Zener Diode

A zener diode is a silicon diode which is capable of operating in the breakdown region unlike PN junction diodes.

1. Introduction

Zener diode finds its applications in voltage regulators, circuits that hold the load voltage almost constant despite large changes in *line voltage* and *load resistance*. The circuit symbol of a zener diode is shown in Fig 9.1

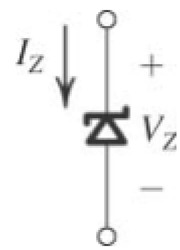


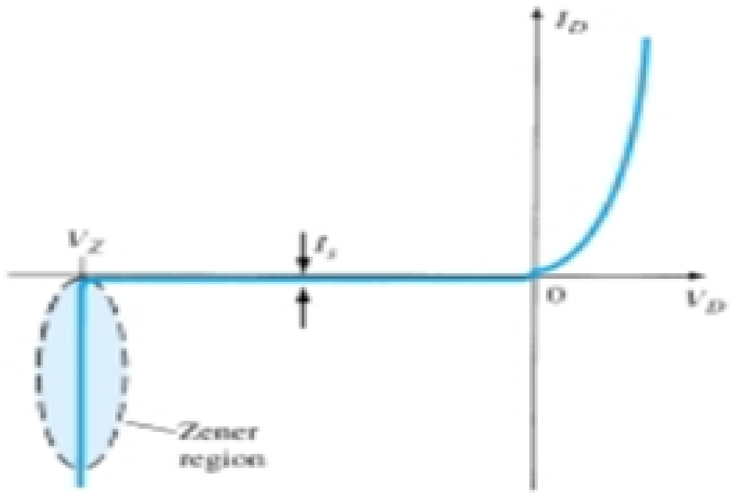
Fig 9.1 Symbol of a Zener Diode

The line in the symbol resembles a 'z' which stands for zener. By varying the doping level of silicon diodes, zener diodes with breakdown voltages from about 2V to 1000 V can be manufactured.

2. V-I Characteristics

Zener diodes operate in any of the three regions namely as shown in Fig 9.2:

- *Forward region*. It starts conducting around 0.7V (for Si and 0.3V for Ge) similar to a silicon diode.
- *Leakage region*. This is the region between zero and breakdown. It has only a small reverse current this is due to the minority carriers present in the diode.
- *Breakdown region*. This region is also called as Zener region. The presence of Zener region in the VI characteristics of a zener diode makes it possible to operate the zener in the breakdown which leads to applications of zener in the design of voltage regulators.



3. How Zener Region is formed?

In a zener diode, the breakdown has a very sharp knee, followed by an almost vertical increase in current. The current increases at a very rapid rate in a direction opposite to that of the positive voltage region. The reverse-bias potential that results in this dramatic change in characteristics is called the Zener Potential and is given the symbol V_Z.

Method 1:

- As the voltage across the diode increases in the reverse-bias region, the *velocity* of the minority carriers responsible for the reverse saturation current I_s will also increase.
- An ionization process will result whereby valence electrons absorb sufficient energy to leave the parent atom.
- These additional carriers can then aid the ionization process to the point where a high avalanche current is established and results in the avalanche breakdown region.
- This region can be brought closer to the vertical axis by increasing the doping levels in the p- and n- type materials.
- An increase in the doping, producing an increase in the number of added impurities, will decrease the Zener potential.

Method 2:

- As Vz decreases to very low levels, such as (-5V), another mechanism, called *Zener breakdown*, will contribute to the sharp change in the characteristic. It occurs because there is a strong *electric field* in the region of the junction that can disrupt the bonding forces within the atom and "generate" carriers.
- Zener breakdown is significant only at lower levels of V_Z.

"The maximum reverse-bias potential that can be applied before entering the Zener region is called the *peak inverse voltage* (referred to simply as the PIV rating) or the *peak reverse voltage* (denoted by PRV rating)."

Zener diodes are available having Zener potentials of 1.8 to 200 V with power ratings from 1/4 to 50 W.

4. **Equivalent Circuit**

   The complete and the approximate equivalent circuits in the zener region are shown in Fig 9.3a and 3b respectively.

