D *4.84 Consider the circuit in Fig. P4.76 with two equal filter capacitors placed across the load resistors R. Assume that the diodes available exhibit a 0.7-V drop when conducting. Design the circuit to provide ±12-V dc output voltages with a peak-to-peak ripple no greater than 1 V. Each supply should be capable of providing 100-mA dc current to its load resistor R. Completely specify the capacitors, diodes, and the transformer.

4.85 The op amp in the precision rectifier circuit of Fig. P4.85 is ideal with output saturation levels of ±13 V. Assume that when conducting the diode exhibits a constant voltage drop of 0.7 V. Find v_-, v_O, and v_A for:

(a) $v_I = +1$ V
(b) $v_I = +3$ V
(c) $v_I = -1$ V
(d) $v_I = -3$ V

Also, find the average output voltage obtained when v_I is a symmetrical square wave of 1-kHz frequency, 5-V amplitude, and zero average.

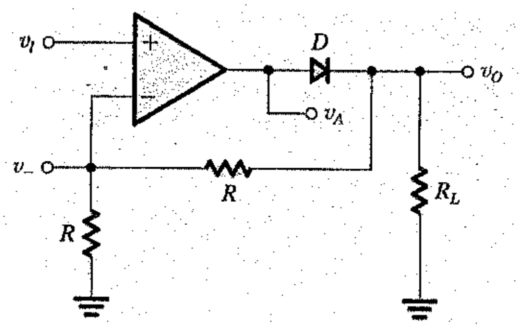

Figure P4.85

4.86 The op amp in the circuit of Fig. P4.86 is ideal with output saturation levels of ±12 V. The diodes exhibit a constant 0.7-V drop when conducting. Find v_-, v_A, and v_O for:

(a) $v_I = +1$ V
(b) $v_I = +3$ V
(c) $v_I = -1$ V
(d) $v_I = -3$ V

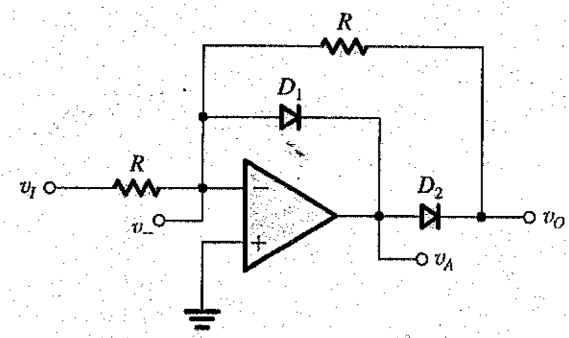

Figure P4.86

Section 4.6: Limiting and Clamping Circuits

4.87 Sketch the transfer characteristic v_O versus v_I for the limiter circuits shown in Fig. P4.87. All diodes begin conducting at a forward voltage drop of 0.5 V and have voltage drops of 0.7 V when conducting a current $i_D \geq 1$ mA.

