5

Decibels

To read technical information, to make sense of catalogs or to compare specifications we need an understanding of *decibels*. This chapter restricts itself to decibels as required for the field of fiber optics.

The decibel is a logarithmic unit

What is a logarithmic unit?

The word *logarithm*, even when abbreviated to the friendlier *log*, is still somewhat frightening. It instils a sense of unease. Don't worry. It's all bluff. It's actually quite simple.

Look at this:

$$10 \times 10 = 100$$

So far so good.

We can use powers of ten to write this in another form:

$$10^2 = 100$$

This is simple enough, so where is the problem? There isn't one really – except in the wording.

We can write:

 ▷ $10^2 = 100$
 ▷ or say 10 squared is equal to 100
 ▷ or even 10 to the power of 2 is 100.

But how would we describe the number 2 in this situation?

It is called the logarithm, or *log* of 100. It is the number to which 10 must be *raised* to equal 100.

As $10^2 = 100$ and the log of 100 is 2, and $10^3 = 1000$ and the log of 1000 is 3, it follows that the log of any number between 100 and 1000 must be between 2 and 3. We cannot work them out for ourselves so we must use a calculator.

For the log of 200

On the calculator:

> ▷   press the log button
> ▷   enter 200

and the answer 2.301029996 appears. So, ignoring some of the decimal places, we can say that 2.301 is the log of 200 or $10^{2.301} = 200$.

To perform a multiplication like $100 \times 1000 = 100\,000$ we could add the logs of the numbers to be multiplied:

> log of 100 = 2
>
> log of 1000 = 3
>
> log of 100 000 = 2 + 3 = 5 or $100 \times 1000 = 10^5$

Similarly:

$$\frac{100\ 000}{1000} = 100$$

or, by subtracting logs:

> $5 - 3 = 2$

or:

$$\frac{100\,000}{1000} = 10^2$$

Summary

> ▷   to multiply, add logs
> ▷   to divide, subtract logs.

Use of decibels in fiber optic circuits

We use decibels to compare the power coming out of a circuit or part of a circuit to the power level at the input. So basically it is an output power/input

power comparison. The decibel is a logarithmic unit and obeys the same rules as logs. The formula is:

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

Note the abbreviation for decibels: small d, capital B, never put an s on the end.

An amplifier has a higher output power than its input power so it is said to have a power gain. This is the case in Figure 5.1:

Figure 5.1

What is the gain in decibels?

Power$_{in}$ = 2 mW ——— Amplifier ——— Power$_{out}$ = 6 mW
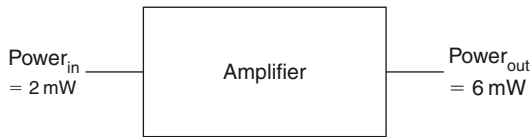
$$\text{gain} = 10 \log \left(\frac{\text{power}_{out}}{\text{power}_{in}} \right) dB$$

Insert the values:

$$\text{gain} = 10 \log \left(\frac{6 \times 10^{-3}}{2 \times 10^{-3}} \right) dB$$

Simplify by dividing out the figures in the brackets. This gives:

$$\text{gain} = 10 \log 3 \, dB$$

Take the log of 3:

$$\text{gain} = 10 \times 0.477 \, dB$$

Simplify by multiplying:

$$\text{gain} = +4.77 \, dB$$

So this amplifier could be said to have a gain of 4.77 dB.

An attenuator, as shown in Figure 5.2, has less output power than input power:

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

Keep the same formula for gains *and* losses. It makes life simpler. To prove it, we're just going to follow the same steps as in the last example.

Figure 5.2

Find the loss in
decibels

Power$_{in}$
= 6 mW

| Attenuator |

Power$_{out}$
= 2 mW

Insert the values:

$$\text{gain} = 10 \log \left[\frac{2 \times 10^{-3}}{6 \times 10^{-3}} \right] \text{dB}$$

Simplify by dividing out the contents of the brackets:

$$\text{gain} = 10 \log 0.03334 \, \text{dB}$$

Taking the log we get:

$$\text{gain} = 10 \times (-0.477) \, \text{dB}$$

Multiplying out we have:

$$\text{gain} = -4.77 \, \text{dB}.$$

Note

This attenuator can be described in two ways and it is vital that we do not get them confused.