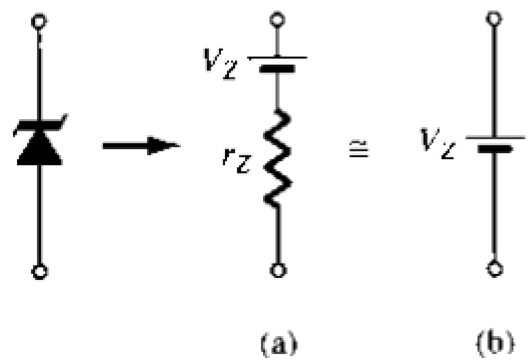


Fig 9.3. Zener Equivalent circuit a) Complete b) Approximate

In forward region,

Forward voltage across a diode = Knee voltage + Voltage across the bulk resistance.

In breakdown region,

Reverse voltage across the diode = Breakdown voltage + Voltage across the zener resistance

More vertical the breakdown region, smaller the value of zener resistance.

Analysis of Zener Diode

For analysing a circuit with a zener diode, 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 equivalents for ON and OFF states are shown in Fig 9.4a and Fig 9.4b respectively.

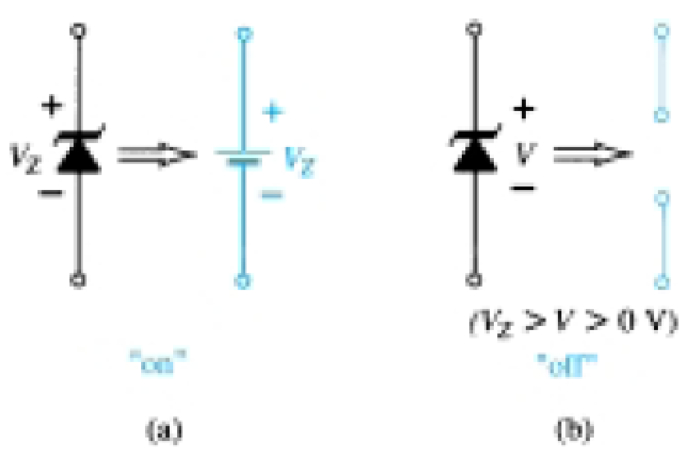


Fig 9.4. Zener diode equivalents: (a) ON (b) OFF

5. Zener Diode as a Regulator

Zener Diodes can be used to produce a stabilized voltage output with *low ripple* under varying load current conditions. By passing a small current through the diode from a voltage source, via a suitable *current limiting resistor* (R_S), the zener diode will conduct sufficient current to maintain a voltage drop of Vout.

- The DC output voltage from the half or full-wave rectifiers contains ripple superimposed onto the DC voltage and that as the load value changes so too does the average output voltage.
- By connecting a simple zener stabilizer circuit as shown below across the output of the rectifier, a more stable output voltage can be produced.

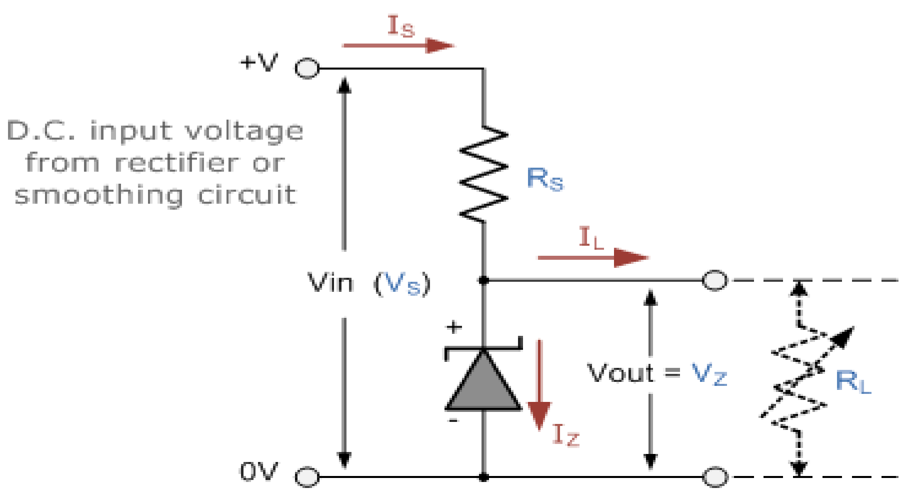


Fig 10.1. Zener Diode Regulator

The resistor, R_S is connected in series with the zener diode to limit the current flow through the diode with the voltage source, V_S being connected across the combination. The stabilized output voltage V_{out} is taken from across the zener diode. The zener diode is connected with its cathode terminal connected to the positive rail of the DC supply so it is reverse biased and will be operating in its breakdown condition. Resistor R_S is selected so to limit the maximum current flowing in the circuit.

