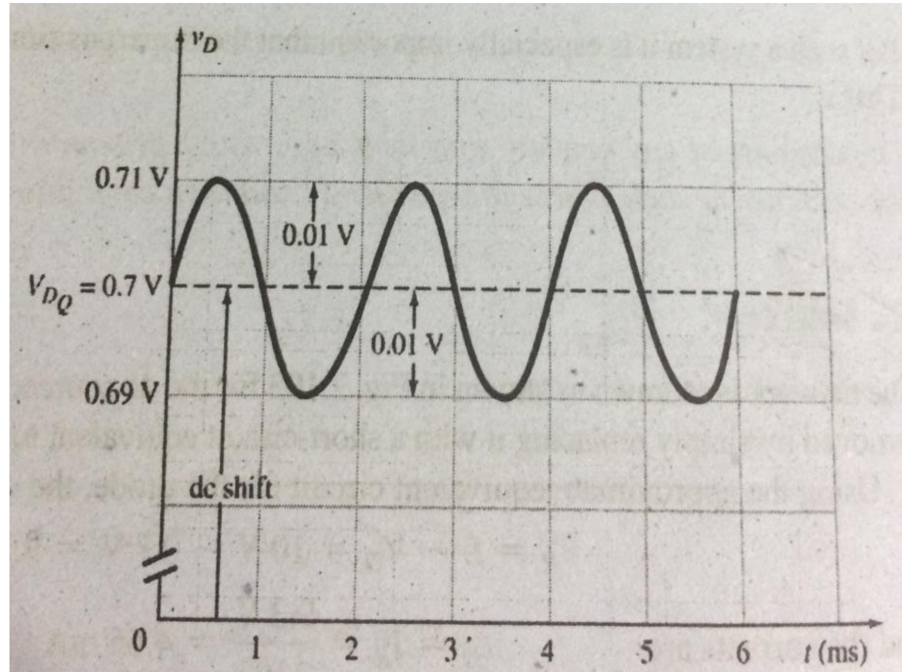
Network with a DC and AC source

$$v_{R_{peak}} = \frac{2\,k\Omega\,(2\,V)}{2\,k\Omega + 5.59\,\Omega} \cong 1.99\,V$$

$$v_{D_{peak}} = v_{s_{peak}} - v_{R_{peak}} = 2\,V - 1.99\,V = 0.01\,V = 10\,mV$$

