Al-Mustaqbal University
College of Engineering and Technologies
Medical Instrumentation Technique Engineering Department
Class: 2nd
Subject: Electronic Circuits
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Lecture: 6- ZENER DIODES

ZENER DIODES

The analysis of networks employing Zener diodes is quite similar to the analysis of semiconductor diodes in previous sections. First the state of the diode must be determined, followed by a substitution of the appropriate model and a determination of the other unknown quantities of the network. **Zener diode can be used to establish reference voltage levels and act as a protection device**. Voltage reference is an electronic device which produces a constant voltage regardless of the loading on the device, temperature changes, passage of time and power supply variations. The voltage reference circuit most commonly used in integrated circuits is the bandgap voltage referenc

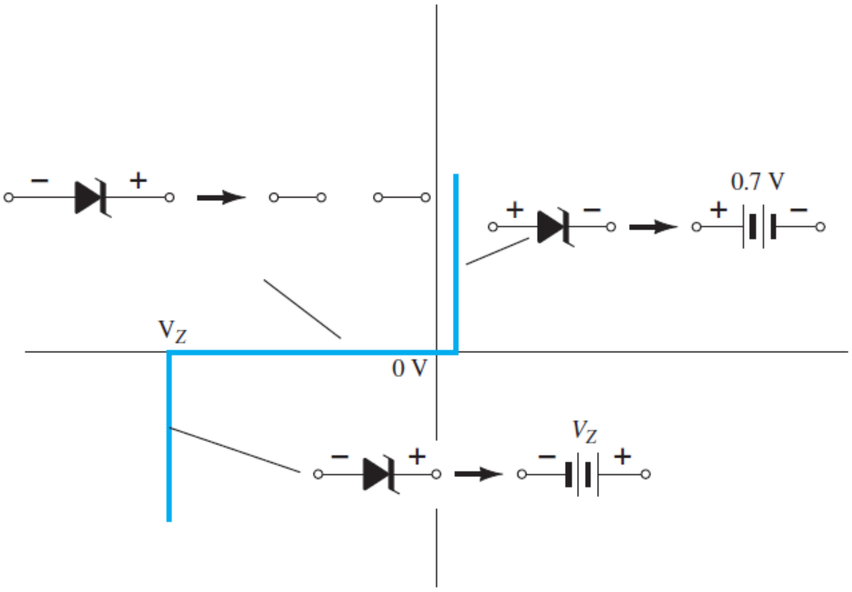

FIG. 2.108

Approximate equivalent circuits for the Zener diode in the three possible regions of application.

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Vi and R Fixed

The simplest of Zener diode regulator networks appears in Fig. 2.112 . The applied dc voltage is fixed, as is the load resistor. The analysis can fundamentally be broken down into **two steps.**

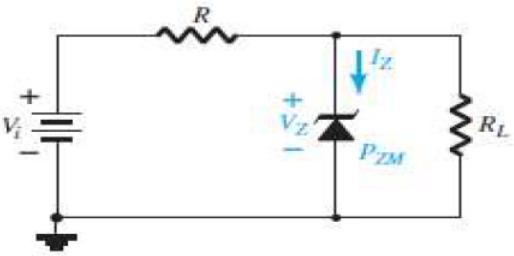

FIG. 2.112
Basic Zener regulator.

Basic Zener regulator.

1. *Determine the state of the Zener diode by removing it from the network and calculating the voltage across the resulting open circuit.*

Applying step 1 to the network of Fig. 2.112 results in the network of Fig. 2.113, where an application of the voltage divider rule results in

$$\boxed{V = V_L = \frac{R_L V_i}{R + R_L}} \qquad (2.16)$$

If $V \geq V_Z$, the Zener diode is on, and the appropriate equivalent model can be substituted. If $V < V_Z$, the diode is off, and the open-circuit equivalence is substituted.

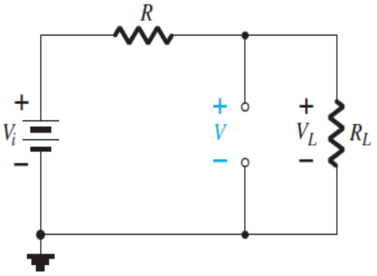

FIG. 2.113
Determining the state of the Zener diode.