The mathematical result was −4.77 dB. If we were to ask someone what the result was, they may well answer, 'The attenuator has a loss of 4.77 dB', or they may reply, 'It has a gain of minus 4.77 dB'.

In the first answer the fact that they mentioned 'loss' will alert us to the fact that an attenuation or loss has occurred. In the second example, the minus sign serves the same purpose.

We must be very careful not to fall into the double negative trap. It is best to avoid saying that the system has an overall loss of −4.77 dB. The 'loss' and the minus could leave the sentence open to differing interpretations.

To summarize

If the number of decibels is negative, the result is a loss of power or an attenuation. If the result is positive, it indicates a gain or an amplification:

▷ + = gain/amplification
▷ − = loss/attenuation.

The big advantage in using decibels is when a circuit consists of several gains and losses as will happen in real situations.

Decibels in a real circuit – what is the output power of the circuit shown in Figure 5.3?
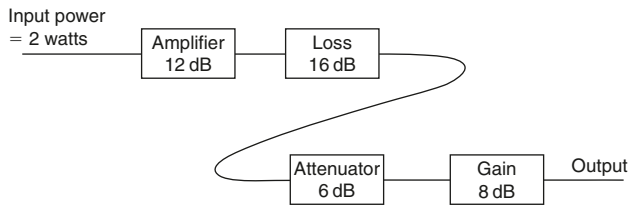
Method

1 Express each change of power level in decibels

An amplifier with a gain of 12 dB is represented by +12 dB

A loss of 16 dB is shown as −16 dB

Figure 5.3

What is the output power in watts?

Input power = 2 watts

| Amplifier 12 dB | Loss 16 dB |

| Attenuator 6 dB | Gain 8 dB | Output |

An attenuation of 6 dB is shown as −6 dB

A gain of 8 dB is shown as +8 dB

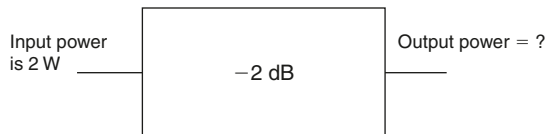Add all the decibels to give an overall result:

$$(+12) + (−16) + (−6) + (8)$$

Taking away the brackets:

$$+12 − 16 − 6 + 8 = −2\,\text{dB}.$$

The result is an overall loss of 2 dB so the circuit could be simplified to that shown in Figure 5.4.

Figure 5.4

Input power is 2 W

−2 dB

Output power = ?

2 Looking at the formula for decibels:

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

and knowing the result to be −2 dB and the input power to be 2 W, we can write:

$$-2 = 10\log\left(\frac{\text{power}_\text{out}}{2}\right)\text{dB}$$

In this formula we know everything except the power out so we can transpose to find it.

It isn't a very obvious transposition so we will work through it one step at a time.

3   Dividing both sides by 10 we have:

$$\frac{-2}{10} = \log\left(\frac{\text{power}_{\text{out}}}{2}\right) \text{dB}$$

or

$$-0.2 = \log\left(\frac{\text{power}_{\text{out}}}{2}\right) \text{dB}$$

4   To undo the effect of the 'log' we must 'antilog' it

This is done by raising both sides to a power of ten.

On the right-hand side, this has the effect of removing the 'log' from the equation as shown:

$$10^{-0.2} = \frac{\text{power}_{\text{out}}}{2}$$

5   Simplify the left-hand side:

$$10^{-0.2} = 0.63$$

so:

$$0.63 = \frac{\text{power}_{\text{out}}}{2}$$

Calculator note: the left-hand side can be simplified by punching in -0.2 and hitting the $10^{\times}$ or the inv log button. The -0.2 is often entered as 0.2 followed by the $-/+$ key.

6   Multiplying both sides by 2 gives:
$$1.26 = \text{power}_{\text{out}}$$

and since we have been working in watts the output power is 1.26 watts.

Notice how we made life easy by simplifying the circuit to obtain a single overall figure in decibels before the conversion. Masochists, on the other hand, may enjoy the difficult approach of calculating the power out of the first amplifier in watts, then repeating the whole procedure to find the power out of the next section and so on through the circuit.

A summary of converting decibels to a ratio of two powers

Method

1   Divide both sides by 10

2   Find the antilog of each side

3   Transpose to find the wanted term

Using a decibel as a power level

The essential point about a decibel is that it is used to express the ratio between two powers.

