Communicating Information

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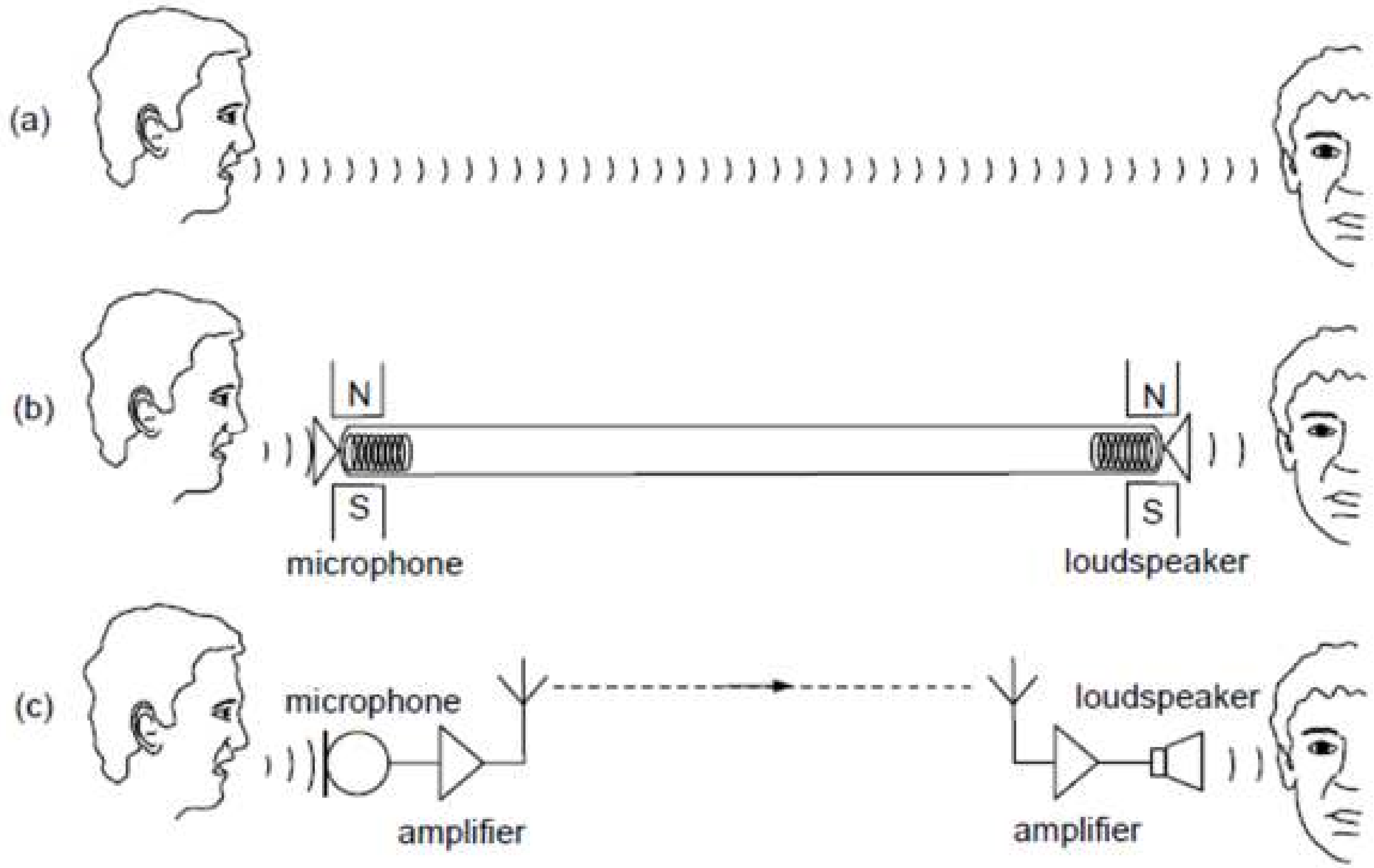
Principles of modulation, sidebands and bandwidth

Communication



Communication

- Communications systems (e.g. radio, TV, telephone) send information from one place to another using electric currents or electromagnetic radiation. This information sent may be sounds, pictures or computer data.
- Any ***communication system*** must have ***transmitter and a receiver.***
- A simple system of communication at a short distance could be one person A speaking to another person B.
  - A is the ***transmitter***
  - B is the ***receiver***
  - Communication system is ***sound waves***
- For 2 people in different rooms, a system of communication could be
  - a ***microphone*** A in one room
  - a ***loudspeaker*** B in another room
  - communication system is a ***twin pair of wires***
  - the microphone converts the sound waves into electrical signals that is transmitted along the wires to the loudspeaker where it is converted back into sound waves
- Communication could also be achieved using ***radio waves***
  - the signal ***from the microphone*** would be amplified and applied ***to a transmitting aerial***.
  - the radio waves produced by the aerial would be transmitted and ***picked up by a receiving aerial.***
  - after amplification the received signals would be passed ***to a loudspeaker***

Disadvantages of such communication

- The 3 systems of communication in the earlier slide have 2 serious disadvantages:

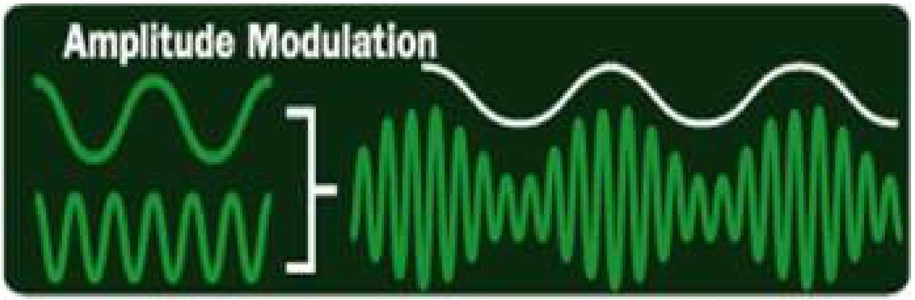
  1) the aerial required for the transmission of the low frequencies of sound waves(about 20 Hz to 20 kHz) would be very long.

