TM355:
COMMUNICATIONS TECHNOLOGY
BLOCK 1

PART 1:
CHANNELS FOR COMMUNICATIONS

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OUTLINE

- Introduction
- Analogue and digital signals
- Optical fibre

1. INTRODUCTION (1/6)

- The simplest type of communications system consists of a transmitter that sends a signal along a channel to a receiver.
- This first part of Block 1 is mainly concerned with the physical channel: the properties of optical fibre and copper cable, and the behaviour of radio waves.
- Each of these transmission media has its own merits and limitations, and this text discusses the suitability of the various types of media for different applications.
- There may be many transmitters and/or receivers, and it is necessary to ensure that the correct sender communicates with the correct recipient.

1. INTRODUCTION (2/6)

- One example is a local area network (LAN) – a computer network covering a relatively small area, such as a company site.
- Another example is the ordinary telephone system, referred to as the public switched telephone network (PSTN).

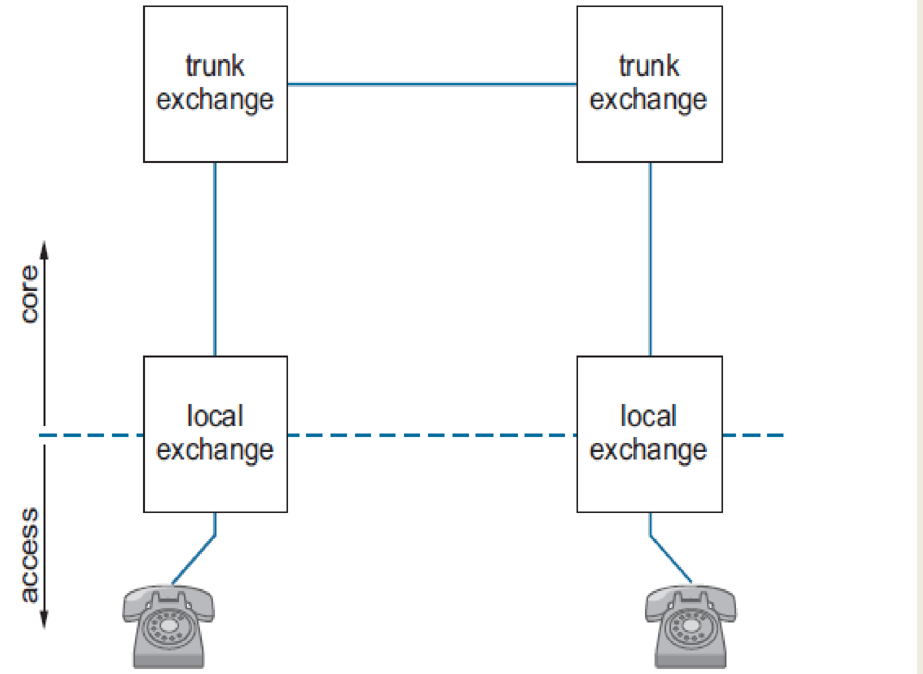

Figure 1.1 Part of the public switched telephone network (PSTN)

1. INTRODUCTION (3/6)

- Figure 1.1 distinguishes between the access network (the local exchange and its connections to the subscribers it serves) and the core network, which is everything beyond the local exchange.
- The technical demands of the access and core networks are rather different.
- The access network may serve millions of subscribers, each on a different site, but with only short distances involved.
- In contrast, trunk lines in the core network carry multiple calls between two places that may be hundreds of miles apart.

1. INTRODUCTION (4/6)

- Different techniques have evolved to meet these demands.
- At one time, the entire system was built with copper cables, which carry information as electrical signals.
- Later the technology of optical fibres was developed, in which messages are sent using light rays that are constrained to follow a path within the fibre.
- Optical fibre has a number of advantages over copper, particularly over long distances, so it now predominates in the core network, although copper still retains a key place in the access network.
- Between them, optical fibre and copper cable serve most of the needs of the PSTN and other fixed networks.

1. INTRODUCTION (5/6)

- Mobile communications systems require radio.
- This is a form of electromagnetic radiation like light, and can propagate through air or space in various ways.
- While the term ‘radio transmitter’ brings to mind the tall masts for radio and television broadcasting, smaller transmitters are everywhere: in mobile phones, computers (to provide a WiFi connection).
- Cables confine signals to a defined route, but radio waves spread out over a wide area.

1. INTRODUCTION (6/6)

- Radio is thus a shared medium, so many different transmissions are competing for attention everywhere, and a receiver has to be able to select the right one.
- The shared nature of radio leads to problems of resource allocation.
- Radio also has security implications, as signals can easily be intercepted.

2. ANALOGUE AND DIGITAL SIGNALS (1/2)

- The term ‘signal’ describes the form in which a message is sent along a communications channel.
- In the case of copper cable, the signal is a varying **electrical voltage**.
- For both optical fibre and radio, the signal is a varying **electromagnetic wave**.

