

13

Couplers

Imagine an optic fiber carrying an input signal that needs to be connected to two different destinations. The signal needs to be split into two. This is easily achieved by a *coupler*. When used for this purpose, it is often referred to as a *splitter*.

Couplers are bi-directional – they can carry light in either direction. Therefore the coupler described above could equally well be used to combine the signals from two transmitters onto a single optic fiber. In this case, it is called a *combiner*. It is exactly the same device; it is just used differently.

The various ways of using couplers are shown in Figure 13.1.

Physically, they look almost the same as a mechanical splice, in fact in some cases we would need to count the number of fibers to differentiate between them. If there is one fiber at each end, it is a mechanical splice; any other number and it is a coupler.

Coupler sizes - Figure 13.2

A coupler with a single fiber at one end and two at the other end would be referred to as a 1×2 coupler (read as *one by two*). Although 1×2 , and 2×2 , are the most common sizes they can be obtained in a wide range of types up to 32×32 and can be interconnected to obtain non-standard sizes. Splitters are more common than combiners and this has made it more natural to refer to the single fiber end as the input.

The numbering of the ports is shown in Figure 13.3 (*port* is just a fancy word used in electronics to mean a connection).

Figure 13.1
The uses of couplers

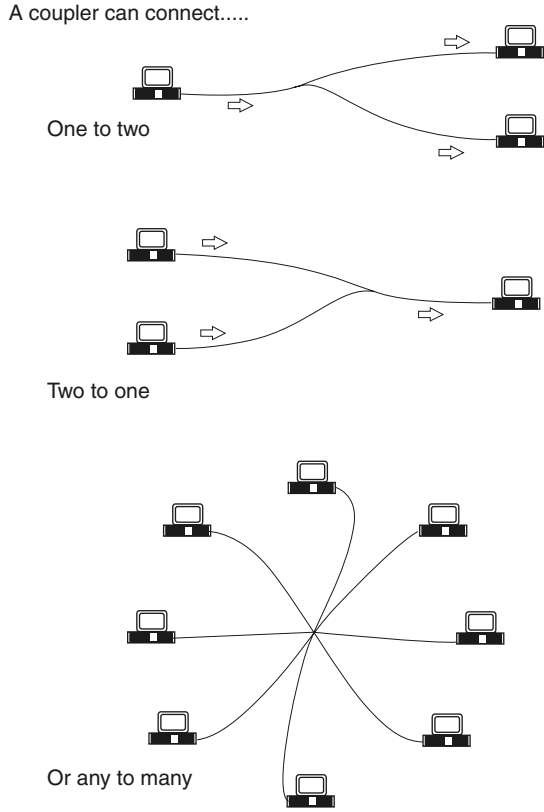


Figure 13.2
The most common types of coupler

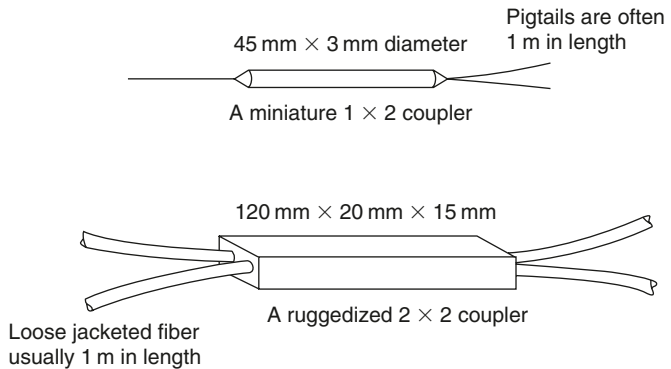
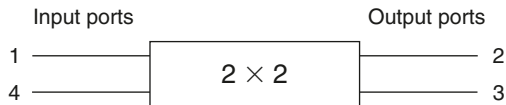


Figure 13.3
One possible numbering system for the ports



Splitting ratio or coupling ratio

The proportion of the input power at each output is called the splitting ratio or coupling ratio. In a 1×2 coupler, the input signal can be split between the two outputs in any desired ratio. In practice however, the common ones are 90:10 and 50:50. These are also written as 9:1 and 1:1.

In the cases where the splitting ratio is not 1:1, the port which carries the higher power is sometimes called the *throughput port* and the other is called the *tap port*.

Coupling tolerance

Even when the splitting ratio is quoted as 1:1, it is very unlikely, due to manufacturing tolerances that the input power is actually shared equally between the two outputs. The acceptable error of between 1% and 5% is called the coupling or splitting tolerance.

Losses

A gloomy note before we start.

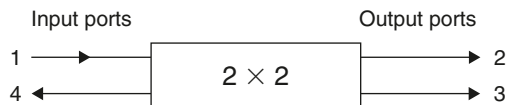
When consulting trade publications, we find that the terms used to describe coupler losses, the naming of the ports and even the numbering of the connections have not been totally standardized. This makes it difficult to avoid meeting several different versions of the formula for each loss.

The only way to combat this is to understand the nature of the losses and then to be fairly flexible when it comes to the way it has been expressed.

Referring to Figure 13.4, the losses are stated in decibels and assume that the input is applied to port 1 and the output is taken from ports 2 and 3. For the moment, we will ignore the other connection shown as port 4 with its outward pointing arrow. This will be discussed further when we look at directionality loss.

