DIODE APPLICATIONS

CLIPPERS

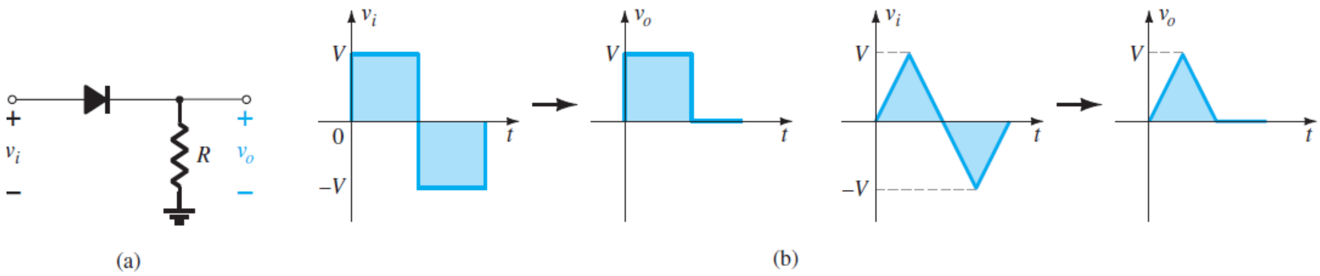
The previous section on rectification gives clear evidence that diodes can be used to change the appearance of an applied waveform. This section on clippers and the next on clampers will expand on the wave-shaping abilities of diodes.

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

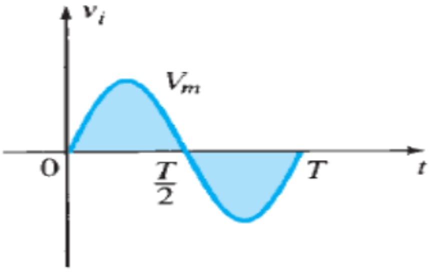
There are two general categories of clippers: ***series*** and ***parallel***. The series configuration is defined as one where the diode is in series with the load, whereas the parallel variety has the diode in a branch parallel to the load.

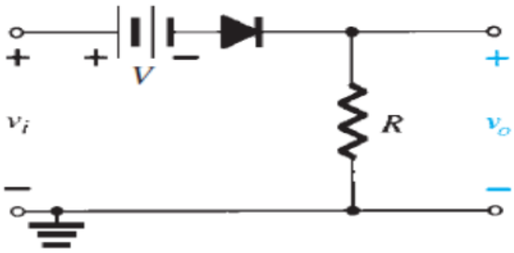
A. Series

The response of the series configuration in figure (a) to a variety of alternating waveforms is provided in figure (b) below. Although first introduced as a half-wave rectifier (for sinusoidal waveforms), there are no boundaries on the type of signals that can be applied to a clipper.



The addition of a dc supply to the network as shown in figure below can have a pronounced effect on the analysis of the series clipper configuration. The response is not as obvious because the dc supply can aid or work against the source voltage, and the dc supply can be in the leg between the supply and output or in the branch parallel to the output.





There are some things one can do to give the analysis some direction. First and most important:

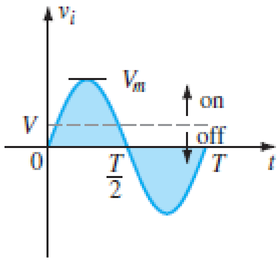
1. **Take careful note of where the output voltage is defined**
2. **Try to develop an overall sense of the response by simply noting the "pressure" established by each supply and the effect it will have on the conventional current direction through the diode.**

In previous figure, for instance, any positive voltage of the supply will try to turn the diode on by establishing a conventional current through the diode that matches the arrow in the diode symbol. However, the added dc supply *V* will oppose that applied voltage and try to keep the diode in the "off" state. The result is that any supply voltage greater than *V* volts will turn the diode on and conduction can be established through the load resistor. Keep in mind that we are dealing with an ideal diode for the moment, so the turn-on voltage is simply 0 V. In general, we can conclude that the diode will be on for any voltage vi that is greater than *V* volts and off for any lesser voltage. For the "off" condition, the output would be 0 V due to the lack of current, and for the "on" condition it would simply be $vo = vi - V$ as determined by Kirchhoff's voltage law.