2. ANALOGUE AND DIGITAL SIGNALS (2/2)

- Figure 1.2(a) illustrates part of a speech signal as produced by the microphone in a telephone.
- The voltage signal follows the air vibrations and is called an analogue signal because the voltage is analogous to the fluctuating air pressure.
- Figure 1.2(b) represents a data signal as might be seen on a cable to a computer on a LAN (such a connection between a home PC and a router.)

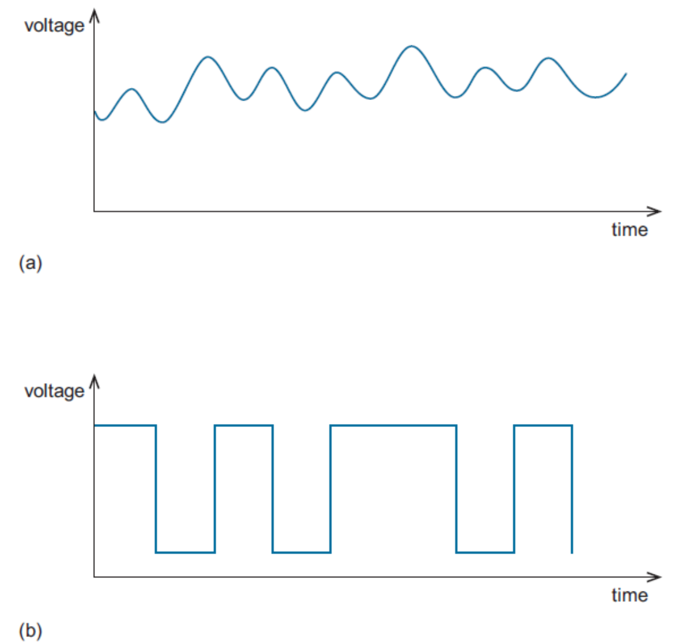

Figure 1.2 Examples of signals: (a) speech signal produced by the microphone in a telephone; (b) data signal in a cable between a PC and a router

2.1 BENEFITS OF TRANSMITTING DIGITAL SIGNALS (1/2)

- Whenever a signal is sent along a communications channel, two things happen to it: it gets smaller (it attenuates) and it gets distorted (the shape changes).
- This is illustrated in Figure 1.3 for both an analogue signal and a digital signal.
- It is possible to compensate for attenuation by amplifying the received signal.
- **With digital signals**, on the other hand, we can in principle get rid of the distortion entirely by the process of regeneration, provided the distortion is not too great (threshold detection).
- **Another reason** for using digital technologies in communications is that voice, music and video can all be handled by the same techniques as computer data if they are first converted to a digital form.

2.1 BENEFITS OF TRANSMITTING DIGITAL SIGNALS (2/2)

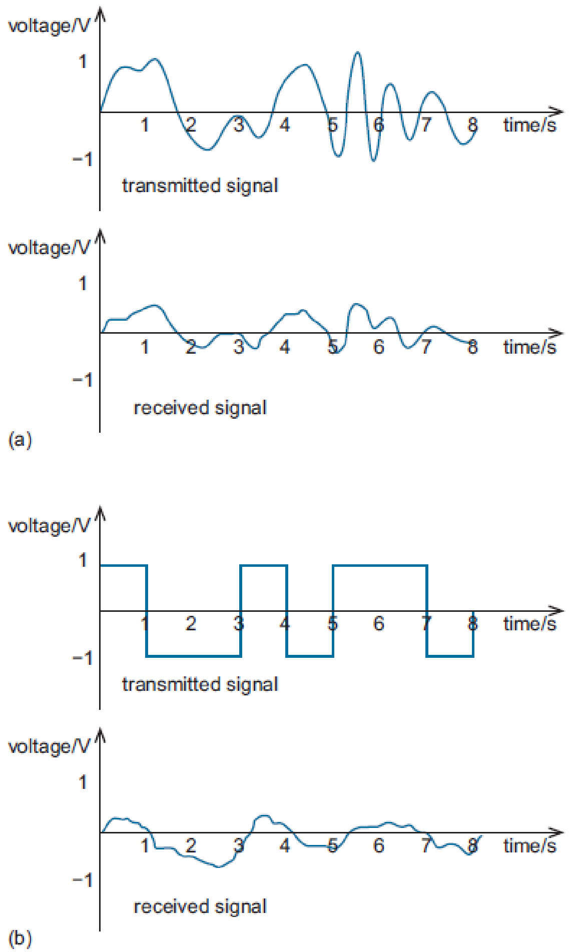

Figure 1.3 The effects of attenuation and distortion on (a) an analogue signal; (b) a digital signal