In the formula:

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

we have two power levels mentioned, the *output power* and the *input power*.

If we wish to use decibels as a measurement of power, we have to get around the ratio problem by assuming a value for the input power.

So the formula is easily changed from:

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

to:

$$\text{power level in decibels} = 10\log\left(\frac{\text{power level}}{\text{assumed power level}}\right)\text{dB}$$

The assumed power is usually 1 mW so the formula becomes:

$$\text{power level in decibels} = 10\log\left(\frac{\text{power level}}{1\,\text{mW}}\right)\text{dB}$$

For this to be of use, two points are important:

1   There must be a standard power level which is assumed and under-stood by everyone. In fiber optics, as with other branches of electron-ics, we use 1 mW.

2   We must indicate that we are now referring to a power level. This is done by changing the symbol to dBm, where dBm means *decibels relative to 1 mW.*

Converting power to dBm

Example: express 5 watts as a power level in decibels.

Method

1   **Start with the formula:**

$$\text{power level in decibels} = 10 \log \left(\frac{\text{power level}}{1\,\text{mW}} \right) \text{dBm}$$

2   **Put in the 5 watts:**

$$\text{power level in decibels} = 10 \log \left(\frac{5}{1 \times 10^{-3}} \right) \text{dBm}$$

3   **Simplify by dividing out the bracket:**

power level in decibels $= 10 \log(5 \times 10^3)$ dBm

4   **Take the log of 5 × 10³:**

power level in decibels $= 10 \times 3.699$ dBm

5   **Multiply out:**

power level in decibels $= 36.99$ dBm

so:

5 watts $= 36.99$ dBm

Example: Converting dBm to a power level

A light source for a fiber optic system has an output power quoted as -14 dBm. Express this power in watts.

Method

1   **Always start with the formula:**

$$\text{power level in decibels} = 10 \log \left(\frac{\text{power level}}{1\,\text{mW}} \right) \text{dBm}$$

2   **Put in the figures that we know:**

$$-14 = 10 \log \left(\frac{\text{power level}}{1 \times 10^{-3}} \right) \text{dBm}$$

3 **Divide both sides by 10:**

$$-1.4 = \log\left(\frac{\text{power level}}{1 \times 10^{-3}}\right) \text{dBm}$$

4 **Find the antilog of both sides:**

$$0.0398 = \left(\frac{\text{power level}}{1 \times 10^{-3}}\right) \text{dBm}$$

5 **Multiply both sides by 1 × 10⁻³:**

$$0.0398 \times 1 \times 10^{-3}$$

or:

$$39.8 \times 10^{-6} = \text{power level}$$

So a power of -14 dBm is the same as $39.8\,\mu\text{W}$.

Decibels used in a system design

Work in decibels for as long as possible. Converting backwards and forwards between decibels and watts is no fun and it is easy to make mistakes.

The nice thing is that dBm and dB are completely compatible – we can just add them up around the circuit to get a final result.
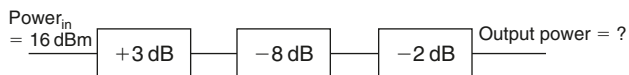
Method of solving the problem in Figure 5.5

1 **Add the decibels:**

$$+16\,\text{dBm} + 3\,\text{dB} + (-8\,\text{dB}) - 2\,\text{dB}$$
$$= +16 + 3 - 8 - 2\,\text{dBm}$$
$$= +9$$

Figure 5.5
What is the
output power
in watts?

Power$_{in}$
= 16 dBm   +3 dB   −8 dB   −2 dB   Output power = ?

As the input power is quoted in dBm, the output power is $+9$ dBm.

To find the output power in watts, we must convert our answer into a power level as we did in the previous example.

2 **Start with the formula:**

$$\text{power level in decibels} = 10\log\left(\frac{\text{power level}}{1\ \text{mW}}\right) \text{dBm}$$

Put in the figures that we know:

$$9 = 10 \log \left(\frac{\text{power level}}{1 \times 10^{-3}} \right) \text{dBm}$$

3   **Divide both sides by 10:**

$$0.9 = \log \left(\frac{\text{power level}}{1 \times 10^{-3}} \right) \text{dBm}$$

4   **Take the antilog of both sides:**

$$7.943 = \frac{\text{power level}}{1 \times 10^{-3}}$$

5   **Multiply both sides by 1×10^{-3}:**

$$7.943 \times 10^{-3} \times \text{power level}$$

So a power of $+9\,\text{dBm}$ is the same as $7.943\,\text{mW}$.

