Devices and Basic Circuits

[Rectifier and Clipping, Clamping Circuits]

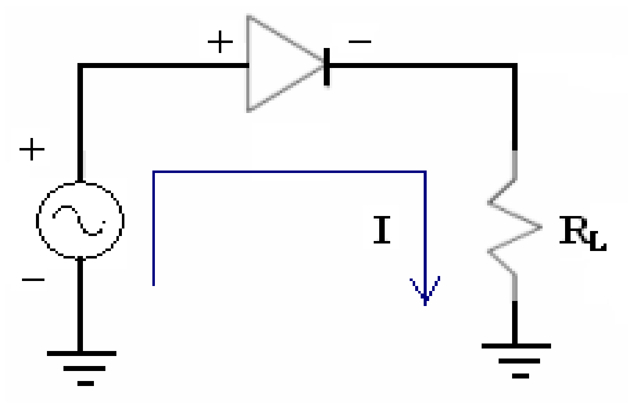
Rectifiers

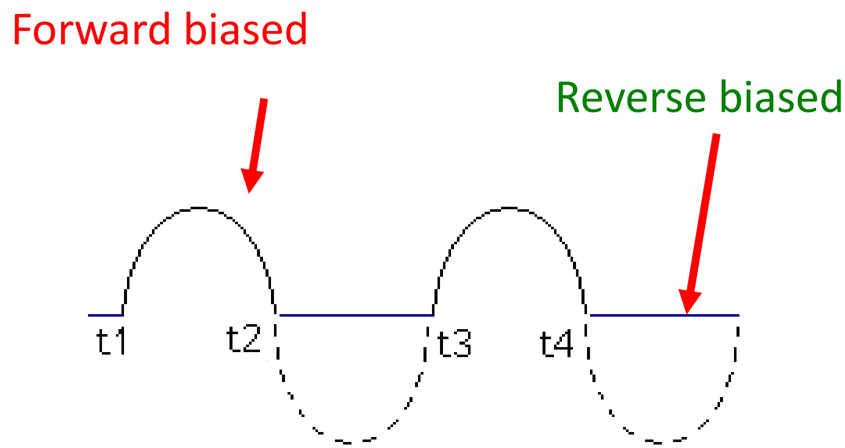
Rectifier Circuits

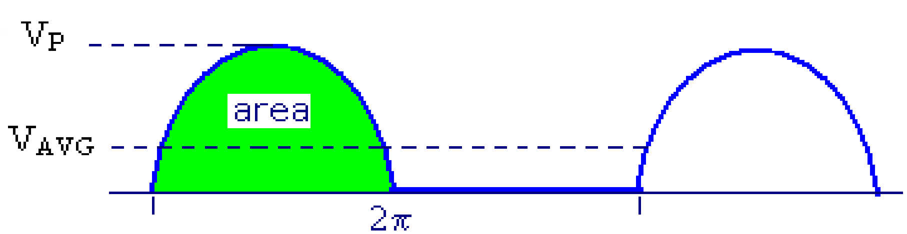
* *Rectifiers* convert ac power to dc power.

* Rectifiers form the basis for electronic power suppliers and battery charging circuits.

Half-wave rectifier



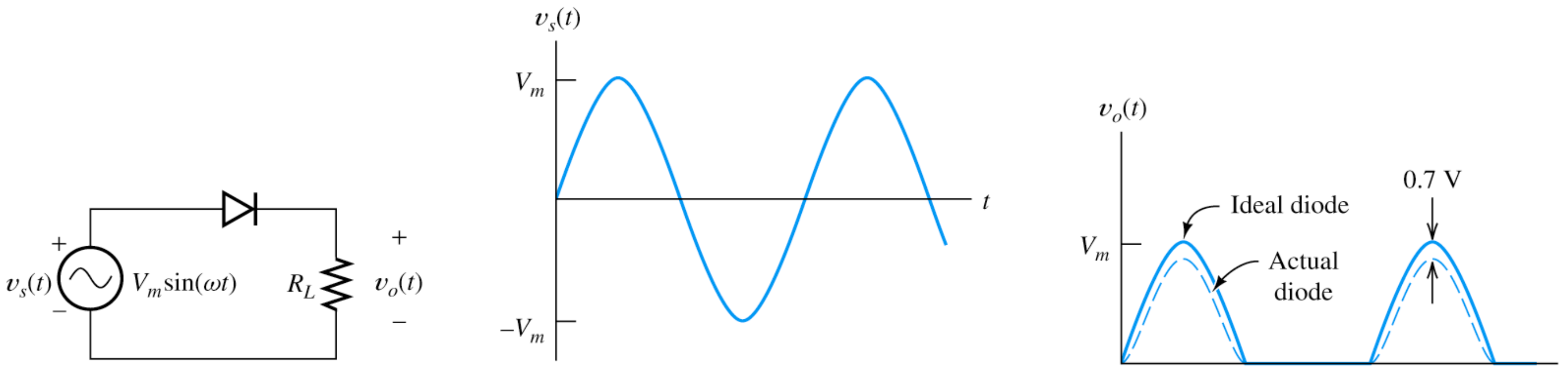




Average value:

$$V_{AVG} = \frac{V_P}{\pi}$$

Applications – Rectifier Circuits



(a) Circuit diagram (b) Source voltage versus time (c) Load voltage versus time

Half-Wave Rectifier Circuits

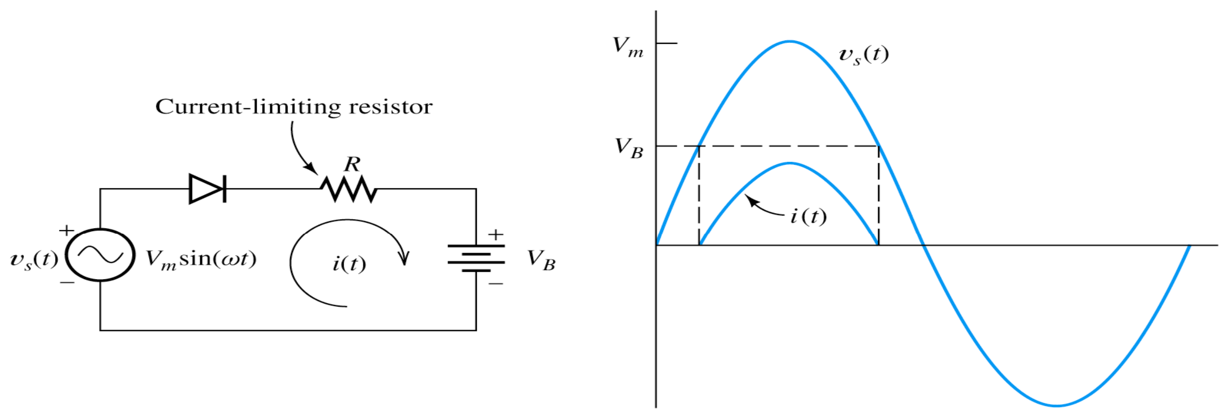
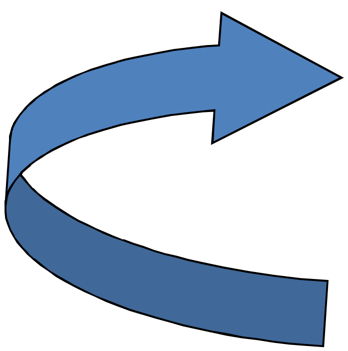


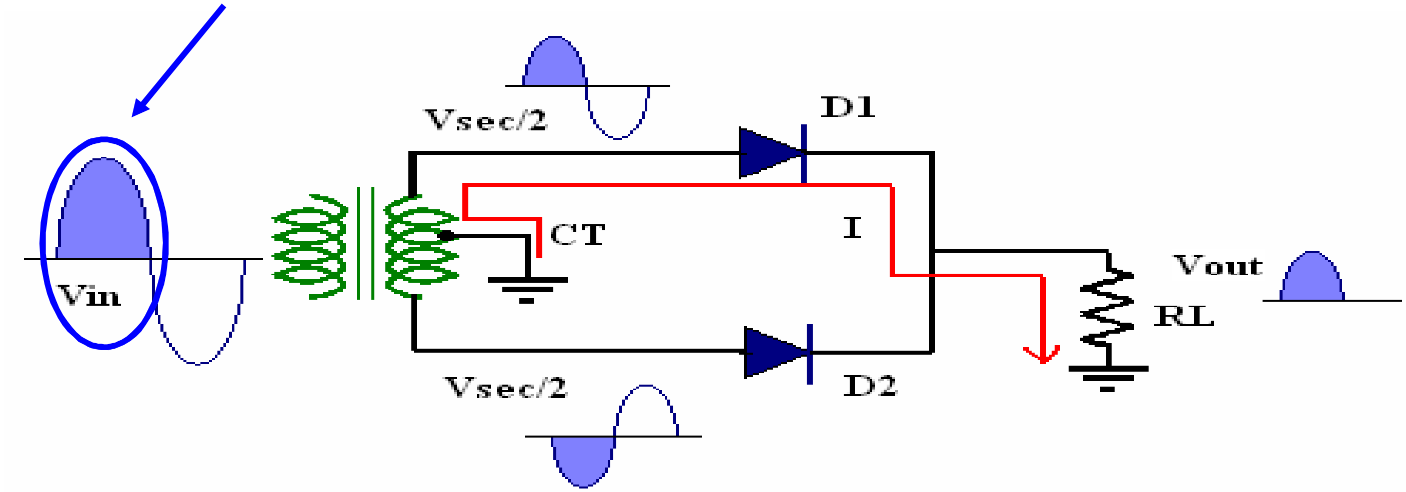
Figure 10.25 Half-wave rectifier used to charge a battery.

