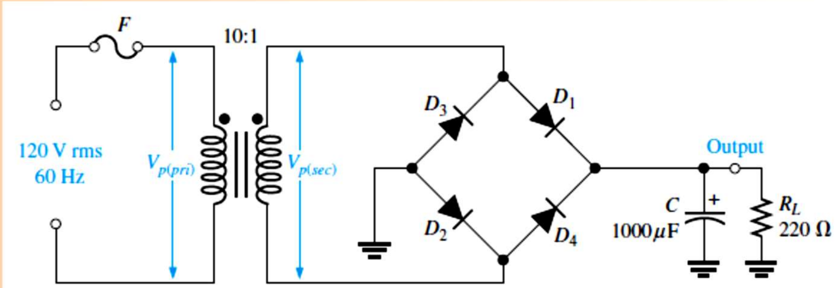
$$V_{r(pp)} \cong \left(\frac{1}{fR_LC}\right)V_{p(rect)}$$ **Equation 2–12**

$$V_{DC} \cong \left(1 - \frac{1}{2fR_LC}\right)V_{p(rect)}$$ **Equation 2–13**

EXAMPLE 2–8

Determine the ripple factor for the filtered bridge rectifier with a load as indicated in Figure 2–48.

▶ **FIGURE 2–48**



Solution The transformer turns ratio is $n = 0.1$. The peak primary voltage is

$$V_{p(pri)} = 1.414V_{rms} = 1.414(120\text{ V}) = 170\text{ V}$$

The peak secondary voltage is

$$V_{p(sec)} = nV_{p(pri)} = 0.1(170\text{ V}) = 17.0\text{ V}$$

The unfiltered peak full-wave rectified voltage is

$$V_{p(rect)} = V_{p(sec)} - 1.4\text{ V} = 17.0\text{ V} - 1.4\text{ V} = 15.6\text{ V}$$

The frequency of a full-wave rectified voltage is 120 Hz. The approximate peak-to-peak ripple voltage at the output is

$$V_{r(pp)} \cong \left(\frac{1}{fR_LC}\right)V_{p(rect)} = \left(\frac{1}{(120\text{ Hz})(220\ \Omega)(1000\ \mu\text{F})}\right)15.6\text{ V} = 0.591\text{ V}$$

The approximate dc value of the output voltage is determined as follows:

$$V_{DC} = \left(1 - \frac{1}{2fR_LC}\right)V_{p(rect)} = \left(1 - \frac{1}{(240\text{ Hz})(220\ \Omega)(1000\ \mu\text{F})}\right)15.6\text{ V} = 15.3\text{ V}$$

The resulting ripple factor is

$$r = \frac{V_{r(pp)}}{V_{DC}} = \frac{0.591\text{ V}}{15.3\text{ V}} = \mathbf{0.039}$$

The percent ripple is 3.9%.

Related Problem Determine the peak-to-peak ripple voltage if the filter capacitor in Figure 2–48 is increased to 2200 μF and the load resistance changes to 2.2 kΩ.

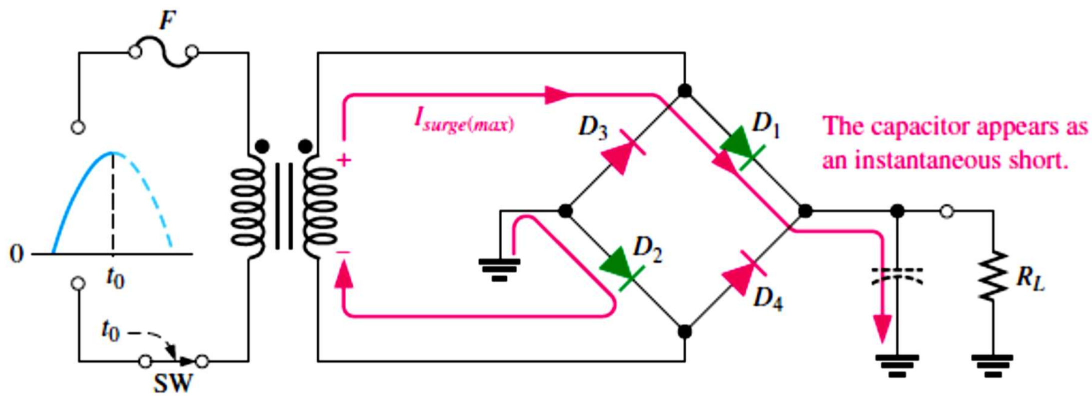
Surge Current in the Capacitor-Input Filter

Before the switch in Figure 2–49 is closed, the filter capacitor is **uncharged**.

At the instant the switch is closed, voltage is connected to the bridge and the uncharged capacitor appears as a short, as shown.

This produces an initial surge of current, I_{surge}, through the two forward-biased diodes D_1 and D_2.

The worst-case situation occurs when the switch is closed at a peak of the secondary voltage and a maximum surge current, $I_{surge(max)}$, is produced, as illustrated in the figure.