With no load connected to the circuit, the load current will be zero, ($I_L = 0$), and all the circuit current passes through the zener diode which in turn dissipates its maximum power. Also a small value of the series resistor R_S will result in a greater diode current when the load resistance R_L is connected and large as this will increase the power dissipation requirement of the diode so care must be taken when selecting the appropriate value of series resistance so that the zener's maximum power rating is not exceeded under this no-load or high-impedance condition.

The load is connected in parallel with the zener diode, so the voltage across R_L is always the same as the zener voltage, ($V_R = V_Z$). There is a minimum zener current for which the stabilization of the voltage is effective and the zener current must stay above this value operating under load within its breakdown region at all times. The upper limit of current is of course dependent upon the power rating of the device. The supply voltage V_S must be greater than V_Z.

One small problem with zener diode stabilizer circuits is that the diode can sometimes generate electrical noise on top of the DC supply as it tries to stabilize the voltage. Normally this is not a problem for most applications but the addition of a large value decoupling capacitor across the zener's output may be required to give additional smoothing.

A zener diode is always operated in its reverse biased condition. A voltage regulator circuit can be designed using a zener diode to maintain a constant DC output voltage across the load in spite of variations in the input voltage or changes in the load current. The zener voltage regulator consists of a current limiting resistor R_S connected in series with the input voltage V_S with the zener diode connected in parallel with the load R_L in this reverse biased condition. The stabilized output voltage is always selected to be the same as the breakdown voltage V_Z of the diode.

Zener Diode Voltages

As well as producing a single stabilized voltage output, zener diodes can also be connected together in series along with normal silicon signal diodes to produce a variety of different reference voltage output values as shown below.

Zener Diodes Connected in Series

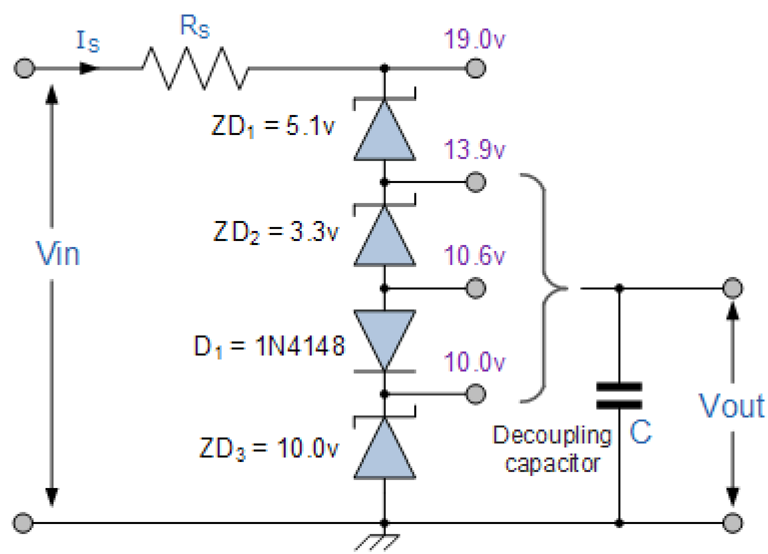


Fig 10.2

The values of the individual Zener diodes can be chosen to suit the application while the silicon diode will always drop about 0.6 – 0.7V in the forward bias condition. The supply voltage, Vin must of course be higher than the largest output reference voltage and in our example above this is 19v.

Design of Regulator

When selecting the zener diode, be sure that its maximum power rating is not exceeded.