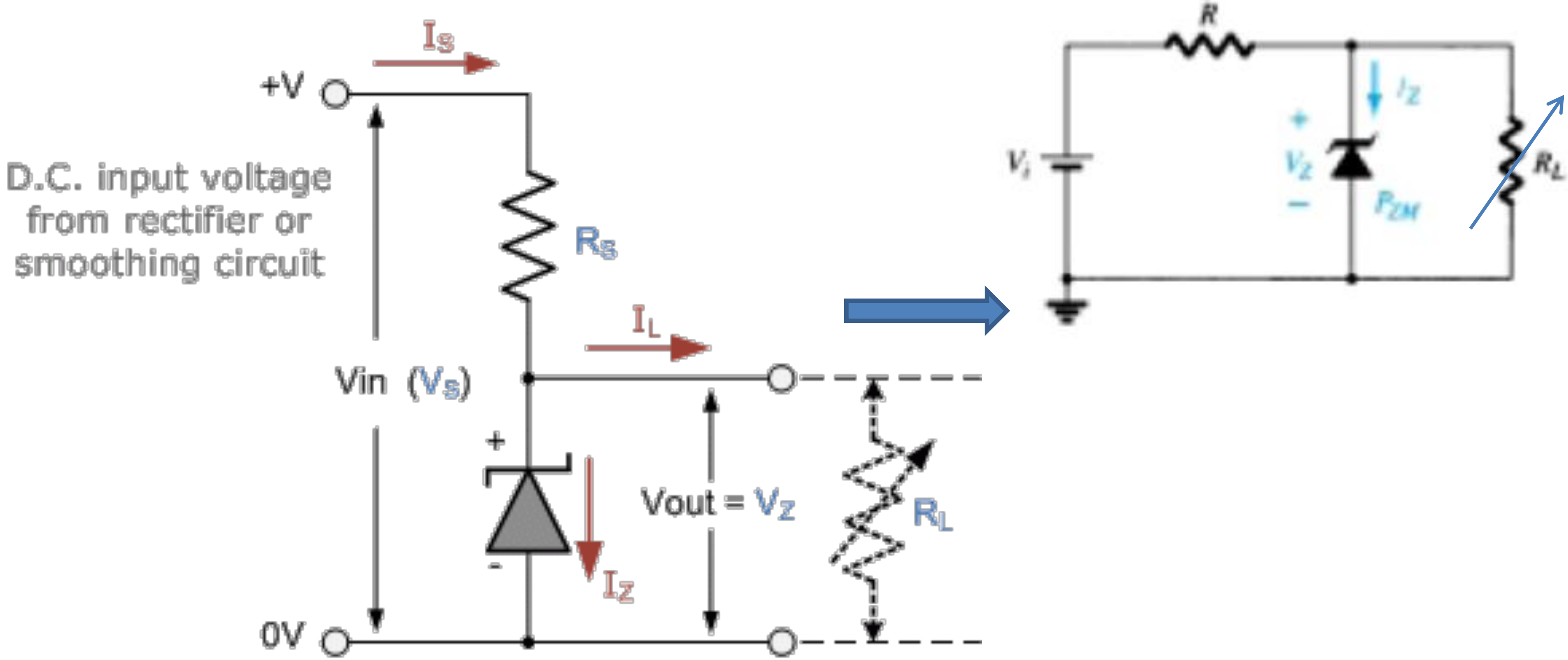


(a)



(b)

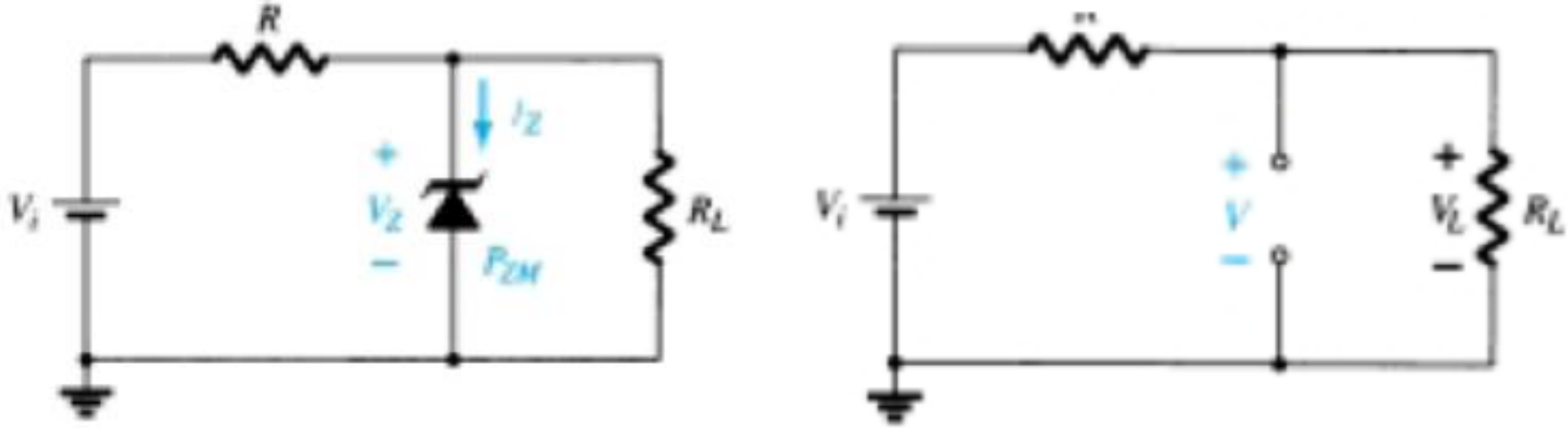
Regulator circuit



Three conditions are analysed for above Zener regulator circuit:

1. Vi and R fixed
2. Fixed Vi, variable R_L
3. Fixed R_L, Variable Vi

Regulator circuit (V_i and R fixed)

