

# 17

## The transmission of signals

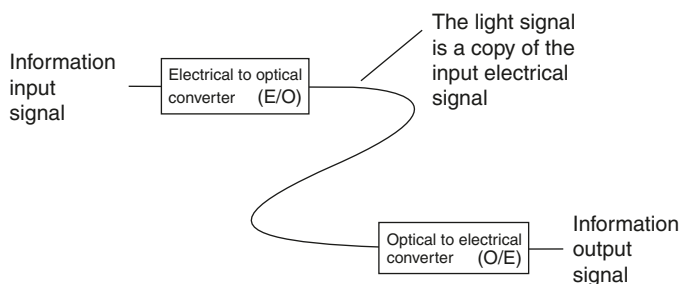
So far we have been concerned with the design and operation of fiber optic systems for the transmission of light. For it to be of use to us, we must be able to send data along the fiber and be able to recover it at the far end.

We will now have a look at some alternative techniques.

### Analog transmission

This is the simplest method and is generally used for short range work. It is illustrated in Figure 17.1.

**Figure 17.1**  
An analog transmission system



The incoming information signal, speech, music, video, etc. is used to control the power output from the LED or the laser. The light output is, as near as possible,

a true copy of the electrical variations at the input. At the far end of the fiber, the receiver converts the light back into an electrical signal, which is, hopefully, the same as the original electrical signal.

Any non-linearity of the characteristics of the transmitter or receiver will reduce the accuracy of the electrical/optical (E/O) and optical/electrical (O/E) conversions and give rise to distortion in the output signal.

Another problem is noise. Since the receiver is receiving an analog signal, it must be sensitive to any changes in amplitude. Any random fluctuations in light level caused by the light source, the fiber or the receiver will cause unwanted noise in the output signal. Electrical noise due to lightning will also give rise to electrical noise in the non-fiber parts of the system.

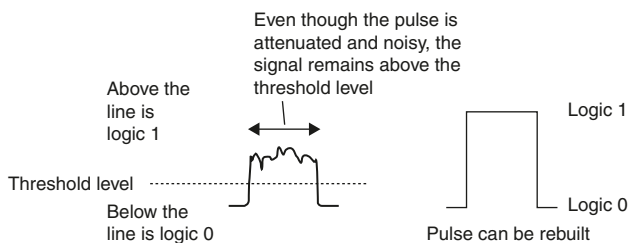
As the signal travels along the fiber, it is attenuated. To restore signal amplitude, we add amplifiers called *repeaters* at regular intervals. The repeater has a limited ability to reduce noise and distortion present, which means that we tend to accumulate problems as we go.

## Digital transmission

In a digital system, the information signal is represented by a sequence of on/off levels. We will see how this is done in a minute or two. The 'on' state is often referred to as logic 1 and the 'off' state as logic 0. The 1 and 0 have no numerical significance and are just convenient ways to differentiate between the two states. We could have called them black and white, up and down, salt and pepper, or anything else.

At the repeaters, and at the final receiver we only have to ask whether or not a signal is present by comparing the signal with a chosen *threshold* level shown in Figure 17.2.

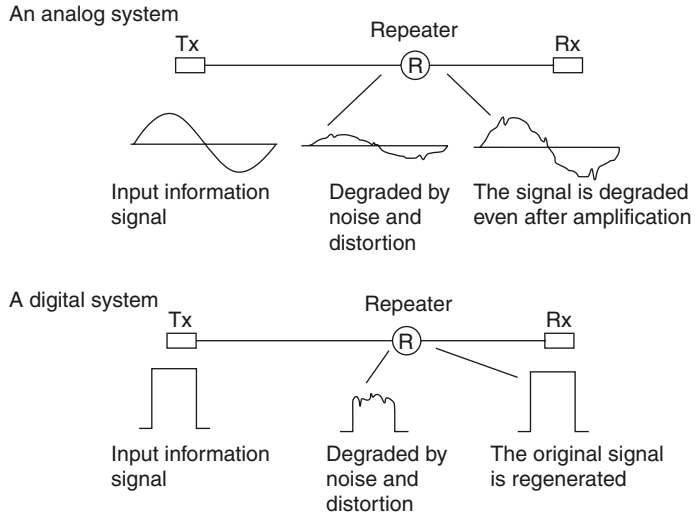
**Figure 17.2**  
Repairing  
damaged  
digital pulses



This 'yes' or 'no' approach means that it ignores noise and distortion since all voltages above the threshold level are recognized as a logic 1 state and all below this level as a logic 0. The signal is then regenerated as a perfect copy of the original signal. Repeaters in digital systems are called regenerators since they regenerate or rebuild the signals rather than just amplifying them. Regenerator spacing can be increased allowing signals to become very small before there is any danger of it becoming lost in the noise.

Figure 17.3 offers a summary of analog and digital systems.