2. *Substitute the appropriate equivalent circuit and solve for the desired unknowns.*

For the network of Fig. 2.112, the "on" state will result in the equivalent network of Fig. 2.114. Since voltages across parallel elements must be the same, we find that

$$\boxed{V_L = V_Z} \qquad (2.17)$$

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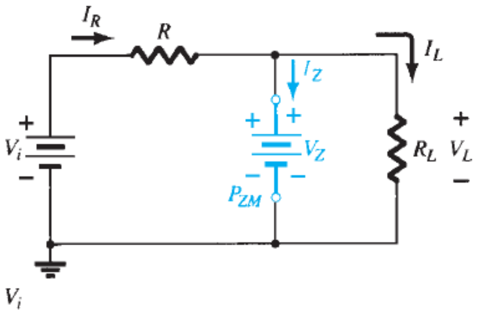

FIG. 2.114
Substituting the Zener equivalent for the "on" situation.

The Zener diode current must be determined by an application of Kirchhoff's current law. That is,

$$I_R = I_Z + I_L$$

and

$$\boxed{I_Z = I_R - I_L} \qquad \textbf{(2.18)}$$

where

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

The power dissipated by the Zener diode is determined by

$$\boxed{P_Z = V_Z I_Z} \qquad \textbf{(2.19)}$$

that must be less than the P_{ZM} specified for the device.

Before continuing, it is particularly important to realize that the first step was employed only to determine the *state of the Zener diode.* If the Zener diode is in the "on" state, the voltage across the diode is not V volts. When the system is turned on, the Zener diode will turn on as soon as the voltage across the Zener diode is V_Z volts. It will then "lock in" at this level and never reach the higher level of V volts.

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EXAMPLE 2.26

a. For the Zener diode network of Fig. 2.115, determine V_L, V_R, I_Z, and P_Z.

b. Repeat part (a) with $R_L = 3\ \text{k}\Omega$.

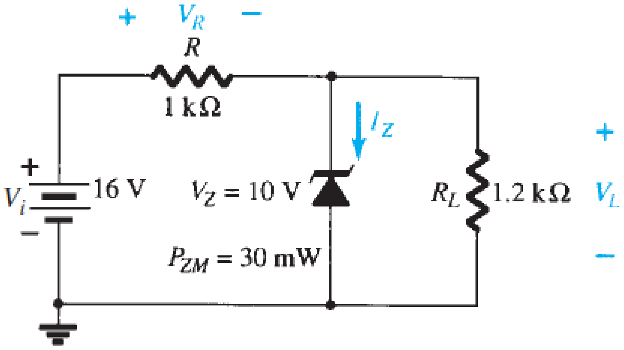

FIG. 2.115

Zener diode regulator for Example 2.26.

Solution:

a. Following the suggested procedure, we redraw the network as shown in Fig. 2.116. Applying Eq. (2.16) gives

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

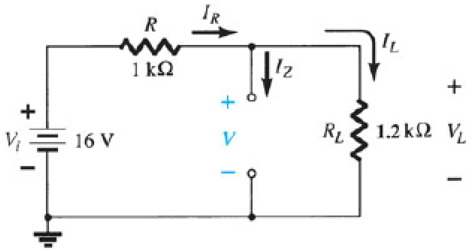

FIG. 2.116
Determining V for the regulator of Fig. 2.115.

Since $V = 8.73$ V is less than $V_Z = 10$ V, the diode is in the “off” state, as shown on the characteristics of Fig. 2.117. Substituting the open-circuit equivalent results in the same network as in Fig. 2.116, where we find that

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

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

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

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

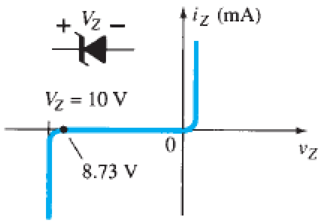

FIG. 2.117
Resulting operating point for the network of Fig. 2.115.

b. Applying Eq. (2.16) results in

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

Since $V = 12$ V is greater than $V_Z = 10$ V, the diode is in the “on” state and the network of Fig. 2.118 results. Applying Eq. (2.17) yields

