Unit 29 Zener diodes

- Increased dopant concentrations in pn diodes reduce the reverse breakdown voltage.
- The avalanche effect dominates at large voltages. The Zener effect dominates at low voltages. The name Zener diode is used for a diode which breaks down in reverse bias due to either mechanism.
- Zener diodes are normally used in reverse bias.
- A Zener diode conducts in reverse bias when the voltage is greater than the Zener voltage for the diode.
- In a circuit the maximum temperature stability is obtained by using Zener diodes rated at about 6 volts.

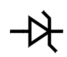

Figure 29.1: Circuit symbol for a Zener diode.

If the reverse voltage across a diode is increased to large values, a voltage called the peak inverse voltage (PIV) is reached when the diode starts to conduct in the reverse direction. A typical diode such as the 1N4005 has a PIV of 600 V. This reverse conduction can cause destruction of the diode, if there is no external resistance in series with the diode to limit the current. The diode current multiplied by the voltage across the diode, $I \times V$, gives the power dissipated within the diode which causes heating and can melt and destroy the diode.

When the current is limited, removal of the large voltage allows the diode to recover fully from the breakdown. In choosing a diode for a particular application, it is important to select a diode having a PIV which is greater than the maximum reverse voltage which will ever appear across the diode in normal use and to use a safety factor of about 1.5 or more.

The voltage at which this reverse breakdown occurs can be decreased from about 1000 V in a rectifying diode down to about 3 V by increasing the dopant concentrations in the p-type and n-type regions of the diode during manufacture. The name Zener diode is used for diodes in which the reverse breakdown occurs at low voltages and Zener diodes are available having design reverse breakdown voltage or Zener voltage values extending from 2.7 V up to about 100 V. In forward bias, Zener diodes behave similarly to normal diodes. The characteristic curves of three Zener diodes are shown in Figure 29.2.

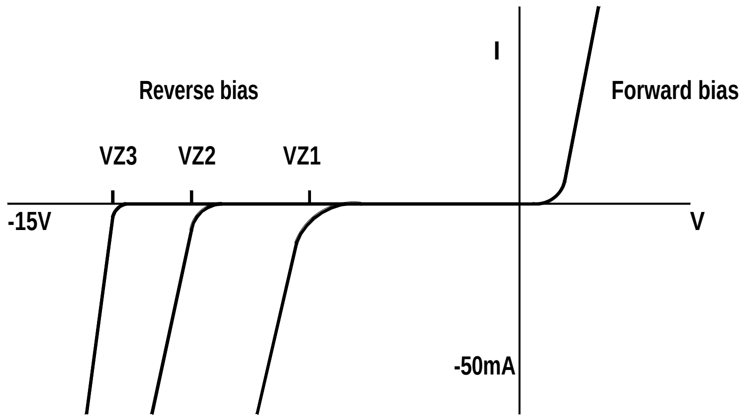

Figure 29.2: Zener diode characteristic curves.

The Zener voltage is the reverse bias voltage at which the current increases rapidly for a very small change of the reverse voltage. In the diagram $|VZ1| < |VZ2| < |VZ3|$, so the convention is to use the magnitude of the Zener voltage in specifying Zener diodes.

Two mechanisms are involved in the reverse breakdown in Zener diodes:

- For voltages greater than about 6 volts, the avalanche effect dominates. A minority carrier is accelerated across the reverse biased junction and gains enough energy to generate electron-hole pairs which themselves generate more pairs leading to a rapid increase in reverse current.

- For voltages below 6 V, the Zener effect dominates. This mechanism is due to quantum mechanical tunnelling of valence or bound electrons to nearby sites in the conduction band on the other side of the junction.

This implies that the junction must be very thin when it is reverse biased because the tunnelling current decreases exponentially with distance. The requirement of a thin junction then implies that the dopant levels in the p-type and n-type regions are very high in order to keep the depletion layer thin when the reverse bias is applied.

The name, Zener diode, is applied to a diode which is designed to exhibit breakdown at a specific voltage irrespective of which mechanism is dominant.

As the dopant concentrations in a diode are increased, the diode progresses from a normal diode with a large reverse breakdown voltage to a Zener diode with a low reverse breakdown voltage.