     **The design of the aerial is usually ½ or ¼ of the wavelength.*

  2) If more than one radio station transmitted waves of these frequencies (20 to 20 kHz) your receiver would pick them all up at the same time. Imagine listening to a radio receiver where you hear every radio station at once.

- Nevertheless, all these problems can be solved by a process known as **modulation.**

Modulation



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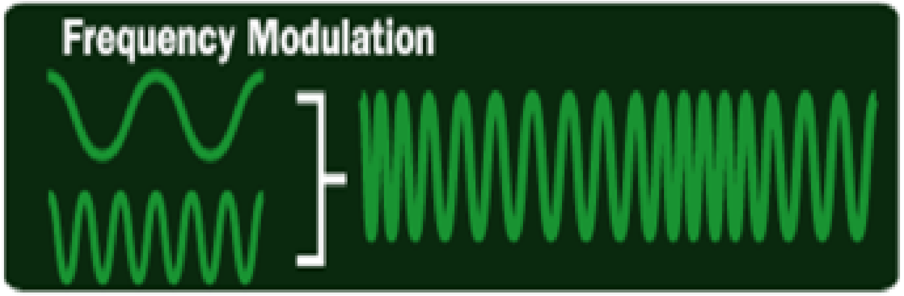

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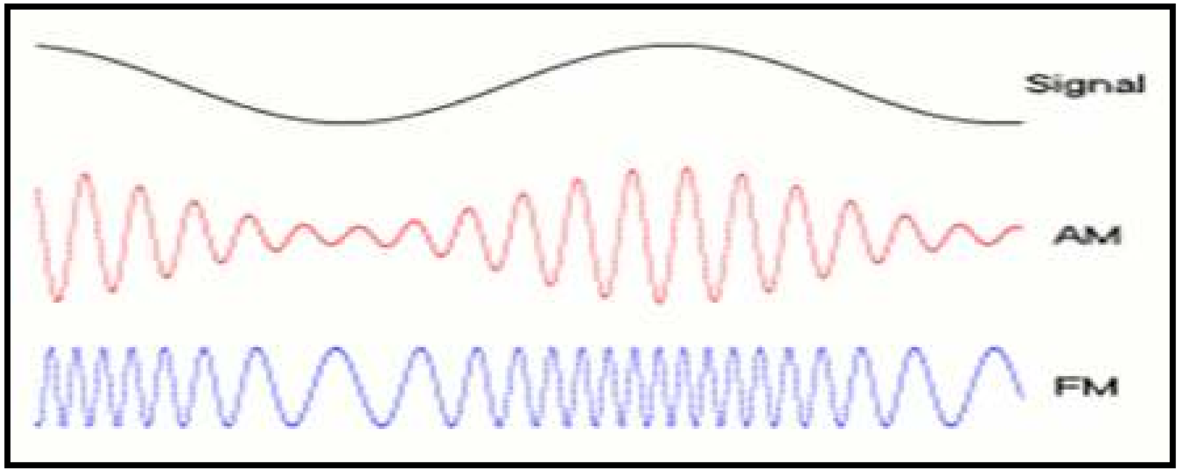
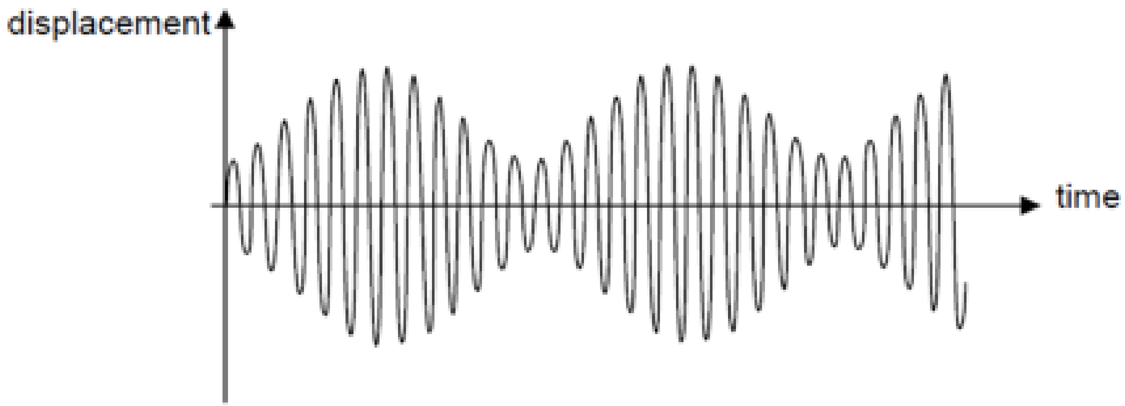