Some dB values that are worth remembering:

▷ $-3\,\text{dB}$ = half power
▷ $3\,\text{dB}$ = a doubling of power
▷ $10\,\text{dB}$ = a tenfold increase
▷ $-10\,\text{dB}$ = a tenth power.

Power loss on an optic fiber

Light power on an optic fiber is lost during transmission either by leakage or due to lack of clarity of the material.

The loss is expressed in decibels per kilometer and is written as dB km^{-1}.

For silica glass fibers we are looking at values around $3\,\text{dB km}^{-1}$ for the fibers used for medium range transmissions. This corresponds to about half the power being lost for each kilometer of travel. For long distance telecommunication fiber the figures are typically $0.3\,\text{dB km}^{-1}$ giving losses of only 7% per kilometer.

If a kilometer has a loss of 3 dB, then 2 km will have a total loss of $2 \times 3 = 6\,\text{dB}$.

It is, after all, just the same as having two attenuators connected in series. So, to obtain the total loss of a fiber, we simply multiply the loss specification in dB km^{-1} by the length of the fiber (measured in kilometers of course).

Example

What is the output power, in watts, in the circuit shown in Figure 5.6?

Figure 5.6

What is the output power in watts?

Input power = −12 dBm

Loss = 0.2 dB

Length = 8.2 km
Loss = 2.4 dB km⁻¹

Length = 150 m
Loss = 3.0 dB km⁻¹
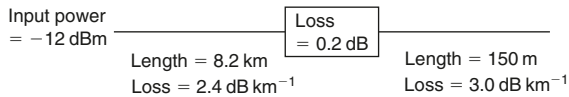
Method

1 Loss in a length of fiber = loss per km × length in km

So in the first length we have a loss of:

$$2.4 \times 8.2 = 19.68\,\text{dB}$$

and in the second case:

$$3.0 \times 0.15 = 0.45\,\text{dB}$$

(remembering to convert the 150 m to 0.15 km).

2 The circuit can now be simplified to that shown in Figure 5.7.

Figure 5.7

A simplified version

−12 dBm   −19.68 dB   −0.2 dB   −0.45 dB

3 This gives a total of −12 − 19.68 − 0.2 − 0.45 = −32.33 dBm

4 Convert this output power to watts by our previous method, giving a result of 0.58 μW.

Quiz time 5

In each case, choose the best option.
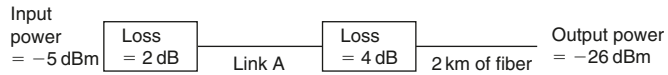
1 A power level of 50 μW could be expressed as:

(a) 1.69 dBm

(b) −4.3 dBm

(c) 1 dBm

(d) −13 dBm

2 The length of the link shown in Figure 5.8 is:

(a) 1 km

(b) 3 km

(c) 5 km

(d) 7 km

Figure 5.8

All fiber used

has a loss of

$3.0\,dB\,km^{-1}$

Input
power
$= -5\,dBm$ | Loss $= 2\,dB$ | Link A | Loss $= 4\,dB$ | 2 km of fiber | Output power $= -26\,dBm$

3   **If a power of 0.25 mW is launched into a fiber system with an overall loss of 15 dB, the output power would be:**

    (a) $250\,\mu W$

    (b) $31.6\,\mu W$

    (c) $7.9\,\mu W$

    (d) 15 dBm

4   **A system having an input power of 2 mW and an output power of 0.8 mW has a loss of:**

    (a) 2.98 dBm

    (b) 3.98 dB

    (c) $3.98\,\mu W$

    (d) 1.98 mW

5   **An output of $-10\,dB$ means that the power has been:**

    (a) halved in value

    (b) increased by a factor of 10

    (c) reduced by a factor of 10

    (d) doubled

6

Losses in optic fibers

In the last chapter we saw that losses of 3 dB (50% of the power) are often incurred over a single kilometer. The exact figures depend on the fiber in use and we will be having a closer look at this in Chapter 7. So, for the moment, where does the light go – and why?