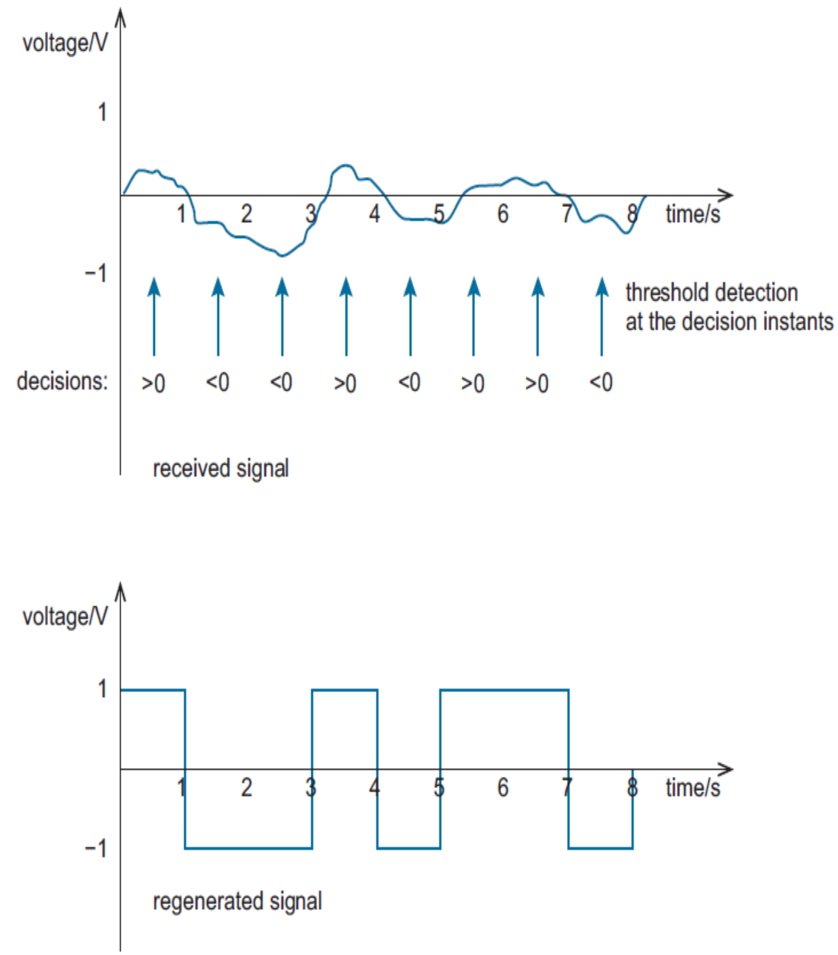

Figure 1.4 Threshold detection at the decision instants to regenerate the digital signal

2.2 CONVERTING ANALOGUE TO DIGITAL (1/3)

- Analogue-to-digital converters (ADCs) and digital-to-analogue converters (DACs) are electronic devices that convert between analogue and digital in each direction.
  - To convert an analogue signal to digital form, it is first sampled by measuring its value at regular intervals in time.

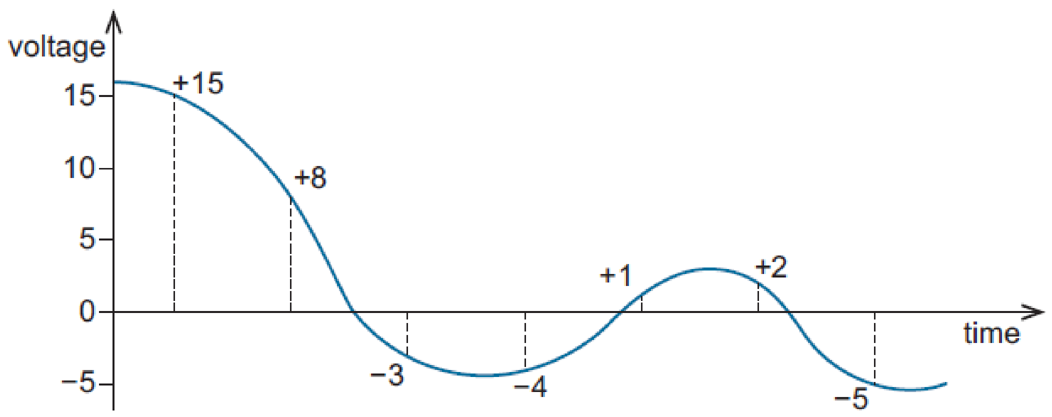

Figure 1.5 Sampling an analogue signal

2.2 CONVERTING ANALOGUE TO DIGITAL (2/3)

- The next step is to encode each of the possible quantisation levels with a binary number.
- To restrict the measured values to a discrete set, the values are quantised.
- Since a binary number ***n*** bits long can take any of 2^n different values, the number of quantisation levels allowed is normally a power of two.
  - Thus a 4-bit number can represent 2^4 = 16 different levels, and an 8-bit number can represent 2^8 = 256 different levels.

2.2 CONVERTING ANALOGUE TO DIGITAL (3/3)

- For a given range of variation, a large value of ***n*** improves the accuracy of the conversion because the quantisation levels are closer together; conversely, a small ***n*** results in a smaller amount of binary data at the expense of conversion accuracy.
- In converting an analogue signal to digital, it appears that information has been lost in two different ways:
  a) The signal is not measured at every instant of time but only at the sampling points.
  b) An approximation has been made by rounding the samples to the nearest quantisation level.