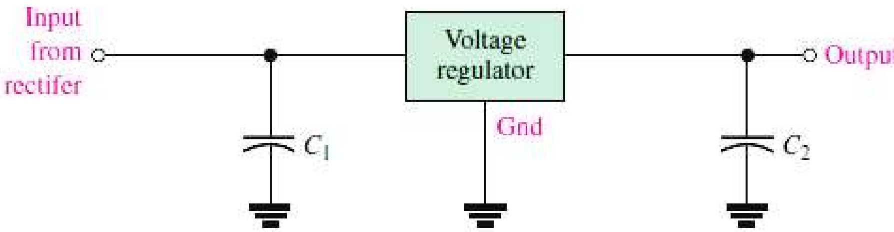


The fuse rating is determined by
calculating the power in the power supply load, which is the output power. Since $P_{in} = P_{out}$ in an ideal transformer, the primary current can be calculated as

$$I_{pri} = \frac{P_{in}}{120\text{ V}}$$

The fuse rating should be at least 20% larger than the calculated value of I_{pri}.

Voltage Regulators

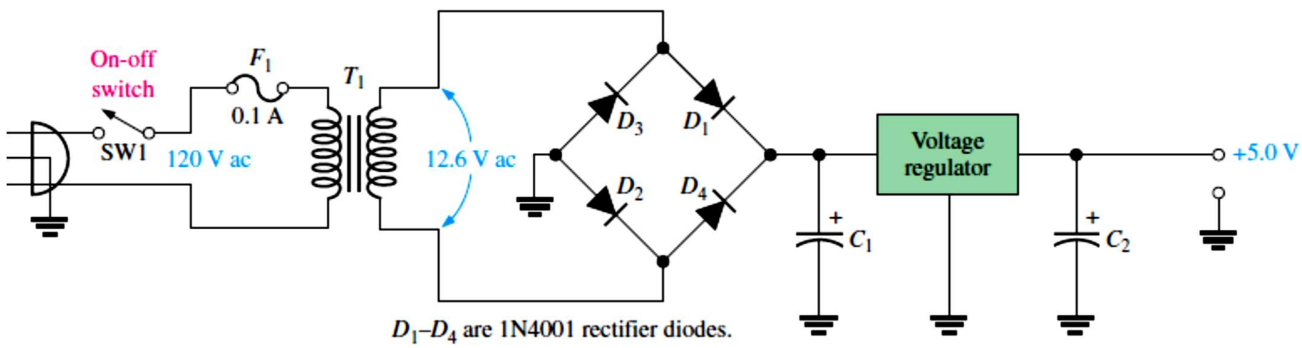


Most regulators are integrated circuits and have three terminals—an input terminal, an output terminal, and a reference (or adjust) terminal. The input to the regulator is first filtered with a capacitor to reduce the ripple to 10%.

Filtering is accomplished by a large-value capacitor between the input voltage and ground.

An output capacitor (typically 0.1 mF to 1.0 mF) is connected from the output to ground to improve the transient response.

A basic fixed power supply with a +5 V voltage regulator is shown in Figure 2–51.



$$\text{Line regulation} = \left(\frac{\Delta V_{OUT}}{\Delta V_{IN}}\right)100\%$$

$$\text{Load regulation} = \left(\frac{V_{NL} - V_{FL}}{V_{FL}}\right)100\%$$

2–7 DIODE LIMITERS AND CLAMPERS

Diode Limiters

As the input voltage goes positive, the diode becomes forward biased and conducts current.

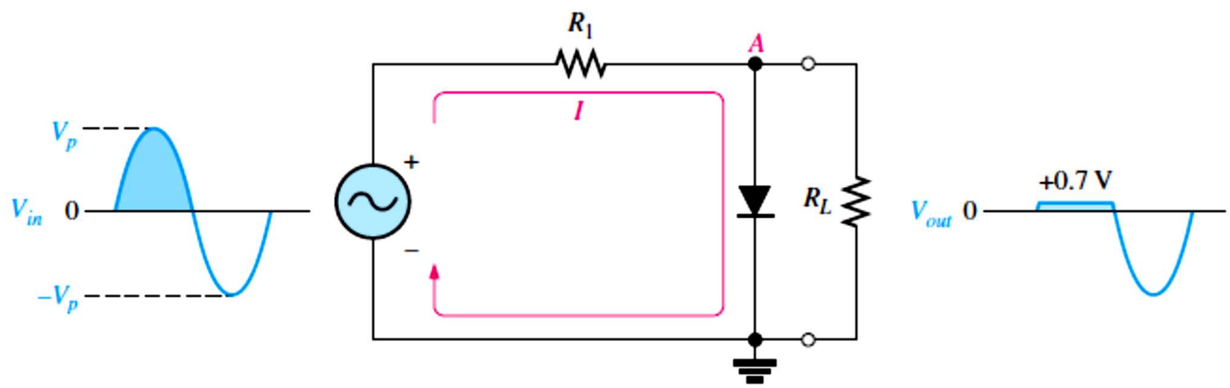
Point *A* is limited to +0.7 V when the input voltage exceeds this value.

When the input voltage goes back below 0.7 V, the diode is reverse-biased and appears as an open.