**Figure 17.3**  
One of the benefits of a digital system

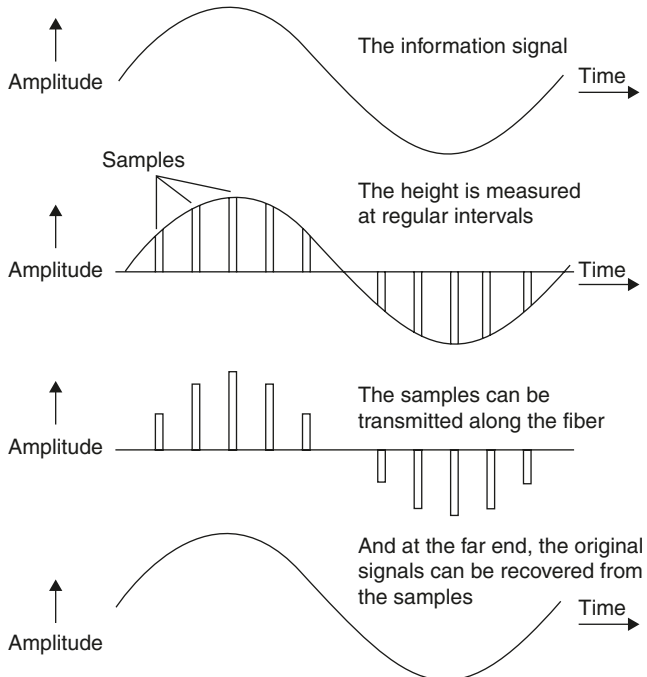


## Converting an information signal into a digital form (digitizing)

### Sampling – Figure 17.4

The first step in the process is to measure the amplitude of the input waveform at regular intervals. These measurements are called *samples*.

**Figure 17.4**  
Pulse amplitude modulation (PAM)



It has been found that providing the samples are taken at frequent enough intervals they will contain sufficient information about the input signal for it to be reformed at the far end of the system.

The sampling rate must be greater than twice the highest frequency contained in the input signal. This is called the *Nyquist criterion*. For example, a typical telephone link would contain frequency components up to a maximum of 3.4 kHz and could be sampled at any frequency greater than 6.8 kHz.

## Pulse amplitude modulation (PAM)

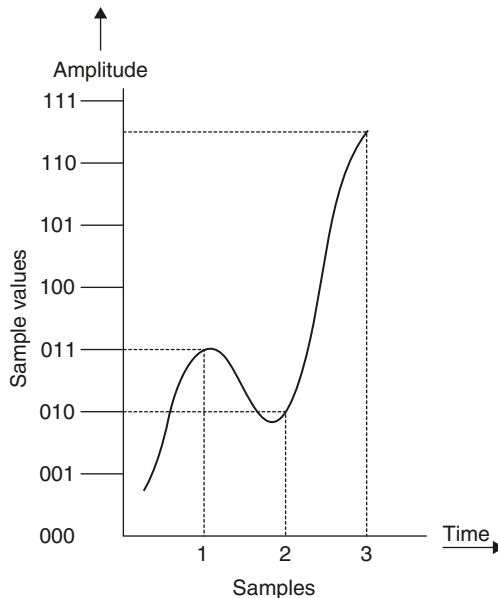
The transmission is a series of pulses and at first glance it appears to be digital but it is actually an analog signal in disguise. The deciding feature that makes it analog is that the sample pulses can be of any amplitude whereas a digital signal is a series of pulses all of which are of the same size.

PAM is rarely used since we have had to go to all the trouble of sampling the signal but we still have an analog signal and it is therefore still susceptible to noise. It seems like we have gone to a lot of trouble for nothing. However, it is the essential first stage in converting the signal into a digital format.

## Pulse code modulation (PCM)

In a PCM system, the information signal is sampled as in the PAM system, and the amplitude of each sample is then represented by a binary code. In Figure 17.5 the

**Figure 17.5**  
PCM coding



Sample 1 has a value of 011  
Sample 2 has a value of 010

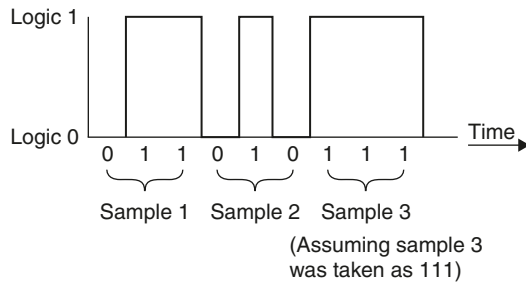
But what about sample 3?

maximum amplitude is divided into 8 levels counting up from 0 to 7 in binary. In some cases, the value of the waveform will fall between two values such as in sample 3 where it is between 110 and 111. Whether the coding circuit decides to value it as 110 or as 111 it will not be a true representation of the information signal. This misrepresentation is called *quantization noise*.

Quantization noise can be reduced by increasing the number of levels used but never eliminated. For example, if an 8 volt signal were to be quantized into 8 levels, the levels would increase in 1 volt steps. If the nearest level was always selected, the quantization noise could have a maximum value of 0.5 volt, being half the step value. Now, if we increased the number of steps to say 80, the levels would be 0.1 volt apart and the maximum possible error would again be half of the step value, or 0.05 volts. Increasing the number of steps means less quantization noise at the expense of having to send more binary digits and hence increasing the transmission bandwidth.

Within the time interval associated with each sample, called a *time slot*, the binary code is transmitted as a digital code. In Figure 17.5, the three samples would be transmitted as 011, 010, and 111 (possibly 110). The resulting transmission is shown in Figure 17.6.

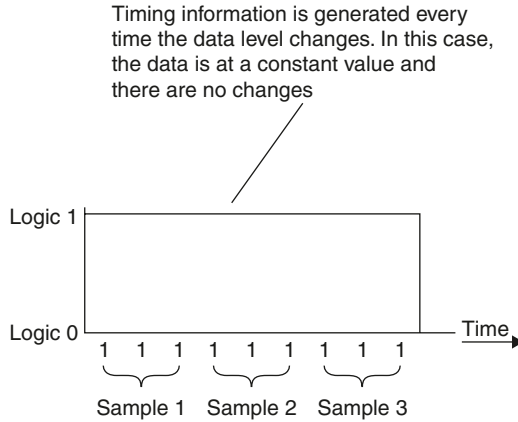
**Figure 17.6**  
PCM  
transmission



At the receiver, the incoming waveform is tested during the sample time to see if the signal is at logic 0 or at logic 1. The data associated with each sample and hence the original information can then be recovered. This relies on the sampling times being synchronized at the transmitter and at the receiver. There are many different ways to achieve this. The least inviting is to send another signal just to provide timing or *clock* information. This is clearly a wasteful method and, in practice, the clock information is extracted from the incoming signal.