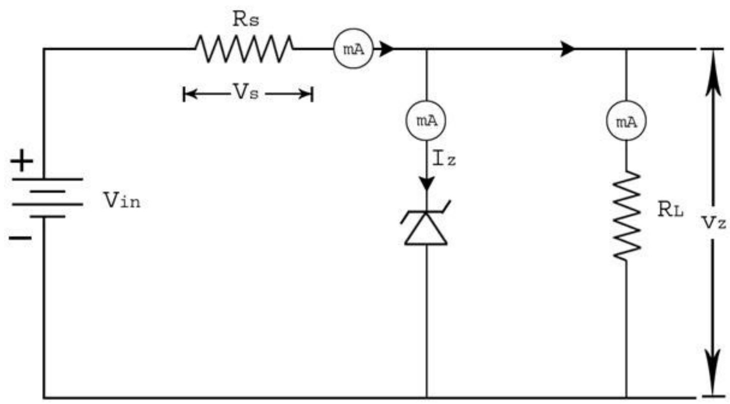


Fig 11.1

$$I_{Max} = \frac{Power}{ZenerVoltage}$$

I_{MAX}-Maximum current for zener diode
V_Z- Zener diode standard voltage
V_{in} - Input voltage (it is known)
V_s - Voltage across series resistance
V_L - Voltage across the load resistance
I_S - Current passing through the series resistance
I_Z - Current passing through the Zener diode
I_L- Current passing through the load resistance

Calculating voltage and current

The total current drawn from the source is the same as that through the series resistor

$$I_S = \frac{V_S}{R_S}$$

The current through the load resistor is

$$I_L = \frac{V_L}{R_L}$$

And the zener diode current is

$$I_Z = I_S - I_L$$

If the voltage source is greater than Vz

$$V_S = V_{IN} - V_L \qquad \text{and} \qquad V_L = V_Z$$

If the voltage source is less than Vz, voltage division rule

$$V_S = \frac{R_S * V_{IN}}{(R_S + R_L)} \qquad \text{and} \qquad V_L = \frac{R_L * V_{IN}}{(R_S + R_L)}$$

Matching the Zener Diode and Resistor to the Situation

Here is a hand-worked example which shows how to choose the correct zener diode and resistor for a known load: we have an unstable 12 Volt supply voltage and need a stable output of 8 Volts to power a 100mA device. 12 volts is sufficiently above 8 volts to ensure that any ripples in the supply will not take us below our target voltage.

1. **Choose a Zener Diode:**

Since we need 8 Volts we can choose between a 7.5V or an 8.2V **zener diode**. 8.2V is close enough to our target voltage so we choose a zener diode with an 8.2 Volt **zener voltage**.

2. **Calculate the Maximum Current in the Circuit:**

Our load device needs 100mA of current, plus we also need at least 5mA for the zener diode, therefore let's set Imax as 110mA to be safe. If you add 10-20% to the load current, this will give you a safe value for the maximum current in the circuit as long as the input voltage is unlikely to jump much *higher*.

3. **Select the Power Rating of the Zener Diode:**

Zener diodes are available in a range of difference power ratings. If a *large current* flows through a *small zener* diode it will be destroyed, therefore we calculate the power to be lost in the diode and select a diode rated above that value. Here the zener power rating is equal to the zener voltage multiplied by the maximum current (Imax) calculated above which equals 8.2 * 0.110 = 0.9 Watts. Therefore a 1.3 Watt power rated zener diode should be perfect.

We multiply the full maximum current by the zener voltage since when no current is flowing through the load - e.g. when the device is switched off - all of the current will flow through the zener diode.

4. **Select the Resistor:**

The voltage dropped across the resistor is equal to the difference between the source voltage and the zener voltage = 12-8 = 4 Volts, and therefore the resistance according to Ohm's Law is the voltage drop divided by I*max* = 4/0.110 = 36 Ohms so choose a 39 Ohm resistor.

If the source voltage is likely to be much over the 12 Volts stated then the voltage dropped across the resistor will be larger and so a resistor with a larger resistance may be required.

5. Select the Power Rating of the Resistor:

The power dissipated in the resistor is equal to the voltage drop across the resistor multiplied by Imax. Therefore in this example power = 4 * 0.110 = 0.440 Watts. Using a 0.5 Watt resistor would be cutting it a bit fine - particularly if the source voltage is going to fluctuate higher regularly, therefore a 1 or 2 Watt rated **resistor** should be used here despite it costing a few pennies extra.

Example Problems

1.A 5.0V stabilised power supply is required to be produced from a 12V DC power supply input source. The maximum power rating P_Z of the zener diode is 2W. Using the zener regulator circuit above calculate: [REF: http://www.electronics-tutorials.ws/diode/diode_7.html]

a). The maximum current flowing through the zener diode.

$$MaximumCurrent = \frac{ZenerPower}{ZenerBDVoltage} = \frac{2W}{5V} = 400mA$$

b). The minimum value of the series resistor, R_S

$$R_S = \frac{V_S - V_Z}{I_Z} = \frac{12-5}{400mA} = 17.5\Omega$$

c). The load current I_L if a load resistor of 1kΩ is connected across the zener diode.

$$I_L = \frac{V_Z}{R_L} = \frac{5V}{1000\Omega} = 5mA$$

d). The zener current I_Z at full load.

$$I_Z = I_S - I_L = 400mA - 5mA = 395mA$$

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Addepalli Satya Hemanth - [...