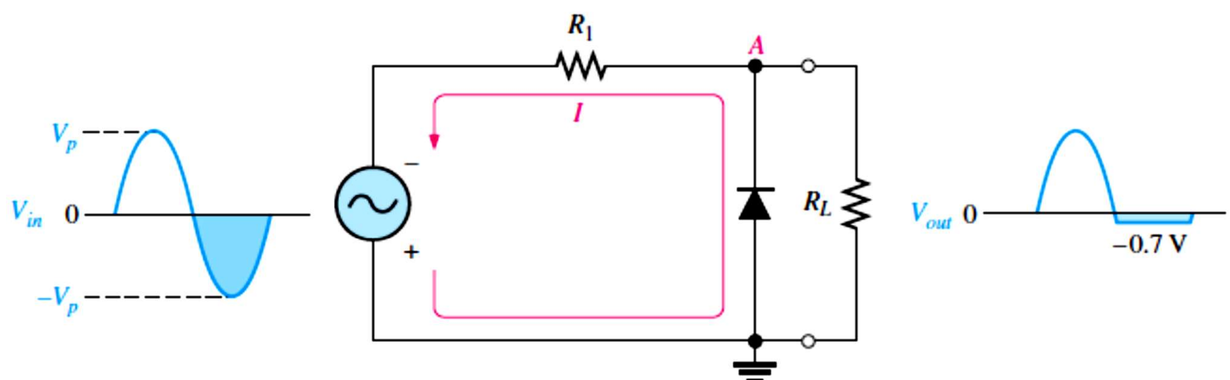
The output voltage looks like the negative part of the input voltage, but with a magnitude determined by the voltage divider formed by R_1 and the load resistor, R_L, as follows:

$$V_{out} = \left(\frac{R_L}{R_1 + R_L}\right)V_{in}$$

If R_1 is small compared to R_L, then $V_{out} \cong V_{in}$.

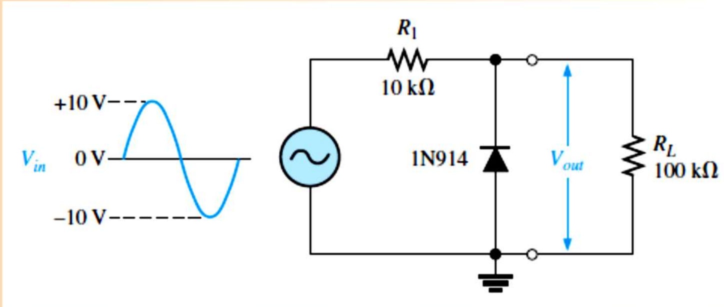


(a) Limiting of the positive alternation. The diode is forward-biased during the positive alternation (above 0.7 V) and reverse-biased during the negative alternation.



(b) Limiting of the negative alternation. The diode is forward-biased during the negative alternation (below −0.7 V) and reverse-biased during the positive alternation.

EXAMPLE 2–10 What would you expect to see displayed on an oscilloscope connected across R_L in the limiter shown in Figure 2–53?



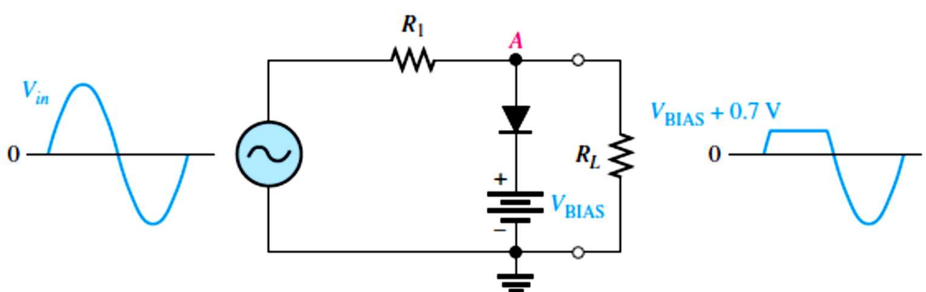
▶ FIGURE 2–53

Solution The diode is forward-biased and conducts when the input voltage goes below −0.7 V. So, for the negative limiter, determine the peak output voltage across R_L by the following equation:

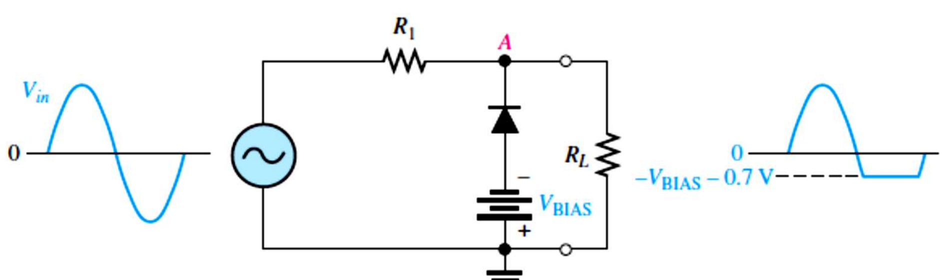
$$V_{p(out)} = \left(\frac{R_L}{R_1 + R_L}\right)V_{p(in)} = \left(\frac{100\text{ k}\Omega}{110\text{ k}\Omega}\right)10\text{ V} = 9.09\text{ V}$$

The scope will display an output waveform as shown in Figure 2–54.