Two other features are worth noting in Figure 29.2.

- The sharpness of the onset of breakdown increases with increasing breakdown voltage.
- The slope of the I–V characteristic changes with breakdown voltage.

The temperature coefficient of the breakdown voltage is negative for the Zener mechanism and positive for the avalanche mechanism. The change over between the two mechanisms is at about 6 V at which voltage the temperature coefficient is nearly zero. If a Zener diode is to be used as a voltage reference device, the maximum temperature stability is achieved by using a Zener diode having a breakdown voltage in the region of 6 V where the temperature coefficient of Zener voltage is near zero.

29.1 Examples

29.1 The circuit shown in Figure 29.3 is a Zener diode voltage regulator. Calculate the maximum current which can be drawn by a load connected to the output before the output voltage drops below 8.2 V.

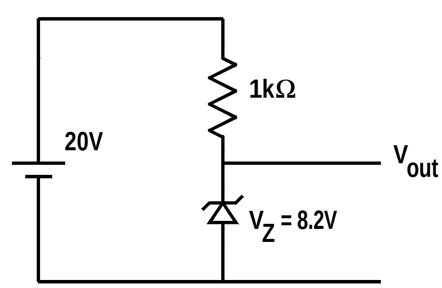

Figure 29.3: Example 29.1.

The positive voltage is applied to the cathode and therefore the diode is reverse biased and has a nominal voltage of 8.2 V across it. (Zener diodes come in the same ±10% tolerances as resistors and capacitors.) Therefore the V_{out} will be 8.2 V. The current in the 1 kΩ resistor is $\frac{20-8.2}{1\,\text{k}\Omega} = 11.8\,\text{mA}$. This 11.8 mA also flows in the Zener diode.

If some external load which draws current is connected to the output then some of this current is diverted into the external load but the output voltage remains constant at 8.2 V as long as some current flows in the reverse biased Zener diode. Therefore, as long as the output current does not exceed 11.8 mA the output voltage remains at 8.2 V. It would be better to allow a margin of safety and not allow the external load to draw more than 8 mA.

29.2 Calculate the maximum current which can be drawn from the power supply shown in Figure 29.4 without causing the output voltage to drop below 6.8 V. Calculate the minimum required power rating for the Zener diode.

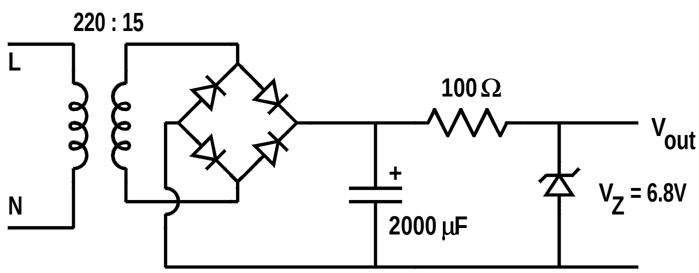

Figure 29.4: Example 29.2.

The mains supply voltage is a nominal 220 V. At times of peak load on the system the actual voltage may drop well below this value. This is sometimes called brown-out. Late at night, the voltage may increase above this nominal value. The smoothed output voltage from the rectifier will change in proportion to these mains voltage fluctuations. There will also be fluctuations due to the ripple voltage which depends on the current drawn. A resistor and Zener diode give a simple method of regulating the voltage for small output currents.

The nominal voltage across the 2000 μF capacitor is approximately 19 V (see Example 28.3) which gives a current in the 100 Ω resistor of $\frac{19-6.8}{100} = 0.12$ A. This is, in principle, the maximum regulated current available.

But the mains voltage may drop by 10% to 200 V which gives 17 V across the capacitor. Allow a 1.5 V ripple to give a worst case of 15.5 V across the capacitor. This gives a current in the 100 Ω of $\frac{15.5-6.8}{100} =$ 0.09 A which is a more conservative estimate of the maximum current which can be drawn without loss of voltage regulation.

Refer back to the Zener diode characteristics in Figure 29.2. The voltage across the Zener diode changes with the current through the diode. This will also cause a change in the output voltage as the fraction of the total current flowing through the diode changes due to a change from no load current to maximum load current.