Modulation

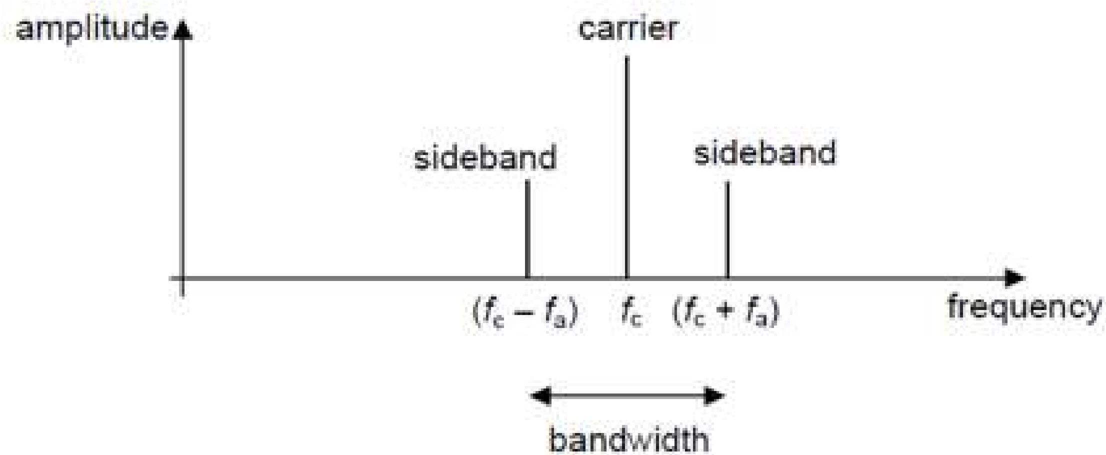
- **Modulation** (means vary) is a process whereby a high frequency wave, known as a ***carrier wave*** is transmitted. This carrier wave has either the ***amplitude varied*** or the ***frequency varied*** so as to carry information.
- In amplitude modulation (AM), the carrier wave has constant frequency. *The amplitude of the carrier wave is made to vary in synchrony with the displacement of the information signal.*
- The rate at which the amplitude of the carrier wave varies is related directly to the frequency of the information signal.
- In frequency modulation(FM), the amplitude of the carrier wave remains constant. *The frequency of the carrier is made to vary in synchrony with the displacement of the information signal.*
- The use of a carrier wave allows different radio stations in the same area to transmit at the same time, but each radio station has a different transmitting carrier wave frequency.
- The receiver is ***tuned*** or adjusted to the frequency of whichever transmitter or radio station is desired i.e. the receiver accepts the signal transmitted on that particular carrier wave and rejects all other carrier wave frequencies.

AM - sidebands and bandwidth

- Figure below shows the waveform resulting from the amplitude modulation of a high frequency carrier wave by a signal that consists of a single audio frequency.



- When this waveform is analyzed in the frequency domain, it is seen to be composed of the sum of three waves of three separate frequencies. These waves are illustrated in the frequency spectrum as below. Conversion to frequency domain in done by using a very powerful mathematical tool called the Fourier transform.



AM - sidebands and bandwidth

- The central frequency f_c is that of the high-frequency carrier wave.

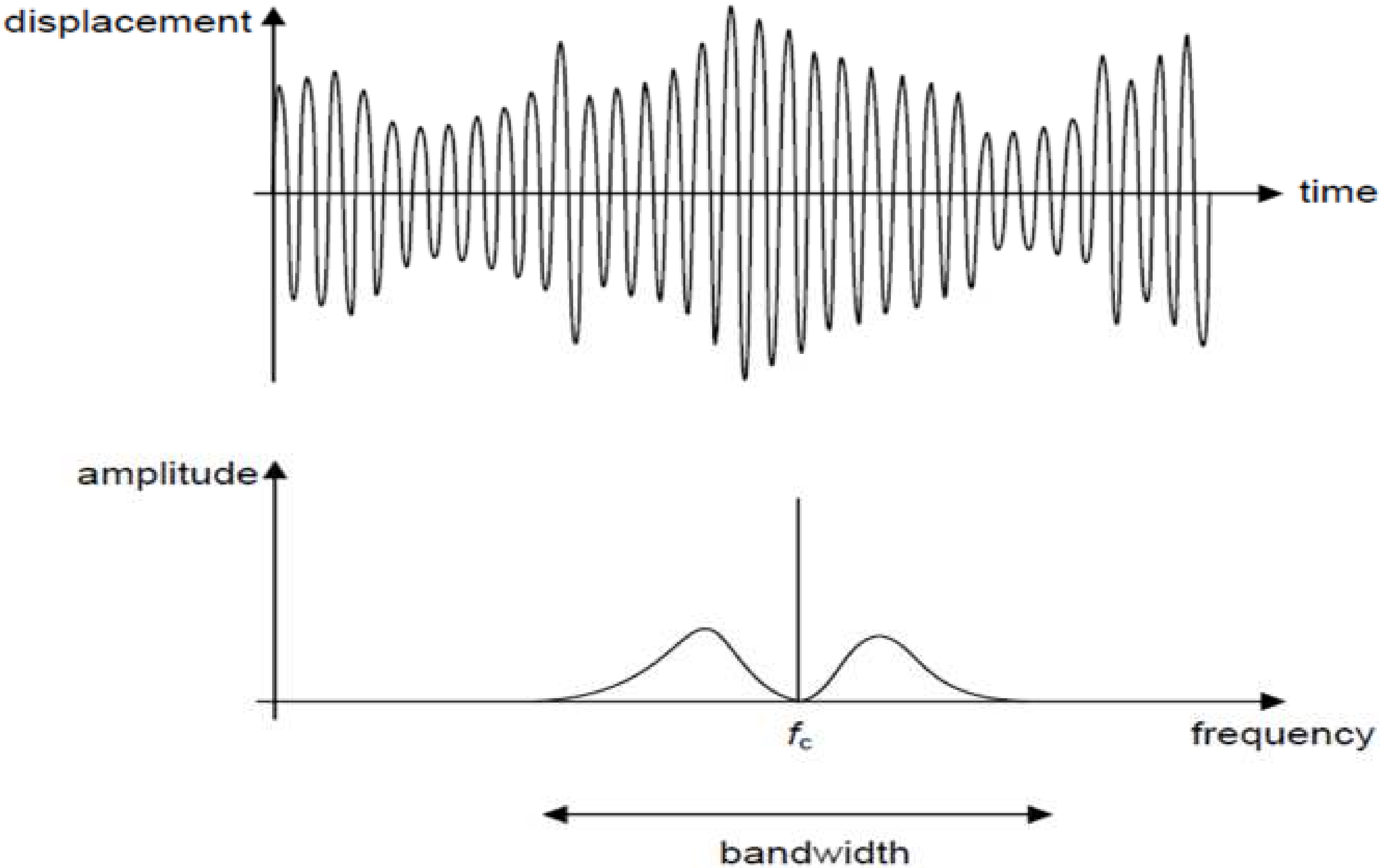
- The other two are known as **sidebands** and for the AM waveform, they occur at frequencies given by $f_c \pm f_a$, where f_a is the frequency of the audio signal.