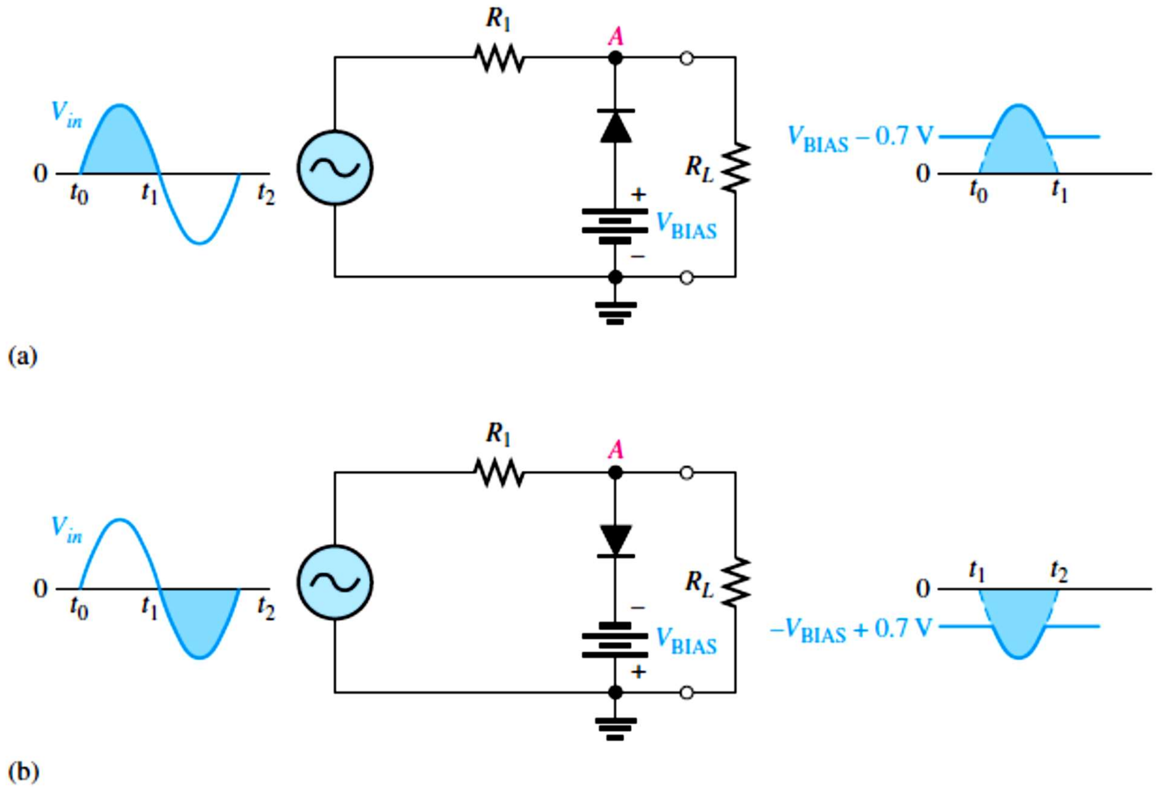
Biased Limiters The level to which an ac voltage is limited can be adjusted by adding a bias voltage, V_{BIAS}, in series with the diode, as shown in Figure 2–55. The voltage at point A must equal $V_{BIAS} + 0.7$ V before the diode will become forward-biased and conduct. Once the diode begins to conduct, the voltage at point A is limited to $V_{BIAS} + 0.7$ V so that all input voltage above this level is clipped off.



To limit a voltage to a specified negative level, the diode and bias voltage must be connected as in Figure 2–56. In this case, the voltage at point A must go below $-V_{BIAS} - 0.7$ V to forward-bias the diode and initiate limiting action as shown.

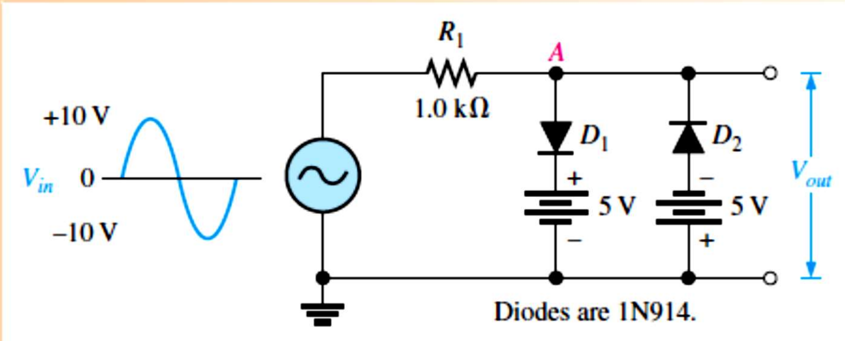


By turning the diode around, the positive limiter can be modified to limit the output voltage to the portion of the input voltage waveform above $V_{BIAS} - 0.7$ V, as shown by the output waveform in Figure 2–57(a). Similarly, the negative limiter can be modified to limit the output voltage to the portion of the input voltage waveform below $-V_{BIAS} + 0.7$ V, as shown by the output waveform in part (b).