Generally, the level changes that occur in a PCM transmission are used to keep the receiver clock synchronized to the transmitter. Every time the transmitted signal changes its level, the sudden change in voltage is detected by the receiving circuit and used to ensure that the receiver clock remains locked on to the transmitter clock. There are problems when the incoming signal stays at a low level or a high level for a long period of time as shown in Figure 17.7. The constant voltage level gives an output of continuous ones or zeros and the timing information would be lost and the receiver clock would drift out of synchronization.

**Figure 17.7**  
Constant level signals can cause timing problems



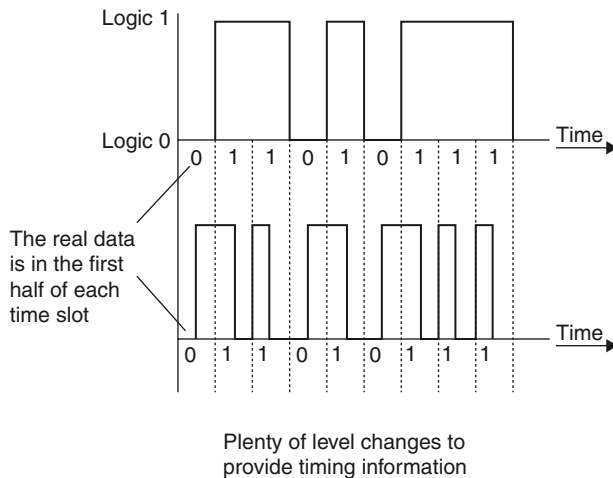
### Biphase (Manchester) code

There are several different methods of coding the data prior to a PCM transmission that overcome the problem of continuous levels. The Biphase (Manchester) code is a popular one and serves to illustrate the possibilities.

The encoding method is to reverse the level of each pulse during the second half of each timeslot. For example, to transmit a 0 level, we send a 0 for half of the available time, and then send a 1. Likewise, to send a level 1, we send a 1 followed by a 0.

Whatever the data being sent there will always be a change of level during each time slot to provide the necessary clock synchronization information (Figure 17.8). At the receiver a circuit called a decoder is used to reconstruct the PAM signal and from that the original information can be extracted.

**Figure 17.8**  
Biphase (Manchester) coding



## How to get more digital signals on a single fiber

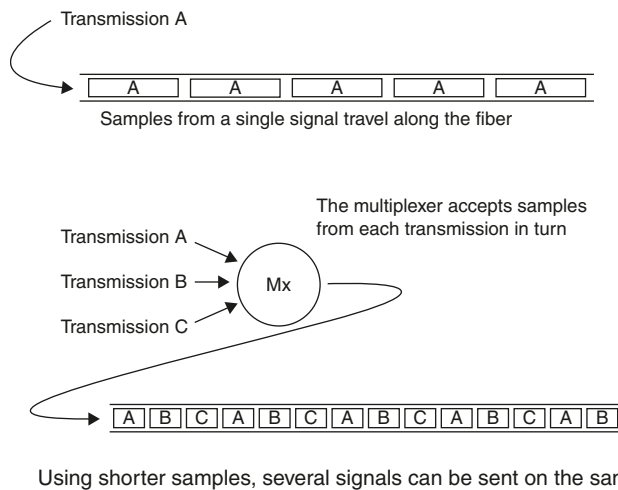
### Time division multiplexing (TDM) – Figure 17.9

This is the most popular method for increasing the number of signals that can be carried on a single fiber.

If the width of the pulses in a PCM system is reduced, then there will be spaces between them. These spaces can be filled with another transmission containing data associated with another, quite separate, information signal.

The further we reduce the width of the transmitted pulses, the larger the number of other signals that can be slotted in to share the same fiber.

**Figure 17.9**  
Time division multiplexing (TDM)



Using shorter samples, several signals can be sent on the same fiber

The interleaving of the samples from the two transmissions is carried out by a circuit called a *multiplexer*.

At the receiving end we use a *demultiplexer* which simply sorts the samples out into their separate signals from which the information can be recovered.

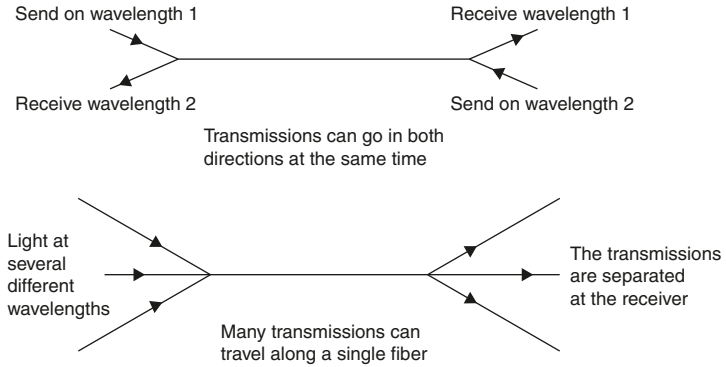
As the pulses become narrower, the bandwidth of the signal increases and this serves to put an upper limit on the number of signals that can be multiplexed by this method.