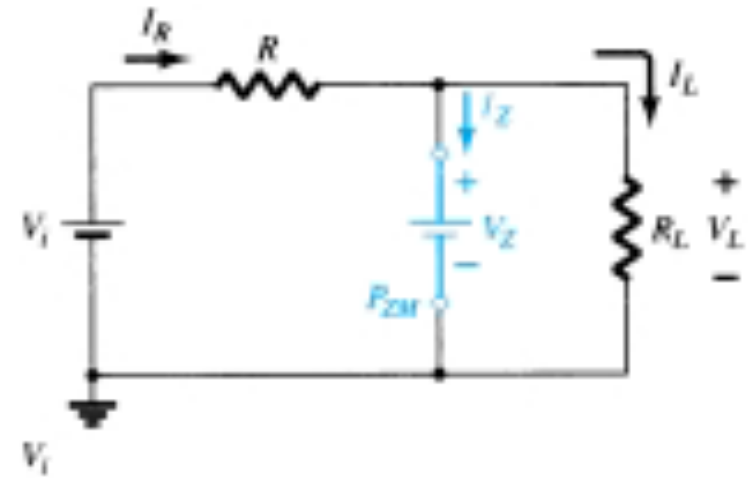


$$V = V_L = \frac{R_L V_i}{R + R_L}$$

If V≥Vz, the zener is on and if less than Vz then zener will be off.

Regulator circuit (V_i and R_L fixed)

$$\boxed{V_L = V_Z}$$



$$I_R = I_Z + I_L$$

$$\boxed{I_Z = I_R - I_L}$$

where

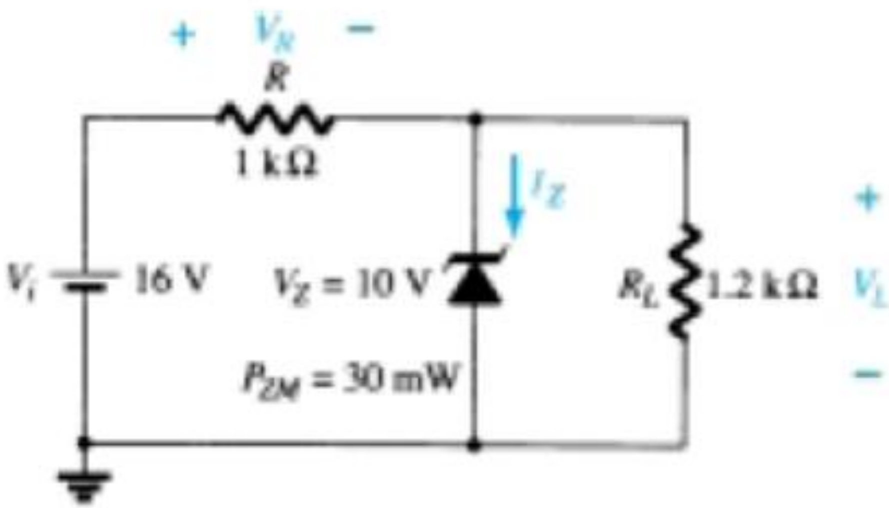
$$I_L = \frac{V_L}{R_L} \quad and \quad I_R = \frac{V_R}{R} = \frac{V_i - V_L}{R}$$

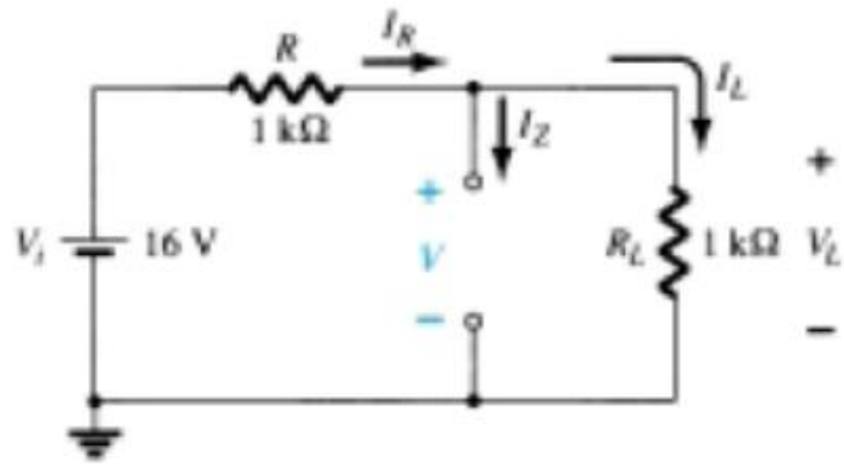
The power dissipated by the Zener diode is determined by

$$\boxed{P_Z = V_Z I_Z}$$

Example-1

(a) For the Zener diode network of Fig. 2.109, determine V_L, V_R, I_Z, and P_Z.
(b) Repeat part (a) with $R_L = 3\ \text{k}\Omega$.