EXAMPLE 2–11

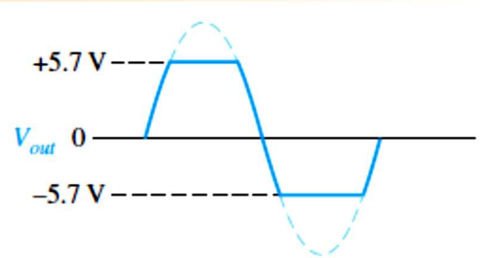
Figure 2–58 shows a circuit combining a positive limiter with a negative limiter. Determine the output voltage waveform.



When the voltage at point A reaches +5.7 V, diode D_1 conducts and limits the waveform to +5.7 V. Diode D_2 does not conduct until the voltage reaches −5.7 V. Therefore, positive voltages above +5.7 V and negative voltages below −5.7 V are clipped off. The resulting output voltage waveform is shown in Figure 2–59.

▶ **FIGURE 2–59**

Output voltage waveform for Figure 2–58.

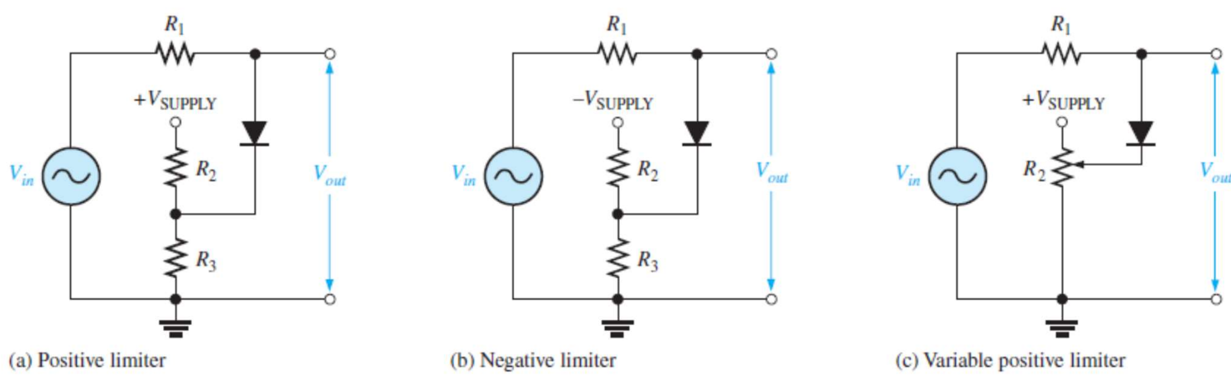


Voltage-Divider Bias The bias voltage sources that have been used to illustrate the basic operation of diode limiters can be replaced by a resistive voltage divider that derives the desired bias voltage from the dc supply voltage, as shown in Figure 2–60. The bias voltage is set by the resistor values according to the voltage-divider formula.

$$V_{BIAS} = \left(\frac{R_3}{R_2 + R_3}\right)V_{SUPPLY}$$

A Limiter Application

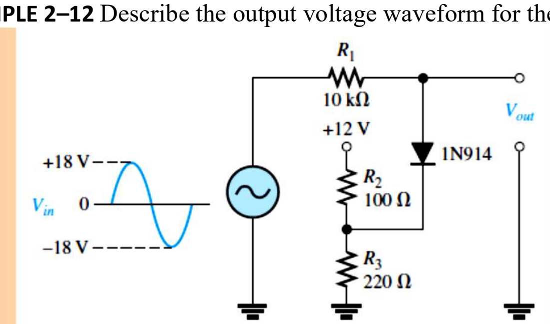
Many circuits have certain restrictions on the input level to avoid damaging the circuit.
For example, almost all digital circuits should not have an input level that exceeds the power supply voltage. An input of a few volts more than this could damage the circuit.
To prevent the input from exceeding a specific level, you may see a diode limiter across the input signal path in many digital circuits.



▲ FIGURE 2–60

Diode limiters implemented with voltage-divider bias.

EXAMPLE 2–12 Describe the output voltage waveform for the diode limiter in Figure 2–61.