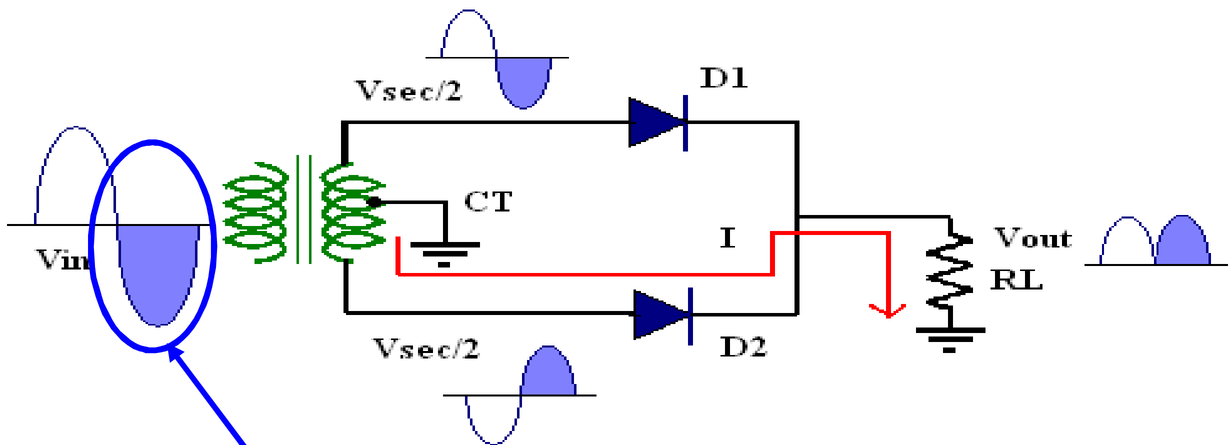


Battery-Charging Circuit

Full-wave rectifier

Positive half-cycle





Negative half-cycle

Circuit Operation

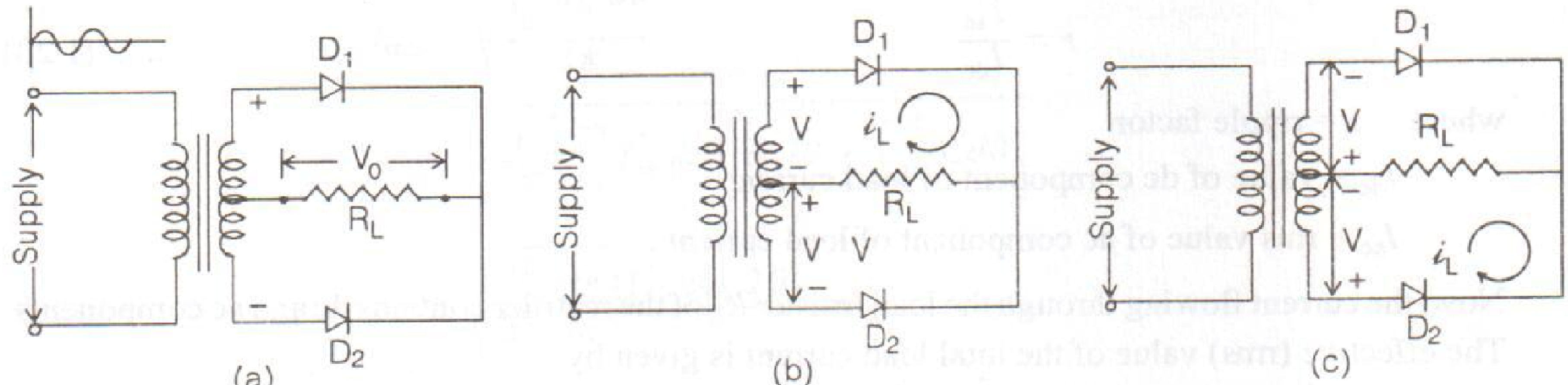


Fig.

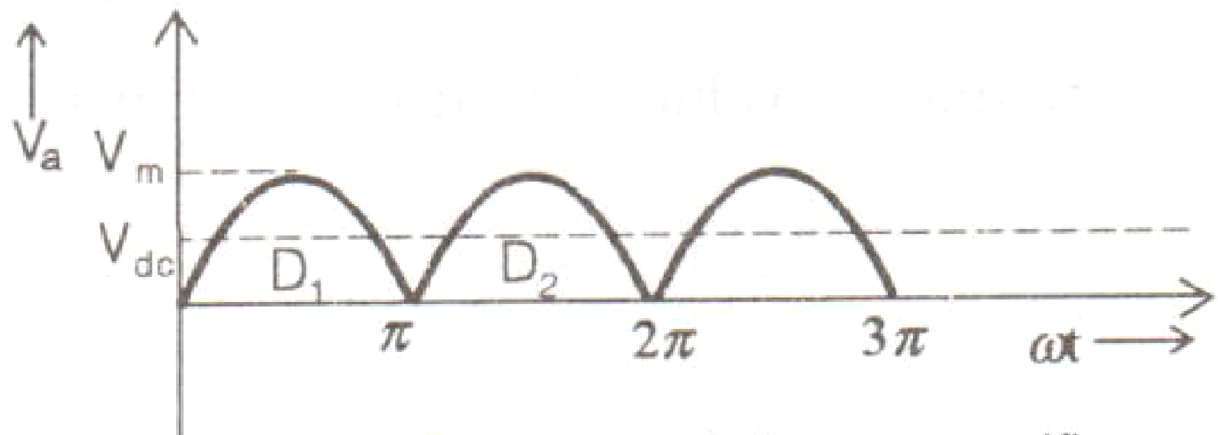


Fig. (d) Centre-tap full-wave rectifier

Peak Inverse Voltage

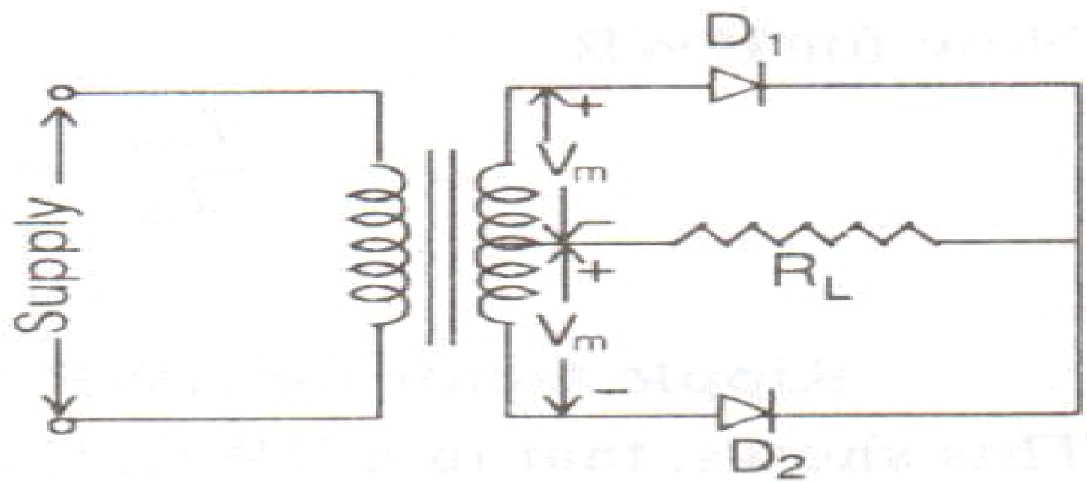


Fig. PIV across the non -conducting diode D_2 in a centre-taprectifier is $2V_m$

$$V_m + V_m = 2V_m.$$

Thus,

$$PIV = 2V_m$$

Output DC voltage

Since a FWR utilises both the half cycles of the input waveform, therefore, the dc or average voltage available in a FWR will be double that of a HWR *i.e.*, the dc voltage of a FWR, would be

$$V_{dc} = \frac{2V_m}{\pi}$$

(assuming resistance of forward biased diode is zero)

can be derived mathematically. The output voltage of a FWR is described as

$$v_0 = V_m \sin\theta \qquad 0 \leqslant \theta \leqslant \pi$$
$$= -\ V_m \sin\theta \qquad \pi \leqslant \theta \leqslant 2\pi$$

(Negative sign indicates that during the second half cycle wave is sinusoidal but inverted.)