Figure 13.4

Assumed
power
directions for
definitions



We may recall that, generally, the loss in decibels is derived from the standard formula:

$$\text{Loss} = 10 \log \left(\frac{\text{power}_{\text{out}}}{\text{power}_{\text{in}}} \right) \text{dB}$$

Excess loss

Excess loss is a real loss. If 10 mW goes into a device and only 9 mW comes out, then it is reasonable enough to think of the other 1 mW to be a loss. The light

energy has been scattered or absorbed within the coupler and is not available at the output. So what we are really saying is that the loss is dependent on the total output power compared to the input power. In the case of the coupler in Figure 13.4, the output power is the sum of ports 2 and 3 and the input is at port 1.

So excess loss would look like this:

$$\text{Excess loss} = 10 \log \left(\frac{P_2 + P_3}{P_1} \right) \text{dB}$$

where P_1 , P_2 , P_3 are the power levels at the respective ports.

Directionality loss or crosstalk or directivity

When we apply power to port 1 we expect it to come out of ports 2 and 3 but not out of port 4, the other input port. Unfortunately, owing to backscatter within the coupler, some of the energy is reflected back and appears at port 4. This backscatter is very slight and is called *directionality loss* or *crosstalk*. The fact that the backscatter comes out of port 4 accounts for the direction of the arrow in Figure 13.4.

$$\text{Directionality loss} = 10 \log \left(\frac{P_4}{P_1} \right) \text{dB}$$

A typical figure is -40 dB.

Directivity puts the same information around the other way – if the reflected power has a level of -40 dB, then the power which is *not* reflected has a ratio of $+40$ dB. In the formula, the power levels are just inverted.

$$\text{Directivity} = 10 \log \left(\frac{P_1}{P_4} \right) \text{dB}$$

Insertion loss or port-to-port loss or throughput loss or tap loss

This looks at a single output power compared with the input power, so in Figure 13.4 there are two possibilities. We could look at the power coming out of port 2 and compare it with the input power at port 1 or we could do a similar thing with port 3 compared with the input power at port 1.

Generally, insertion loss for any output port could be written as:

$$\text{Insertion loss} = 10 \log \left(\frac{P_{\text{output port}}}{P_{\text{input port}}} \right) \text{dB}$$

As an example, the insertion loss at port 2 is:

$$\text{Insertion loss} = 10 \log \left(\frac{P_2}{P_1} \right) \text{ dB}$$

This would then be referred to as the insertion loss of port 2 or simply the *port-to-port loss* between port 1 to port 2.

If, in the above example, the splitting ratio was not 1:1, then port 2 may be referred to as the throughput port and so the formula above becomes the throughput loss. Similarly, if ports 3 and 1 were used, the loss could be called the tap loss.

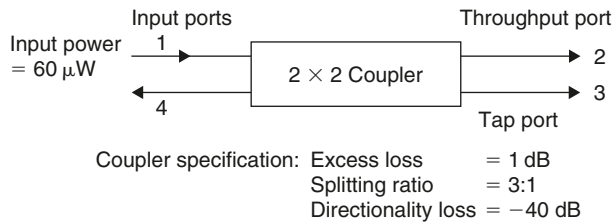
Coupling loss

This is often overlooked. Whenever a coupler is used, it has to be joined to the rest of the circuit. This involves two pairs of connectors and a splice at each end. The losses caused by these connectors or splices must be added to the losses introduced by the coupler.

Example

Calculate the output power at each port in the coupler shown in Figure 13.5.

Figure 13.5
A worked
example



What is the value of the output power at each port?

Output power at port 4

The directionality loss is quoted as -40 dB.

Starting with the standard formula for decibels.

$$\text{Loss} = 10 \log \left(\frac{\text{power}_{\text{out}}}{\text{power}_{\text{in}}} \right) \text{ dB}$$

The input power is 60 μW and the loss figure in decibels is -40 dB so we make a start by inserting these figures into the formula:

$$-40 \text{ dB} = 10 \log \left(\frac{\text{power}_{\text{out}}}{60 \times 10^{-6}} \right)$$

Divide both sides by 10:

$$-4 = \log \left(\frac{\text{power}_{\text{out}}}{60 \times 10^{-6}} \right)$$

Take the antilog of each side:

$$10^{-4} = \left(\frac{\text{power}_{\text{out}}}{60 \times 10^{-6}} \right)$$

So:

$$60 \times 10^{-6} \times 10^{-4} = \text{power out}$$

So power out of port 4 = $60 \times 10^{-10} = 600 \text{ nW}$.

As the output from port 4 is so small, it is often ignored.

Output power at port 2

Port 2 is the throughput port, i.e. the port with the largest output power. With a splitting ratio of 3:1, for every four units of power leaving the coupler there are three at port 2 and only one at port 3. This means that 0.75 of the power leaving the coupler goes via port 2.

But how much power is leaving the coupler? This is the input power minus the excess loss. Port 4 output can be ignored since it is so slight compared with the other power levels.

In this example, the excess loss is 1 dB so if we convert this 1 dB into a ratio, we can find the output power.