- The relative amplitude of the sidebands and the carrier depends on the relative amplitudes of the audio and the carrier waveforms. If there is no audio frequency signal, there are no sidebands!

- **Bandwidth** is the frequency range occupied by the AM waveform. This is equal to $2f_a$.

- Figure in the next slide illustrates the AM waveform and the corresponding frequency spectrum for a voice signal.

AM - sidebands and bandwidth



Relative advantages of AM and FM transmissions

- **Range**
  - AM radio transmissions on long-wave (LW), medium-wave (MW) and short-wave (SW) wavebands are broadcast over very large distances so that one transmitter can serve a large area.
  - FM transmissions have a range of only about 30 km and this range is by line-of-sight hence many transmitters are required in order to broadcast over a large area.

- **Interference and Quality**
  - AM is more susceptible to noise compared to FM.
  - Therefore, the quality of FM reception is generally better than that of AM since there will be less noise or interference.

- **Cost and simplicity**
  - It is simpler and cheaper to broadcast and receive using AM, as the AM transmitters are much simpler electronically than those for FM

Relative advantages of AM and FM transmissions

- **Bandwidth and Quality**
  - The bandwidth of AM broadcasts on the LW and MW wavebands is 9 kHz which means that the highest frequency that can be broadcast is 4.5 kHz which is quite adequate for speech but not for music for which distortion can be easily noticed
  - The bandwidth of an FM broadcast on the very-high-frequency(VHF) waveband is about 200 kHz, giving a maximum frequency that can be transmitted or broadcast of about 15 kHz hence offering higher quality.

- ***Transmission waveband and transmitters***
  - The LW waveband has a range of frequencies from about 30 kHz to 300 kHz
  - If the bandwidth of each AM broadcast is 9 kHz, then theoretically (300-30)/9 = 30 transmitters could broadcast in the same area without causing interference between each other.
  - For FM broadcasting(300-30)/200 = 1 transmitter only can broadcast in the LW band
  - Hence the number of transmitters that can share the same waveband is much larger for AM than FM
  - For this reason FM is broadcast only at frequencies in excess of 1 MHz

Digital transmission

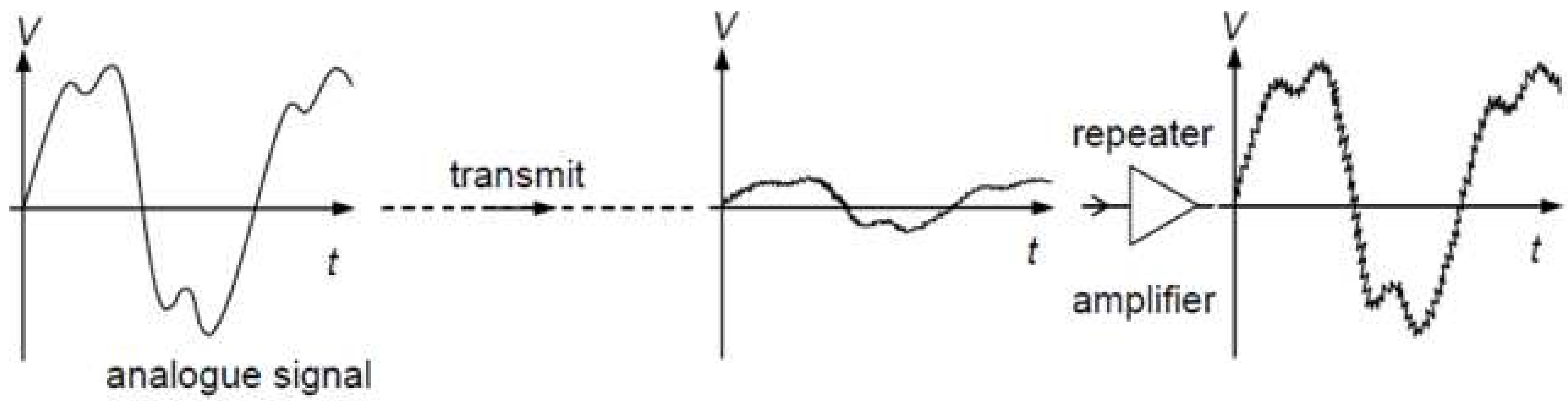
Analogue signals

- Any information that has the same variations with time as the information itself is known as an **analogue signal.**

  e.g. the signal produced by a microphone is analogous to the sound wave incident on the microphone
- Much of the information that is to be communicated in the real world is analogue information (e.g. the voltage output of a microphone that varies with time in a similar manner to the sound waveform that caused it). If this analogue signal is to be transmitted over a large distance (either by radio or by cable) it will be attenuated and it will pick up noise.
- Attenuation is a gradual reduction in signal power. This could be, for example, ohmic losses in a metal cable.
- In any electrical system there is always unwanted power present that adds itself in a random manner to the signal. This unwanted random power is called *noise* and it causes distortion of the signal.
- There are several sources of noise. One arises from the thermal vibrations of the atoms of the material through which the signal is passing. As a result, noise power cannot be totally eliminated.