Now,
$$V_{dc} = \frac{1}{2\pi}\int_0^{2\pi} v_0\, d\theta$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} V_m \sin\theta\ d\theta + \int_{\pi}^{2\pi} - V_m \sin\theta\ d\theta\right]$$

$$= \frac{1}{2\pi}\left[(-\ V_m \cos\theta)_0^{\pi} + (V_m \cos\theta)_{\pi}^{2\pi}\right]$$

$$= \frac{V_m}{2\pi}\left[(-\cos\theta)_0^{\pi} + (\cos\theta)_{\pi}^{2\pi}\right]$$

$$= \frac{V_m}{2\pi}\left[-((-1)-1)+(1-(-1))\right]$$

$$= \frac{4V_m}{2\pi} = \frac{2V_m}{\pi}$$

$\therefore$ $$V_{dc} = \frac{2V_m}{\pi}$$ this is same as equation

Similarly, for a FWR

$$I_{dc} = \frac{2I_m}{\pi}$$

Rectifier Efficiency

The efficiency of a FWR is defined as the ratio of dc power output to the input ac power *i.e.*,

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{\text{dc power output}}{\text{input ac power}}$$

For a FWR, the dc power delivered to the load is,

$$P_{dc} = I_{dc}^2 R_L = \left(\frac{2I_m}{\pi}\right)^2 R_L \qquad \left\{\because \quad I_{dc} = \frac{2I_m}{\pi} \text{ for a FWR}\right\}$$

$$\text{Input ac power} = I_{rms}^2 (r_f + R_L).$$

The rms value of the current for a FWR can be given as

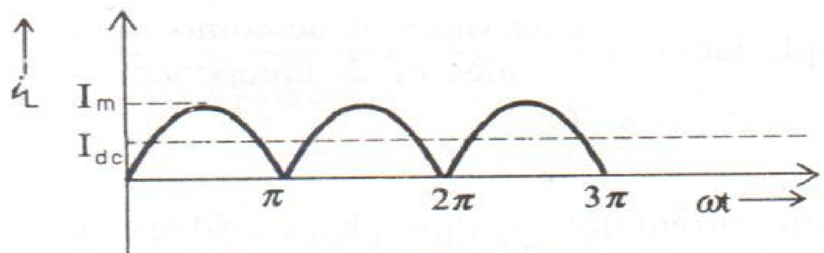


Fig. Full-wave rectified current wave

$$I_{rms} = \sqrt{\frac{\int_0^{\pi} i_i^2 \, d\theta}{\pi}} \qquad \text{where } \omega t \to \theta$$

$$= \sqrt{\frac{1}{\pi}\int_0^{\pi} I_m^2 \sin\theta \, d\theta} = \sqrt{\frac{I_m^2}{\pi}\int_0^{\pi}\left(\frac{1-\cos 2\theta}{2}\right) d\theta}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\left[\int_0^{\pi} d\theta - \int_0^{\pi} \cos 2\theta \, d\theta\right.}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\left[(0)_0^\pi - \left(\frac{\sin 2\theta}{2}\right)_0^\pi\right.}$$

$$= \sqrt{\frac{I_m^2}{2\pi}(\pi - 0)} = \frac{I_m}{\sqrt{2}}$$

$$\therefore \qquad I_{\text{rms}} = \frac{I_m}{\sqrt{2}}$$

Hence $\qquad P_{\text{ac}} = I_{\text{rms}}^2 (r_f + R_L) = \left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)$

Putting the values of equation

$$\eta = \frac{P_{\text{dc}}}{P_{\text{ac}}} = \frac{\left(\frac{2I_m}{\pi}\right)^2 R_L}{\left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)} \times 100\%$$

$$= \frac{0.812\, R_L}{r_f + R_L} \times 100\% = \frac{81.2}{1 + r_f/R_L}\%$$

$$\therefore \qquad \eta_{\max} = 81.2\%$$

How to get a better DC ?

The object of rectification is to provide a steady dc voltage, similar to the voltage from a battery. But rectifiers do not provide ripple-free dc voltage, they provide a 'pulsating dc'. Thus, we can filter or smooth out the ac variations by using a filter or smoothing circuit.

Filter Circuits

An electronic circuit or device which blocks the ac component but allows the dc component of the rectifier to pass to the load is called a filter circuit.

The main components used in a filter circuit are capacitor and inductor.

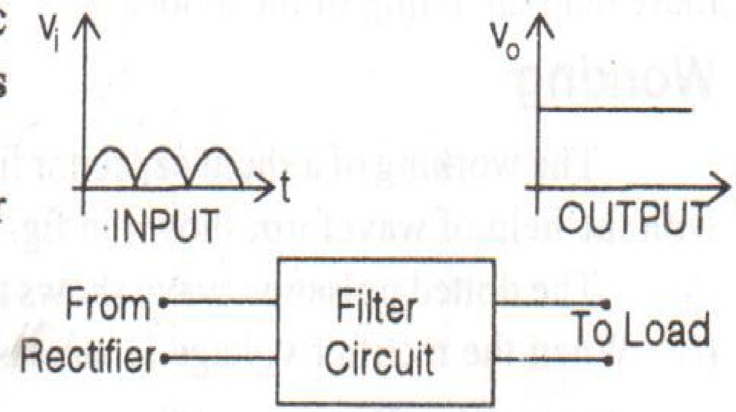


Fig. 1.11 Filter circuit

(i) Capacitor

The capacitive reactance is given by $X_C = \dfrac{1}{2\pi f c}$

$\therefore$ for dc, $f = 0 \Rightarrow$ hence $X_c = \infty$.

Hence, it provides an open circuit for dc. However, it allows ac to pass through it.

Thus, a capacitor is connected in parallel to the circuit so that it bypass the ac component and blocks the dc component to reach to the load.

(ii) Inductor

The inductive reactance is given by $X_L = 2\pi fL$.

For dc, $f = 0 \because X_L = 0$

Hence, it provides an easy path to dc component. However, it provides high opposition to the ac component and blocks it.

Thus, an inductor is connected in series with the circuit so that it blocks the ac component and give an easy path to the dc component to reach to the load.