Into the standard formula we put the -1 dB (minus, as it is a loss) and the input power:

$$-1 \text{ dB} = 10 \log \left(\frac{\text{power}_{\text{out}}}{60 \times 10^{-6}} \right)$$

Divide both sides by 10:

$$-0.1 = \log \left(\frac{\text{power}_{\text{out}}}{60 \times 10^{-6}} \right)$$

Take the antilog of each side:

$$10^{0.1} = \left(\frac{\text{power}_{\text{out}}}{60 \times 10^{-6}} \right)$$

So:

$$60 \times 10^{-6} \times 10^{-0.1} = \text{power out}$$

By calculator, $10^{-0.1} = 0.794$

So total power out of the coupler = input power \times 0.794, or:

$$60 \times 10^{-6} \times 0.794 = 47.64 \times 10^{-6} \text{ W}$$

Of the $60 \mu\text{W}$ that entered the coupler, $47.64 \mu\text{W}$ is able to leave. Of this amount 75% leaves via port 2 so:

$$\text{power out of port 2} = 0.75 \times 47.64 \mu\text{W} = 35.73 \mu\text{W}$$

Output power at port 3

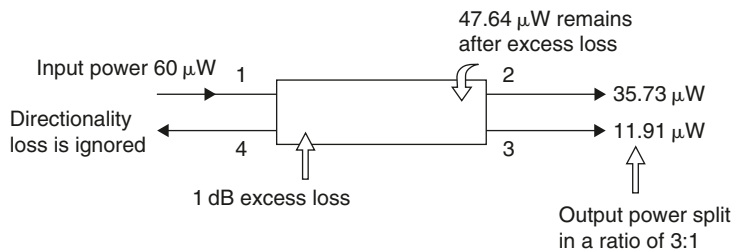
We have already calculated the power remaining after the excess loss to be $47.64 \mu\text{W}$ and since we are dealing with port 3, the tap port, the proportion of power leaving by this port is only 0.25 of the total.

Thus the output power at port 3 is $0.25 \times 47.64 \mu\text{W} = 11.91 \mu\text{W}$.

The results are shown in Figure 13.6.

Figure 13.6

The resulting power levels



The tee-coupler - Figure 13.7

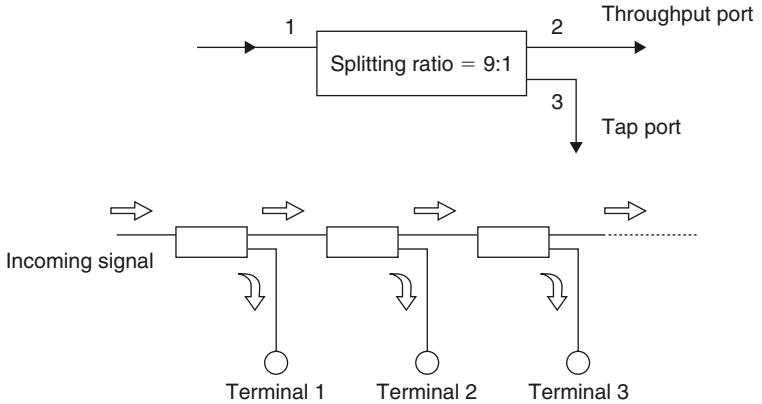
This is simply a 1×2 coupler used to convey a single signal to a number of different workstations. Such stations are said to be connected on a network. It would use a high splitting ratio of 9:1 or similar to avoid draining the power from the incoming signal.

Advantages and disadvantages of a tee network

The main advantage is its simplicity. The couplers are readily available and, if required, can be supplied with connectors already fitted. This means that the network can be on-line very quickly indeed.

The disadvantage is the rapid reduction in the power available to each of the workstations as we connect more and more terminals to the network. As the power is reduced, the number of data errors increases and the output becomes increasingly

Figure 13.7
A tee network



unreliable. At first glance we could solve this problem by simply increasing the input power level. However we run the very real risk of overloading the first workstation.

Power levels in a tee network

Specification for our example system:

- ▷ incoming power = 1 mW
- ▷ splitting ratio of each coupler = 9:1
- ▷ excess loss of each coupler = 0.3 dB. The couplers are joined by connectors with an insertion loss of 0.2 dB each.

Step 1 – Figure 13.8

The incoming power level is reduced by 0.2 dB by the first connector, and 0.3 dB by the excess loss.

Total power reduction is 0.2 + 0.3 = 0.5 dB.

By inserting the values into the standard decibel formula, remembering to use -0.5 dB as it is a loss, we have:

$$-0.5 \text{ dB} = 10 \log \left(\frac{\text{power}_{\text{out}}}{1 \times 10^{-3}} \right)$$

Divide both sides by 10:

$$-0.05 \text{ dB} = \log \left(\frac{\text{power}_{\text{out}}}{1 \times 10^{-3}} \right)$$

and antilog:

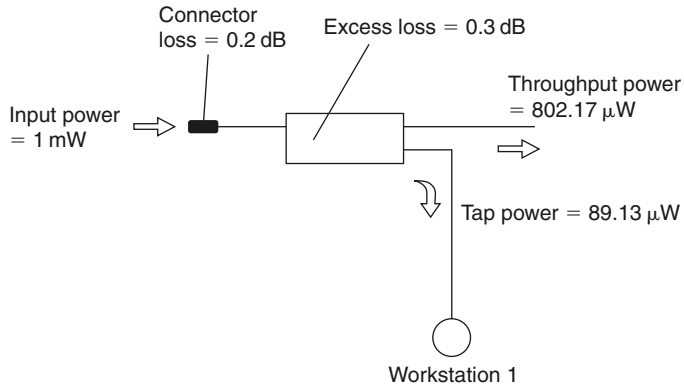
$$0.8913 = \left(\frac{\text{power}_{\text{out}}}{1 \times 10^{-3}} \right)$$

So, the input power is:

$$0.8913 \times 1 \times 10^{-3} = \text{power out} = 891.3 \mu\text{W}$$

Figure 13.8

The first terminal



Step 2

The 891.3 μW is the power just before it is split into the two output ports.