$$V = \frac{R_L V_i}{R + R_L} = \frac{1.2\ \text{k}\Omega(16\ \text{V})}{1\ \text{k}\Omega + 1.2\ \text{k}\Omega} = 8.73\ \text{V}$$

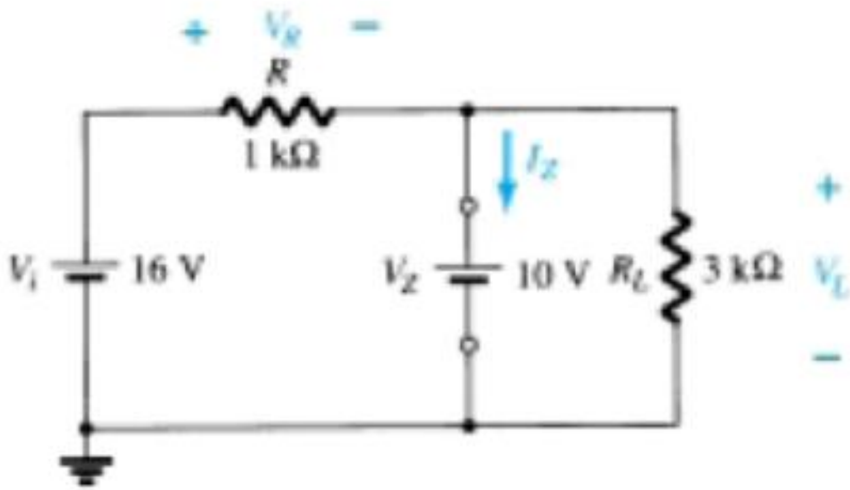
$$V_L = V = \mathbf{8.73\ V}$$

$$V_R = V_i - V_L = 16\ V - 8.73\ \text{V} = \mathbf{7.27\ V}$$

$$I_Z = \mathbf{0\ A}$$

$$P_Z = V_Z I_Z = V_Z(0\ \text{A}) = \mathbf{0\ W}$$

Solution to example-1



$$V = \frac{R_L V_i}{R + R_L} = \frac{3\ \text{k}\Omega(16\ \text{V})}{1\ \text{k}\Omega + 3\ \text{k}\Omega} = 12\ \text{V}$$

$$V_L = V_Z = \mathbf{10\ V}$$

$$V_R = V_i - V_L = 16\ \text{V} - 10\ \text{V} = \mathbf{6\ V}$$

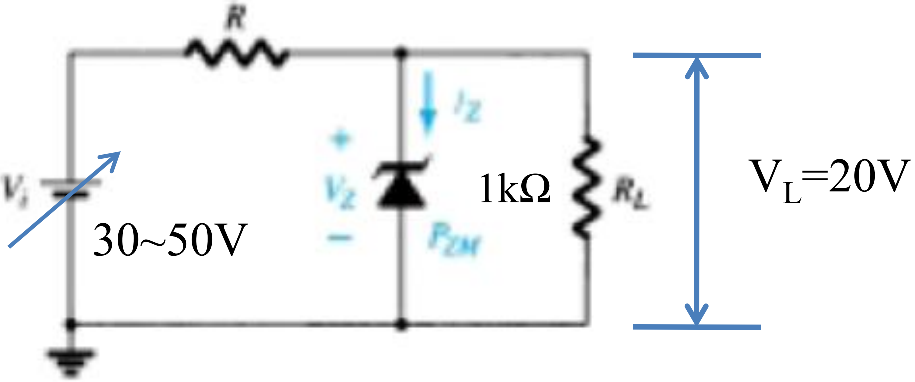
$$I_L = \frac{V_L}{R_L} = \frac{10\ \text{V}}{3\ \text{k}\Omega} = 3.33\ \text{mA}$$

$$I_R = \frac{V_R}{R} = \frac{6\ \text{V}}{1\ \text{k}\Omega} = 6\ \text{mA}$$

$$I_Z = I_R - I_L \ \text{[Eq. (2.18)]}$$
$$= 6\ \text{mA} - 3.33\ \text{mA}$$
$$= \mathbf{2.67\ mA}$$

$$P_Z = V_Z I_Z = (10\ \text{V})(2.67\ \text{mA}) = \mathbf{26.7\ mW}$$

Example-2



At 30 V we have to be sure Zener diode is "on".