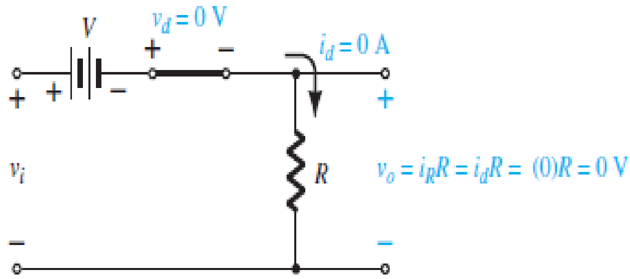
3. **Determine the applied voltage (transition voltage) that will result in a change of state for the diode from the "off" to the "on" state.**

This step will help to define a region of the applied voltage when the diode is on and when it is off. On the characteristics of an ideal diode this will occur when V_D=0 V and I_D=0 mA. For the approximate equivalent this is determined by finding the applied voltage when the diode has a drop of 0.7 V across it (for silicon) and I_D=0 mA. Note the substitution of the short-circuit equivalent for the diode and the fact that the voltage across the resistor is 0 V because the diode current is 0 mA. The result is *vi-V* =0, and so is the transition voltage.

$$v_i = V$$



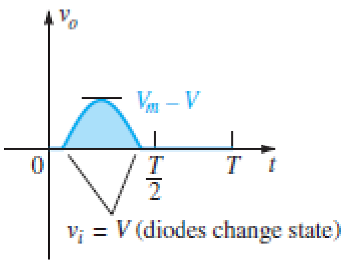
$$v_o = v_i - V$$



4. **It is often helpful to draw the output waveform directly below the applied voltage using the same scales for the horizontal axis and the vertical axis.**

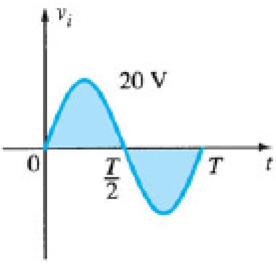
Using this last piece of information, we can establish the 0-V level on the plot of figure below for the region indicated. For the "on" condition, the above equation can be used to find the output voltage when the applied voltage has its peak value:

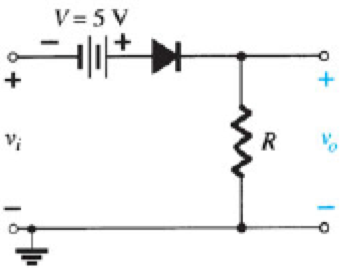
$v_{o\,peak} = V_m - V$



<u>EXAMPLE 7</u>

Determine the output waveform for the sinusoidal input

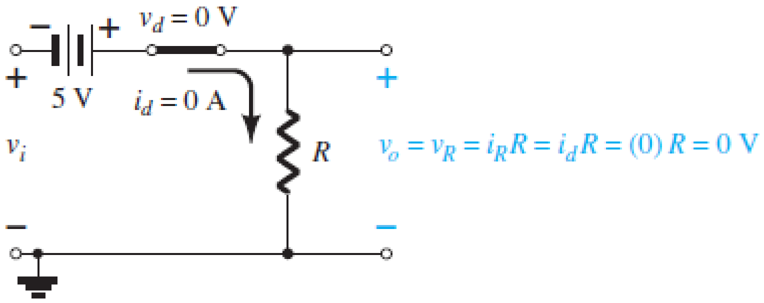




The transition model is substituted in figure below, and we find that the transition from one state to the other will occur when

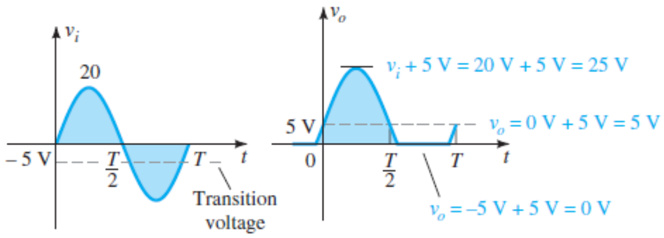
$$vi + 5\ V = 0\ V$$

or $$vi = -5\ V$$



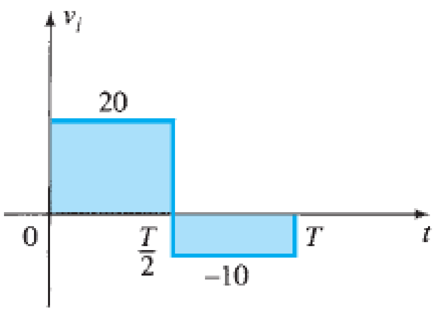
In figure below a horizontal line is drawn through the applied voltage at the transition level. For voltages less than -5V the diode is in the open-circuit state and the output is 0V, as shown in the sketch of vo. Using figure below, we find that for conditions when the diode is on and the diode current is established the output voltage will be the following, as determined using Kirchhoff's voltage law:

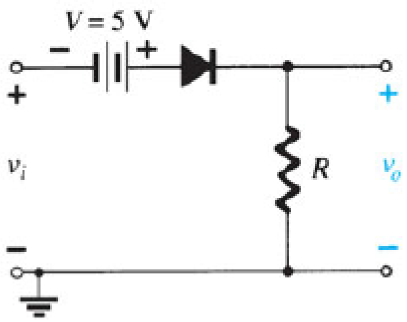
$$vo = vi + 5\ V$$



EXAMPLE 8

Find the output voltage for the network examined in the figure



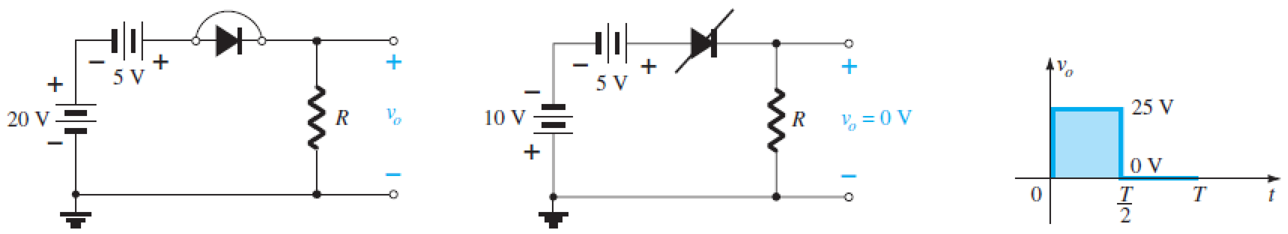


Solution:

For vi = 20 V (0 $T/2$) the network of Fig results. The diode is in the short-circuit state, and

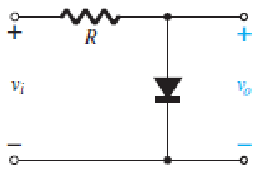
vo = 20 V + 5 V = 25 V. For vi = -10 V the network

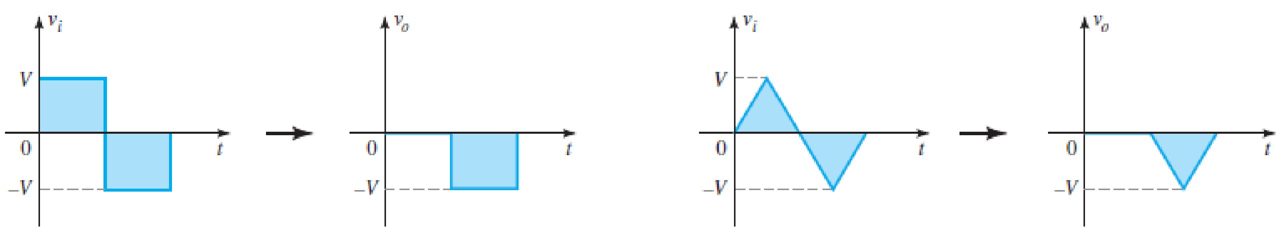
results, placing the diode in the “off” state, and $vo = i_R$ R = (0)R = 0 V.



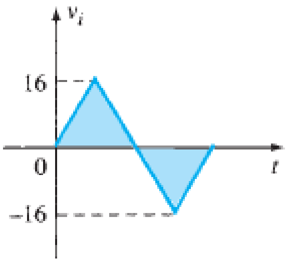
B. Parallel

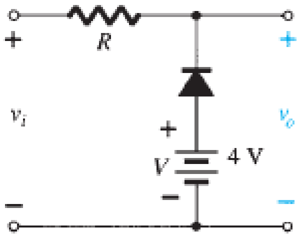
The network of figure below is the simplest of parallel diode configurations with the output. The analysis of parallel configurations is very similar to that applied to series configurations, as demonstrated in the next example.