Basically, there are just two ways of losing light. Either the fiber is not clear enough or the light is being diverted in the wrong direction.

We will start with the first problem.

Absorption

Any impurities that remain in the fiber after manufacture will block some of the light energy. The worst culprits are hydroxyl ions and traces of metals.

The hydroxyl ions are actually the form of water which caused the large losses at 1380 nm that we saw in Figure 3.2. In a similar way, metallic traces can cause absorption of energy at their own particular wavelengths. These small absorption peaks are also visible.

In both cases, the answer is to ensure that the glass is not contaminated at the time of manufacture and the impurities are reduced as far as possible. We are aiming at maximum levels of 1 part in 10^9 for water and 1 part in 10^{10} for the metallic traces.

Now for the second reason, the diversion of the light.

Rayleigh scatter

This is the scattering of light due to small localized changes in the refractive index of the core and the cladding material. The changes are indeed very localized.

We are looking at dimensions which are less than the wavelength of the light.

There are two causes, both problems within the manufacturing processes.

The first is the inevitable slight fluctuations in the 'mix' of the ingredients. These random changes are impossible to completely eliminate. It is a bit like making a currant bun and hoping to stir it long enough to get all the currants equally spaced.

The other cause is slight changes in the density as the silica cools and solidifies.

One such discontinuity is illustrated in Figure 6.1 and results in light being scattered in all directions. All the light that now finds itself with an angle of incidence less than the critical angle can escape from the core and is lost. However, much of the light misses the discontinuity because it is so small. The scale size is shown at the bottom.

Figure 6.1

The light is scattered in all directions
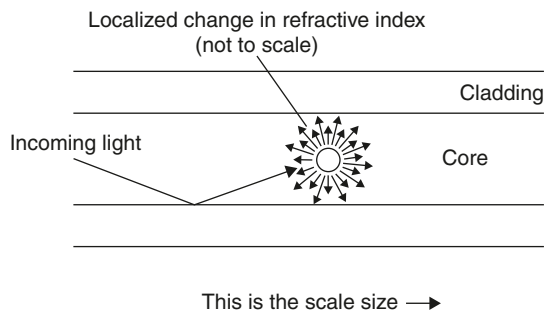
The amount of scatter depends on the size of the discontinuity compared with the wavelength of the light so the shortest wavelength, or highest frequency, suffers most scattering. This accounts for the blue sky and the red of the sunset. The high frequency end of the visible spectrum is the blue light and this is scattered more than the red light when sunlight hits the atmosphere. The sky is only actually illuminated by the scattered light. So when we look up, we see the blue scattered light, and the sky appears blue. The moon has no atmosphere, no scattering, and hence a black sky. At sunset, we look towards the sun and see the less scattered light which is closer to the sun. This light is the lower frequency red light.

Fresnel reflection

On a point of pronunciation, the 's' in Fresnel is silent.

When a ray of light strikes a change of refractive index and is approaching at an angle close to the normal, most of the light passes straight through as we saw in a previous chapter.

Most of the light but not all. A very small proportion is reflected back off the boundary. We have seen this effect with normal window glass. Looking at a clean window we can see two images. We can see the scene in front of us and

we can also see a faint reflection of what is behind us. Light therefore is passing through the window and is also being reflected off the surface.

We are most concerned about this loss when considering the light leaving the end of the fiber as shown in Figure 6.2. At this point, we have a sudden transition between the refractive index of the core and that of the surrounding air. The effect happens in the other direction as well. The same small proportion of light attempting to enter the fiber is reflected out again as in Figure 6.3.
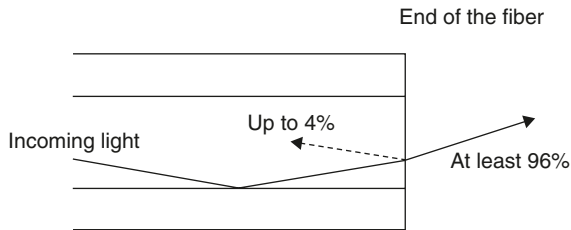
The actual proportion of the light is determined by the amount by which the refractive index changes at the boundary and is given by the formula:

$$\text{reflected power} = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2$$