### Wave division multiplexing (WDM) – Figure 17.10

The technique allows thousands of different signals to be carried along a single fiber at the same time or a fiber to be used for two-directional transmission. It achieves this by using different wavelengths for each transmission and can be employed on single mode or multimode fibers using lasers or LEDs.

We can derive the different frequencies from independent light sources or we can take the light from a broadband device like an LED and split the light into separate channels. The combination and separation can be achieved by wavelength sensitive couplers.

**Figure 17.10**  
Two benefits  
of wavelength  
division  
multiplexing  
(WDM)



Advocates of this system suggest an increased capacity of between a hundred and a thousandfold. It is also a simple way to expand an existing fiber link – just send another signal at a different wavelength along the same route.

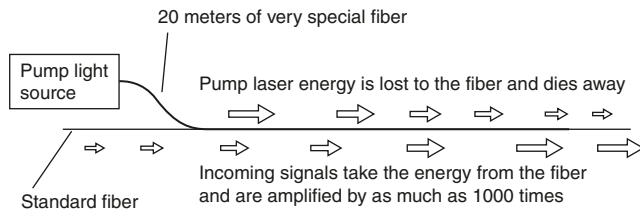
### How to send data further

To overcome the effects of attenuation in the fiber, we must introduce repeaters at intervals to amplify the signals. This involves a light detector to convert the signal from light to an electrical signal. The electrical signal is then amplified and used to power another light source for the next section of fiber.

Much development is continuing on an alternative approach. Optic fiber amplifiers enable a signal to be amplified without converting it to an electrical signal first; a direct light in/light out repeater.

The heart of the matter is a length of very special fluoride based fiber. It is constructed in the same manner as the standard silica fiber but it has the property of being able to transfer light energy between two different signals which are traveling in the same direction in the fiber (Figure 17.11).

**Figure 17.11**  
An optic fiber  
amplifier



We use a light source called a *pump* to inject energy into the fluoride fiber. The pump light and the weak incoming signal pass through the fiber and as it does so, energy is passed from the pump light into the molecules of the fiber and from there into the signal to be amplified. The wavelength of the pump is critical and is determined by the design of the amplifying fiber in use.

As the light energy travels along the fiber, the pump light becomes weaker as the energy is absorbed by the fiber and the incoming signal is amplified by absorbing energy from the fiber.



A length of about 20 meters can provide an amplification of up to +30 dB ( $\times 1000$ ) giving the possibility of using repeaters at distances of well over 100 km.

## Quiz time 17

In each case, choose the best option.

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**1 PAM is:**

- (a) a pulse system immune from noise
- (b) a digital system
- (c) a popular system for telephone transmissions
- (d) an analog system

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**2 A suitable sampling rate for a signal containing frequency components between 40 Hz and 4 kHz would be:**

- (a) 10 kHz
- (b) 80 Hz
- (c) 90 Hz
- (d) 4.04 kHz

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**3 Quantization noise can be reduced by:**

- (a) taking samples at a faster rate
- (b) using a PCM system
- (c) increasing the number of levels during sampling
- (d) using higher amplitude signals

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**4 A bi-phase (Manchester) system:**

- (a) is not a real digital system
- (b) generates timing information, even when the incoming data is held at a constant level
- (c) eliminates quantization noise
- (d) does not require a receiver clock

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**5 TDM:**

- (a) requires a light source able to produce light at more than one wavelength
- (b) allows more than one signal to be transmitted along a single optic fiber
- (c) cannot be used to transmit digital signals
- (d) stands for time duplication multiplexing

# 18

## Designing an optical system and selecting components

The world of communications cabling is now dominated and controlled by standards. The cabling itself is called structured cabling or premises cabling to reflect the ordered set of rules that now apply to campus and building cable networks.

### **National and international standards**

Adherence to the rules will guarantee that your communications protocol of choice will work on the cable plant you have installed – copper or fiber. Most manufacturers now give extensive warranties that the cable system will handle all protocols for decades: **as long as you have obeyed the rules, and can prove it.**

The number of international standards has proliferated over the last ten years but there are a few to focus on. First of all we must understand that there are three major ‘blocks’ of standards activity:

- 1 USA: standards for cabling are written by the TIA (Telecommunications Industry Association – with input from others) and approved by ANSI, the American National Standards Institute. These standards are closely followed by the CSA, Canadian Standards Authority.
- 2 Europe: the body known as CENELEC writes all electrical standards for the European Union.

- 3 The world in general: ISO and IEC, based in Switzerland, write standards for a worldwide audience. ISO concentrates on systems and methods, whereas IEC concentrates on components and test methods, e.g. IEC writes the optical connector and all the test standards whereas ISO writes the overall cable system design standard.

This then leads to the three main cabling system standards which are:

**ANSI/TIA/EIA-568-B-2001** Commercial Building Telecommunications Cabling Standard

**EN 50173-1:2002** Information technology – Generic cabling systems – Part 1: General requirements and office areas

**ISO 11801:2002** Information technology – Generic cabling for customer premises.

All of these standards branch off to hundreds of other standards, which in turn detail every component and test method possible. The three standards listed above are the key ones however. Nowadays all the standards bodies and committees actually talk to each other so the practical differences between the standards are quite low.

In the UK the CENELEC standards are published by the British Standards Institution and are prefixed with BS as in BS EN 50173.