Types of Filter Circuits

The filter circuits may be classified as follows

(i) Shunt capacitor filter

(ii) Series inductor filter

(iii) Choke-input (*LC*) filter

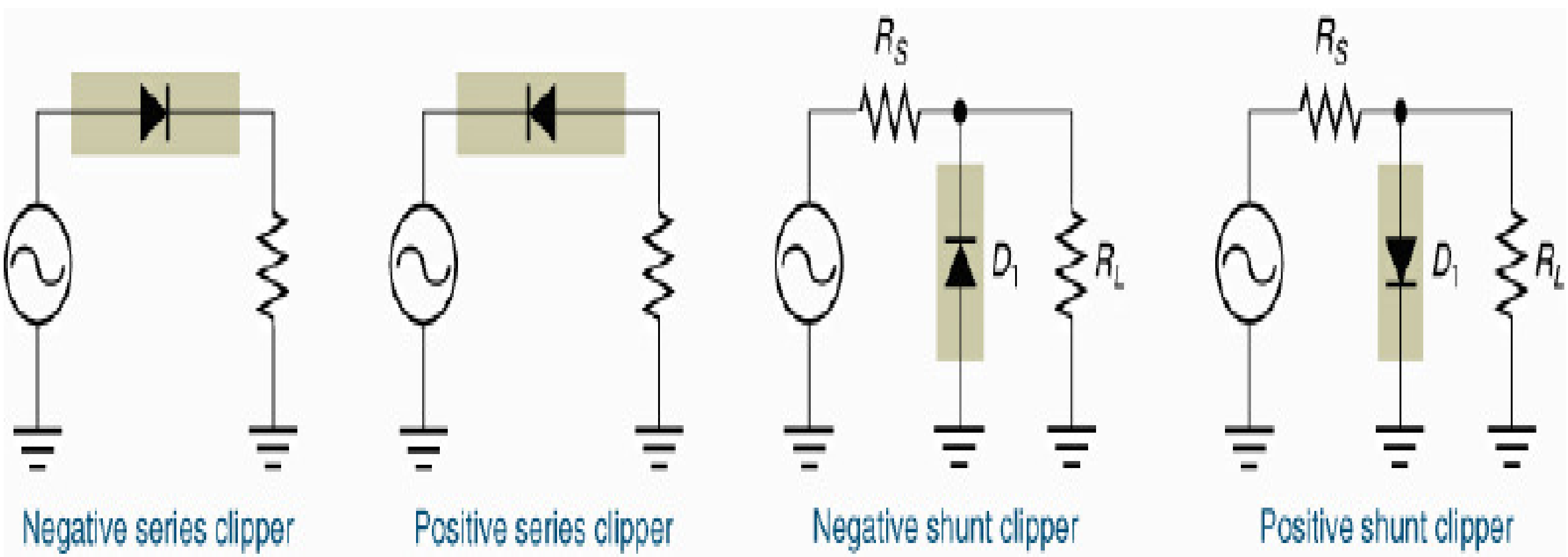
(iv) Capacitor input (π) filter

Clipping circuit

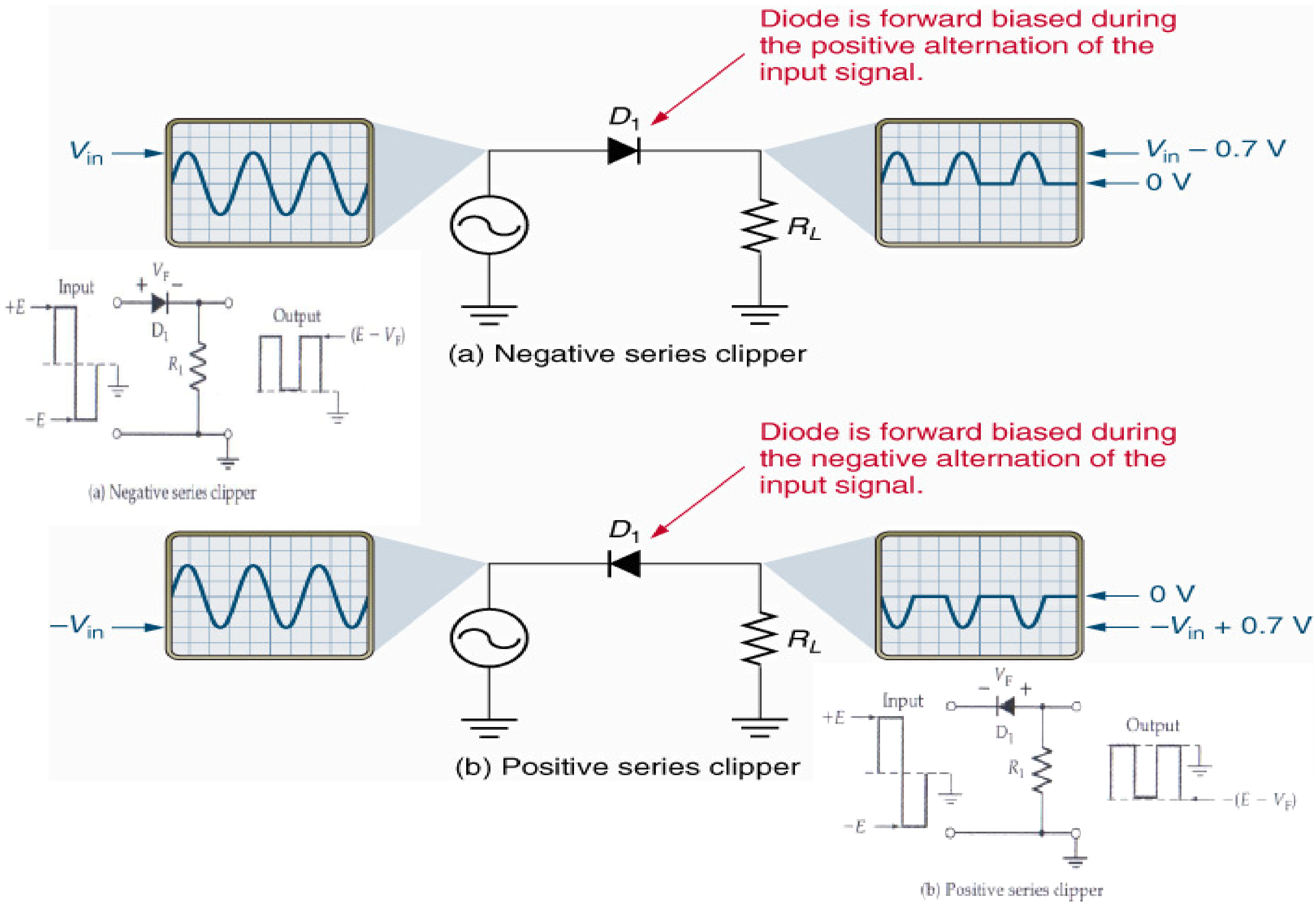
Clippers are networks that employs diodes to ***"clip" away a portion of an input signal*** *without distorting the remaining part of the applied waveform.*

A clipper (or limiter) is a circuit used to eliminate some portion (or portions) of a waveform.