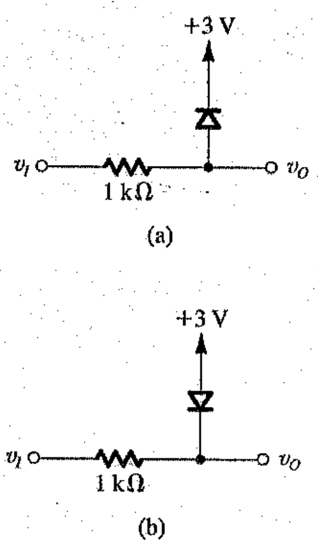

Figure P4.87

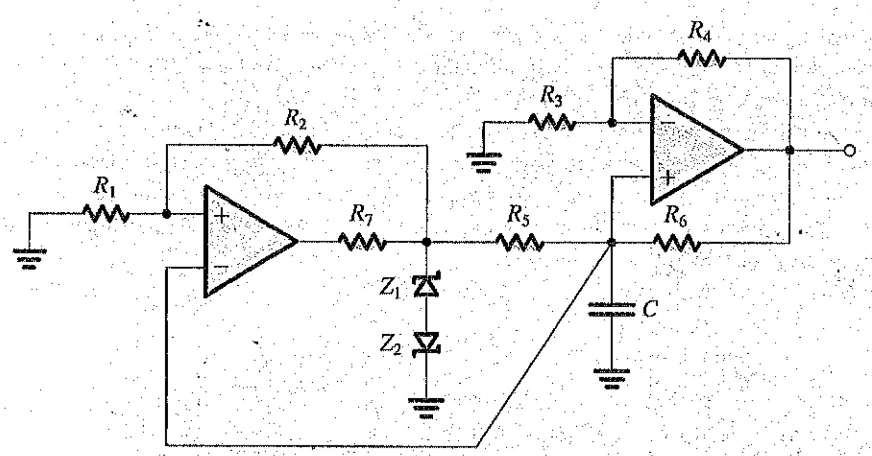

Figure P18.41

Section 18.5: Generation of Square and Triangular Waveforms Using Astable Multivibrators

18.38 Find the frequency of oscillation of the circuit in Fig. 18.26(b) for the case $R_1 = 10\ \text{k}\Omega$, $R_2 = 16\ \text{k}\Omega$, $C = 5$ nF, and $R = 62\ \text{k}\Omega$.

D 18.39 Augment the astable multivibrator circuit of Fig. 18.26(b) with an output limiter of the type shown in Fig. 18.25(b). Design the circuit to obtain an output square wave with 5-V amplitude and 1-kHz frequency using a 10-nF capacitor C. Use $\beta = 0.462$, and design for a current in the resistive divider approximately equal to the average current in the RC network over a half-cycle. Assuming ±13-V op-amp saturation voltages, arrange for the zener to operate at a minimum current of 1 mA. Specify the values of all resistors and the zenor voltage.

D 18.40 Using the scheme of Fig. 18.27, design a circuit that provides square waves of 10 V peak to peak and triangular waves of 10 V peak to peak. The frequency is to be 1 kHz. Implement the bistable circuit with the circuit of Fig. 18.25(b). Use a 0.01-μF capacitor and specify the values of all resistors and the required zener voltage. Design for a minimum zener current of 1 mA and for a maximum current in the resistive divider of 0.2 mA. Assume that the output saturation levels of the op amps are ±12 V.

D *18.41 The circuit of Fig. P18.41 consists of an inverting bistable multivibrator with an output limiter and a noninverting integrator. Using equal values for all resistors except R_7 and a 0.5-nF capacitor, design the circuit to obtain a square wave at the output of the bistable multivibrator of 15-V peak-to-peak amplitude and 10-kHz frequency. Sketch and label the waveform at the integrator output. Assuming ±13-V op-amp saturation levels, design for a minimum zener current of 1 mA. Specify the zener voltage required, and give the values of all resistors.

Section 18.6: Generation of a Standardized Pulse—The Monostable Multivibrator

D 18.42 For the monostable circuit considered in Exercise 18.22, calculate the recovery time.

***18.43** Figure P18.43 shows a monostable multivibrator circuit. In the stable state, $v_O = L_+$, $v_A = 0$, and $v_B = -V_{ref}$. The circuit can be triggered by applying a positive input pulse of height greater than V_{ref}. For normal operation, $C_1R_1 \ll CR$. Show the resulting waveforms of v_O and v_A. Also, show that the pulse generated at the output will have a width T given by

$$T = CR\ln\left(\frac{L_+ - L_-}{V_{ref}}\right)$$

Note that this circuit has the interesting property that the pulse width can be controlled by changing V_{ref}.