2.3 ANALYSING SIGNALS
2.3.1 SINUSOIDS (1/2)

- **Sinusoids** are important not only because they turn up naturally in a wide variety of situations, but also for their mathematical simplicity.
- A sinusoid is a periodic signal ➔ repeats at regular time intervals.
- A section of a periodic signal between two consecutive corresponding points, such as the maxima, is called a **cycle**, and the duration of a cycle is the **period**.
- The number of cycles in one second is the **frequency.**
- The unit of frequency is the hertz (Hz), where 1 Hz = 1 cycle per second.

$$f = 1/T$$

- **Amplitude** is the maximum value of the sinusoid.

2.3.1 SINUSOIDS (2/2)

- Another characteristic of a sinusoidal signal is its **phase**. **This relates to the point that the sinusoid has reached at a particular time.**
  - For example, at zero time the signal is zero and rising. Shifting the signal to the right or left changes its phase.
- One of the reasons that sinusoids are so significant in communications is that **they form the components of other periodic signals.**

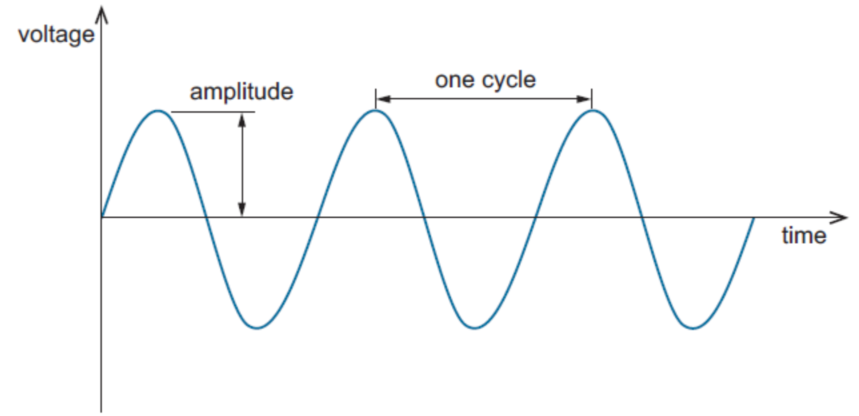

Figure 1.6 A sinusoidal signal

2.3.2 OTHER PERIODIC SIGNALS (1/4)

- An important result in communications theory, due to Joseph Fourier (1768–1830), shows that **any periodic signal may be expressed as a sum of multiple sinusoids**.
- The graph on **the left** of Figure 1.7(a) shows a **sinusoid as it progresses in time**, while the graph on the **right** shows another representation of the signal: a **<u>function of frequency</u>**.

➔ *These are known respectively as **time-domain** and **frequency-domain** representations.*

  - The frequency domain is also known as the **spectrum**.

2.3.2 OTHER PERIODIC SIGNALS (2/4)

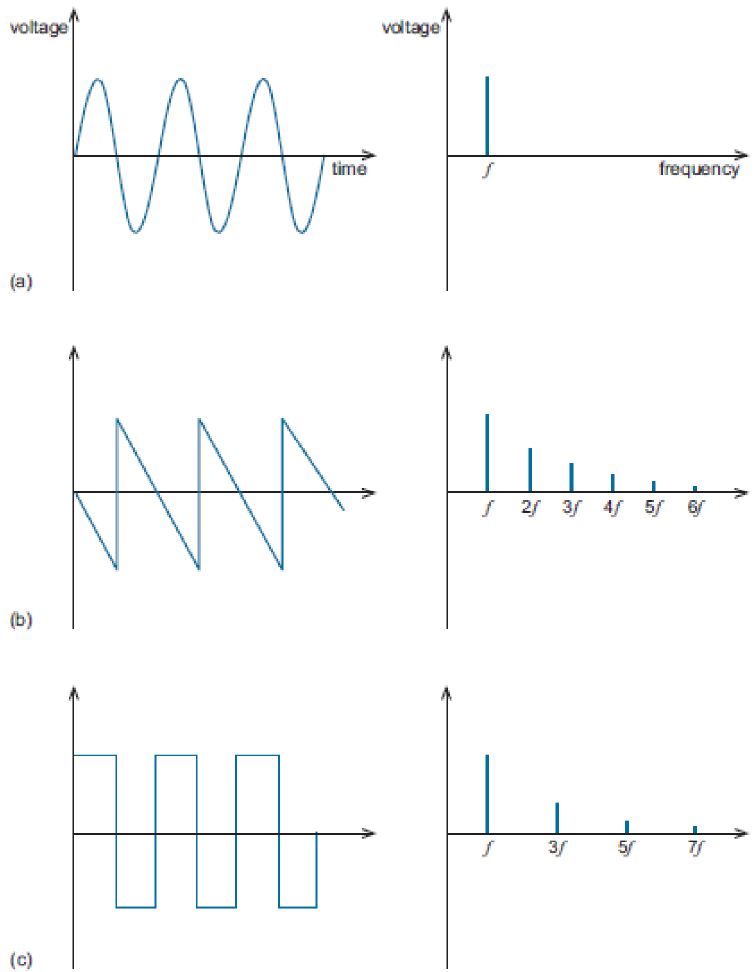

Figure 1.7 (a) Sine wave, (b) sawtooth wave and (c) square wave, in time and frequency domains

2.3.2 OTHER PERIODIC SIGNALS (3/4)

- **Any signal can be represented in either the time or the frequency domain.**
- A sinusoid, is shown as a single line in the frequency domain because it represents a single frequency of a particular strength.
- Figure 1.7(b) shows a periodic signal with a different shape (**or waveform as it is sometimes called**), known as a saw-tooth wave from its appearance.
- **The corresponding frequency-domain representation reveals that it is made up of the sum of sinusoids of decreasing amplitude**.