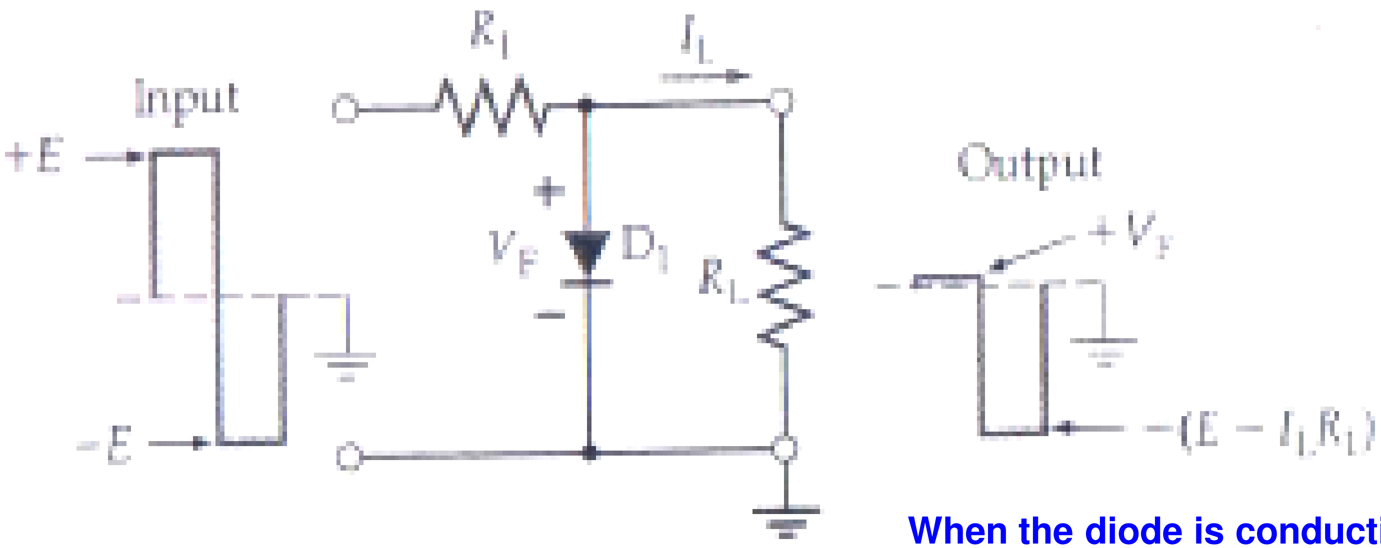
- A series clipper is in series with its load.
- A shunt clipper is in parallel with its load.