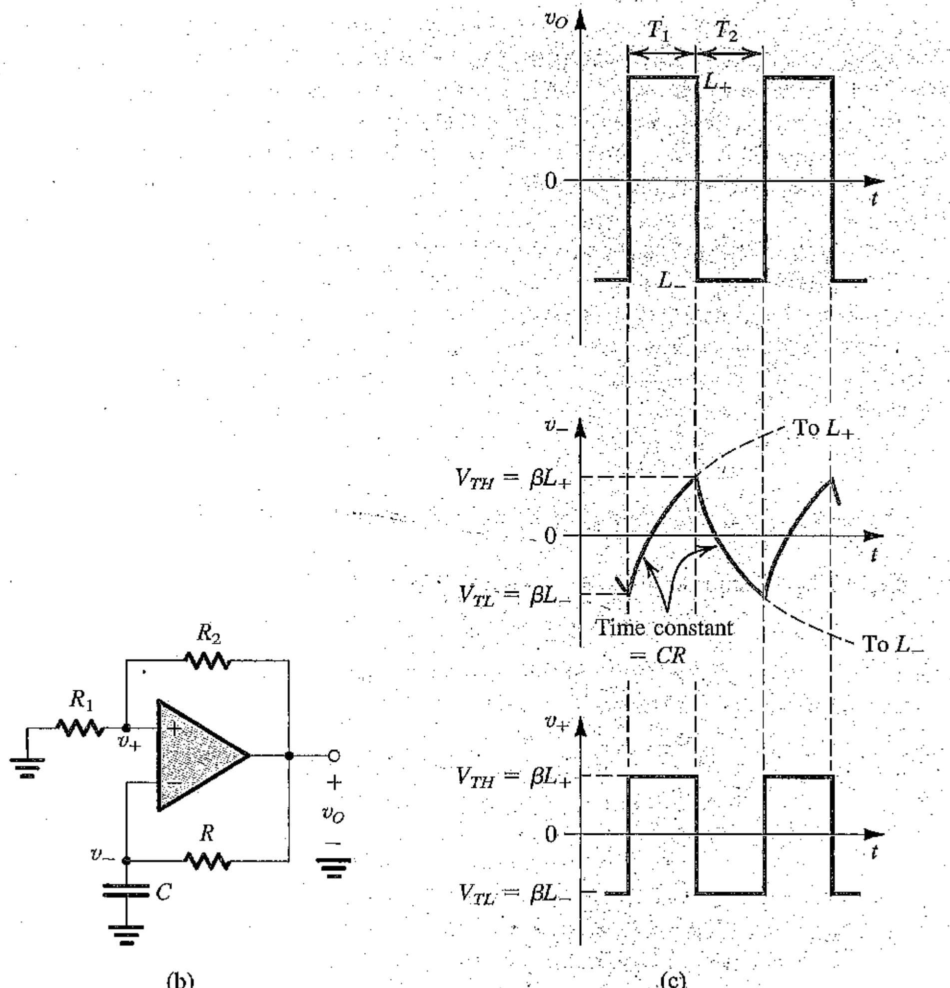

Figure 18.26 *continued* (b) The circuit obtained when the bistable multivibrator is implemented with the circuit of Fig. 18.21(a). (c) Waveforms at various nodes of the circuit in (b). This circuit is called an astable multivibrator.

discharging through a resistance R toward a final voltage V_∞ has a voltage $v(t)$,

$$v(t) = V_\infty - (V_\infty - V_{0+})e^{-t/\tau}$$

where V_{0+} is the voltage at $t = 0+$ and $\tau = CR$ is the time constant.

18.5.1 Operation of the Astable Multivibrator

To see how the astable multivibrator operates, refer to Fig. 18.26(b) and let the output of the bistable multivibrator be at one of its two possible levels, say L_+. Capacitor C will charge toward this level through resistor R. Thus the voltage across C, which is applied to the negative input terminal of the op amp and thus is denoted v_-, will rise exponentially toward L_+ with a time constant $\tau = CR$. Meanwhile, the voltage at the positive input terminal

4.4.1 Specifying and Modeling the Zener Diode

Figure 4.19 shows details of the diode i–v characteristic in the breakdown region. We observe that for currents greater than the **knee current** I_{ZK} (specified on the data sheet of the zener diode), the i–v characteristic is almost a straight line. The manufacturer usually specifies the voltage across the zener diode V_Z at a specified test current, I_{ZT}. We have indicated these parameters in Fig. 4.19 as the coordinates of the point labeled Q. Thus a 6.8-V zener diode will exhibit a 6.8-V drop at a specified test current of, say, 10 mA. As the current through the zener deviates from I_{ZT}, the voltage across it will change, though only slightly. Figure 4.19 shows that corresponding to current change ΔI the zener voltage changes by ΔV, which is related to ΔI by

$$\Delta V = r_z \Delta I$$

where r_z is the inverse of the slope of the almost-linear i–v curve at point Q. Resistance r_z is the **incremental resistance** of the zener diode at operating point Q. It is also known as the **dynamic resistance** of the zener, and its value is specified on the device data sheet. Typically, r_z is in the range of a few ohms to a few tens of ohms. Obviously, the lower the value of r_z is, the more constant the zener voltage remains as its current varies, and thus the more ideal its performance becomes in the design of voltage regulators. In this regard, we observe from Fig. 4.19 that while r_z remains low and almost constant over a wide range of current, its value increases considerably in the vicinity of the knee. Therefore, as a general design guideline, one should avoid operating the zener in this low-current region.