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

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

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

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

so that
$$\begin{aligned} I_Z &= I_R - I_L \quad [\text{Eq. (2.18)}] \\ &= 6\text{ mA} - 3.33\text{ mA} \\ &= \mathbf{2.67\ mA} \end{aligned}$$

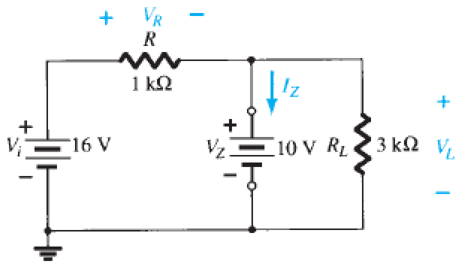

FIG. 2.118
Network of Fig. 2.115 in the “on” state.

The power dissipated is

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

which is less than the specified $P_{ZM} = 30$ mW.

Fixed Vi , Variable R_L

Due to the offset voltage V Z , there is a specific range of resistor values (and therefore load current) that will ensure that the Zener is in the “on” state. Too small a load resistance R L will result in a voltage V L across the load resistor less than V Z , and the Zener device will be in the “off” state.

To determine the minimum load resistance of Fig. 2.112 that will turn the Zener diode on, simply calculate the value of R_L that will result in a load voltage $V_L = V_Z$. That is,

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

Solving for R_L, we have

$$\boxed{R_{L_{\min}} = \frac{R V_Z}{V_i - V_Z}} \qquad \textbf{(2.20)}$$

Any load resistance value greater than the R_L obtained from Eq. (2.20) will ensure that the Zener diode is in the “on” state and the diode can be replaced by its V_Z source equivalent.

The condition defined by Eq. (2.20) establishes the minimum R_L, but in turn specifies the maximum I_L as

$$\boxed{I_{L_{\max}} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L_{\min}}}} \qquad \textbf{(2.21)}$$

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

$$\boxed{V_R = V_i - V_Z} \qquad \textbf{(2.22)}$$

and I_R remains fixed at

$$\boxed{I_R = \frac{V_R}{R}} \qquad \textbf{(2.23)}$$

The Zener current

$$\boxed{I_Z = I_R - I_L} \qquad \textbf{(2.24)}$$

resulting in a minimum I_Z when I_L is a maximum and a maximum I_Z when I_L is a minimum value, since I_R is constant.

Since I_Z is limited to I_{ZM} as provided on the data sheet, it does affect the range of R_L and therefore I_L. Substituting I_{ZM} for I_Z establishes the minimum I_L as

$$\boxed{I_{L_{\min}} = I_R - I_{ZM}} \qquad \textbf{(2.25)}$$

and the maximum load resistance as

$$\boxed{R_{L_{\max}} = \frac{V_Z}{I_{L_{\min}}}} \qquad \textbf{(2.26)}$$

EXAMPLE 2.27

a. For the network of Fig. 2.119, determine the range of R_L and I_L that will result in V_{RL} being maintained at 10 V.

b. Determine the maximum wattage rating of the diode.

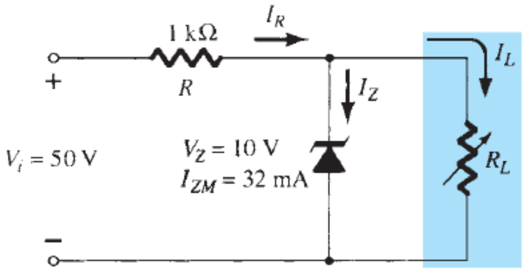

FIG. 2.119

Voltage regulator for Example 2.27.

Solution:

a. To determine the value of R_L that will turn the Zener diode on, apply Eq. (2.20):

$$R_{L_{\min}} = \frac{RV_Z}{V_i - V_Z} = \frac{(1\text{ k}\Omega)(10\text{ V})}{50\text{ V} - 10\text{ V}} = \frac{10\text{ k}\Omega}{40} = \mathbf{250\ \Omega}$$