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Akshara S Nair - [CB.EN.U4C...

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B Balanisha - [CB.EN.U4CSE194...

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GD Gokuldas D - [CB.EN.U4CSE194... •••

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HV Harsha Vardhan V - [CB.EN....

KR Kaaviya Ramesh - [CB.EN.U4...

KM Karan M - [CB.EN.U4CSE19428] •••

KV Kocherla Vaishnavi - [CB.EN....

KK Kolagani Venkata Sai Pavan ...

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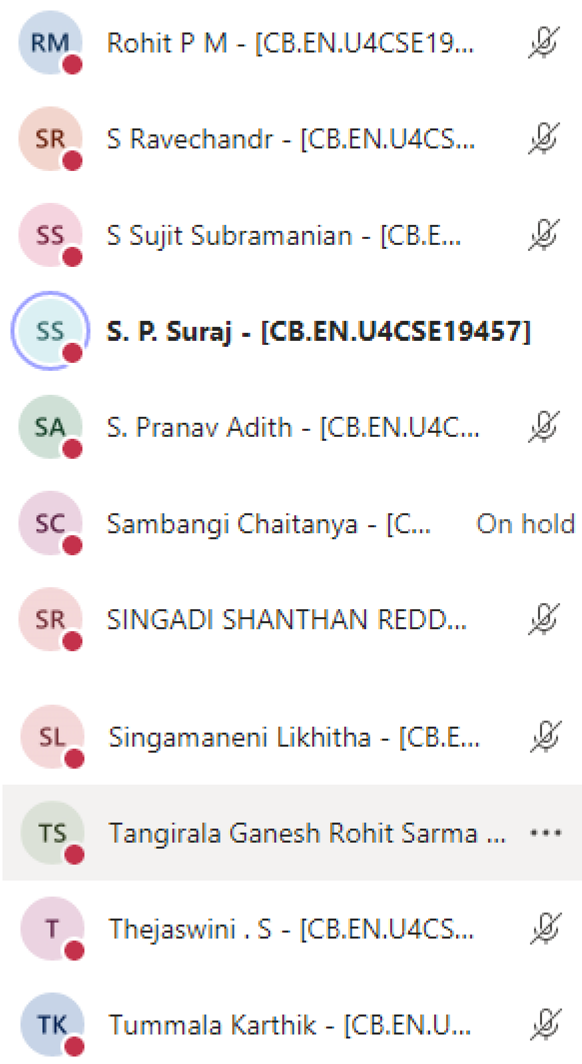
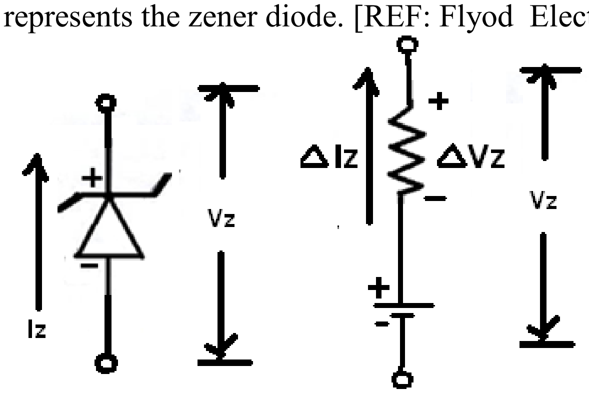


2.A 1N4736A zener diode has a Z_Z of 3.5Ω. The datasheet gives $V_Z = 6.8$ V at a test current, I_Z, of 37 mA. What is the voltage across the zener terminals when the current is 50 mA? When the current is 25 mA? Figure represents the zener diode. [REF: Flyod Electronic Devices page 119]



For I_Z = 50 mA: The 50 mA current is a 13 mA increase above the test current, I_Z, of 37 mA.