  ➔ **Notice that the frequencies of these sinusoids are exact whole-number multiples of the lowest frequency**. These higher-frequency sinusoids are called **harmonics.**

2.3.2 OTHER PERIODIC SIGNALS (4/4)

- The waveform in Figure 1.7(c), known as a square wave, may be regarded as a binary signal with alternate 1s and 0s.
- In the frequency domain there are again sinusoids at multiples of the lowest frequency, though in this case the even multiples (or harmonics) are missing.
  - A consequence of this theory is that a communications channel that can transmit, say, a 1 MHz sine wave correctly may not be able to transmit a 1 MHz periodic signal with a different waveform, unless it can also transmit sinusoids at 2 MHz, 3 MHz and so on.
- A complete frequency-domain representation would also include phase.
  - For many purposes, though, phase is less important than frequency; it is not a consideration in allocating radio spectrum, for example.

2.3.3 NON-PERIODIC SIGNALS (1/2)

- Non-periodic signals (also known as **aperiodic** signals) also have both a time-domain and a frequency-domain representation, but the details are different.

➔ *There are no longer lines at particular frequencies*; instead, **the spectrum is spread out over a continuous range of frequencies**.

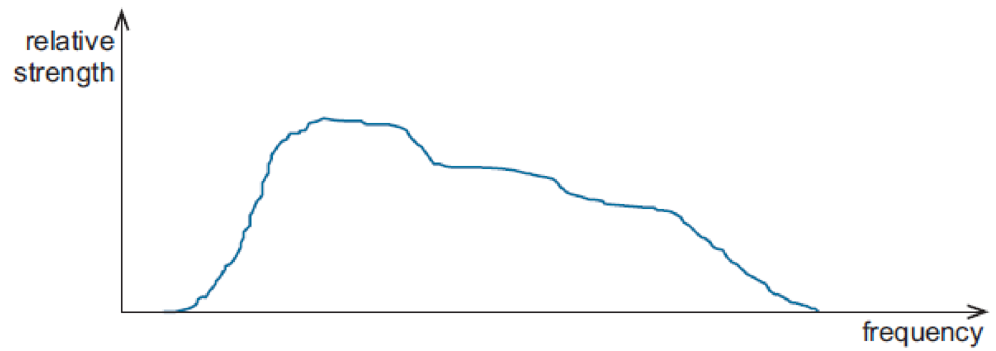

Figure 1.8 Example frequency-domain representation for a non-periodic signal

2.3.3 NON-PERIODIC SIGNALS (2/2)

- For example, a speech signal ranges from around 100 Hz to a few thousand Hz (for telephone-quality speech, a range of 300 Hz to 3400 Hz is often assumed).
- In practical communications, exactly periodic signals are the exception.
- Signals that carry real information, such as speech, music or video, do not repeat endlessly.

3. OPTICAL FIBRE (1/2)

- **Optical fibre can transmit large amounts of information rapidly over long distances using light signals**, and so has become the preferred technology for trunk cable communications and increasingly for LANs.
- A basic optical-fibre link has **three main** components (Figure 1.10):
  - a suitable source of light (not necessarily within the visible range), controlled by input data in the form of an electrical signal
  - the optical fibre itself, which carries the resulting pulses of light to …
  - a detector, which converts the pattern of light and dark back to an electrical signal.