As the splitting ratio is 9:1, the throughput power at port 2 is 0.9 of the available power or 802.17 μW . Similarly; the tap power is 0.1 of 891.3 μW or 89.13 μW .

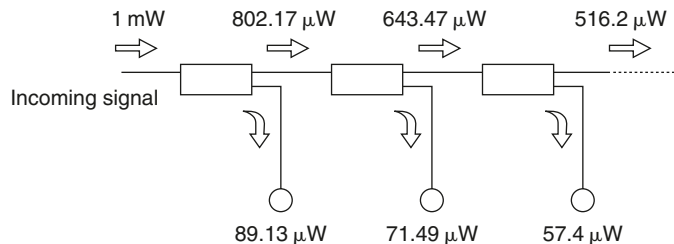
Step 3 – Figure 13.9

The throughput power, 802.17 μW , is actually the input power to the next section of the network and is simply a replacement for the 1 mW input in Step 1.

This new input power suffers the same connector insertion loss, coupler excess loss and splitting ratio and so the calculations would involve exactly the same steps as we have already used.

Figure 13.9

The power levels quickly decrease



The results we would obtain are throughput loss = 643.47 μW and the tap power going to terminal 2 = 71.49 μW .

Step 4

The next section would decrease the powers by the same proportions and it would result in a throughput loss of 516.2 μW and a tap power of 57.4 μW . The same proportional loss would occur at each section of the network.

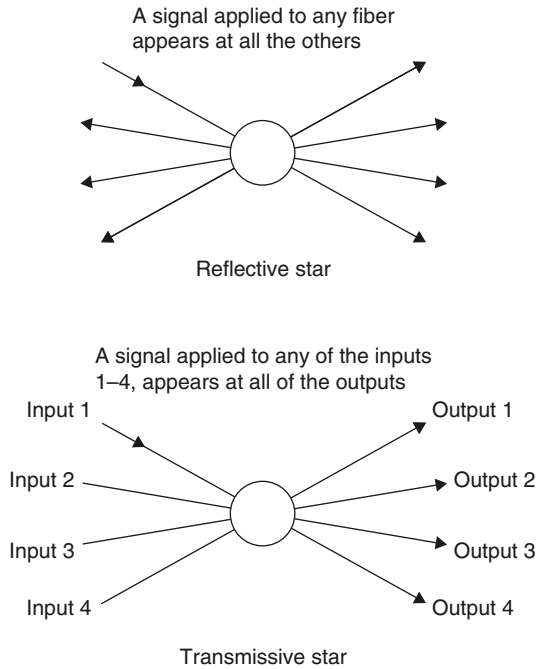
The star coupler

This is an alternative to the tee coupler when a larger number of terminals is involved as shown in Figure 13.10.

The star coupler takes the input signal to a central location, then splits it into many outputs in a single coupler. Styles of up to 1×32 and up to 32×32 are commonly available.

Figure 13.10

Two forms of 4×4 star couples

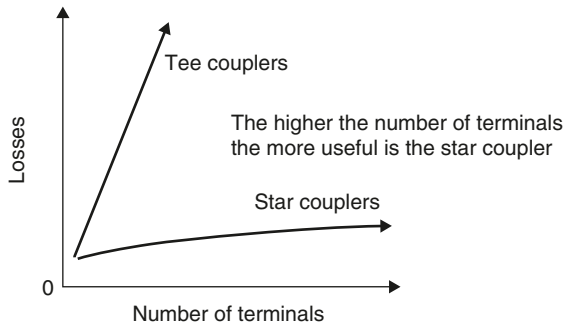


Advantages and disadvantages

The main advantage of using star couplers is that the losses are lower than a tee coupler for networks of more than three or four terminals as in Figure 13.11. This is because the star coupler requires only one input connector and suffers only one excess loss. The larger the number of terminals, the more significant are the benefits.

Figure 13.11

Loss comparison



The disadvantage is that the star coupler will normally use much larger quantities of cable to connect the terminals since the star is located centrally and a separate cable is connected to each of the terminals. A tee network can use one cable to snake around the system from terminal to terminal.

Construction of couplers

Fused couplers

This is the most popular method of manufacturing a coupler. It is, or appears to be, a very simple process.

The fibers are brought together and then fused, just like in a fusion splicer as seen in Figure 13.12. The incoming light effectively meets a thicker section of fiber and spreads out. At the far end of the fused area, the light enters into each of the outgoing fibers.