The voltage across the resistor R is then determined by Eq. (2.22):

$$V_R = V_i - V_Z = 50\text{ V} - 10\text{ V} = \mathbf{40\ V}$$

and Eq. (2.23) provides the magnitude of I_R:

$$I_R = \frac{V_R}{R} = \frac{40\text{ V}}{1\text{ k}\Omega} = \mathbf{40\ mA}$$

The minimum level of I_L is then determined by Eq. (2.25):

$$I_{L_{\min}} = I_R - I_{ZM} = 40\text{ mA} - 32\text{ mA} = \mathbf{8\text{ mA}}$$

with Eq. (2.26) determining the maximum value of R_L:

$$R_{L_{\max}} = \frac{V_Z}{I_{L_{\min}}} = \frac{10\text{ V}}{8\text{ mA}} = \mathbf{1.25\text{ k}\Omega}$$

A plot of V_L versus R_L appears in Fig. 2.120a and for V_L versus I_L in Fig. 2.120b.

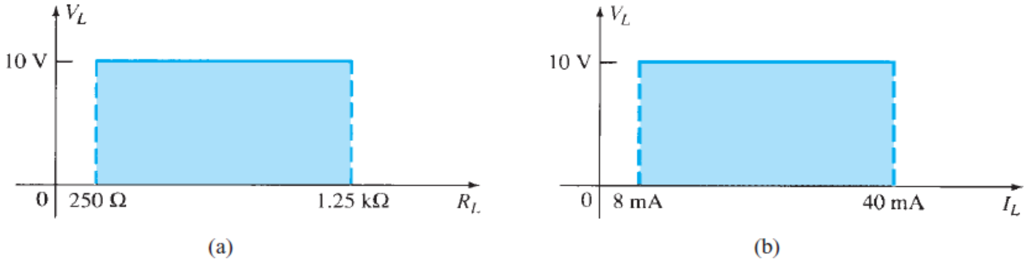

FIG. 2.120

V_L versus R_L and I_L for the regulator of Fig. 2.119.

b. $P_{\max} = V_Z I_{ZM}$
$= (10\text{ V})(32\text{ mA}) = \mathbf{320\text{ mW}}$

Fixed R_L, Variable V_i

For fixed values of R_L in Fig. 2.112, the voltage V_i must be sufficiently large to turn the Zener diode on. The minimum turn-on voltage $V_i = V_{i_{\min}}$ is determined by

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

and

$$\boxed{V_{i_{\min}} = \frac{(R_L + R)V_Z}{R_L}} \qquad \mathbf{(2.27)}$$

The maximum value of V_i is limited by the maximum Zener current I_{ZM}. Since $I_{ZM} = I_R - I_L$,

$$\boxed{I_{R_{\max}} = I_{ZM} + I_L} \qquad \mathbf{(2.28)}$$

Since I_L is fixed at V_Z/R_L and I_{ZM} is the maximum value of I_Z, the maximum V_i is defined by

$$V_{i_{\max}} = V_{R_{\max}} + V_Z$$

$$\boxed{V_{i_{\max}} = I_{R_{\max}}R + V_Z} \qquad \mathbf{(2.29)}$$

EXAMPLE 2.28 Determine the range of values of V_i that will maintain the Zener diode of Fig. 2.121 in the "on" state.

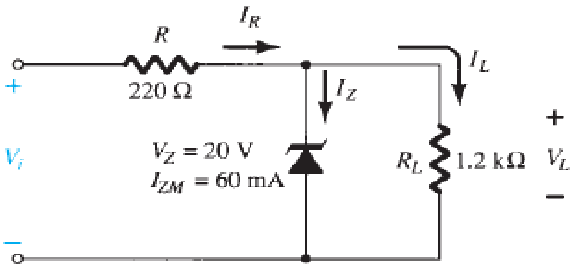

FIG. 2.121
Regulator for Example 2.28.

Solution:

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

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

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

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

A plot of V_L versus V_i is provided in Fig. 2.122.

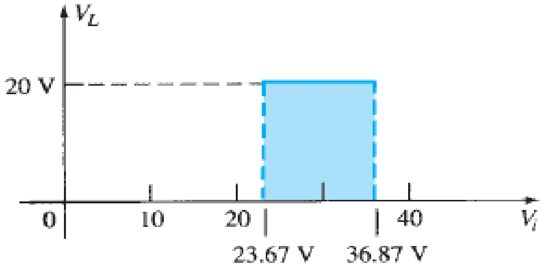

FIG. 2.122
V_L versus V_i for the regulator of Fig. 2.121.

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