You should note that there are integrated circuit regulators available which give better stability and greater output current capacity than the simple Zener diode regulator shown here. These regulators do, however, incorporate a reference Zener in a circuit similar to the one discussed here.

29.3 Calculate the voltages at the points A, B and C in the circuit shown in Figure 29.5.

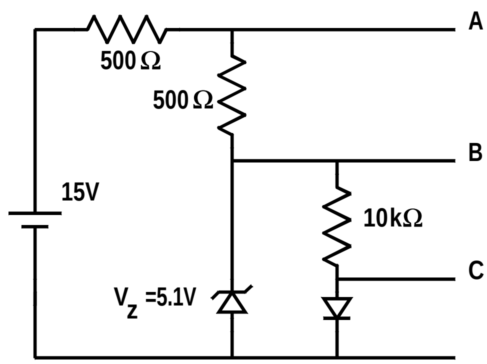

Figure 29.5: Example 29.3.

The diode is forward biased, therefore the voltage at C is 0.7 V.
The Zener diode is reverse biased, therefore the voltage at B is 5.1 V.
The two 500 Ω resistors form a potential divider between 15 V and 5.1 V.
The current in the resistors is $\frac{15-5.1}{500+500} = 9.9\,\text{mA}$.
The voltage at A is therefore $9.9\,\text{mA} \times 500\,\Omega + 5.1\,\text{V} = 10.05\,\text{V}$.
Alternatively, the voltage at A is $15\,\text{V} - 9.9\,\text{mA} \times 500\,\Omega = 10.05\,\text{V}$ as before.

29.2 Problems

29.1 Calculate the voltages at points A, B and C in the circuit shown in Figure 29.6.

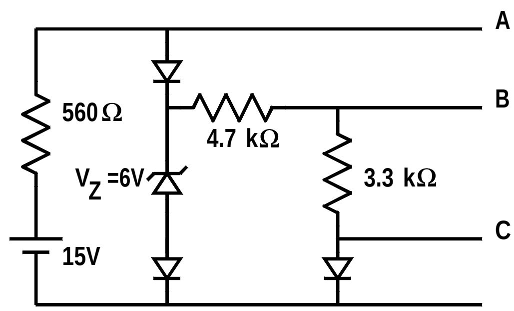

Figure 29.6: Problem 29.1.

29.2 Calculate the Thévenin equivalent for the circuit shown in Figure 29.7.

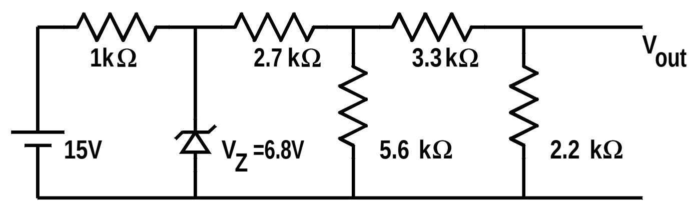

Figure 29.7: Problem 29.2.

29.3 Plot a graph of the output voltage from the circuit shown in Figure 29.8 for an input voltage which is varied from $-30\,\text{V}$ to $+30\,\text{V}$.

(Circuits similar to this are used in Zener barriers to limit the voltages and currents on instrumentation wires leading to hazardous areas in chemical plants where flammable gases may be present. The energy in any spark which may occur due to a fault will then be limited to an energy value below that which can cause ignition of the flammable gases which are likely to be present in the plant. Nonreplaceable fuses are also included which isolate the system in the event of a fault.)

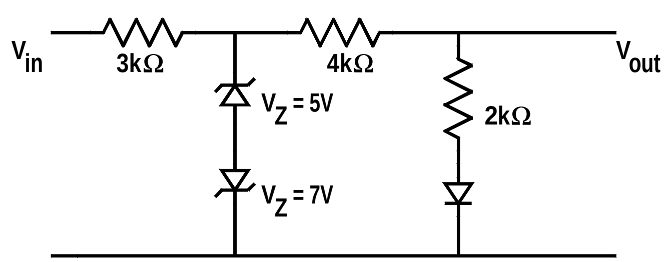

Figure 29.8: Problem 29.3.