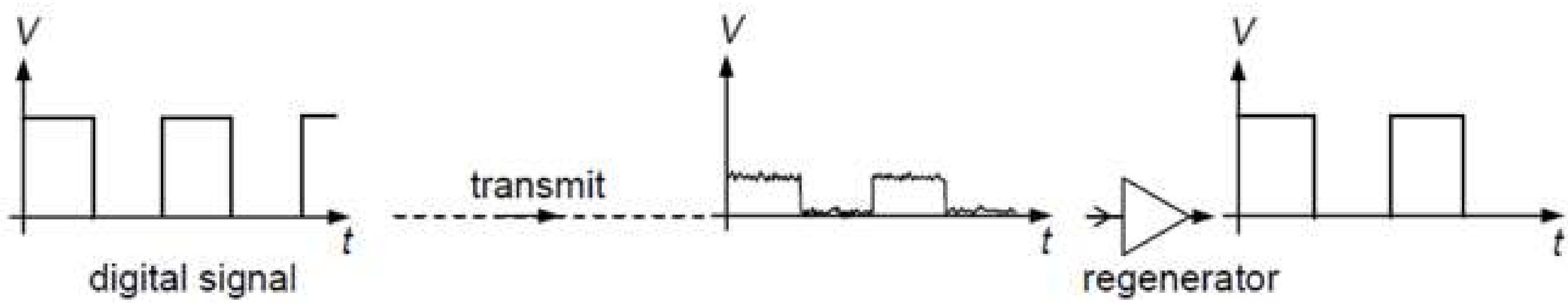
Analogue signals

- Attenuation will mean that, eventually, the signal will have to be amplified so that it can be distinguished from the background noise.
- This is achieved using a repeater amplifier that amplifies the signal before passing it further on.
- The amplifier will, however, amplify the noise as well as the original signal. After several of these repeater amplifications (required for transmission over long distances), the signal will become very ‘noisy’. This effect is illustrated in figure below.



Digital signals

- If the signal is transmitted in digital form, then it also suffers from attenuation and the addition of noise.
- However, the amplifiers that are used for amplifying digital signals are required only to produce a ‘high’ voltage or a ‘low’ voltage.
- They are not required to amplify small fluctuations in amplitude, as is the situation for amplification of an analogue signal. Since noise consists, typically, of small fluctuations, the amplification of a digital signal does not also amplify the noise.
- Such amplifiers are called *regenerator amplifiers* and are able to reproduce the original digital signal and, at the same time, ‘filter out’ the noise. This is illustrated in below.