A fused star coupler is made in a similar way (Figure 13.13). The fibers are twisted round to hold them in tight proximity, and then the center section is fused. In the

Figure 13.12

Light sharing in a fused coupler

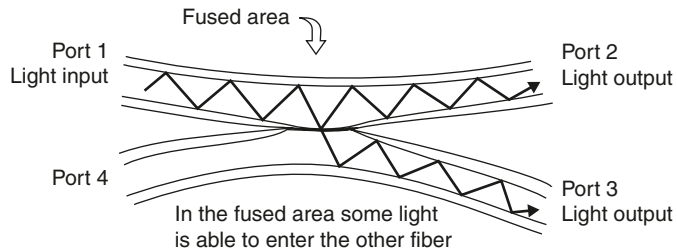
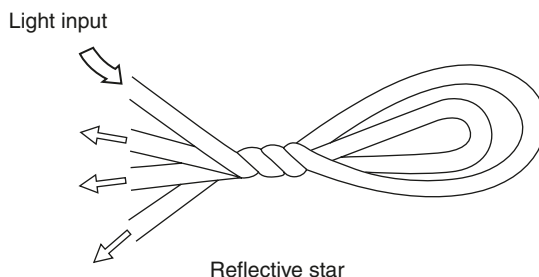
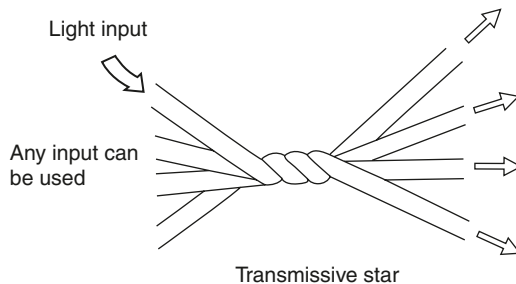


Figure 13.13

Fused star couplers



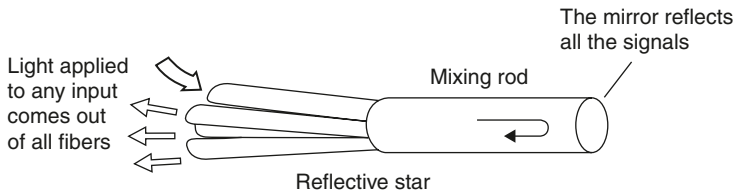
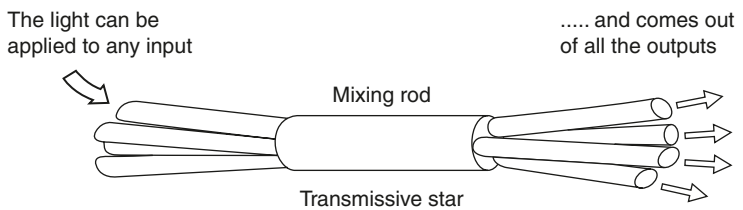
case of the reflective star, the fibers are bent back on themselves before being fused.

Mixing rod couplers – Figure 13.14

If several fibers are connected to a short length of large diameter fiber, called a *mixing rod*, the incoming light spreads out until it occupies the whole diameter of the fiber. If several fibers are connected to the far end they each receive some of the light.

A reflective coupler can be produced by putting a mirror at the end of the mixing rod. The light traveling along the mixing rod is reflected from the end mirror and all the attached fibers receive an equal share of the incoming light.

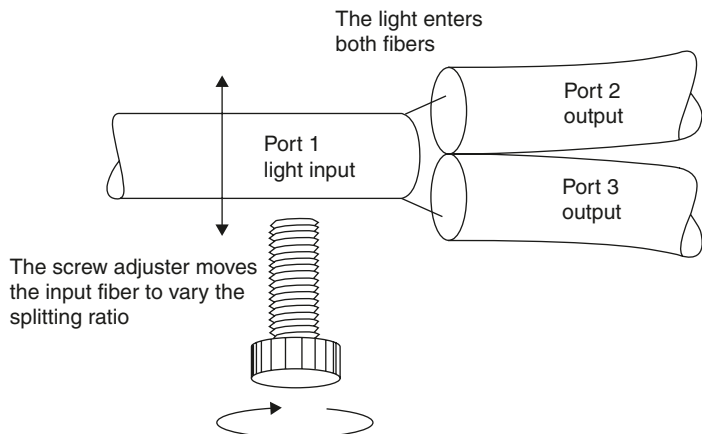
Figure 13.14
Star couplers
by mixing
rods



Variable coupler - Figure 13.15

This is more of an experimental or test laboratory tool than for the installation environment. It enables the splitting ratio to be adjusted to any precise value

Figure 13.15
The variable
coupler



up to 19:1, which allows us to try out the options before the final type of coupler is purchased.

The design principle is very simple. A vernier adjustment allows precise positioning of the incoming fiber so that the light can be split accurately between the two output fibers to provide any required splitting ratio.

This form of variable coupler is available for all plastic as well as glass fibers, single mode and multimode.

Quiz time 13

In each case, choose the best option.

1 A 4 × 4 coupler would have a total of:

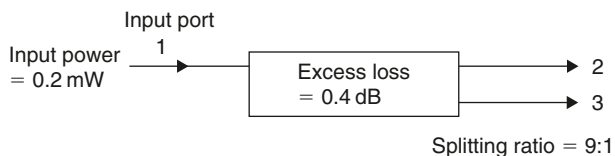
- (a) 16 ports
- (b) 4 ports
- (c) 9 ports
- (d) 8 ports

2 In the coupler shown in Figure 13.16, the tap power would have a value of approximately:

- (a) 18.2 μW
- (b) 0.182 W
- (c) 163.8 μW
- (d) 21.9 μW

Figure 13.16

Question 2



3 The main advantage of using a star coupler to connect a large number of terminals is that:

- (a) more cable would be used and hence system reliability would increase
- (b) the power loss is lower than would be the case if tee couplers were to be used
- (c) higher levels of data errors could be tolerated
- (d) less cable is used

4 Coupling ratio is also known as:

- (a) directionality loss
- (b) coupling loss
- (c) splitting ratio
- (d) directivity ratio

5 The output connection which carries the highest power level is the:

- (a) tap port
- (b) power port
- (c) star
- (d) throughput port

14

Light sources and detectors

Most light sources and detectors are electronic devices built from the same semiconductor materials as are used in transistors and integrated circuits.