3. OPTICAL FIBRE (2/2)

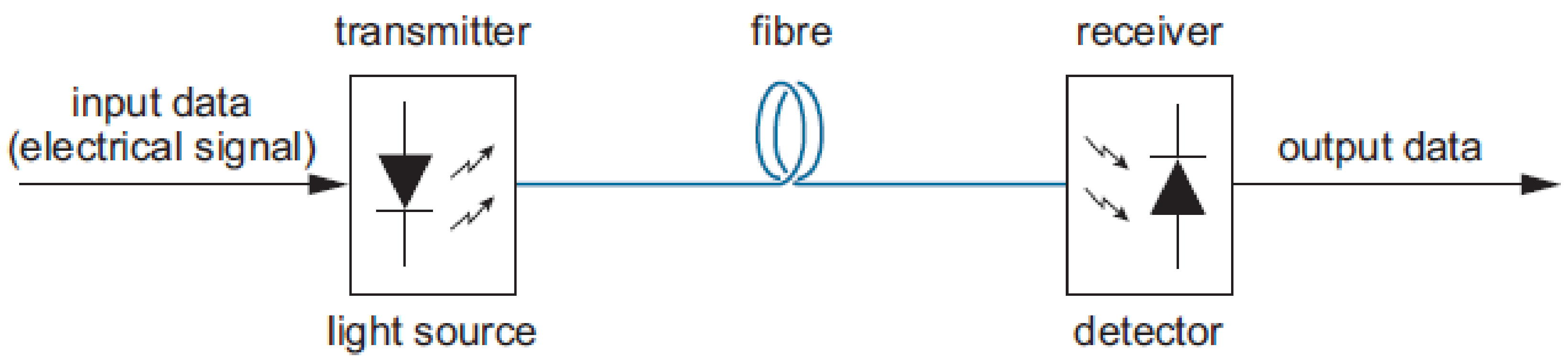

Figure 1.10 Optical-fibre link

3.1 ELECTROMAGNETIC RADIATION (1/6)

- Electromagnetic radiation includes radio waves, light, the radiation felt as heat, and ultraviolet radiation from the Sun.
- **Light,** as an electromagnetic wave**, is a wave pattern carried by interdependent electric and magnetic fields.**
- In electromagnetic wave, electricity and magnetism are in fact intimately related.
- **Electric fields, like magnetic fields, are invisible but can exert forces on objects.**
- Strong electric fields form in thunderclouds and break down when lightning strikes.

3.1 ELECTROMAGNETIC RADIATION (2/6)

- Electric fields and magnetic fields can both store and release energy.
- They are also linked together by a set of relationships known as **Maxwell's equations**.
- Changing electric fields generate changing magnetic fields, and vice versa.
- The effect of all of this is that disturbances in the fields can be self-sustaining, and spread outwards like waves in a pond.

3.1 ELECTROMAGNETIC RADIATION (3/6)

- Figure 1.13 represents a an electromagnetic wave in terms of its electric and magnetic components.
- The axis along the direction of travel measures distance along the wave.
- The other axes represent the strength of the electric and magnetic fields at any point along the wave.

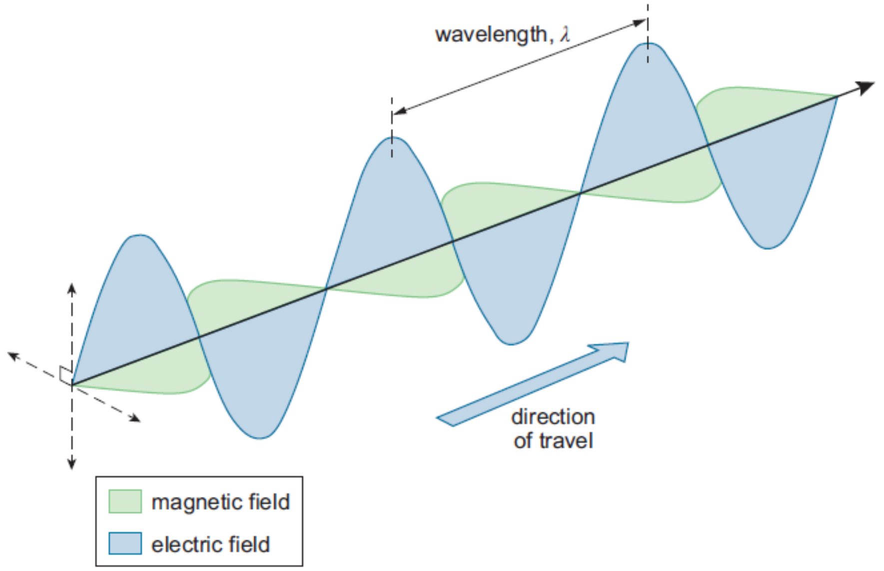

Figure 1.13 An electromagnetic wave: the magnetic and electric fields are at right angles to each other, and the wave travels forwards in the direction that is at right angles to both

3.1 ELECTROMAGNETIC RADIATION (4/6)

- The electric field and magnetic field are both sinusoidal and are at right angles to each other.
  - *This is just a snapshot of the wave at one particular instant in time.*
- The whole wave pattern moves forward at the speed of light, which in free space (a vacuum) is about 300 000 000 m/s = 3×10^{8} m/s and is conventionally denoted $\mathbf{c}$.
- All electromagnetic waves travel at this same speed in free space.

3.1 ELECTROMAGNETIC RADIATION (5/6)

- In free space, **the electric field contains half the power in an electromagnetic wave and the magnetic field contains the other half**.
- As the wave moves forward, it conveys energy.
- So, for example, light from the Sun can be converted to electrical energy by solar panels.
- The power generated by such a panel is simply the energy it produces per unit time.

3.1 ELECTROMAGNETIC RADIATION (6/6)

- **Note on Energy and Power:**
  - **Power is the rate of flow of energy**, and is measured in watts **(W)**.
  - Energy and power are related as follows:

    energy = power × time.
  - **Example**: Suppose a 2 kW kettle takes three minutes to boil. Three minutes is 0.05 hours, so the energy used is: 2000 W × 0.05 h = 100 Wh or 0.1 kWh (kilowatt-hours).
  - However, although energy is quoted as kWh on electricity bills, the SI unit of energy is the joule (J), where energy in joules is the power in watts multiplied by the time in seconds.
    - Repeating the kettle example using SI units gives: 2000 W × 180 s = 360 000 J or 360 kJ.