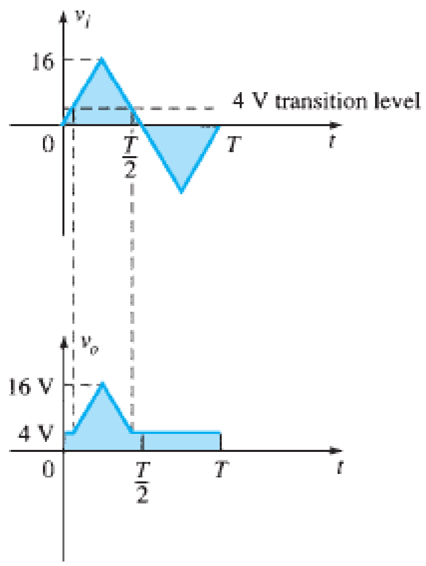


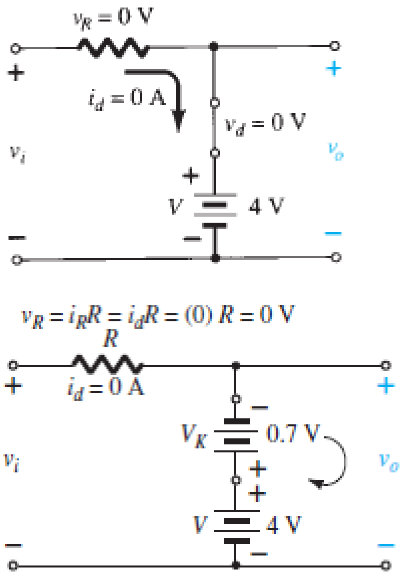
EXAMPLE 9: Determine *vo* for the network





Solution:





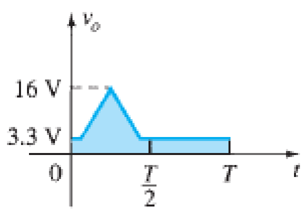
If the diode is silicon:

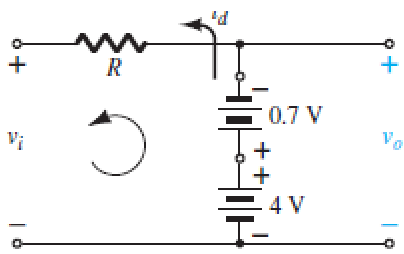
$vi + V_K - V = 0$

and $vi = V - V_K$ = 4V - 0.7 V = **3.3 V**

For input voltages greater than 3.3 V, the diode will be an open circuit and *vo* = *vi*. For input voltages less than 3.3 V, the diode will be in the "on" state

vo = 4 V - 0.7V = **3.3 V**

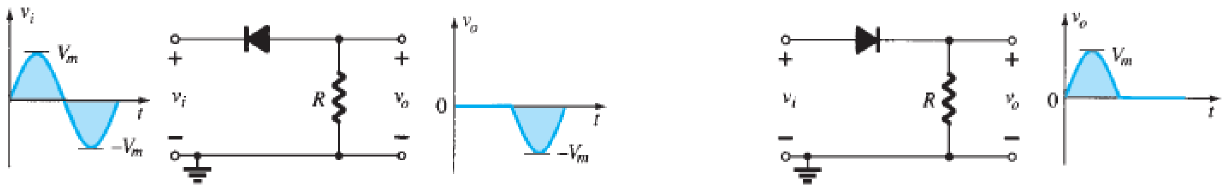




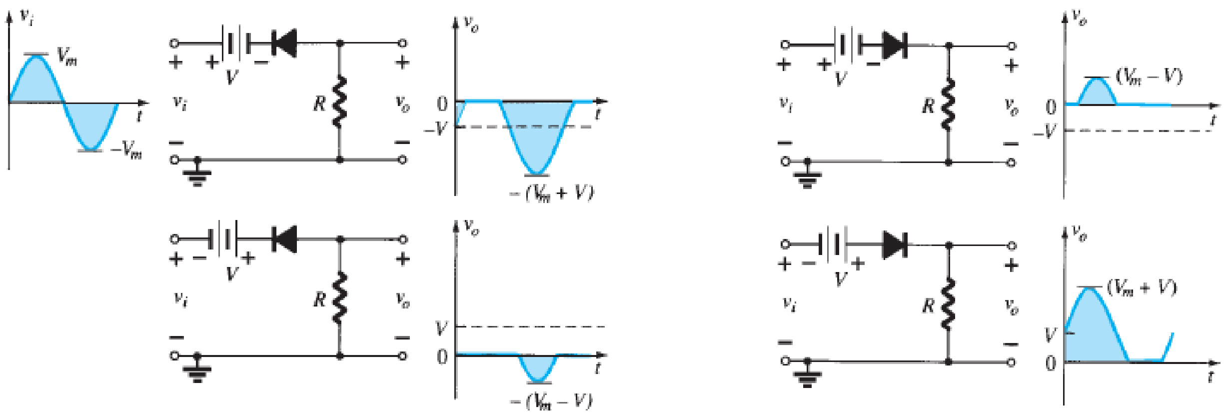
Summary

Simple Series Clippers (Ideal Diodes)