### Picking the right fiber

We have learned by now that we can select 50/125, 62.5/125 or even single mode fiber for an installation. Plastic and a range of other speciality fibers are also available, of course, but 50/125, 62.5/125 and single mode are the only ones that the premises cabling standards currently recognize.

The standards (ISO 11801 and EN 50173) try to make life a little easier by standardizing on the performance of a range of fibers and have given them the following names:

- ▷ OM1 which can be 50/125 or 62.5/125
- ▷ OM2 which can also be 50/125 or 62.5/125
- ▷ OM3 which is only seen as a 50/125
- ▷ OS1 a standard telecommunications grade single mode

Table 18.1 gives the minimum bandwidths available for each fiber. We can see that OM3 seems to have two different bandwidths. It turns out that multimode fibers don't have quite the same useable bandwidth when using an LED as the launching device as they do when a laser is used.

This is because an LED launches light into an optical fiber like a searchlight aimed into a drinking straw. It completely fills the core and the cladding at the start of the fiber. The resulting bandwidth of the fiber is then called the *overfilled launch bandwidth*.

When using a laser however, as we must do for gigabit and beyond transmission schemes, the effect is like shining a laser pointer into a drainpipe and only a small section of the fiber core is illuminated by the beam. The resulting bandwidth is called the *effective modal bandwidth*.

**Table 18.1** ISO 11801:2002 optical fiber classes and their bandwidth.

Fiber type	Core diameter, microns	Minimum modal bandwidth (MHz · km)		
		Overfilled launch bandwidth		Effective modal bandwidth
		850 nm	1300 nm	850 nm
OM1	50 or 62.5	200	500	Not specified
OM2	50 or 62.5	500	500	Not specified
OM3	50	1500	500	2000
OS1	Single mode	n/s	n/s	Not specified

The first multimode fibers were never really intended to be used with lasers and so the ‘laser bandwidth’ of these fibers is a bit unpredictable. When lasers started to appear in gigabit LANs (Local Area Networks) some of these fibers became a bit of a problem. OM3 was developed principally for the gigabit Ethernet market where the low cost 850 nm VCSEL is used and we can see from Table 18.1 that it provides the remarkable bandwidth of 2000 MHz · km at 850 nm – good enough for at least 300 m of ten gigabit Ethernet transmission.

### Maximum length of optic fiber cable runs

The maximum lengths possible depend upon how fast you want the link to operate (hence limited by the bandwidth of the fiber) and how much optical power is needed to make the receiving equipment work (hence limited by the attenuation of the fibers and connectors).

This used to be (and sometimes still is) quite complex, as touched upon in Chapter 16 where the bandwidths and attenuations of the cable plant would have to be matched to manufacturers’ data sheets for different communications protocols and even components.

The modern standards have simplified this to some extent by offering tables that offer simple choices between transmission speed and distances required and allow an appropriate fiber to read off from the table, i.e. Table 18.2.

**Table 18.2** Distance versus speed for the four fiber types.

Max. transmission speed	Transmission distance		
	300 m	500 m	2000 m
10 Mb/s	OM1	OM1	OM1
100 Mb/s	OM1	OM1	OM1
1000 Mb/s	OM1	OM2	OS1
10 000 Mb/s	OM3	OS1	OS1

The standards also helpfully list out the optical power budgets required for most standard Local Area Networks (LANs) as a final check to ensure the link will work. Failing that, the standards give default maximum cable lengths for when the cable appears in a campus or building backbone, the final horizontal link to the desk or in a 'home-run' architecture called COA, Centralized Optical Architecture.

### **Living with copper cables**

Optical fiber has never displaced copper cables to the extent predicted by the pundits twenty years ago. Indeed, the advance of microchips affording massive amounts of signal processing power has eked out every last Hertz of bandwidth out of copper cables so installations are nearly always a mix of copper and fiber cables nowadays, each picked for its particular price and performance position.

### **Advantages of copper**

- 1 Many technicians are happier when using copper cables because they are familiar and unless they have taken the trouble to get to grips with optic fiber, copper cables seem so much simpler.
- 2 Connections are easier with hand tools and do not require expensive equipment and great precision.
- 3 A simple metal detector can find a buried cable. This is only half an advantage because many optic fiber cables use metallic foil for moisture protection and metallic armoring.

### **Disadvantages of copper**

These have been explained in Chapter 8 as advantages of optic fibers but to save the trouble of finding them again they are listed below as disadvantages of copper.

- 1 Susceptible to electrical interference and crosstalk.
- 2 Care has to be taken in high voltage environments.
- 3 Reduced bandwidths.
- 4 Security.
- 5 Higher losses.
- 6 Size and weight.
- 7 Two wires are used to send a single signal.

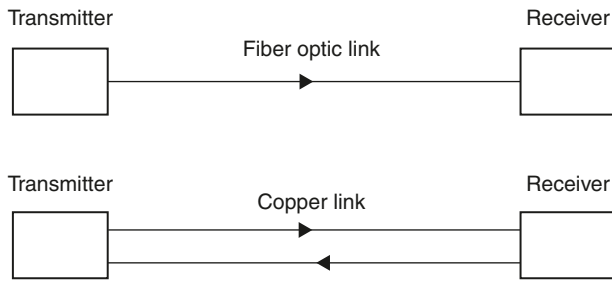
### **How copper cables work**

To send a telecommunication signal by copper cable requires an electric circuit. This means that we need two wires, usually referred to as a single pair (see Figure 18.1).

The transmitter generates a voltage signal between the two wires at the input and this results in a current flowing along one wire, through the receiving circuitry and back along the other wire. Compared with fiber, this doubles the number of connections necessary.