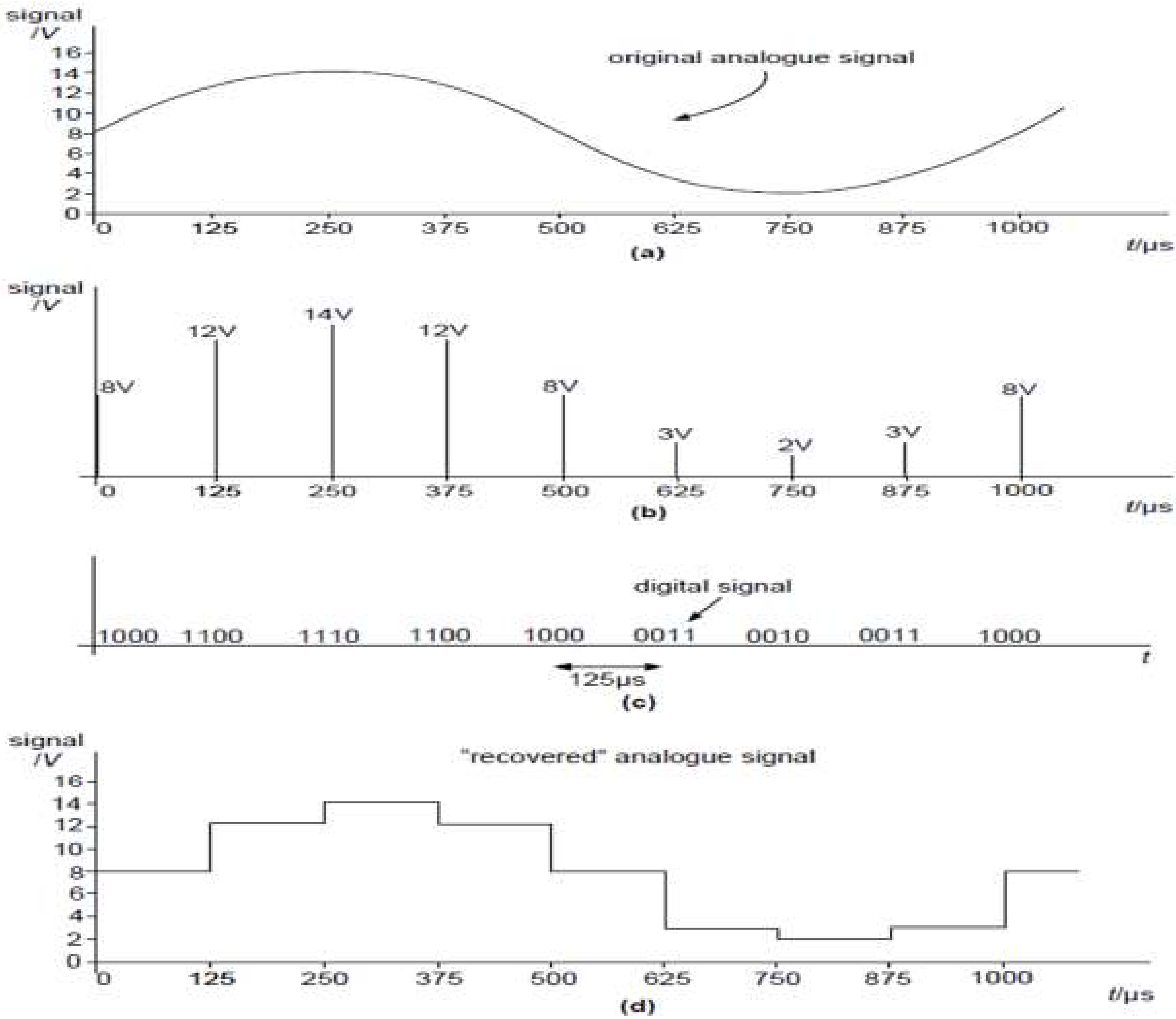
Digital signals

- As a result, a digital signal can be transmitted over very long distances with regular regenerations without becoming increasingly noisy, as would happen with an analogue signal.
- A further advantage of digital transmissions is that they can have extra information – extra bits of data – added by the transmitting system. These extra data are a code to be used by the receiving system to check for errors and to correct them before passing the information on to the receiver.
- Nowadays, digital circuits are generally more reliable and cheaper to produce than analogue circuits. This is, perhaps, the main reason why, in the near future, almost all communication systems will be digitally based.

Digital signals

- The electrical signals derived from speech or music are analogue audio-frequency signals. The voltage generated varies continuously. To convert an analogue signal into a digital signal involves taking samples of the analogue waveform (i.e. measuring its instantaneous voltage) at regular intervals of time. The instantaneous or sample voltage is converted into a binary number that represents its value.
- For example, if the instantaneous value of the analogue signal is 6 V, the binary number could be 0110. For an instantaneous value of 13 V, the binary number could be 1101.
- Note that a binary digit is referred to as a ***bit.*** The most significant bit (MSB) – the bit representing the largest decimal number is written first. The bit representing the lowest decimal number (1) is known as the least significant bit (LSB) and is written last.
- A digital signal consists of a series of 'high' and 'low' voltages. A 1 represents a 'high' voltage and a 0 represents a 'low' voltage. A 4-bit system is used in the example. In reality, 8 or more bits would be used for any sampling.

Use of ADC on transmission & DAC on reception of digital signals



Use of ADC on transmission & DAC on reception of digital signals

- Fig. (a) shows an analogue signal of frequency 1 kHz. This signal is sampled every 125 μs (a sampling frequency of 8 kHz). The sample voltages are shown in Fig. (b).
- It should be noted that the value given to the sampled voltage is always the value of the nearest increment ***below*** the actual sample voltage.
- In this particular example, an analogue signal of 14.3 V would be sampled as 14 V and one of 3.8 V would be sampled as 3 V. The resulting digital signal is shown in Fig. (c). Each number is a group of 4 bits and these groups are separated in time by 125 μs.
- The choice of sampling frequency is important. A lower sampling frequency means that less information can be gathered from the analogue signal.
- More than eighty years ago, it was shown by Nyquist that, in order to be able to recover the analogue signal from its digital conversion, the sampling has to occur at a frequency greater than twice the highest frequency component in the original signal.

Use of ADC on transmission & DAC on reception of digital signals

- As a result, in the telephone system, the highest frequency is restricted to 3.4 kHz because the sampling frequency is 8 kHz. In the manufacture of compact discs, the highest frequency is 20 kHz and the sampling frequency is 44.1 kHz.
- After the analogue signal has been converted to a 4-bit digital signal by the **analogue-to-digital converter (ADC),** the digital signal is transmitted.
- The original signal can be recreated by passing the 4-bit numbers into a **digital-to-analogue converter (DAC).**
- This is illustrated in Fig. (d) where the original analogue signal of Fig. (a) has been recreated.
- The output of the DAC is 'grainy' and is not smooth because the number of bits limits the number of possible voltage levels (with 4 bits there are $2^4 = 16$ levels; with 8 bits, there are $2^8 = 256$ levels).
- As described above, a higher sampling frequency also enables more detail of the analogue signal to be recovered.

Channels of communication

Transfer of information

- A signal whether analogue or digital is transmitted and received using ***channels of communication***.
- This may be achieved in various ways using different channels of communication including