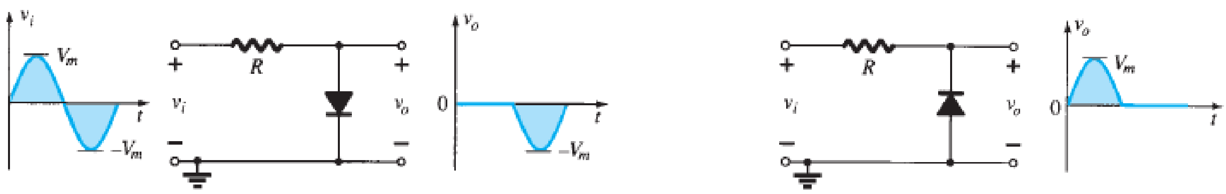
POSITIVE NEGATIVE



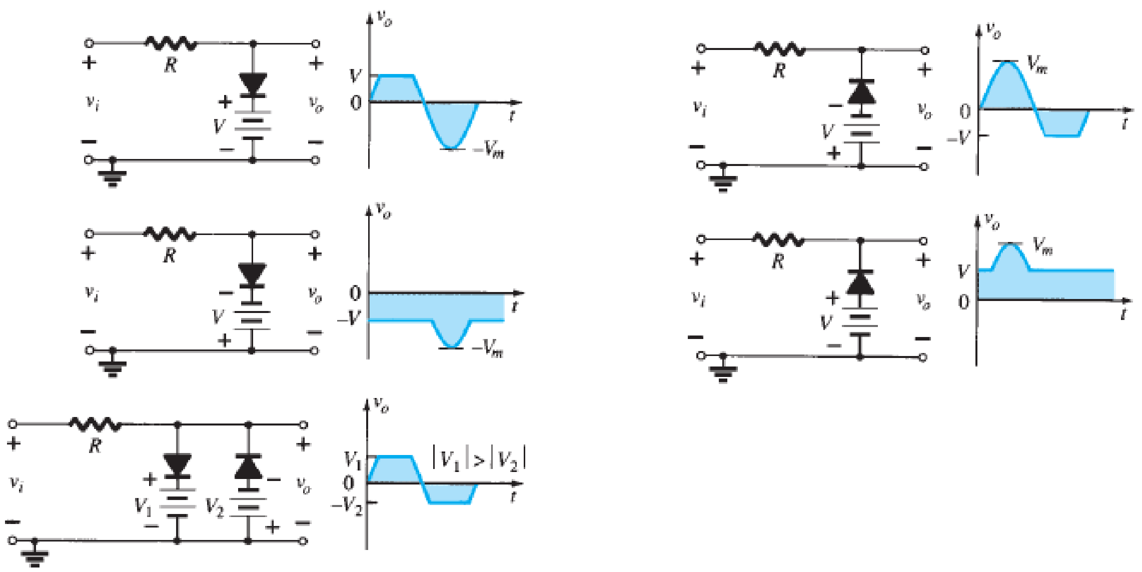
Biased Series Clippers (Ideal Diodes)



Simple Parallel Clippers (Ideal Diodes)



Biased Parallel Clippers (Ideal Diodes)

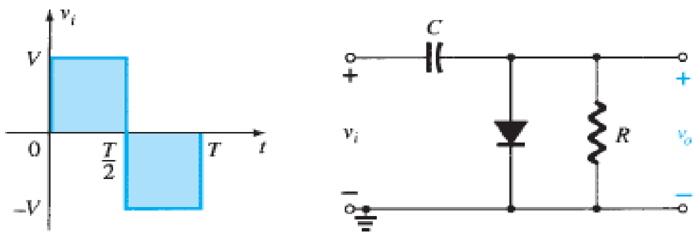


Clampers

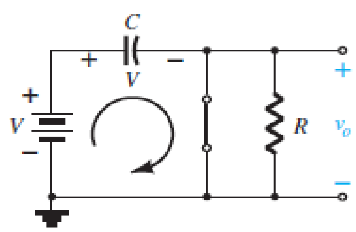
A clamper is a network constructed of a diode, a resistor, and a capacitor that shifts a waveform to a different dc level without changing the appearance of the applied signal.

