Diodes

1.0 Diodes

So far, we have looked at how resistors operate. Resistors are special in the sense that they are a linear circuit element: if you plot the voltage across a resistor as a function of the current flowing through it, you get a straight line whose slope is equal to the resistance of the resistor.

One circuit element that has a very non-linear current-voltage relationship is a diode. A diode is the electrical equivalent of a mechanical valve: under certain conditions, it allows current to flow in one direction, but always (unless it is a special type of diode) prevents current from flowing in the opposite direction. The circuit symbol for the diode is shown in Figure 1. In practice the cathode of a diode is usually marked with a stripe.

Diodes are semiconductors, and their operation is covered in great detail in more advanced electrical engineering courses (or you can look this up in textbooks or on the Internet). Here we concern ourselves with a simple, practical model of diode operation (known as the constant voltage drop model) that can be used to explain its behaviour in practice. This model describes the diode as an ideal voltage source whenever the voltage applied to the diode $V_D$ is greater than the ‘turn-on voltage’ $V_{on}$, and an open circuit whenever $V_D$ is less than the turn-on voltage. Practical diodes have a turn-on voltage around 0.6 to 0.7 V. The current/voltage relationship of the diode is shown in Figure 2.

Consider Figure 3. When $V_{in} > V_{on}$, the diode is said to be forward-biased. In this mode, it conducts current, operating like an ideal voltage source with voltage $V_{on}$. When $V_{in} < V_{on}$, the diode is said to be reverse-biased. In this mode, the diode does not conduct current, operating like an open circuit.
For $V_{in} < V_{on}$, the diode acts as an open circuit. Since no current flows through the circuit, $V = 0$.

For $V_{in} > V_{on}$, the diode has a voltage of $V_D = V_{on}$ across it, so that $V = V_{in} - V_{on}$. The current is determined as $I = \frac{V}{R} = \frac{V_{in} - V_{on}}{R}$.

Note that the above analysis, for a circuit containing a diode, is very different to the analysis used in purely resistive circuits. Clearly there is a different type of analysis required depending on whether the diode is forward or reverse-biased. Thus it is very important to determine whether a diode is forward or reverse-biased when attempting to analyse, test or debug a circuit.

Diodes are used in a wide range of applications, and for a number of different purposes. Example applications include protection, i.e. ensuring that current only flows in a single direction, to protect sensitive components; rectification, e.g. converting AC voltages to DC voltages; peak detection etc.

### 2.0 Zener Diodes

A Zener diode (Figure 4) is a type of diode you may come across that has the same forward-biased operation as described in section 1, but different reverse-biased operation.

Zener diodes have a property, known as reverse breakdown, in which they act similarly to a voltage source when they are reverse-biased with voltage greater than $V_Z$, the Zener voltage. A typical practical value is $V_Z = 5.6$ V. This gives the current-voltage relationship seen in Figure 5.
Zener diodes are widely used in voltage regulation or as a voltage reference, where they can be used to maintain a constant voltage given an input voltage supply that may vary with time. They are also very handy for stepping down voltages for use with integrated circuits, for example stepping down a 6V battery supply to a 5V supply for logic circuits (better still is a voltage regulator, like the 7805 integrated circuit). In Figure 6, for example, as long as $V_{in} > V_Z$, $V = V_Z$.

To analyse the circuit in Figure 6, consider the three different possible modes of operation:

$V_{in} > V_Z$: The diode operates in the reverse breakdown region, so $V = V_Z$, $I = \frac{V_{in} - V_Z}{R}$

and $I_L = \frac{V_Z}{R_L}$

$-V_{on} < V_{in} < V_Z$: The diode conducts no current, i.e. acts as an open circuit, so $I = I_L = \frac{V_{in}}{R + R_L}$

$V_{in} < -V_{on}$: The diode is forward-biased, so $V = -V_{on}$ (note: negative sign is due to the polarity of $V$; check this against Figure 1), so $I = \frac{V_{in} - (-V_{on})}{R}$ and $I_L = \frac{-V_{on}}{R_L}$

### 3.0 Some Special Diodes

#### 3.1 Light-Emitting Diodes (LEDs)

LEDs are essentially just diodes (of the kind described in section 1) that are designed to give off light in the forward-biased mode. The only difference is that the turn-on voltage is different (typically 1.6 to 3.5 V) and varies between the different available
colours (including infra-red and ultraviolet). The circuit symbol is shown in Figure 7, and the physical device layout is shown in Figure 8.

To turn on an LED, a voltage greater than or equal to the turn-on (forward) voltage (sometimes indicated as $V_F$) must be applied, and a current of typically 10-20 mA must be supplied. To determine the correct turn-on voltage and supply current for your LED, consult the data sheets. A simple circuit that will turn on an LED is that of Figure 3 (the positions of the resistor and diode can be interchanged), providing $V_{in}$ and $R$ are chosen to match the correct turn-on voltage and supply current.

### 3.2 Photodiodes

Photodiodes (see Figure 9) are essentially just diodes (of the kind described in section 1) that are capable of converting light into a small current. Photodiodes are typically reverse biased when photoconducting, and should be supplied with a small current, according to the data sheets, for example using in a circuit like that seen in Figure 10. When a light signal (or infrared signal, if it is an infrared photodiode) is detected, the current in the photodiode increases (typically by a small amount), so the voltage $V$ will change in response to the increased current.