To see how bad it can get, let's take a worst-case situation – a core of refractive index 1.5 and the air at 1.0.
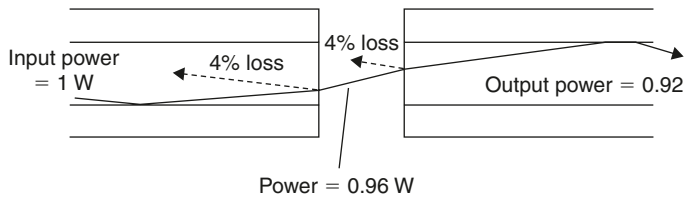
Figure 6.2

Fresnel

reflection

End of the fiber

Incoming light

Up to 4%

At least 96%

Figure 6.3

A Fresnel

reflection from

each surface

Input power = 1 W

4% loss

4% loss

Output power = 0.92

Power = 0.96 W

Method

Start by inserting the figures in the above equation:

$$\text{reflected power} = \left(\frac{1.5 - 1.0}{1.5 + 1.0} \right)^2$$

Simplify the top and bottom terms inside the brackets:

$$\text{reflected power} = \left(\frac{0.5}{2.5} \right)^2$$

Divide out the terms in the bracket:

reflected power $= (0.2)^2 = 0.04 = 4\%$

So, 96% of the incident light power penetrates the boundary and the other 4% is reflected. This reflected power represents a loss of 0.177 dB.

It may be worth mentioning in passing that if we try to squirt light from one fiber into another, we suffer this 0.177 dB loss once as the light leaves the first fiber and then again as the light attempts to enter the other fiber.

Remember that these figures are worst-case. We get up to all sorts of tricks to improve matters as we shall see when we look at ways of connecting lengths of optic fibers together.

Making use of Fresnel reflection

The return of the Fresnel reflection from the end of a fiber gives us a convenient and accurate method of measuring its length. Imagine a situation in which we have a drum of optic fiber cable marked 5 km. Does the drum actually contain 5 km? or 4.5 km? or is it in five separate lengths of 1 km? It is inconvenient, to say the least, to uncoil and measure all fiber as it is delivered.

The solution is to make use of Fresnel reflection that will occur from the far end. We send a short pulse of light along the fiber and wait for the reflection to bounce back. Since we can calculate how fast the light is traveling and can measure the time interval, the length is easily established. This magic is performed for us by an instrument called an *optical time domain reflectometer* (OTDR), as discussed in Chapter 15.

Bending losses

Macrobends

A sharp bend in a fiber can cause significant losses as well as the possibility of mechanical failure.

It is easy to bend a short length of optic fiber to produce higher losses than a whole kilometer of fiber in normal use.

The ray shown in Figure 6.4 is safely outside of the critical angle and is therefore propagated correctly.

Remember that the normal is always at right angles to the surface of the core. Now, if the core bends, as in Figure 6.5, the normal will follow it and the ray will now find itself on the wrong side of the critical angle and will escape.

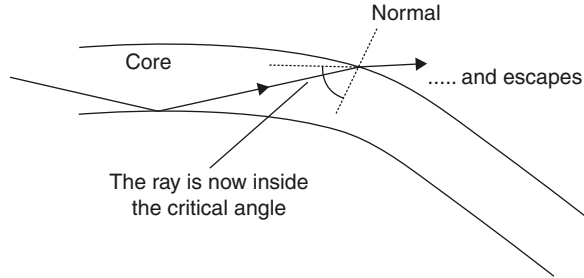Tight bends are therefore to be avoided but how tight is tight?

The real answer to this is to consult the specification of the optic fiber cable in use, as the manufacturer will consider the mechanical limitations as well as the bending losses. However, a few general indications may not be out of place.

Figure 6.4

The usual

situation

The light approaches
outside of the critical angle

Normal

Core

Critical angle
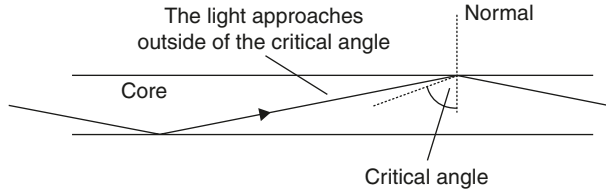
Figure 6.5

Sharp bends

are bad news

Normal

Core

..... and escapes

The ray is now inside
the critical angle

A bare fiber – and by this is meant just the core/cladding and the primary buffer – is safe if the radius of the bend is at least 50 mm. For a cable, which is the bare fiber plus the outer protective layers, make it about ten times the outside diameter or 50 mm, whichever is the greater (Figure 6.6).