$$\therefore\ V_L = 20\text{ V} = \frac{R_L V_i}{R_L + R_s} = \frac{1\text{ k}\Omega(30\text{ V})}{1\text{ k}\Omega + R_s}$$

Solving, $R_s = \mathbf{0.5\ k\Omega}$

At 50 V, $I_{R_s} = \dfrac{50\text{ V} - 20\text{ V}}{0.5\text{ k}\Omega} = 60\text{ mA},\ I_L = \dfrac{20\text{ V}}{1\text{ k}\Omega} = 20\text{ mA}$

$$I_{ZM} = I_{R_s} - I_L = 60\text{ mA} - 20\text{ mA} = \mathbf{40\ mA}$$

Regulator circuit (Fixed *Vi* and Variable R_L)

$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$R_{L_{\min}} = \frac{R V_Z}{V_i - V_Z}$$

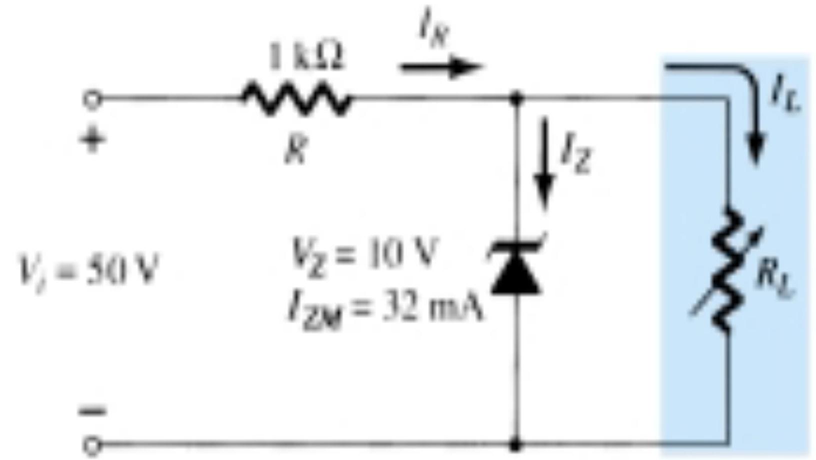
$$I_{L_{\max}} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L_{\min}}}$$

Once the diode is in the "on" state, the voltage across R remains fixed at

$$V_R = V_i - V_Z$$

and I_R remains fixed at

$$I_R = \frac{V_R}{R}$$



The Zener current

$$I_Z = I_R - I_L$$

$$I_{L_{\min}} = I_R - I_{ZM}$$

$$R_{L_{\max}} = \frac{V_Z}{I_{L_{\min}}}$$

Regulator circuit (Fixed *RL*, Variable *Vi*)

EXAMPLE 2.28 Determine the range of values of V_i that will maintain the Zener diode of Fig. 2.115 in the "on" state.

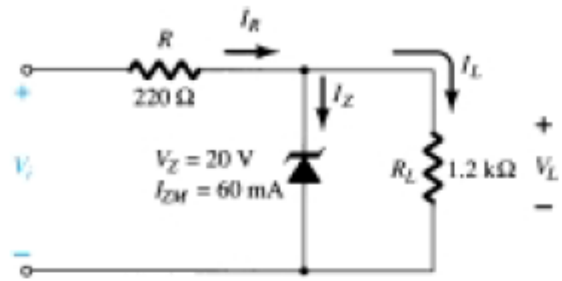


Figure 2.115 Regulator for Example 2.28.

Solution

$$\text{Eq. (2.27):}\quad V_{i_{\min}} = \frac{(R_L + R)V_Z}{R_L} = \frac{(1200\ \Omega + 220\ \Omega)(20\ \text{V})}{1200\ \Omega} = \mathbf{23.67\ V}$$

$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{20\ \text{V}}{1.2\ \text{k}\Omega} = 16.67\ \text{mA}$$

$$\text{Eq. (2.28):}\quad I_{R_{\max}} = I_{ZM} + I_L = 60\ \text{mA} + 16.67\ \text{mA}$$
$$= 76.67\ \text{mA}$$

$$\text{Eq. (2.29):}\quad V_{i_{\max}} = I_{R_{\max}}R + V_Z$$
$$= (76.67\ \text{mA})(0.22\ \text{k}\Omega) + 20\ \text{V}$$
$$= 16.87\ \text{V} + 20\ \text{V}$$
$$= \mathbf{36.87\ V}$$

A plot of V_L versus V_i is provided in Fig. 2.116.