3.1.1 WAVELENGTH AND FREQUENCY

- Electromagnetic waves are characterised by their wavelength, the distance between two consecutive peaks (or other corresponding points.)
- Light waves have short wavelengths, measured in nanometres (nm, 10^{-9} m).
  - Light of different wavelengths is perceived as different colours, for example 650 nm is red and 520 nm is green.
- A wave can also be described by its frequency, where:

$$\boldsymbol{c = \lambda \times f}$$

3.1.2 THE ELECTROMAGNETIC SPECTRUM

- Figure 1.14 shows the complete electromagnetic spectrum.

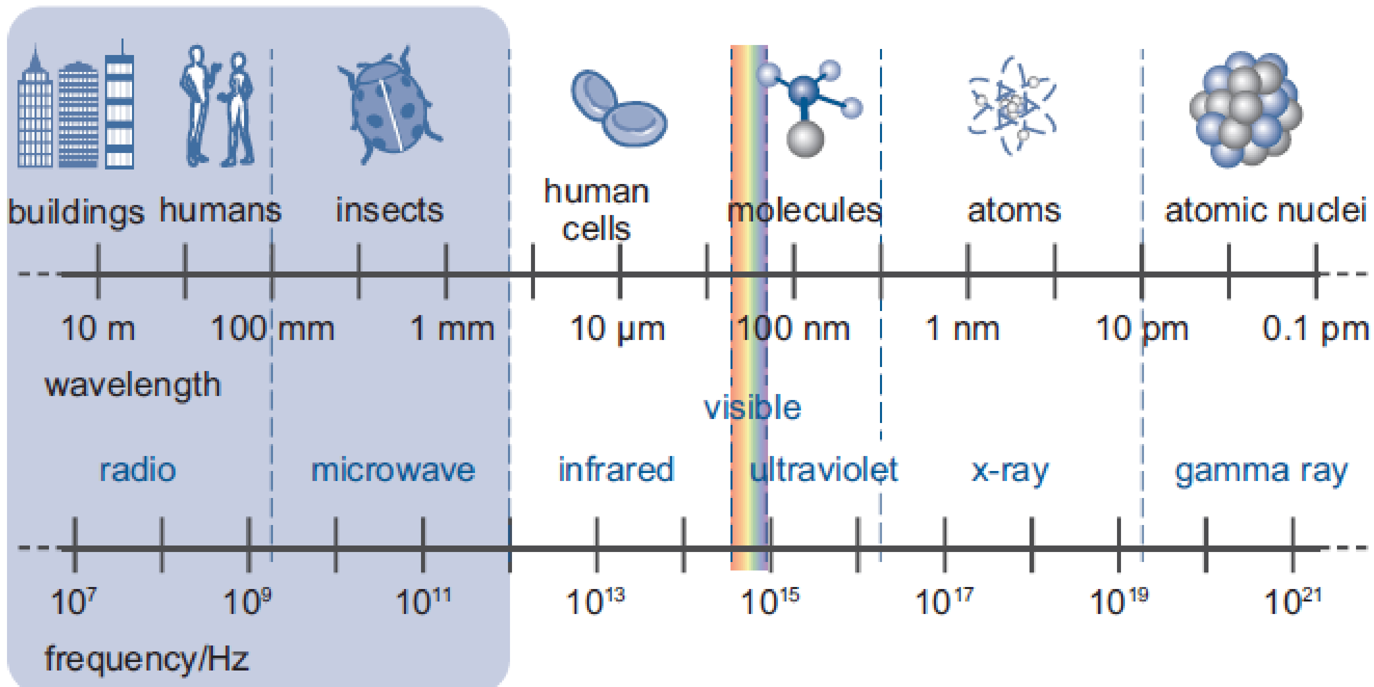

Figure 1.14 The electromagnetic spectrum

3.2 LIGHT WAVES IN OPTICAL FIBRE (1/3)

- In optical fibres, light travels through highly transparent glass along guided paths, so there are some differences from propagation in free space.
- For one thing, **light travels significantly more slowly in glass than in a vacuum** (or in air).
- The speed of light, $\boldsymbol{v}$, in a medium such as glass is found by:

$$\boldsymbol{v = c/n}$$

where "$\boldsymbol{n}$" is the refractive index and depends on the material. It is around 1.5 for most optical glasses.

3.2 LIGHT WAVES IN OPTICAL FIBRE (2/3)

- **So what keeps light guided along its path in an optical fibre?**
- **Why does the light not just stop when it comes to the first bend?**
- Optical fibres work because **the refractive index is not the same all the way across the fibre, but is higher in the central core than it is in the cladding around the core**.
- **Light can change direction by two processes, refraction and reflection**, which take place in lenses and mirrors respectively.
- Refraction can occur when a ray of light travels from one medium to another medium with a different refractive index.
- The light continues within the second medium, but on a diverted path (Figure 1.15a).

3.2 LIGHT WAVES IN OPTICAL FIBRE (3/3)

- **However,** if light is directed from one medium towards another with a **lower refractive index**, and it hits the boundary at a sufficiently **small angle**, it is not refracted but ***reflected back into the first medium.***
- This process is known as **total internal reflection** (Figure 1.15b).
- Thus in an optical fibre, provided the light enters the fibre from the right direction (not too large an angle from the axis of the fibre), it will continue all the way along the fibre, relying on total internal reflection to keep it on course.