The tighter the bend, the worse the losses. Shown full size, the results obtained with a single sample of bare fiber were shown in Figure 6.7. Attached instruments indicated a loss of over 6 dB before it broke.
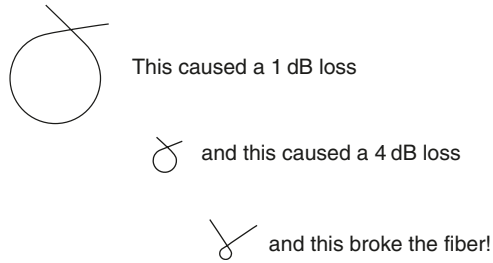
The problem of macrobend loss is largely in the hands of the installer.

Figure 6.6

Minimum safe

bend radius –

shown full size

Bare fiber

100 mm diameter
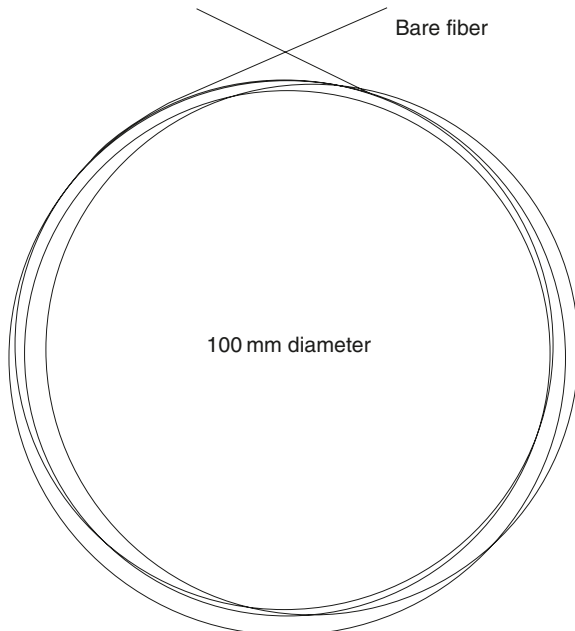
Figure 6.7
Bends are
shown full
size – and may
have caused
damage to the
fiber

This caused a 1 dB loss

and this caused a 4 dB loss

and this broke the fiber!

Making use of bending losses

There are many uses of bending losses which are based on either the increase in the attenuation or on making use of the light which escapes from the optic fiber.
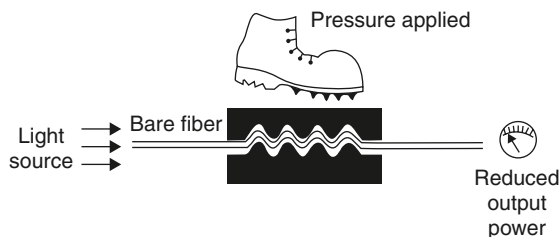
A fiber optic pressure sensor

This makes use of the increased attenuation experienced by the fiber as it bends.

A length of bare fiber is sandwiched between two serrated pieces of rubber or plastic matting. The fiber is straight and the light detector is 'on guard' at the far end (Figure 6.8).