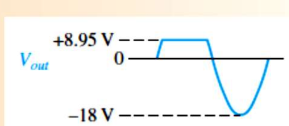


ution The circuit is a positive limiter. Use the voltage-divider formula to determine the bias voltage.

$$V_{BIAS} = \left(\frac{R_3}{R_2 + R_3}\right)V_{SUPPLY} = \left(\frac{220\ \Omega}{100\ \Omega + 220\ \Omega}\right)12\text{ V} = 8.25\text{ V}$$

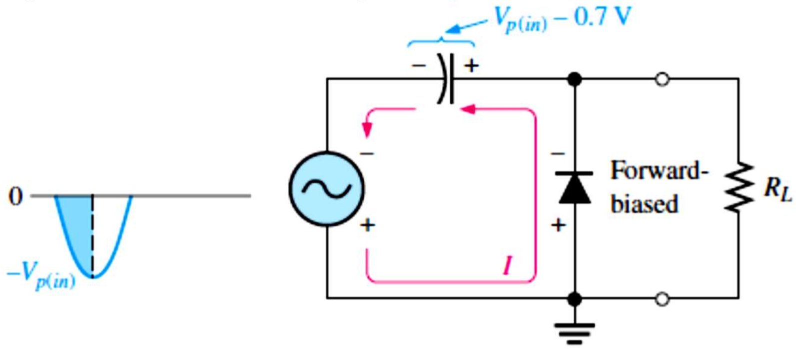
The output voltage waveform is shown in Figure 2–62. The positive part of the output voltage waveform is limited to $V_{BIAS} + 0.7$ V.

► FIGURE 2–62

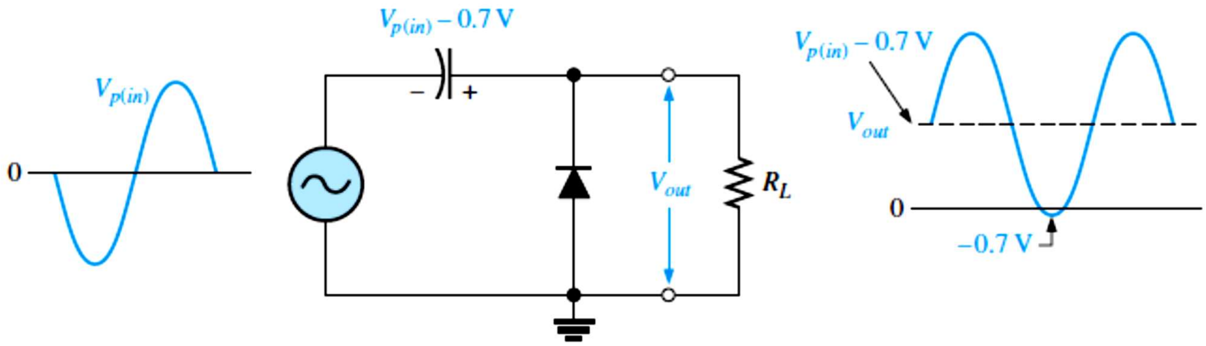


Diode Clampers

A clamper adds a dc level to an ac voltage. **Clampers** are sometimes known as *dc restorers.*



(a)



(b)

If the capacitor discharges during the period of the input wave, clamping action is affected.

If the *RC* time constant is 100 times the period, the clamping action is excellent.

An *RC* time constant of ten times the period will have a small amount of distortion at the ground level due to the charging current.

The net effect of the clamping action is that the capacitor retains a charge approximately equal to the peak value of the input less the diode drop.

The capacitor voltage acts essentially as a battery in series with the input voltage. The dc voltage of the capacitor adds to the input voltage by superposition, as in Figure 2–63(b).

If the diode is turned around, a negative dc voltage is added to the input voltage to produce the output voltage as shown in Figure 2–64.

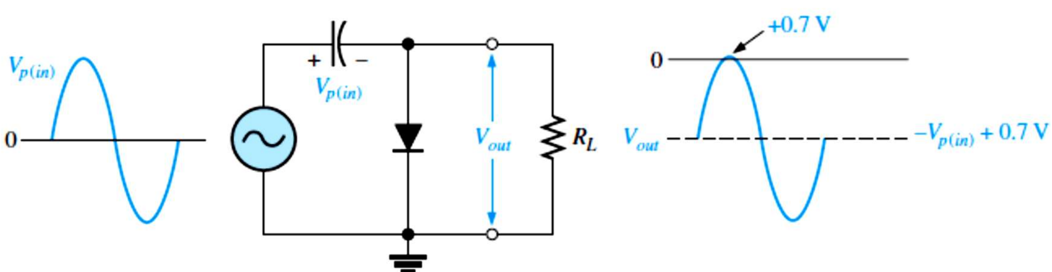
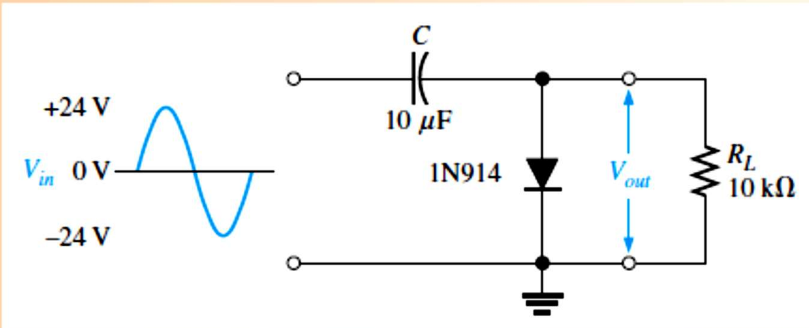


FIGURE 2–64
Negative clamper.