One problem with any electrical signal is that whenever electric current flows, it causes a changing magnetic field. This is, in itself, not a worry unless there is

**Figure 18.1**  
A copper link  
needs more  
wires

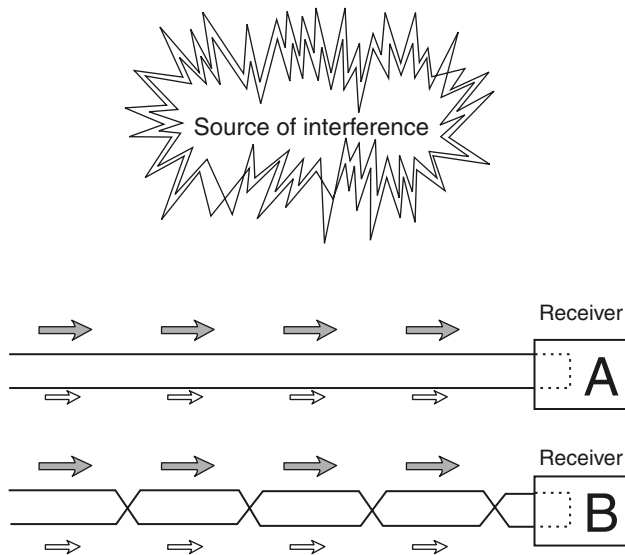


another copper wire nearby. The changing magnetic field caused by the signal will cause a voltage to be induced into the copper wire causing a weak copy of the original signal. This effect is called *crosstalk*.

The magnitude of the induced voltage decreases by the square of the distance away from the source of the interference, so if we double the distance, we reduce the induced voltage by a factor of four. If two copper wires are running side-by-side, the one closest to the source of interference will pick up a larger signal than the one further away.

We can also reduce, but not entirely eliminate, this effect by twisting the copper wires (Figure 18.2).

**Figure 18.2**  
Twisted wires  
reduce  
interference



In circuit A, the upper wire is closer to the source and hence has a higher voltage induced. This larger voltage is indicated by the larger arrows and, at the moment shown, is trying to push the current clockwise round the circuit while the other wire is trying to push the current counterclockwise. The big arrows will win and the overall effect will be to produce a small current that will be a copy of the interference signal.

In a communication system the interference signal may be a conversation on a nearby telephone or a crackle from electrical machinery, or lightning, or any other source of interference.

In circuit B, each wire changes position so that the total value of the induced voltage is equal in each wire. This would give the happy result of no overall effect and hence no interference.

To work efficiently, the two wires must be twisted very carefully to keep them both balanced. When we have several pairs close together in a single cable, the rate of twist is varied and this helps to reduce the likelihood of two wires accidentally running parallel with their twists in step.

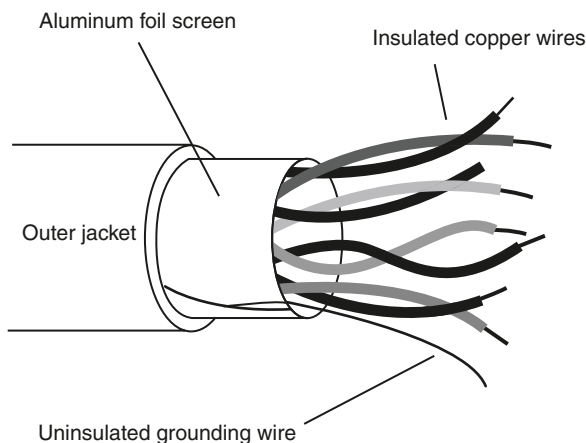
### Copper cable designs

Cables can all look similar from the outside, in fact, apart from markings on the outer cover, there is no way of telling them apart so we must be careful not to cut into an optic fiber cable only to find copper cores.

### Twisted pair cables

Just as in fiber optics, a range of copper cables is available for indoor use from just two pairs of conductors up to enormous armored underground cables containing up to 4200 pairs of conductors. Figure 18.3 shows a typical four-pair screened copper cable.

**Figure 18.3**  
A four-pair  
copper cable



There are three similar versions of twisted pair cables all looking very similar to Figure 18.3. The differences are in the screening; also known as shielding. The simplest is no screening at all and is just called *unscreened* or often *UTP*, meaning 'unscreened twisted pair'.

Then comes the grounded (also known as earthed) screen that helps to reduce high frequency interference signals from reaching (or leaving) the cable. The other alternative is to wrap each pair separately in aluminum foil and then add braid under the jacket to screen the whole cable. This also provides protection against low frequency interference.

Twisted pair cables are nowadays known by their 'Category' of operation; usually shortened to 'Cat'. Cat 3 cable offers a frequency range of up to 16 MHz and is only used for backbone telephone cables. Cat 5 offers 100 MHz and is the most prevalent 'to-the-desk' cable in the world. Cat 6 provides 250 MHz and is now specified in most new projects. Cat 7 gives at least 600 MHz, but in a very heavily screened and expensive cable. Augmented Category 6 will give 500 MHz of usable bandwidth and is being designed for the next generation 10GBASE-T Ethernet, or ten thousand million bits per second – an incredible speed for a twisted pair cable.

If you are wondering what happened to Categories 1, 2 and 4; well, the system actually only got going with Cat 3 and the ill-fated Cat 4 was overtaken by Cat 5 almost before it was developed!