The design of these devices is a separate study and will not be considered here. Instead, our view will be restricted to the characteristics which are of interest to the user.

Lasers

The most common form of laser diode is called an *injection laser diode* (ILD) or just *injection diode* (ID). The word *injection* is not of interest – it merely refers to part of the process occurring inside the semiconductor material.

A laser provides a light of fixed wavelength which can be in the visible region around 635 nm or in any one of the three infrared windows. The light has a very narrow bandwidth, typically only a few nanometers wide. This ensures that chromatic dispersion is kept to a low value and this, together with fast switching, allows high data transmission rates.

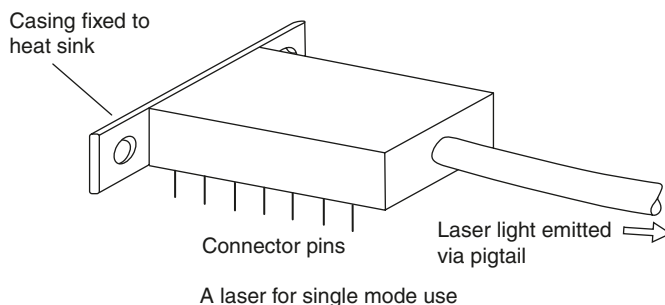
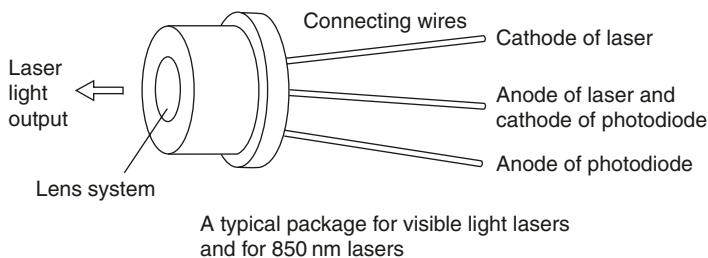
As the laser device itself is barely visible to the unaided eye, it must be contained in some form of package. Two typical examples are shown in Figure 14.1.

Lasers for visible light

The light is launched via a lens system to allow it to be concentrated into a beam. Visible laser light finds applications in bar code readers, CD players,

Figure 14.1

Lasers



medical and communication systems. They are usually fitted with a built-in light detector so that they can receive reflected information, as in the case of the bar code reader.

Lasers for 850 nm use

These can be packaged in either of the ways illustrated in Figure 14.1 depending on their application. The fact that their output is not visible allows for use in security, ranging, automotive and industrial and military applications. They also provide the light source for short and medium range fiber communications.

Lasers for single mode communications

Successful launching into single mode fibers requires very high precision and this is achieved by optimizing the position of an attached pigtail which can then be connected to the main fiber run by any desired method.

A photo-electric cell is also included as a monitoring device to measure the output power. This provides feedback to allow for automatic control of the laser output power. The output power of a laser is affected by any change in its temperature, generally decreasing in power as the temperature increases. Some laser modules include a temperature sensor to combat this problem. It provides internal temperature information which is used to control a thermo-electric cooler like a small refrigerator, to maintain the temperature. The temperature stability is also improved by bolting the laser package to some form of heat sink such as the instrument casing.

'VCSEL' lasers

In the mid 1990s a new style of laser was developed, known as a VCSEL, or Vertical Cavity Surface Emitting Laser. This effectively is a laser with the manufacturing costs of a good LED. VCSELs are currently available at 850 nm and can inject gigabit datastreams into multimode fibre. VCSEL 850 nm transmission devices are assumed for use in the optical gigabit Ethernet standard 1000-BASE-SX (IEEE 802.3z) which was published in 1998. 850 nm VCSELs will also be used in Fibre Channel, ATM and other Ethernet physical layer presentations. A single mode 1300 nm VCSEL is currently working its way through the laboratories of the world, a device that could totally transform the economics of using single mode fibre in campus and premises cabling.

Laser safety

Both visible and infrared light can cause immediate and permanent damage to the eyes. The shorter wavelengths cause damage to the retina and the longer wavelengths attack the cornea; in neither case can medical science offer remedy once the damage is done. Permanent loss of eyesight can take less than a second by exposure to light we can't even see!

It is extremely important that we take sensible precautions.

Never look into:

- ▷ a live laser source
- ▷ an unknown light source
- ▷ any fiber until you have ascertained that it is safe. Check it yourself even if trusted colleagues say 'its OK we've just checked it out'. They may be talking about a different fiber or they may have made a mistake.

If an instrument such as a live fiber detector is used, make sure it is working.

Beware of concentrating the light by instruments such as will happen when checking a cleave or the end condition of a connector with a microscope.