EXAMPLE 2–13

What is the output voltage that you would expect to observe across R_L in the clamping circuit of Figure 2–65? Assume that RC is large enough to prevent significant capacitor discharge.



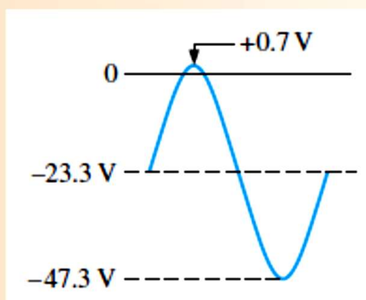
Ideally, a negative dc value equal to the input peak less the diode drop is inserted by the clamping circuit.

$$V_{DC} \cong -(V_{p(in)} - 0.7\text{ V}) = -(24\text{ V} - 0.7\text{ V}) = \mathbf{-23.3\text{ V}}$$

Actually, the capacitor will discharge slightly between peaks, and, as a result, the output voltage will have an average value of slightly less than that calculated above. The output waveform goes to approximately +0.7 V, as shown in Figure 2–66.

► FIGURE 2–66

Output waveform across R_L for Figure 2–65.



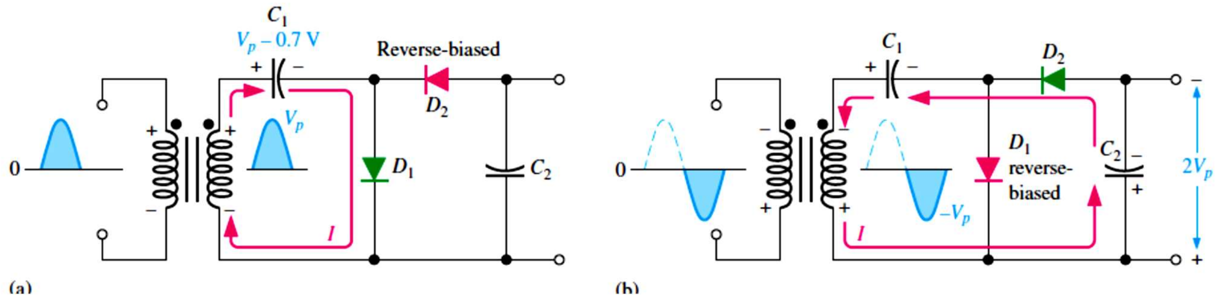
2–8 VOLTAGE MULTIPLIERS

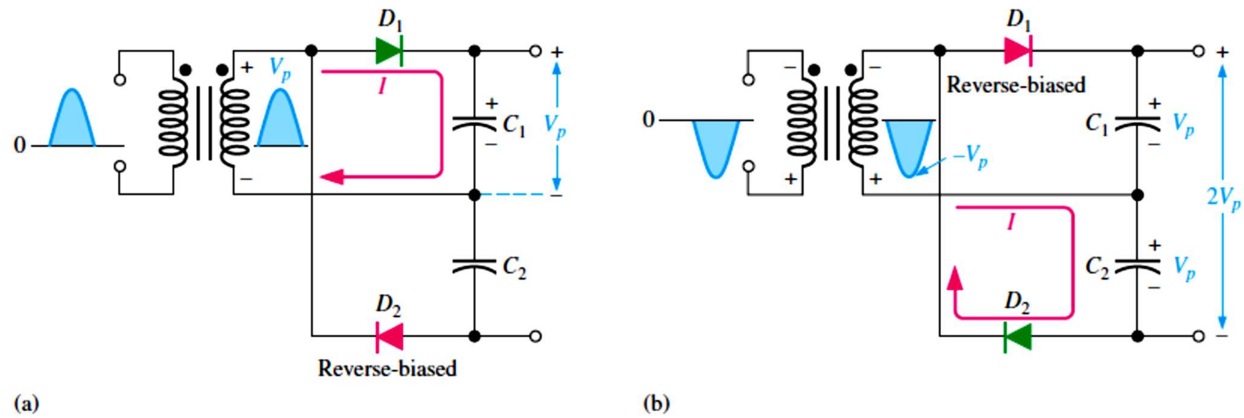
Voltage Doubler

$$V_{C1} - V_{C2} + V_p = 0$$
$$V_{C2} = V_p + V_{C1}$$

Neglecting the diode drop of D_2, $V_{C1} = V_p$. Therefore,

$$V_{C2} = V_p + V_p = 2V_p$$

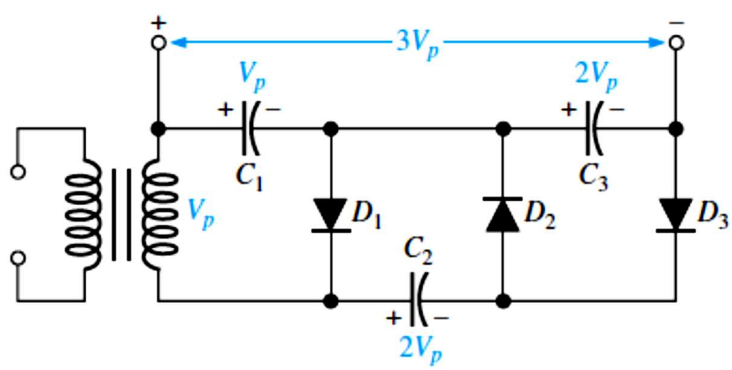




▲ FIGURE 2–68

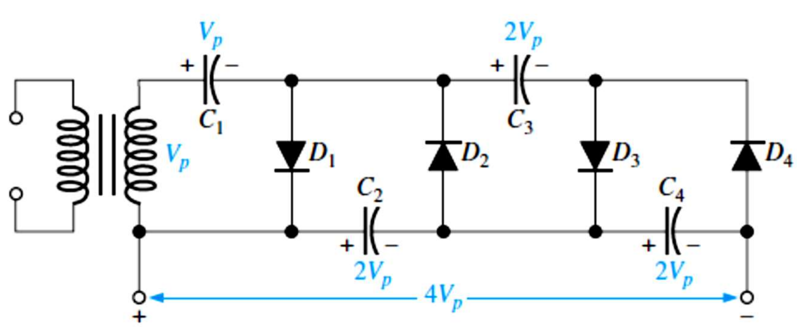
► FIGURE 2–69

Voltage tripler.



► FIGURE 2–70

Voltage quadrupler.



2–9 THE DIODE DATASHEET

Data Categories

Absolute Maximum Ratings

The absolute maximum ratings indicate the maximum values of the several parameters under which the diode can be operated without damage or degradation.

Generally, the maximum ratings are specified for an operating ambient temperature (T_A) of **25**°C unless otherwise stated. Ambient temperature is the temperature of the air surrounding the device

V_{RRM} The peak reverse voltage that can be applied repetitively across the diode. Notice that it is 50 V for the 1N4001 and 1000 V for the 1N4007. This rating is the same as the PIV.

$I_{F(AV)}$ The maximum average value of a 60 Hz half-wave rectified forward current. This current parameter is 1.0 A for all of the diode types and is specified for an ambient temperature of 75°C.

I_{FSM} The maximum peak value of nonrepetitive single half-sine-wave forward surge current with a duration of 8.3 ms. This current parameter is 30 A for all of the diode types.

T_{stg} The allowable range of temperatures at which the device can be kept when not operating or connected to a circuit.

T_J The allowable range of temperatures for the *pn* junction when the diode is operated in a circuit.

1N4001 - 1N4007

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Symbol	Parameter	Value							Units
		4001	4002	4003	4004	4005	4006	4007	
V_{RRM}	Peak Repetitive Reverse Voltage	50	100	200	400	600	800	1000	V