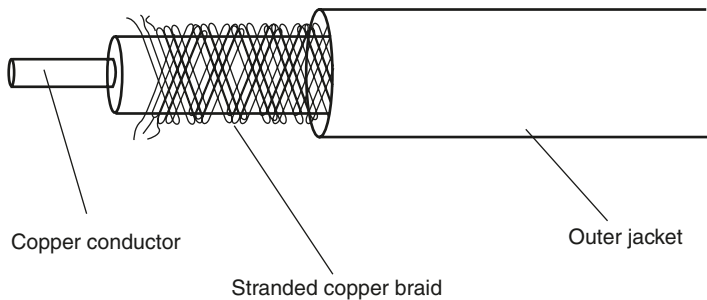
All of these cables can be supplied with or without screening elements, except Cat 7, which due to the very high frequency of operation will only work with adequate levels of screening.

### Coaxial cable

These give improved protection against interference and are familiar cables at home where they provide the signal inputs to televisions and videos, etc.

Some minor variations occur. The outer braid sometimes has two layers, and some include aluminum foil wrapping around the center conductor, but they are all easily recognizable (see Figure 18.4).

**Figure 18.4**  
Coaxial cable



### Fiber in and between buildings

In this section we will have a look at a typical layout in a building or group of buildings. In reality, the installation may differ owing to local customs or special circumstances but the trend is towards using a standard layout of this form. Such harmonization will make life easier for everyone in the industry whether they are installing, extending or repairing a system.

#### Making an entrance

Getting the fiber into a building is usually a matter of balancing the immediate and long-term costs. We can have a low initial cost but accept higher costs when repairs or modifications are required or we can pay higher immediate costs but less in the future. Let's start with the cheap initial cost since this may win us the contract if the customer does not take the long-term view.



### The dig a hole and throw it in method

This is easy. Get a trench digger or plow and prepare a hole, then pass a length of conduit through the wall of the building. Next we lay the copper and fiber cables in the trench, pass them through the conduit into the building and make the connections to the service provider in their manhole. Finally, refill the trench. Job done. Out of sight, nice and cheap.

There are some problems. What would the digger person do if they came across an obstruction? They would simply go around it, however long the detour, so long as they can finish at the conduit through the wall. The cables would be added and the trench refilled. Is the actual route of the cables going to be accurately recorded in the plans? What do you think?

The cables are not protected and in years to come when the cable needs attention will we be able to find it? Is it now under the new staff car park? Or the new building? Will it be cut by the utility company laying pipes?

### The spend more and do it better method

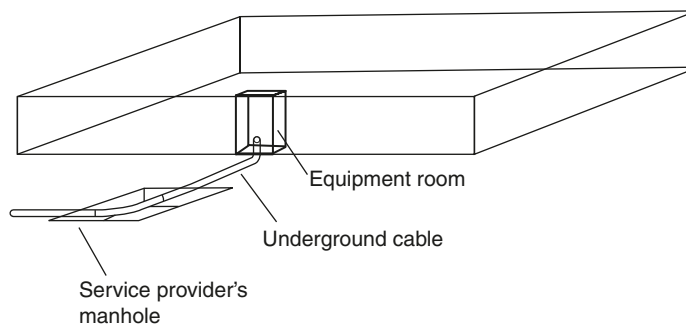
If the cables are installed in duct or conduit or other proper mechanical enclosure it takes a little extra time and money but the cable is better protected and is in a known place so extra cables can easily be installed. The access point of the conduit through the wall needs to be sealed to prevent water or gas gaining access to the building.

## Making a start

In this example we have used an underground route to bring the cable from the service provider's manhole into our building. It is fed into an equipment room from which our cables can wander off around the building. This situation is shown in Figure 18.5.

**Figure 18.5**

The cable(s) enter our building



The equipment room will be something between a proper room and a cupboard where the brushes are kept.

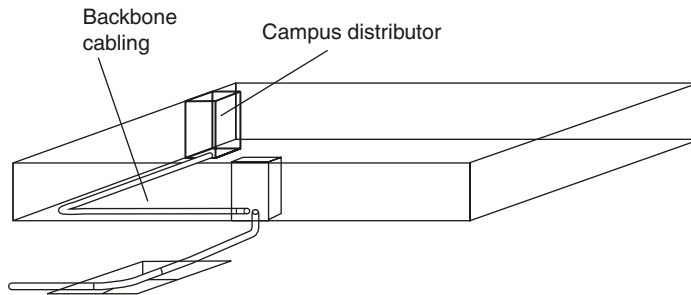
Somewhere between the manhole in the road and the equipment room outlets, the responsibility for the cabling is transferred to us from the service provider.

We need to be aware of where this transition occurs for all sorts of legal reasons otherwise it may result in our lawyers getting richer and us getting poorer – not the idea at all.

## Inside the building

So far we have got from the road to just inside our building. The cables, copper and fiber, now go to another equipment room called the *campus distributor* or *main cross-connect*. This is the main interconnection point for the remainder of the system. The system may be a single room, a multistory building or several buildings like a business park or university campus. The bundles of cables going between equipment rooms are called *backbone cables* as in Figure 18.6. The cabling may be hidden away in ceiling spaces or under the floors or in channels or conduit – wherever convenient.