Series Clippers

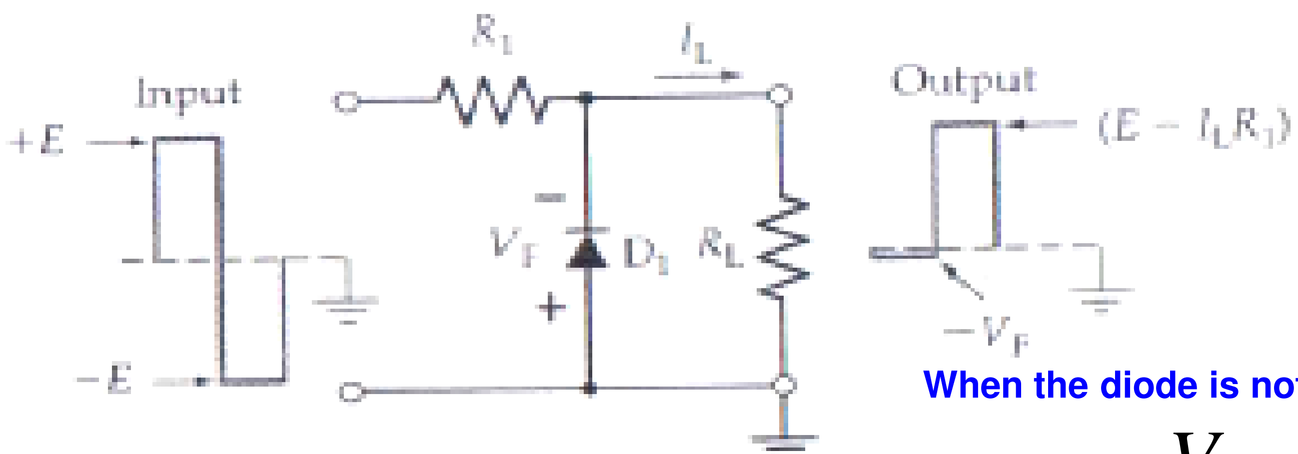


Positive and Negative Shunt Clipper Operation



When the diode is conducting: $V_L = V_F$

(a) Positive Shunt Clipper



When the diode is not conducting

$$V_L = V_{in} \frac{R_L}{R_L + R_S}$$

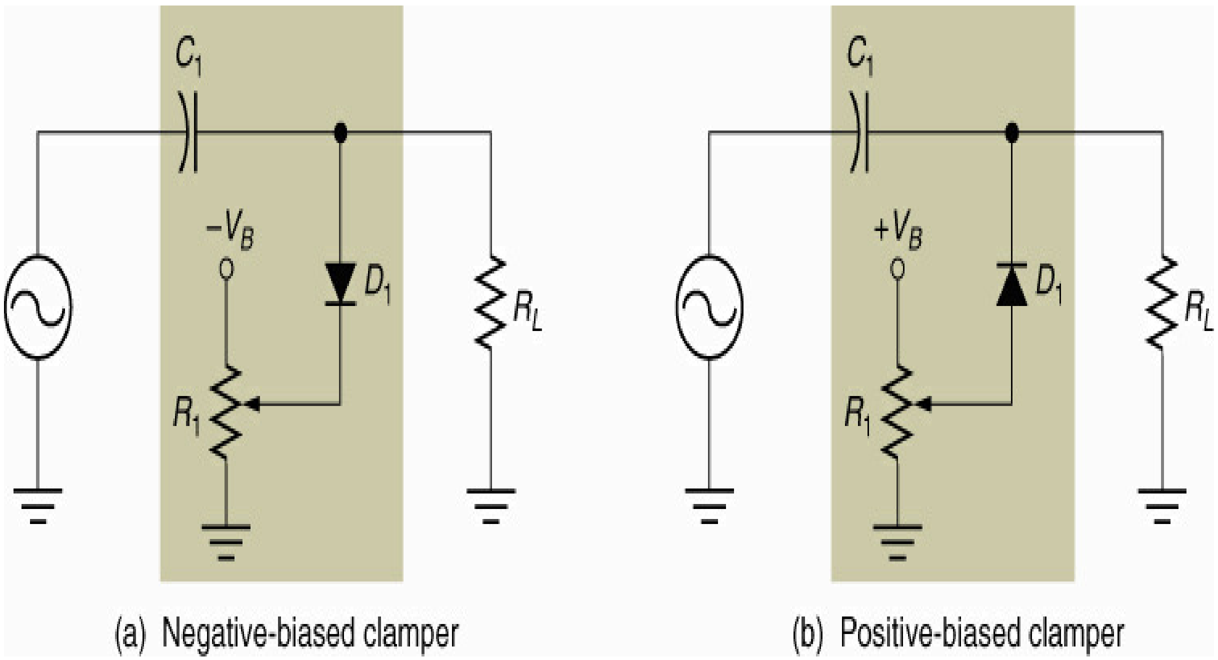
(b) Negative Shunt Clipper

Clamping circuit & Clamper Operation

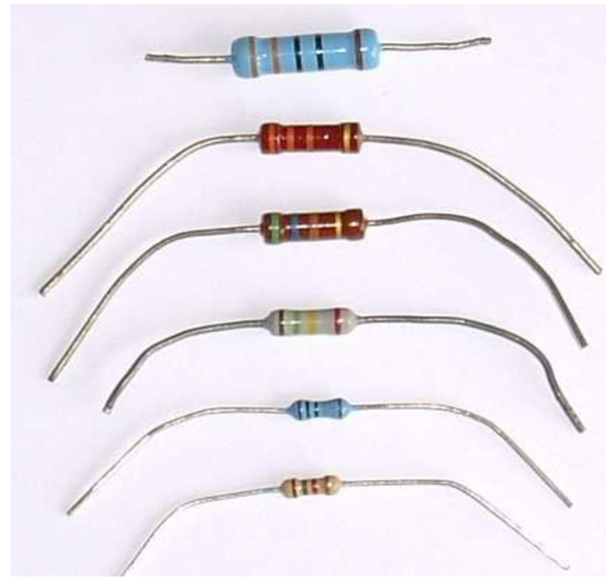
A clamper is a network constructed of a diode, a resistor, and a capacitor that shifts a waveform to a different dc level without changing the appearance of the applied signal.

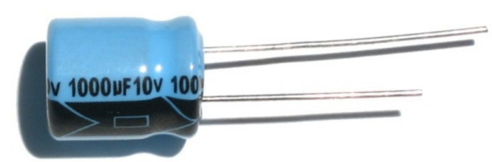
Biased clampers allow a waveform to shifted above or below a dc reference other than 0 V.

The dc reference is determined by the biasing voltage (V_B) and the setting of the potentiometer (R_1).



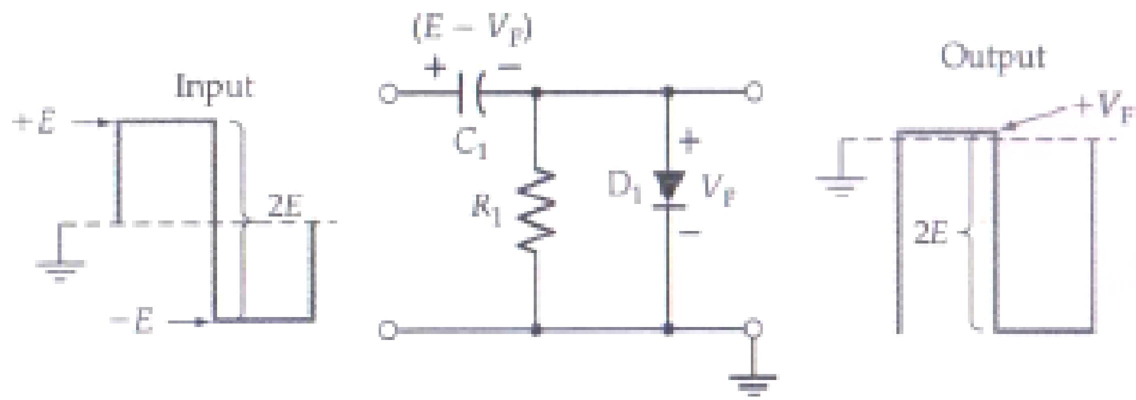
(a) Negative-biased clamper (b) Positive-biased clamper





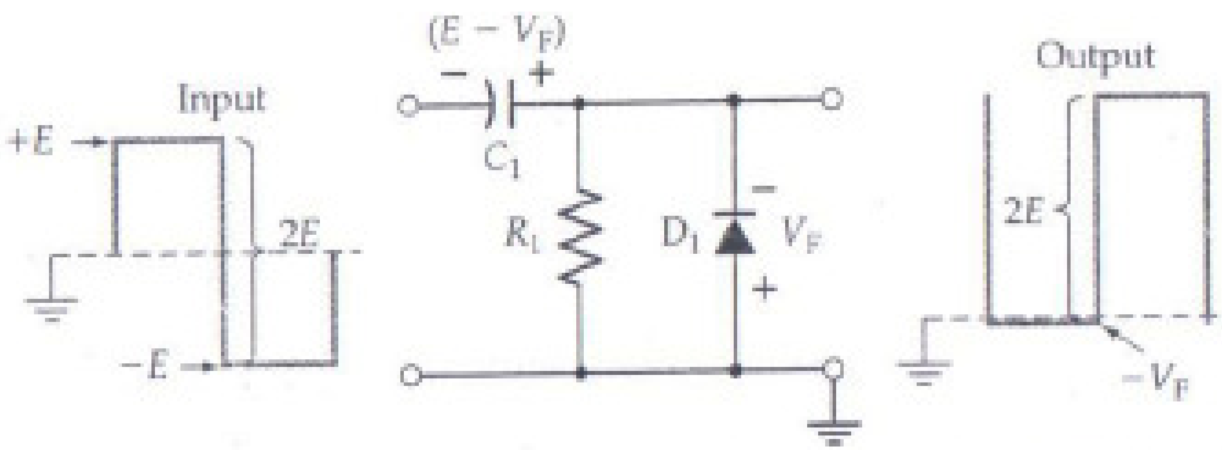
Examples:

Negative Voltage Clamping



(a)

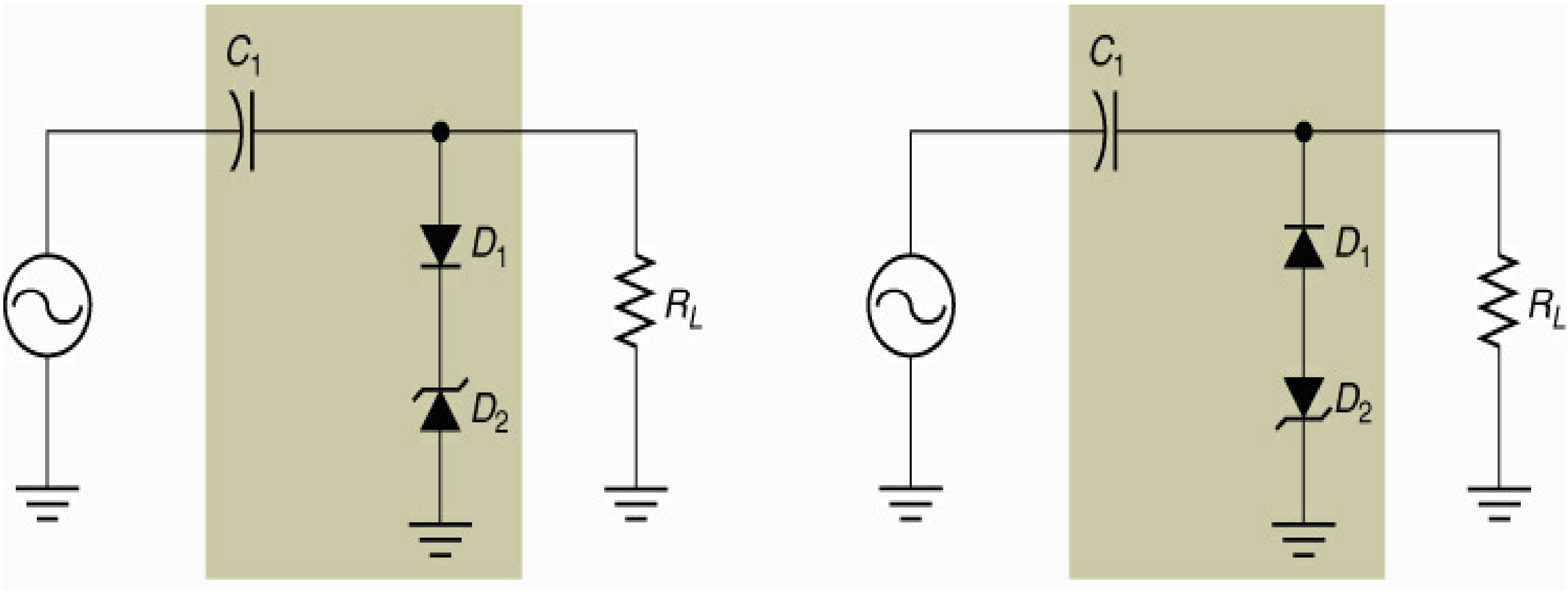
Positive Voltage Clamping



(b)

Zener clampers

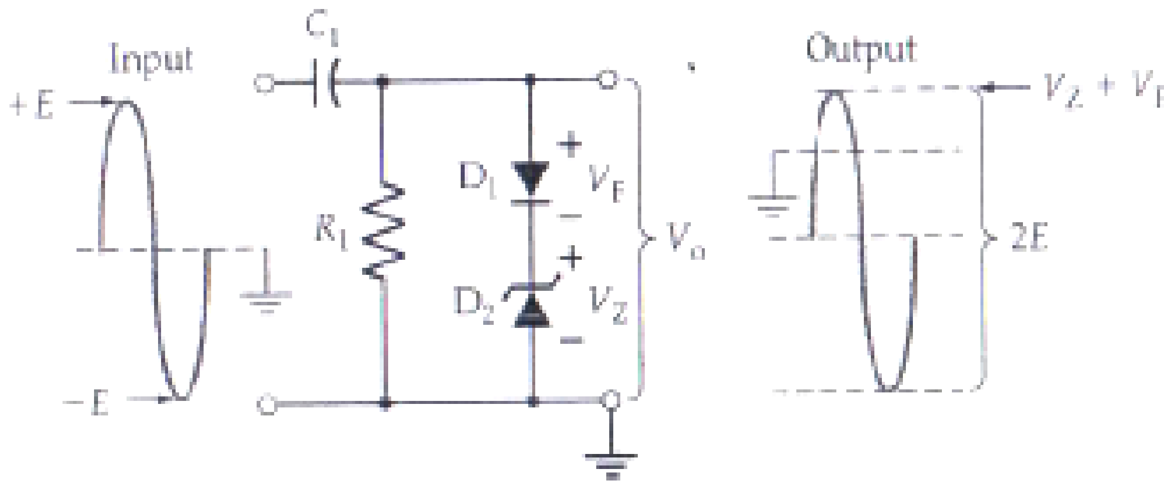
The diodes in (a) are in a common-cathode configuration.
The diodes in (b) are in a common-anode configuration.



(a) Negative zener clamper

(b) Positive zener clamper

Operating Principle of Zener Diode Clamping Circuits



$$V_o = V_Z + V_F$$

and C_1 charges (+ on the left) to

$$V_C = E - (V_Z + V_F)$$

When the input goes to its negative peak, the output voltage is

$$V_o = -(E + V_C)$$

$$V_o = -[E + E - (V_Z + V_F)]$$

$$= -(2E - V_Z - V_F)$$

The peak-to-peak output remains equal to the peak-to-peak input voltage (2E). If the polarity of the diodes (and the capacitor) are reversed, the negative output peak is clamped at $-(V_Z + V_F)$.

Practical Applications

- **Rectifier Circuits**
  - Conversions of AC to DC for DC operated circuits
  - Battery Charging Circuits

- **Simple Diode Circuits**
  - Protective Circuits against
  - Overcurrent
  - Polarity Reversal
  - Currents caused by an inductive kick in a relay circuit

- **Zener Circuits**
  - Overvoltage Protection
  - Setting Reference Voltages