  1.) Wire-pairs

  2.) Coaxial cables

  3.) Radio links

  4.) Microwave links

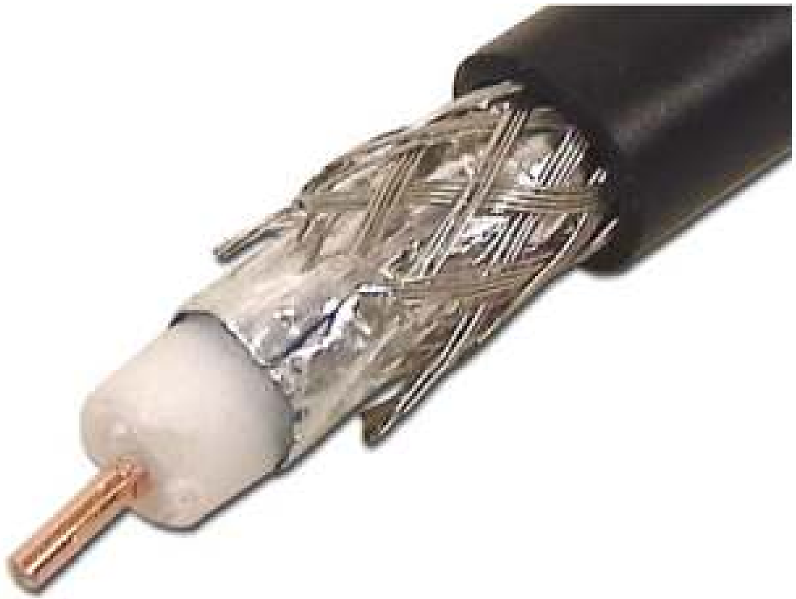
  5.) Optic fibres

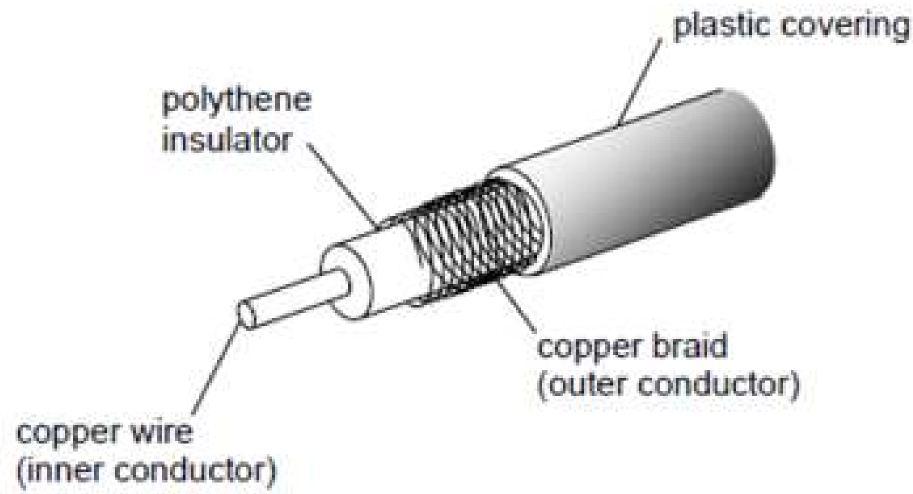
1.) Wire-pairs

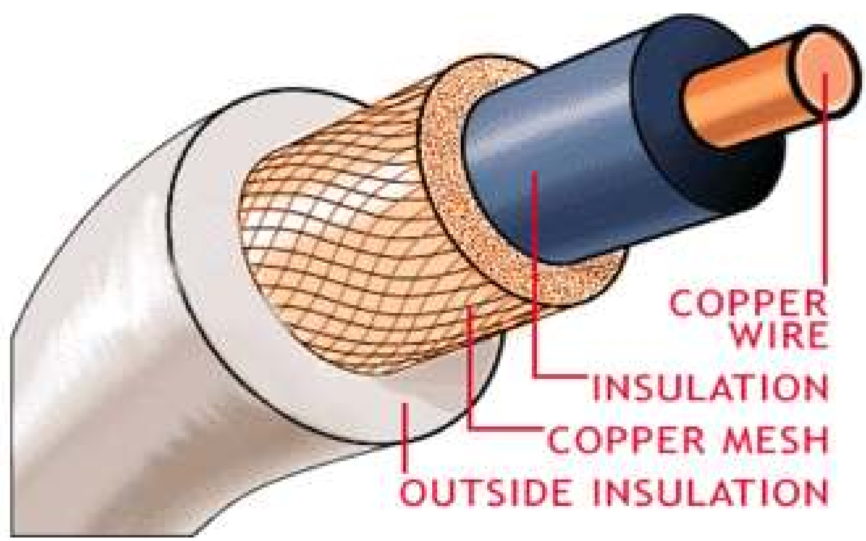
1.) Wire-pairs

- Wire-pairs provide a very simple link. In modern communications, wire-pairs are used mainly for very short distances with low frequencies.
- If high frequency signals are transmitted along a pair of wires over an appreciable distance, repeated amplification must be provided at regular intervals.
- This is due to the very high attenuation of the signal. Energy is lost as heat in the resistance of the wires and also as radiation since the wires act as aerials.
- A further problem is that the wires easily pick up external interference that degrades the original signal.
- If several wire-pairs are arranged next to one another, they will pick up each other's signals. This effect is known as *cross-talk* or *cross-linking* and gives very poor security as it is easy to 'tap' a telephone conversation.
- The bandwidth of a pair of wires is only about 500 kHz. Consequently, as a means of carrying a large amount of information, it has extremely limited bandwidth.

2.) Coaxial cable







2.) Coaxial cables

- A coaxial cable consists of 2 wire conductors which are insulated
  - an inner metal conductor covered by an insulator
  - a second conductor(in the form of thin wire braid) that covers the first insulator
  - another protective layer of insulation covering the braided conductor

- The signal is transmitted down the inner conductor and the outer conductor acts as the return wire and also shields the inner one from external interference. The outer conductor is usually connected to earth.
- Coaxial cable causes less attenuation of the signal. This means that, for long distance communication, repeater amplifiers can be arranged further apart.
- Coaxial cables are less prone to external interference, though not immune to it, so they do offer slightly greater security compared to wire-pairs.
- The bandwidth of coaxial cables is about 50 MHz, hence much more information can be carried along a coaxial cable than along a wire-pairs.
- However, coaxial cables are more costly.

3.) Radio waves

- When radio was first developed, an electrical oscillation of a very low rate, a few kilohertz (the carrier wave) was linked to a long wire – the aerial.
- It then soon became possible to modulate the carrier wave (by AM or by FM) so that information could be sent at a much faster and higher rate. Different carrier frequencies allowed different radio stations to share the same air space (frequency multiplexing).
- Energy that is radiated from an aerial is in the form of electromagnetic waves and is propagated at the speed of light. If the frequency of the transmitted waves are somewhere in the range from 30 kHz to 3 GHz, then the waves are known as radio waves.
- The electromagnetic radiation that is emitted from a transmitting aerial can be arranged (by suitable choice of the aerial) to radiate in all directions (e.g. for national broadcasting).
- For point-to-point communications, the aerial can be arranged to radiate mostly in one direction. No matter what aerial is used, there is always energy loss and the power of the signal picked up by a receiving aerial is reduced as the distance between the transmitter and the receiving aerial is increased.