Additional shifts can also be obtained by introducing a dc supply to the basic structure. The chosen resistor and capacitor of the network must be chosen such that the time constant determined by $\tau = RC$ is sufficiently large to ensure that the voltage across the capacitor does not discharge significantly during the interval the diode is nonconducting. Throughout the analysis we assume that for all practical purposes the capacitor fully charges or discharges in five time constants.

Clamping networks have a capacitor connected directly from input to output with a resistive element in parallel with the output signal. The diode is also in parallel with the output signal but may or may not have a series dc supply as an added element.

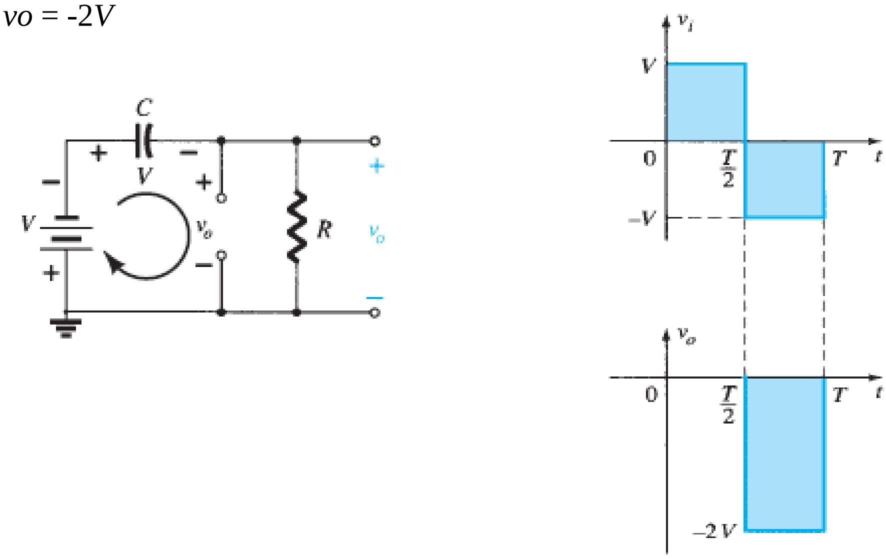


For the interval 0 to *T/2* the network will appear as shown in Fig. below. The short-circuit equivalent for the diode will result in *vo*= 0V for this time interval. During this same interval of time, the time constant determined by τ=RC is very small because the resistor R has been effectively "shorted out" by the conducting diode. The result is that the capacitor will quickly charge to the peak value of V volts



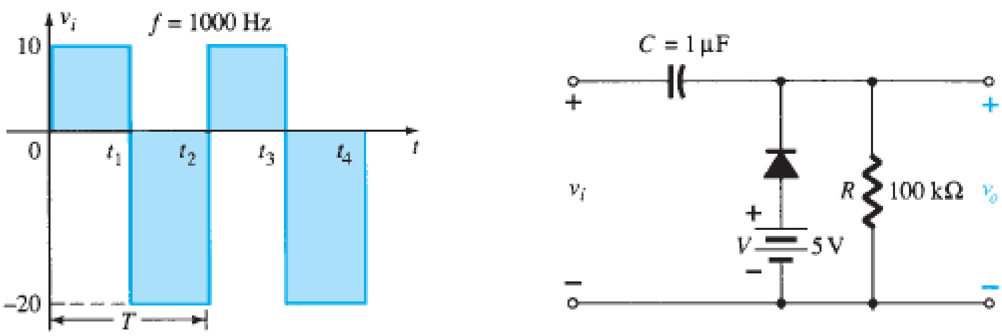
When the input switches to the *-V* state, the network will appear as shown in Fig. below, with the open-circuit equivalent for the diode determined by the applied signal and stored voltage across the capacitor—both "pressuring" current through the diode from cathode to anode. Now that *R* is back in the network the time constant determined by the *RC* product is sufficiently large to establish a discharge period 5τ, much greater than the period *T/2*→T, Applying Kirchhoff's voltage law around the input loop results in

$-V - V - v_o = 0$
$v_o = -2V$

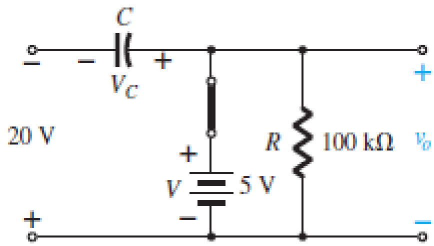


EXAMPLE 10

Determine *v o* for the network



Solution: The analysis of clamping circuits is started by considering that the part of the input signal that will forward bias the diode. For the circuit, the diode is forward bias ("on" state) during the negative half period of the input signal (*vi*) and the capacitor will charge up instantaneously to a voltage level determined by the circuit.