Laser classifications are based on an international standard titled *Radiation Safety of Laser Products, Equipment Classification, Requirements and User's Guide*, referred to as *IEC standard 60825*. Additional national standards apply in each country. In the European Union they are published as *EN 60825* or more specifically:

EN 60825 *Safety of laser products (IEC 60825)*

EN 60825-1 *Safety of laser products – Part 1: Equipment classification, requirements and user's guide (IEC 60825-1:1993)*

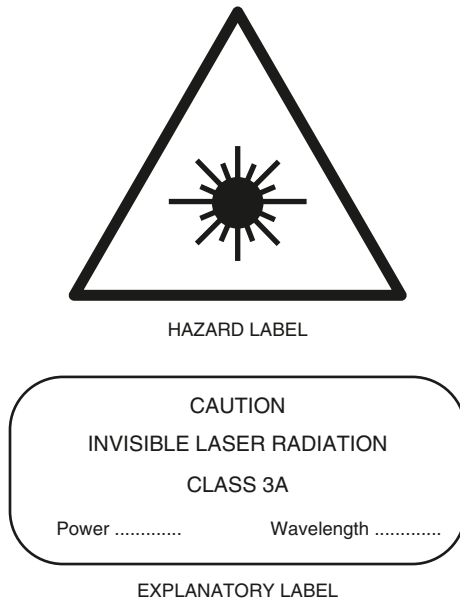
EN 60825-2:2004 *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*

In the USA see **ANSI Z136.1** *Safe Use of Lasers*

The IEC 60825 classification has used four classes of laser based on the accessible emission limit (AEL). Every laser must carry a warning label stating the class of laser as shown in Figure 14.2. It is the responsibility of the manufacturer to

determine the classification of the laser and they do so by measuring the wavelength, output power and the pulsing characteristics.

Figure 14.2
Laser warning
labels



IEC classifications

Class 1

Safe under reasonably foreseeable conditions of operations. Note that it doesn't say 'safe under any conditions'.

Class 2

Visible lasers with light output within the visible spectrum of 400–700 nm. There is an assumption here that the blink reflex will close the eyes within a fraction of a second and hence provide protection. Prolonged exposure will cause damage.

Class 3a

Safe for viewing by the unaided eye either visible or infrared light but possibly unsafe when viewed with instruments.

Class 3b

Direct viewing is hazardous but reflected light is normally OK. Note the *normally*. Not to be viewed with instruments.

Class 4

Very dangerous. Even reflections are hazardous and the direct beam can cause fires and skin injury. Not normally used for communications.

Control measures

For classes 2, 3 and 4, control measures are employed such as interlocks, keys, laser 'on' warning lights, remote switching, prevention of reflections across walkways. The precautions depend on the situation, use and power of the laser. The appropriate national standards as well as IEC 60825 should be consulted for guidance.

Laser specifications

Wavelength

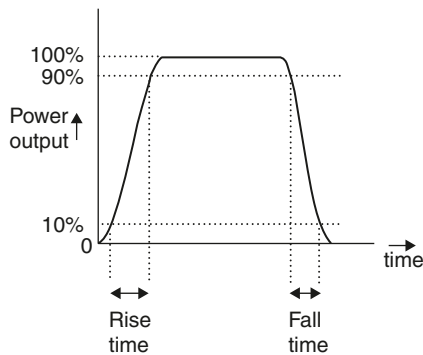
The wavelength quoted is only a typical value. So if we want to buy a laser for the 1300 nm window, the one offered may well be quoted as 1285–1320 nm and the actual wavelength will fall somewhere between these limits. Sometimes it would just be sold as 1300 nm (nominal).

Rise and fall time – Figure 14.3

This is a measure of how quickly the laser can be switched on or off measured between the output levels of 10–90% of the maximum. A typical value is 0.3 ns.

Figure 14.3

Rise and fall time

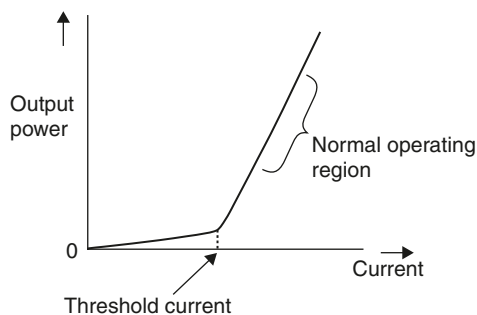


Threshold current – Figure 14.4

This is the lowest current at which the laser operates. A typical value is 50 mA and the normal operating current would be around 70 mA.

Figure 14.4

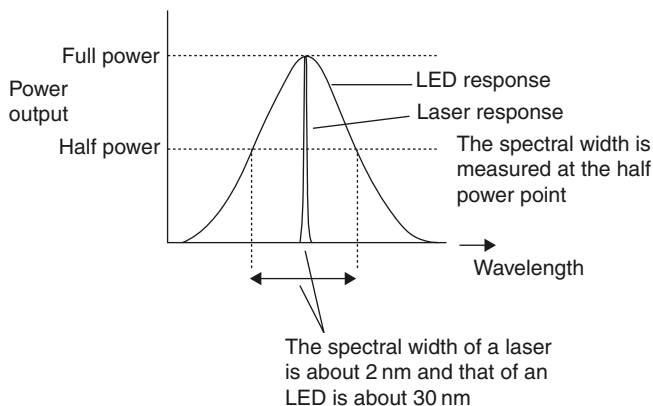
Laser characteristic



Spectral width – Figure 14.5

This is the bandwidth of the emitted light. Typical spectral widths lie between 1 nm and 5 nm. A laser with an output of 1310 nm with a spectral width of 4 nm, would emit infrared light between 1308 nm and 1312 nm.