Figure 6.8
The fiber is
straight when
no pressure is
applied

Light
source

Bare fiber
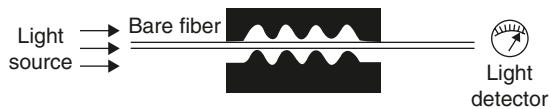
Light
detector

Figure 6.9
Pressure
causes loss at
the bends

Pressure applied

Light
source

Bare fiber

Reduced
output
power

Someone steps on the mat (Figure 6.9). Bends are created and the reduction in the light intensity at the far end is detected and the alarm goes off. By changing the size of the serrations and the materials it is obviously possible to change the sensitivity of the device to detect a wide range of pressures. The length of the fiber doesn't matter so a single light source and detector can be used to monitor many pressure pads at the same time.
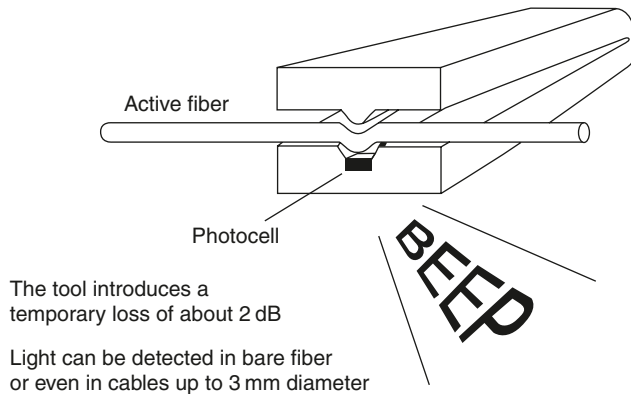
Active fiber detector

This uses the escaping light.

Many fibers used in telecommunications carry invisible infrared light of sufficient intensity to cause permanent eye damage. Before starting any work on fiber it is obviously of the greatest importance to know whether the fiber is carrying light and is therefore 'live' or 'active'.

It works on a principle which is very similar to the pressure detector except that it sniffs the light escaping. One example of such as device is shown in Figure 6.10.

Figure 6.10

Is the fiber in use?

Active fiber

Photocell

The tool introduces a temporary loss of about 2 dB

Light can be detected in bare fiber or even in cables up to 3 mm diameter

BEEP

The fiber is placed between the jaws of the tool and, as they close, a sharp bend is created and some of the light escapes. The escaping light is detected by a photocell and is used to switch on a warning light or beeper. Some versions will also detect the direction of the traffic on the fiber.

Talkset

As all light paths are reversible, it follows that a sharp bend can allow light to enter the fiber as well as to leave it. Two devices similar in outline to the active fiber detector are clipped on to the same piece of fiber. Using a microphone to control a light source means that we can speak into the microphone and put a light signal onto the fiber. At the other end, maybe a hundred kilometers away, a friend clips on a similar device to extract the light. The output from the photocell, after suitable amplification, is fed to a pair of headphones. Putting both a transmitter and a receiver at each end allows communication between the two sites during testing or installation.

Even in a small building, it saves endless running up and down the stairs shouting 'are you ready?'

Microbends

These are identical in effect to the macrobend already described but differ in size and cause. Their radius is equal to, or less than, the diameter of the bare fiber – very small indeed (Figure 6.11).

Figure 6.11
Differential
contraction
can cause
microbends
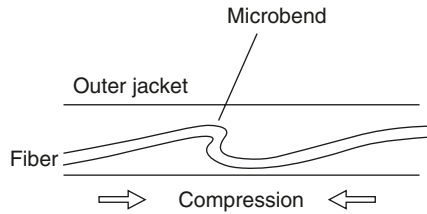
These are generally a manufacturing problem. A typical cause is differential expansion of the optic fiber and the outer layers. If the fiber gets too cold, the outer layers will shrink and get shorter. If the core/cladding shrinks at a slower rate, it is likely to kink and cause a microbend.

With careful choice of the fiber to be installed, these are less likely to be a problem than the bending losses caused during installation since optic fiber cables are readily available with a wide range of operating temperatures from $-55°C$ to $+85°C$.

Quiz time 6

In each case, choose the best option.

1   An active fiber detector:

(a) is used to prevent accidental exposure to invisible light

(b) is a communication system used during installation

(c) detects movement of fiber in security systems

(d) can be used to weigh objects

2   If light leaves a material of refractive index 1.45 and crosses an abrupt boundary into a material of refractive index 1.0, the Fresnel loss would be:

(a) 0.346 dB

(b) 0.149 dB

(c) 1.613 dB

(d) 3 dB

3   Absorption loss is caused by:

(a) insufficient stirring of the ingredients during manufacture

(b) changes in the density of the fiber due to uneven rates of cooling

(c) microscopic cracks in the cladding which allow leakage of the vacuum
    in the core

(d) impurities in the fiber

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4   Rayleigh scatter is most severe:

(a) in light with a short wavelength

(b) in blue light on the Earth and black light on the moon

(c) in low frequency light

(d) at sunset

5   Bending losses:

(a) always result in breakage of the fiber

(b) can be caused by microbends and macrobends

(c) are used to detect the length of fiber on a drum

(d) are caused by the difference in the operating temperature of the core
    compared with the cladding on active fibers