$$\Delta I_Z = I_Z - 37mA = 50mA - 37mA = +13mA$$

$$\Delta V_Z = \Delta I_Z Z_Z = (13mA) * (3.5\Omega) = +45.5mV$$

The change in voltage due to the increase in current above the I_Z value causes the zener terminal voltage to increase. The zener voltage for I_Z = 50 mA is

$$V_Z = 6.8V + \Delta V_Z = 6.8V + 45.5mV = 6.85V$$

For I_Z = 25 mA: The 25 mA current is a 12 mA decrease below the test current, IZ, of 37 mA.

$$\Delta I_Z = -12mA$$

$$\Delta V_Z = \Delta I_Z Z_Z = (-12mA) * (3.5\Omega) = -42mV$$

The change in voltage due to the decrease in current below the test current causes the

Zener terminal voltage to decrease. The zener voltage for I_Z = 25 mA is

$$V_Z = 6.8V - \Delta V_Z = 6.8V - 42mV = 6.76V\ .$$

3.A zener regulator has V_Z = 15V. The input voltage may vary from 22 V to 40 V and load current from 20 mA to 100 mA. To hold load voltage constant under all conditions, what should be the value of series resistance?

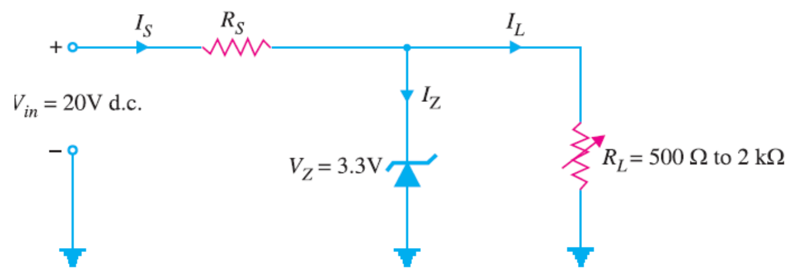
[REF:http://www.talkingelectronics.com/Download%20eBooks/Principles%20of%20electronics/CH-17.pdf]

In order that zener regulator may hold output voltage constant under all operating conditions, it must operate in the breakdown region. In other words, there must be zener current for all input voltages and load currents. The worst case occurs when the input voltage is minimum and load current is maximum because then zener current drops to a minimum.

$$R_{S(\max)} = \frac{V_{in} - V_{Out}}{I_{L(Max)}} = \frac{22-15}{0.1} = \frac{7V}{0.1A} = 70\Omega$$

4.Determine the minimum acceptable value of R_S for the zener voltage regulator circuit shown in Fig. The zener specifications are: V_Z=3.3V, I_Z(min) = 3mA, $I_{Z(max)}$ =100mA.

[REF:http://www.talkingelectronics.com/Download%20eBooks/Principles%20of%20electronics/CH-17.pdf]



When load R_L goes open (*i.e.* $R_L \rightarrow \infty$), the entire line current I_S will flow through the zener and the value of R_S should be such to prevent line current I_S from exceeding $I_{Z(max)}$ if the load opens.

$$R_{S(\min)} = \frac{V_{in} - V_Z}{I_{Z(\max)}} = \frac{20V - 3.3V}{100mA} = 167\Omega$$

5. Determine the maximum allowable value of R_S for the zener voltage regulator circuit shown in Fig above in problem 4.
[REF:http://www.talkingelectronics.com/Download%20eBooks/Principles%20of%20electronics/CH-17.pdf]

The maximum value of R_S is limited by the total current requirements in the circuit. The value of R_S must be such so as to allow I_Z (min) to flow through the zener diode when the load is drawing maximum current.

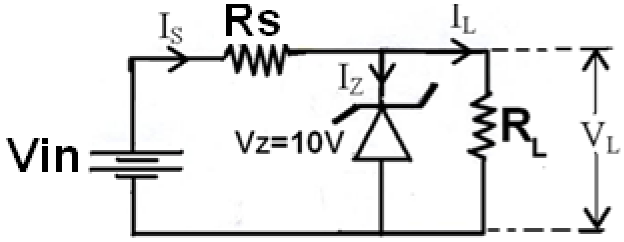
$$R_{S(\max)} = \frac{V_{in} - V_Z}{I_{L(\max)} + I_{Z(\min)}}$$

$$I_{L(\max)} = \frac{V_Z}{R_{L(\min)}} = \frac{3.3V}{500\Omega} = 6.6mA$$

$$R_{S(\max)} = \frac{20V - 3.3V}{6.6mA + 3mA} = \frac{16.7V}{9.6mA} = 1739\Omega$$

__Tutorial Problem__

1.(a)Determine V_L, I_L, I_Z, Is for the network in figure if R_L=100Ω, R_S=100Ω, Vin=30V, P_{Zmax}=200mW.