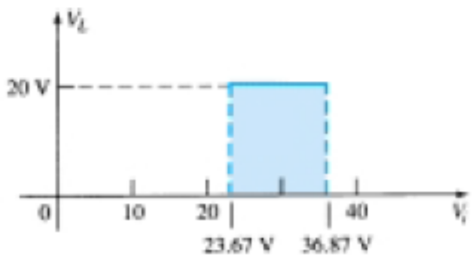


Figure 2.116 V_L versus V_i for the regulator of Fig. 2.115.

Half-wave Voltage Doubler

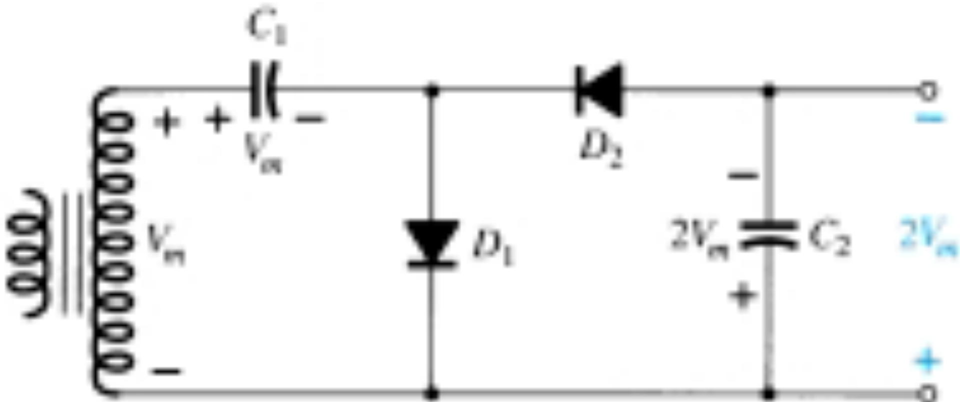


Figure 2.121 Half-wave voltage doubler.

$$-V_m - V_{C_1} + V_{C_2} = 0$$

$$-V_m - V_m + V_{C_2} = 0$$

from which

$$V_{C_2} = 2V_m$$

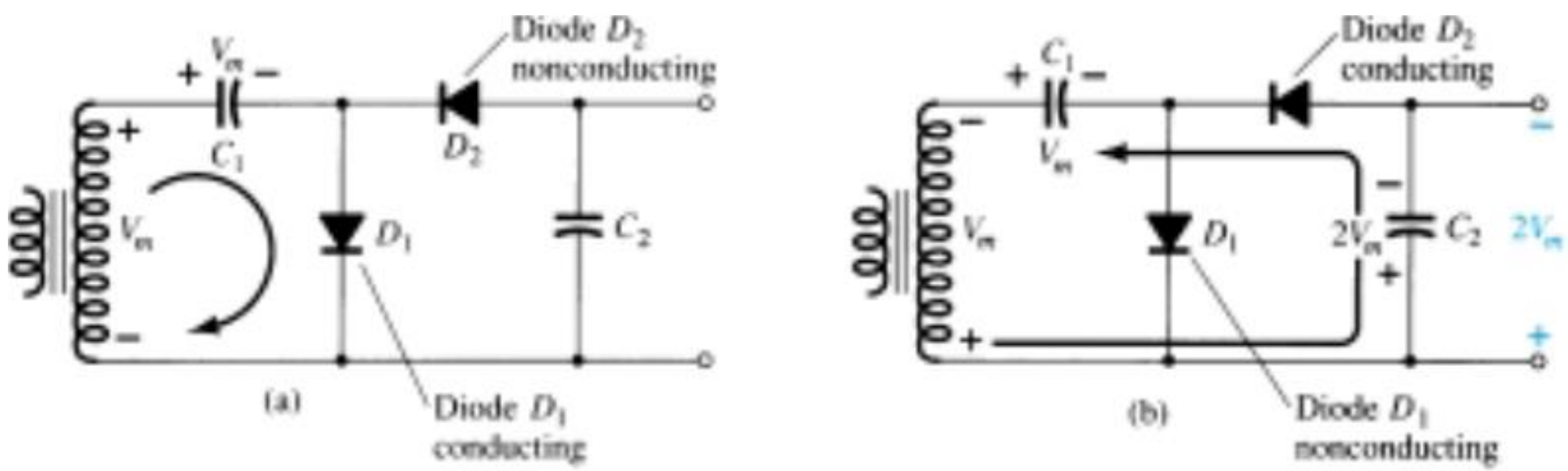


Figure 2.122 Double operation, showing each half-cycle of operation: (a) positive half-cycle; (b) negative half cycle.