$I_{F(AV)}$	Average Rectified Forward Current, .375 " lead length @ T_A = 75°C	1.0							A
I_{FSM}	Non-repetitive Peak Forward Surge Current 8.3 ms Single Half-Sine-Wave	30							A
T_{stg}	Storage Temperature Range	-55 to +175							°C
T_J	Operating Junction Temperature	-55 to +175							°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

All devices have a limit on the amount of heat that they can tolerate without failing in some way.

P_D Average power dissipation is the amount of power that the diode can dissipate under any condition. A diode should never be operated at maximum power, except for brief periods, to assure reliability and longer life.

$R_{θJA}$ Thermal resistance from the diode junction to the surrounding air. This indicates the ability of the device material to resist the flow of heat and specifies the number of degrees difference between the junction and the surrounding air for each watt transferred from the junction to the air.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	3.0	W
$R_{θJA}$	Thermal Resistance, Junction to Ambient	50	°C/W

Electrical Characteristics

The electrical characteristics are specified under certain conditions and are the same for each type of diode. These values are typical and can be more or less for a given diode. Some datasheets provide a minimum and a maximum value in addition to a typical value for a parameter.

V_F The forward voltage drop across the diode when there is 1 A of forward current. To determine the forward voltage for other values of forward current, you must examine the forward characteristics graph.

I_{rr} Maximum full load reverse current averaged over a full ac cycle at 75°C.

I_R The reverse current at the rated reverse voltage (V_{RRM}). Values are specified at two different ambient temperatures.
C_T This is the total diode capacitance including the junction capacitance in reverse bias at a frequency of 1 MHz.
Most of the time this parameter is not important in low frequency applications, such as power supply rectifiers.

Electrical Characteristics $T_A = 25°C$ unless otherwise noted

Symbol	Parameter	Device							Units
		4001	4002	4003	4004	4005	4006	4007	
V_F	Forward Voltage @ 1.0 A	1.1							V
I_{rr}	Maximum Full Load Reverse Current, Full Cycle $T_A = 75°C$	30							µA
I_R	Reverse Current @ rated V_R $T_A = 25°C$ $T_A = 100°C$	5.0 500							µA µA
C_T	Total Capacitance $V_R = 4.0$ V, f = 1.0 MHz	15							pF

Graphical Characteristics

The Forward Current Derating Curve
Forward Characteristics Curve
Nonrepetitive Surge Current
Reverse Characteristics

2–10 TROUBLESHOOTING