For the input section KVL will result in

$- 20V + V_C - 5\ V = 0$

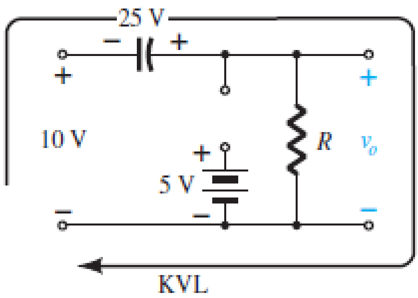
$V_C = 25\ V$

The capacitor will therefore charge up to 25 V. In this case the resistor R is not shorted out by the diode.

The open-circuit equivalent for the diode removes the 5-V battery from having any effect on vo, and applying Kirchhoff's voltage law around the outside loop of the network results in

$+ 10V + 25\ V - v_o = 0$

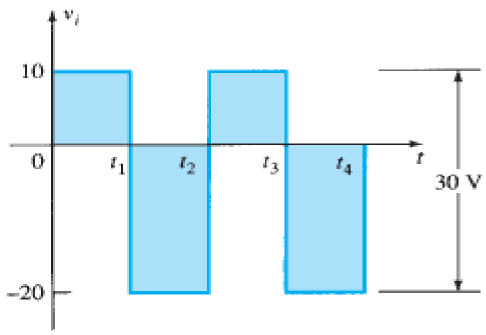
$v_o = 35\ V$

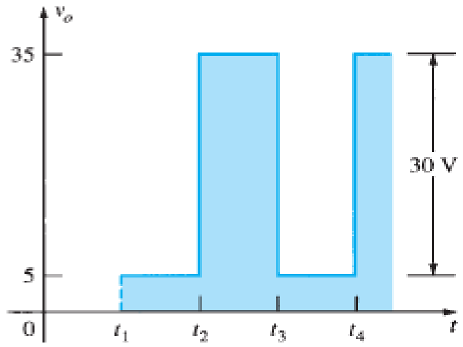


The time constant of the discharging network of above figure is determined by the product RC and has the magnitude $\tau = RC = (100\ k\Omega)(0.1\ \mu F) = 0.01\ s = 10\ ms$

The total discharge time is therefore $5\tau = 5(10\ ms) = 50\ ms$.

Since the interval $t_2 \rightarrow t_3$ will only last for 0.5 ms, it is certainly a good approximation that the capacitor will hold its voltage during the discharge period between pulses of the input signal. The resulting output appears in Fig. below with the input signal. Note that the output swing of 30 V matches the input swing.





EXAMPLE 11: Repeat Example 10 using a silicon diode with V_K = 0.7 V.

Solution: For the short-circuit state the network now takes on the appearance of Fig. 2.97 , and v_o can be determined by Kirchhoff's voltage law in the output section:

+5 V - 0.7 V - v_o = 0

and v_o = 5 V - 0.7 V = 4.3 V

For the input section Kirchhoff's voltage law results in

-20 V + V_C + 0.7 V - 5 V = 0

and V_C = 25 V - 0.7 V = 24.3 V

For the period $t_2 \rightarrow t_3$ the network will now appear as in Fig. 2.98 , with the only change

being the voltage across the capacitor. Applying Kirchhoff's voltage law yields

+10 V + 24.3 V - v_o = 0

and v_o = 34.3 V

The resulting output appears in Fig. 2.99 , verifying the statement that the input and output swings are the same.