**Figure 18.6**  
The campus distributor

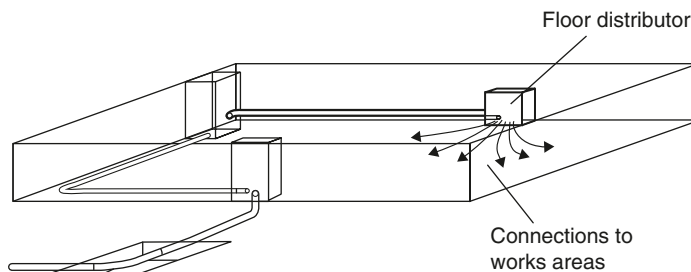


## Inside the room

To connect the 'campus distributor' or 'main cross-connect' to the individual work areas inside the room is the function of a junction box called a *floor distributor* or *horizontal cross-connect*. Despite the name, cables can be installed vertically as well as horizontally. By having an organized hierarchy of connections like this, faults can be traced back and isolated more systematically.

The final connections within a room are shown in Figure 18.7.

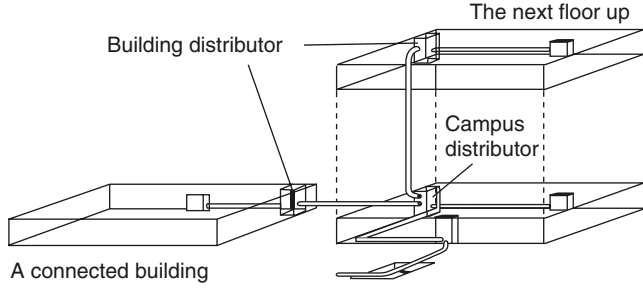
**Figure 18.7**  
The floor distributor



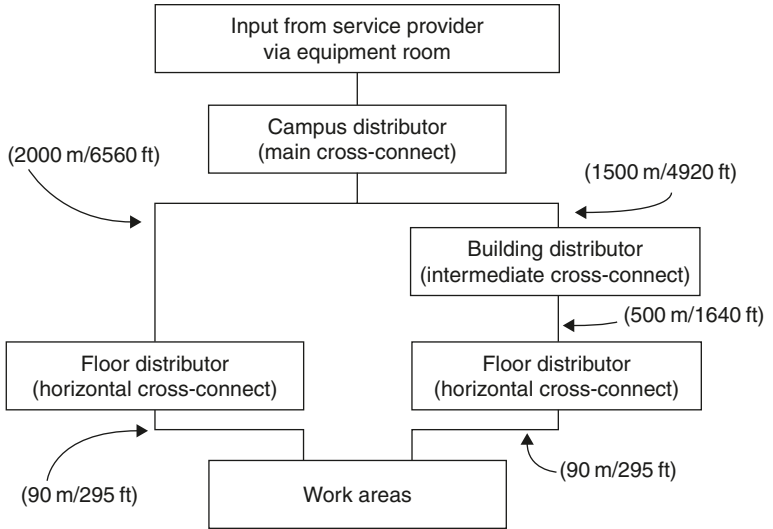
## Other buildings and other floors

To connect a communication system to another building or another floor in the same building, the cables are taken from the campus connector (main cross-connect) to the building distributor (intermediate cross-connect) and from there to another floor distributor and then on to the work areas (see Figure 18.8).

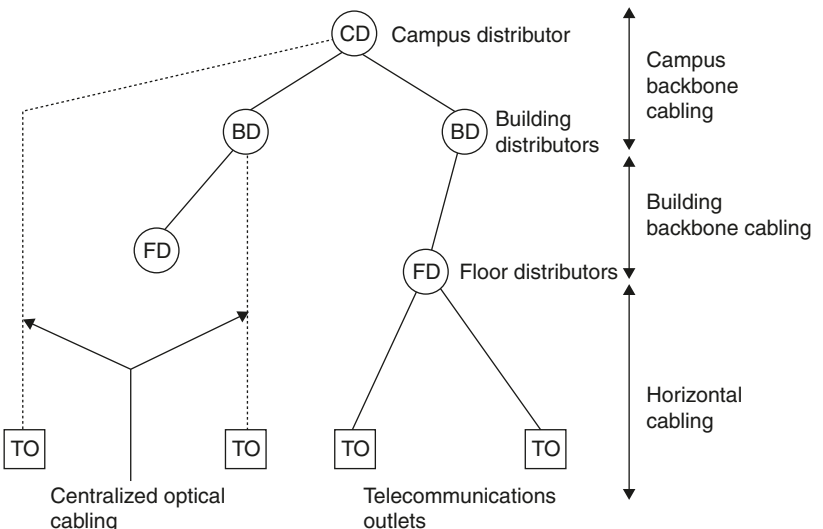
**Figure 18.8**  
The building distributor



**Figure 18.9**  
Connection summary



**Figure 18.10**  
Hierarchical model with Centralized Optical Architecture



## Quiz time 18

In each case, choose the best option.

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**1 A floor distributor is also called a:**

- (a) main cross-connect
- (b) horizontal cross-connect
- (c) building cross-connect
- (d) intermediate cross-connect

---

**2 An installation in single story building may not include:**

- (a) an intermediate cross-connect
- (b) a work area
- (c) a campus distributor
- (d) a horizontal cross-connect

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**3 A pair of copper conductors are often twisted to:**

- (a) make the cable more flexible during installation
- (b) provide screening to prevent lightning strikes
- (c) allow the cable to stretch
- (d) reduce crosstalk

---

**4 The longest cable run is likely to be found between the:**

- (a) building distributor and the floor distributor
- (b) campus distributor and the building distributor
- (c) campus distributor and the floor distributor
- (d) work area and the floor distributor

---

**5 When external cables are passed through the wall of a building they should:**

- (a) always be of twisted construction to prevent signals from entering the building
- (b) be sealed to prevent water or gas from gaining access to the building
- (c) have separate access points for optic and copper cables
- (d) be enclosed in conduit