Voltage Tripler and Quadrupler

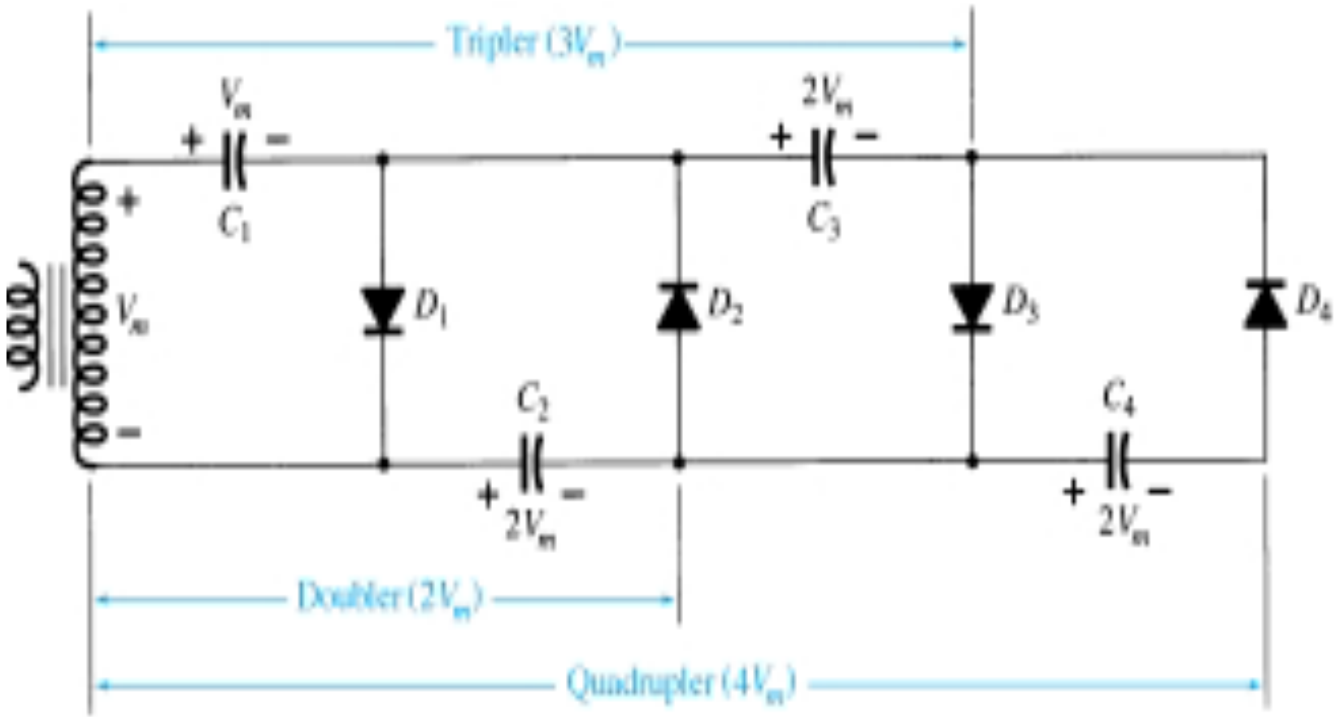
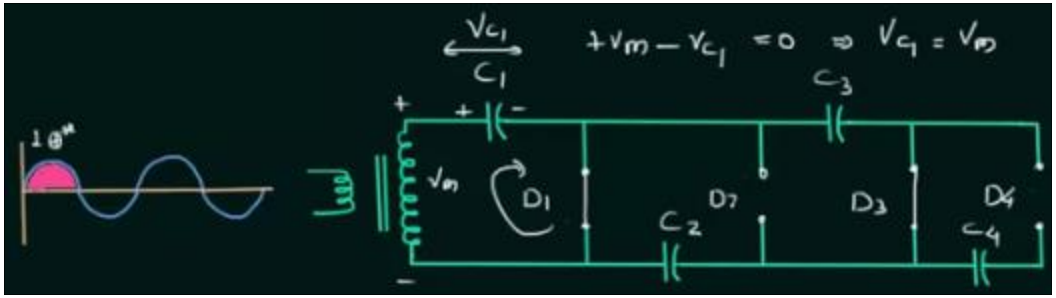