Zener diodes are fabricated with voltages V_Z in the range of a few volts to a few hundred volts. In addition to specifying V_Z (at a particular current I_{ZT}), r_z, and I_{ZK}, the manufacturer

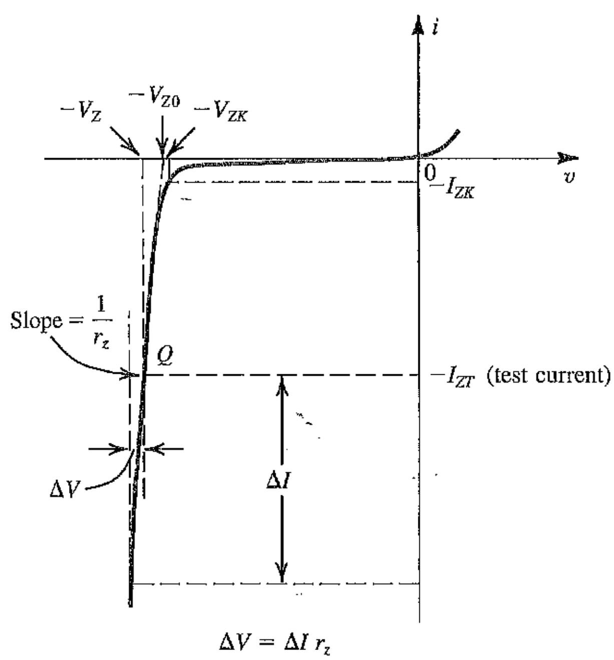

Figure 4.19 The diode i–v characteristic with the breakdown region shown in some detail.

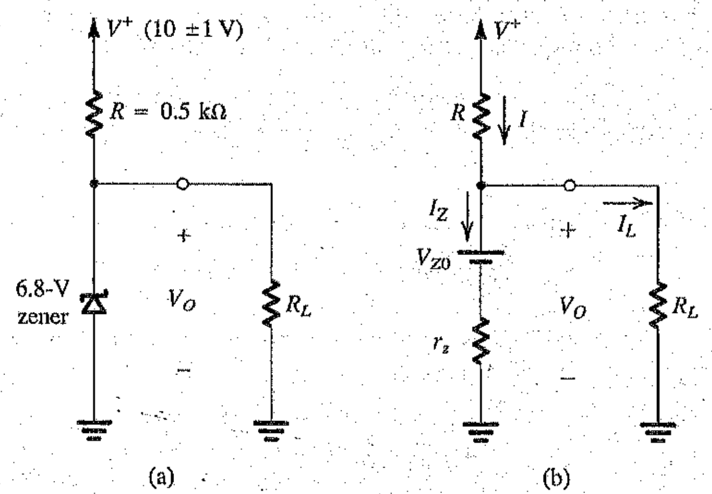

Figure 4.21 (a) Circuit for Example 4.7. (b) The circuit with the zener diode replaced with its equivalent circuit model.

Solution

First we must determine the value of the parameter V_{Z0} of the zener diode model. Substituting $V_Z = 6.8$ V, $I_Z = 5$ mA, and $r_z = 20\ \Omega$ in Eq. (4.20) yields $V_{Z0} = 6.7$ V. Figure 4.21(b) shows the circuit with the zener diode replaced with its model.

(a) With no load connected, the current through the zener is given by

$$I_Z = I = \frac{V^+ - V_{Z0}}{R + r_z}$$

$$= \frac{10 - 6.7}{0.5 + 0.02} = 6.35 \text{ mA}$$

Thus,

$$V_O = V_{Z0} + I_Z r_z$$

$$= 6.7 + 6.35 \times 0.02 = 6.83 \text{ V}$$

(b) For a ±1-V change in V^+, the change in output voltage can be found from

$$\Delta V_O = \Delta V^+ \frac{r_z}{R + r_z}$$

$$= \pm 1 \times \frac{20}{500 + 20} = \pm 38.5 \text{ mV}$$

Thus,

$$\text{Line regulation} = 38.5 \text{ mV/V}$$