Figure 14.5
Spectral widths of LEDs and lasers



Operating temperature

No surprises here. Typical values are -10°C to $+65^{\circ}\text{C}$ and therefore match the temperature ranges of fibers quite well.

Voltages and currents

The specifications also list the operating voltages and currents of the monitor detector, the cooler current and the thermistor resistance. These are generally only of interest to the equipment designer or the repair technician.

Output power

The output power may be quoted in watts or in dBm.

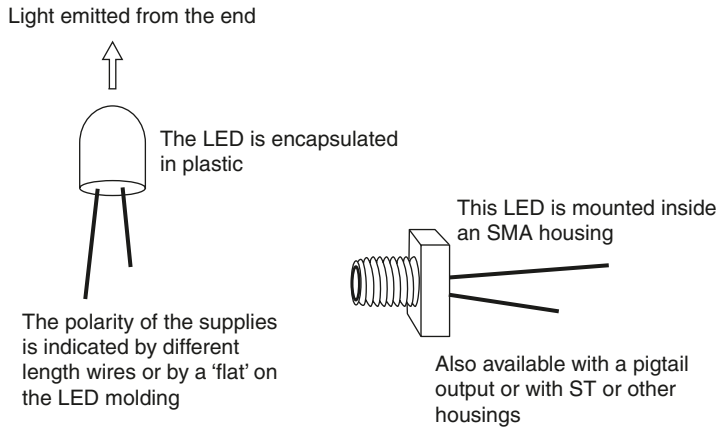
LEDs – light emitting diodes

LEDs can provide light output in the visible spectrum as well as in the 850 nm, 1300 nm and the 1550 nm windows.

Compared with the laser, the LED has a lower output power, slower switching speed and greater spectral width, hence more dispersion. These deficiencies make it inferior for use with high-speed data links and telecommunications. However, it is widely used for short and medium range systems using both glass and plastic fibers because it is simple, cheap, reliable and is less temperature dependent. It is also unaffected by incoming light energy from Fresnel reflections, etc.

Although the lower power makes it safer to use, it can still be dangerous when the light is concentrated through a viewing instrument. Typical packages are shown in Figure 14.6.

Figure 14.6
LEDs –
encapsulated
and SMA
packages



PIN diodes

A PIN diode is the most popular method of converting the received light into an electronic signal. Their appearance is almost identical to LEDs and lasers. Indeed the diagrams in Figure 14.6 would serve equally well for PIN diodes if the labels were changed. They can be terminated with ST, SC, and a variety of other connectors or a pigtail.

It may be of interest to have a brief look at its name. It uses a semiconductor material, either germanium or silicon. The pure semiconductor material is called an intrinsic semiconductor – this is the I in the name. To make it work, we have to add a controlled amount of impurity into the semiconductor to change its characteristics. The semiconductor is converted into two types, one called P-type semiconductor and the other called N-type. These are arranged either side of the I material to make an I sandwich. Hence P-I-N or PIN diode. The theory of its operation need not be considered further.

While we can still buy straightforward PIN diodes, it is more usual for it to have an amplifier built into the module to provide a higher output signal level.

Avalanche diode (also called an avalanche photo diode or APD)

Higher output signals can be achieved by an avalanche diode. It uses a small internal current to generate a larger one in the same way that a snowball rolling down a mountainside can dislodge some more snow which, in turn, dislodges even more snow and eventually gives rise to an avalanche.

It has the advantages of a good output at low light levels and a wide dynamic range, i.e. it can handle high and low light levels. However there are a number of disadvantages which tend to outweigh the benefits. It has higher noise levels, costs more, generally requires higher operating voltages and its gain decreases with an increase in temperature.

Light receiver specifications

Wavelength

This is quoted as a range, e.g. 1000 nm to 1600 nm, or by stating the frequency that provides the highest output, e.g. peak wavelength = 850 nm.

Dynamic range or optical input power

Dynamic range is the ratio of the maximum input power to the lowest. It is quoted in decibels, e.g. 21 dB.

The optical input power is the same information expressed in watts, e.g. 1 μW to 125 μW .

Responsivity

A measure of how much output current is obtained for each watt of input light, e.g. 0.8 A W^{-1} . This means that the current will increase by 0.8 amps for every watt of increased light power.

Response time

This is the rise and fall time that we saw in Figure 14.3. It determines the fastest switching speed of the detector and hence limits the maximum transmission rate, e.g. t_r or $t_f = 3.5 \text{ ns}$.

Bit rate or data rate or bandwidth

These are all measures of the maximum speed of response to incoming signals and are therefore determined by the response time above.

Quiz time 14

In each case, choose the best option.

1 The safest type of laser is referred to as:

- (a) infrared
- (b) class 1
- (c) pulsed
- (d) class 4

2 A typical value for the spectral width of a laser is:

- (a) 1310 nm
- (b) 3 nm
- (c) 850 nm
- (d) 30 nm

3 An APD:

- (a) can produce visible light as well as infrared light at 850 nm, 1300 nm and 1550 nm
- (b) has good electrical output in low light conditions
- (c) has a lower dynamic range than a PIN diode
- (d) is cheaper than a PIN diode

4 LEDs are not used as the light source for high speed telecommunications because of their:

- (a) higher cost
- (b) poor reliability
- (c) inability to provide a visible light output
- (d) slow switching speed and higher spectral width

5 A typical value of t_r for a laser would be:

- (a) 3.5 ns
- (b) 3 nm
- (c) 90%
- (d) 0.3 ns