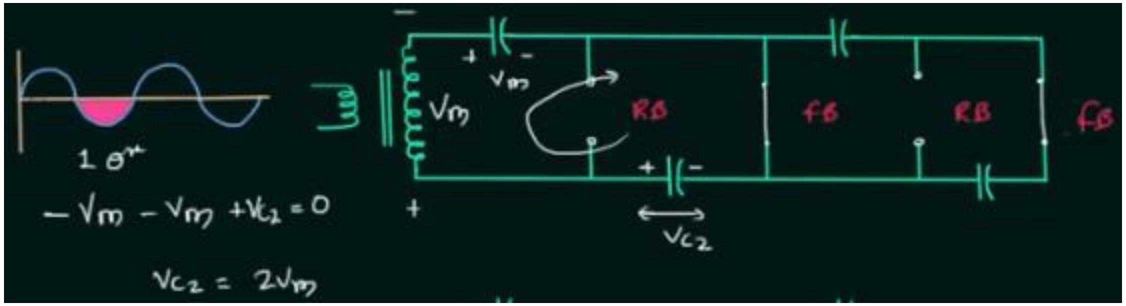
Figure 2.125 Voltage tripler and quadrupler.

Voltage Tripler and Quadrupler

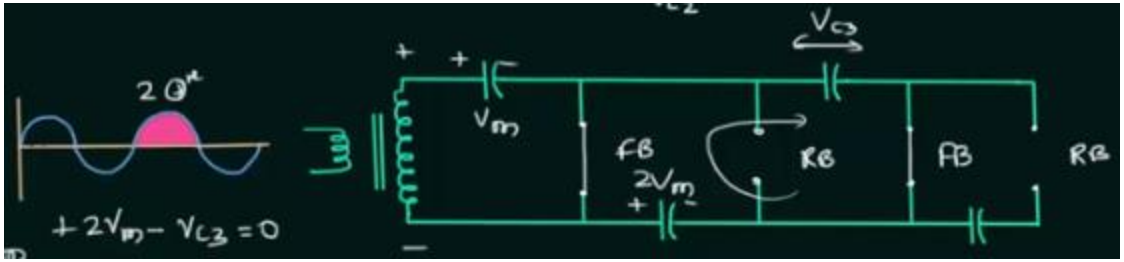
Step: 01



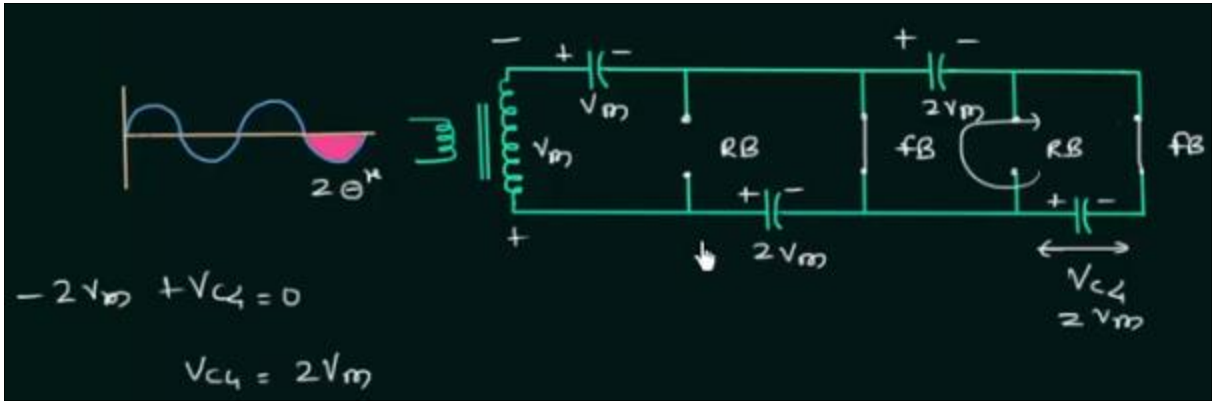
Step: 02



Step: 03



Step: 04



Practical Applications Summary

- Rectification
- Protective configurations
- Polarity insurance
- Controlled battery-powered backup
- Polarity detector
- Ac regulator and square-wave generator

Thank You