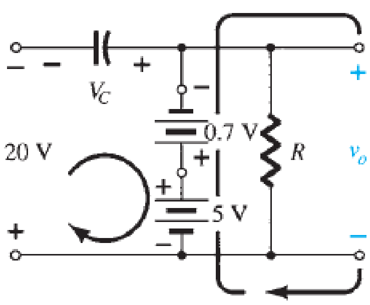


FIG. 2.97

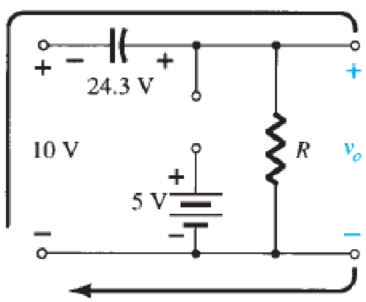
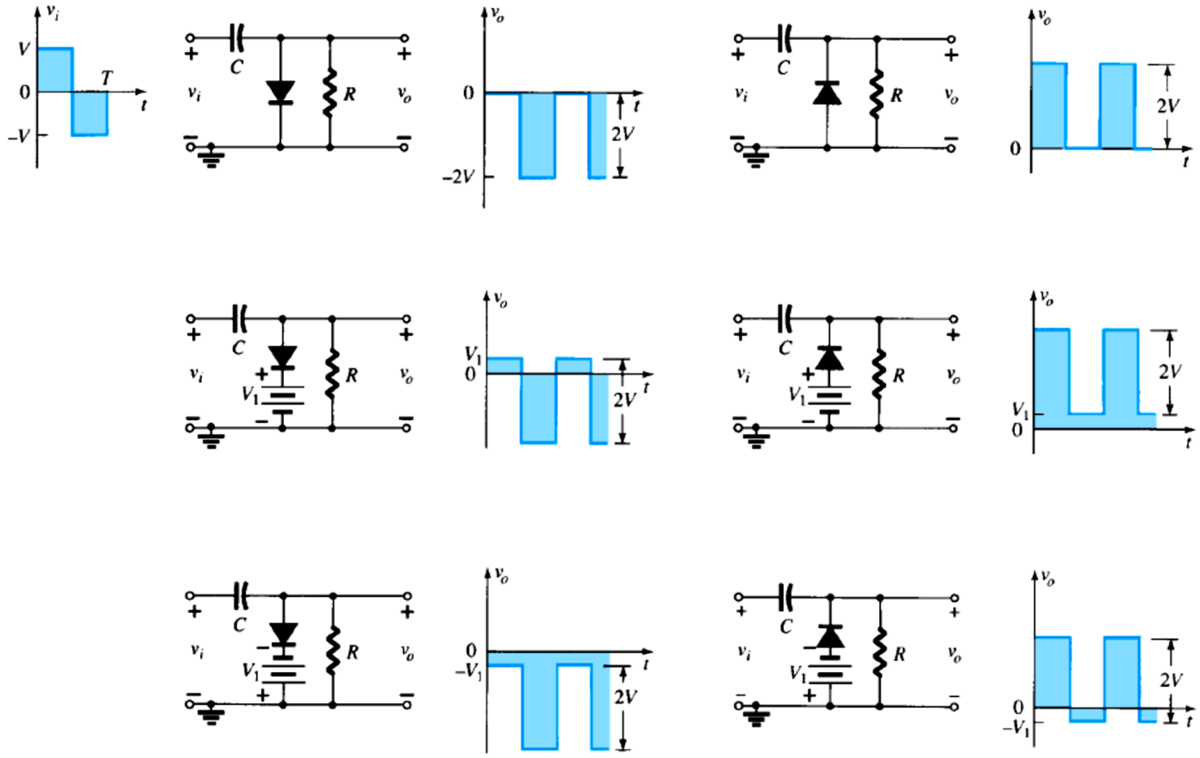


FIG. 2.98

Clamping Networks



A number of clamping circuits and their effect on the input signal are shown in Fig. 2.100. Although all the waveforms appearing in Fig. 2.100 are square waves, clamping networks work equally well for sinusoidal signals. In fact, one approach to the analysis of clamping networks with sinusoidal inputs is to replace the sinusoidal signal by a square wave of the same peak values. The resulting output will then form an envelope for the sinusoidal response as shown in Fig. 2.101 for a network appearing in the bottom right of Fig. 2.100.

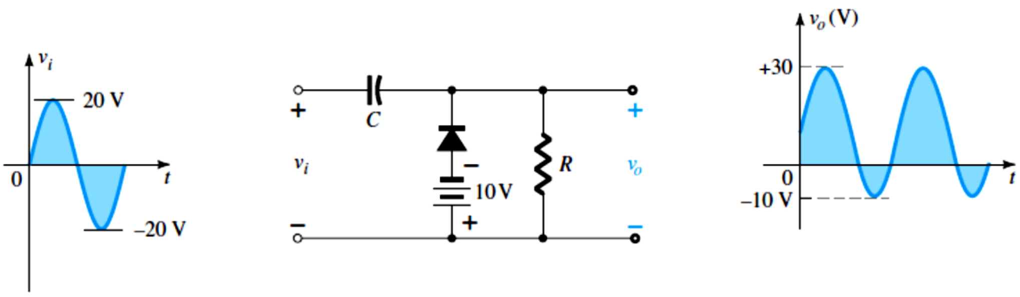


FIG. 2.101
Clamping network with a sinusoidal input.