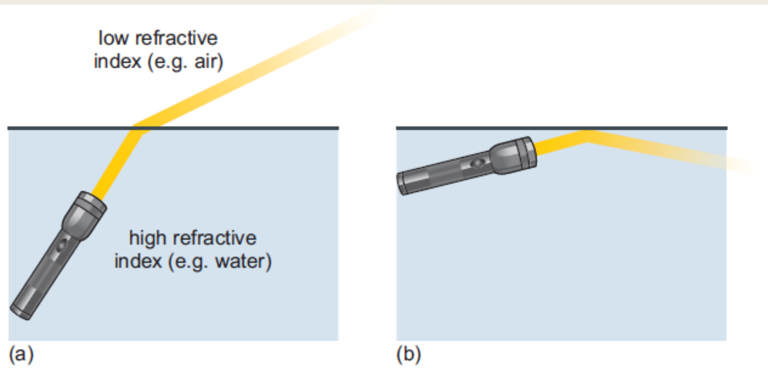

Figure 1.15 Bending of the beam from a torch at the boundary between two media: (a) at a large angle to the boundary, the beam is refracted; (b) at a small angle, it is totally internally reflected

3.3 TYPES OF FIBRE (1/4)

- The diameter of the core is a key feature of an optical fibre.
  - the larger the diameter of the fibre, the more light it will let through.
- **A large-diameter fibre also has some practical advantages**: aligning fibres to join them together becomes easier.
- **However, when it comes to transmitting data over distances at high data rates**, it turns out that a large diameter is not necessarily the best.
- A fibre with a core diameter that is large in comparison with the wavelength is known as a **multimode fibre** *because light can travel along it in a variety of ways.*

3.3 TYPES OF FIBRE (2/4)

- Commonly, the diameter of the core for a **multimode fibre** is 50 μm, much larger than the wavelengths typically used (which are in the order of 1.5 μm).
- The cladding diameter is 125 μm.
- From Fig. 1.16, some paths that the light can take are more direct than others, meaning two rays of light that set off at the same time **may not reach** the other end of the fibre exactly simultaneously.
- A fibre (as the one shown in Fig. 1.16) where the refractive index changes abruptly between core and cladding is called **a step-index fibre.**

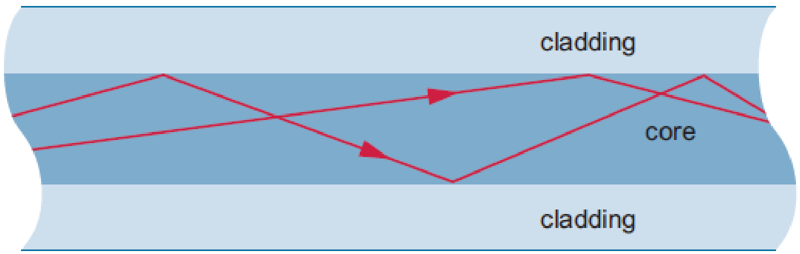

Figure 1.16 Multimode fibre

3.3 TYPES OF FIBRE (3/4)

- Another variant of the multimode fibre is called a **graded-index fibre** (Fig. 1.17) ➔ the refractive index **varies smoothly** from a maximum in the centre of the core to a minimum within the cladding.
- This means waves that take slightly longer paths travel slightly faster, and so different waves setting off at the same time arrive nearly simultaneously at the other end of the fibre.

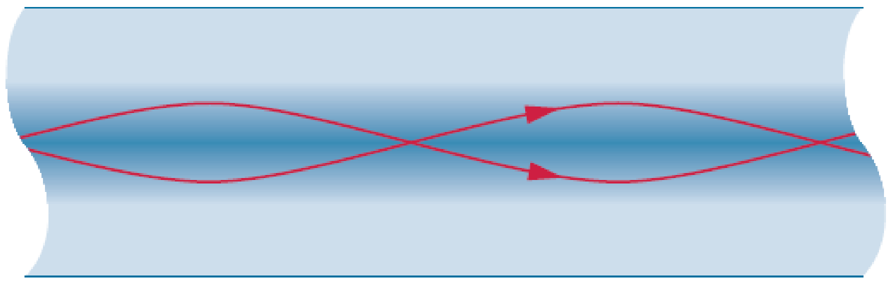

Figure 1.17 Graded-index fibre

3.3 TYPES OF FIBRE (4/4)

- **If the core diameter of a step-index fibre is reduced, there are fewer ways or modes in which the wave can propagate.**
- There comes a point where only one mode can propagate, and signals all travel along the same path.
  - This happens when the **core** is a few wavelengths in diameter – typically **10 µm.**
- This type of fibre is called a **single-mode fibre**, and it provides the best performance over long distances in a number of respects.
- For this reason, single-mode fibre is preferred over multimode types for **long-haul communications**.
- The cladding diameter is typically 125 µm, the same as for multimode fibre.