Solution

$$V_{TH} = V_{IN} * \frac{R_S}{R_S + R_L} = 30 * \frac{100}{100+100} = 15V$$

So it's in breakdown region.

$$V_Z = V_L = 10V$$

$$I_L = \frac{V_L}{R_L} = \frac{10}{100} = 0.1A$$

$$I_S = \frac{30-10}{100} = 0.2A$$

$$I_Z = I_S - I_L = 0.1A$$

Example Problems

1. (a) For the Zener diode network of Fig.a, determine V_L, V_R, I_Z, and P_Z.
(b) Repeat part (a) with R_L = 3 kΩ.

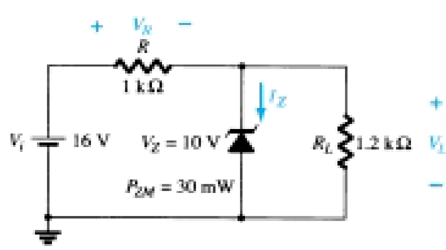


Fig a

Solution:

(a) Following the suggested procedure the network is redrawn as shown in Fig.a. Solving we get $V = R_L V_i / R + R_L$ = 1.2kΩ (16V) / 1KΩ+1.2KΩ = 8.73V

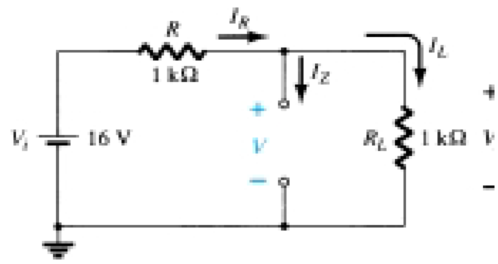


Fig b

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. a. Substituting the open-circuit equivalent will result in the same network as in Fig. b, where we find that

$V_L = V =$ **8.73 V**

$V_R = Vi - V_L = 16\text{ V} - 8.73\text{ V} =$ **7.27 V**

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

(b) Applying the equation we get $V = R_L V_i / R + R_L = 3k\Omega\,(16V) / 1K\Omega + 3K\Omega = 12V$

Since $V = 12$ V is greater than $V_Z = 10$ V, the diode is in the **"on"** state and the network of Fig. b will result. Applying Eq. will yield

$V_L = V_Z =$ **10 V**

$V_R = Vi - V_L = 16\text{ V} - 10\text{ V} =$ **6 V**

$I_L = V_L / R_L = 10V / 3K\Omega = 3.33$ mA

And $I_R = V_R / R = 6V / 1K\Omega = 6$ mA

$I_Z = I_R - I_L = 6\text{ mA} - 3.33\text{mA} = 2.67\text{mA}$

The power dissipated, $P_Z = V_Z I_Z = (10\text{ V})(2.67\text{ mA}) =$ **26.7 mW** which is less than the specified $P_{ZM} = 30$ mW.

2. Determine the range of values of V_i that will maintain the Zener diode of Fig. C in the "on" state.

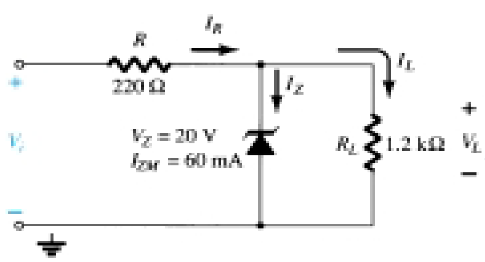


Fig C

Solution

$V_{I\ min} = (R_L + R)V_Z / R_L = (1200\Omega + 220\Omega)(20V) / 1200\Omega = 23.67V$

$I_L = V_L / R_L = V_Z / R_L = 20V / 1.2K\Omega = 16.67mA$

$I_{Rmax} = I_{ZM} + I_L = 60mA + 16.67mA = 76.67mA$

$V_{I\ max} = I_{Rmax}\, R + V_Z = (76.67mA * 0.22k\Omega) + 20V = 36.87V$

A plot of V_L Versus V_i is shown.