3.) Radio waves

- The actual distance any particular waves propagate is dependent on frequency, as illustrated in table below.

type of wave	frequency	range
surface wave	below 3 MHz	up to 1000 km
sky wave	3 MHz → 30 MHz	worldwide by means of reflection from ionosphere and ground
space wave	greater than 30 MHz	line of sight – including satellite communication

- ***Surface waves*** have low frequencies (but travel the furthest) and follow the Earth's surface.
- ***Sky waves,*** which are mostly high frequency waves, are reflected by the ionosphere and the Earth.
- ***Space waves*** are waves with frequencies above 30 MHz and not reflected by the ionosphere. They can only be used for 'line of sight'(i.e. straight) communication but their range can be extended by a satellite link.

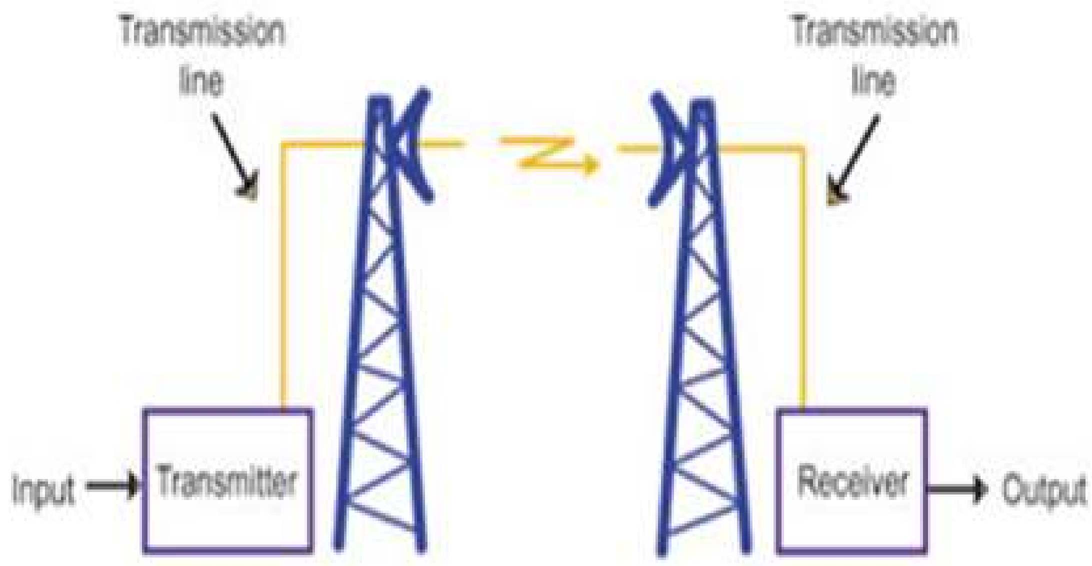
3.) Radio waves

- As a means of communicating from a single transmitter over a large area, the AM broadcasts on the LW and MW are relatively cheap and technically simple.
- In modern communication, considerable use is made of the VHF and UHF wavebands for mobile phones, walkie-talkie radio etc.
- This is due to the fact that, at these frequencies, the wavelength is relatively small and hence the aerial can be made conveniently short.
- The part of the electromagnetic spectrum used for radio communication is shown below.

	frequency band	frequencies	wavelengths (in a vacuum)
LW radio	low frequencies LF	30 kHz → 300 kHz	10 km → 1 km
MW radio	medium frequencies MW	300 kHz → 3 MHz	1 km → 100 m
SW radio	high frequencies HF	3 MHz → 30 MHz	100 m → 10 m
FM radio	very high frequencies VHF	30 MHz → 300 MHz	10 m → 1 m
TV broadcast	ultra-high frequencies UHF	300 MHz → 3 GHz	1m → 10 cm
microwave/satellite	super-high frequencies SHF extra-high frequencies EHF	3 GHz → 30 GHz 30 GHz → 300 GHz	10 cm → 1 cm 1 cm → 1mm

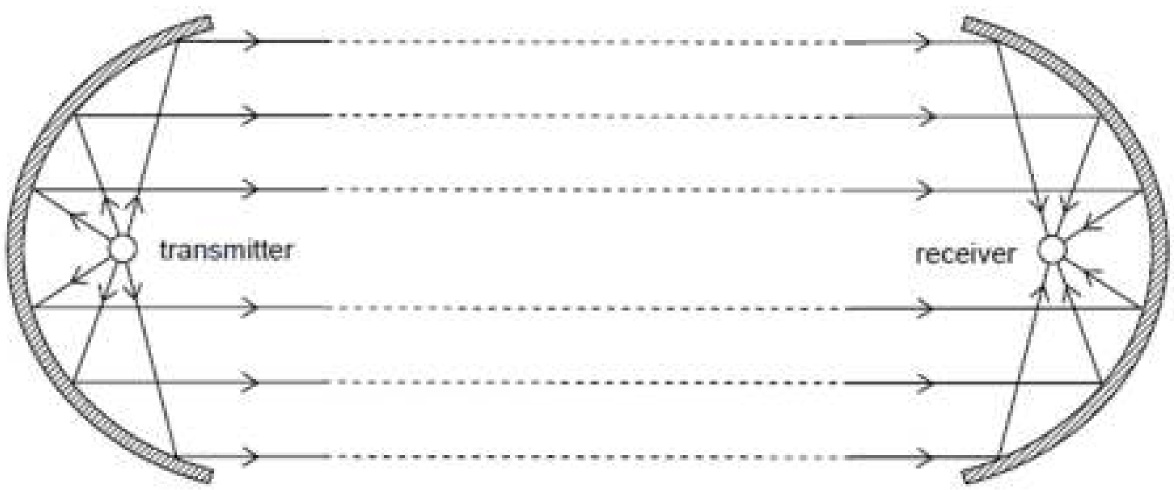
- The bandwidth of a radio link increases as the frequency of the carrier wave increases.

4.) Microwave link

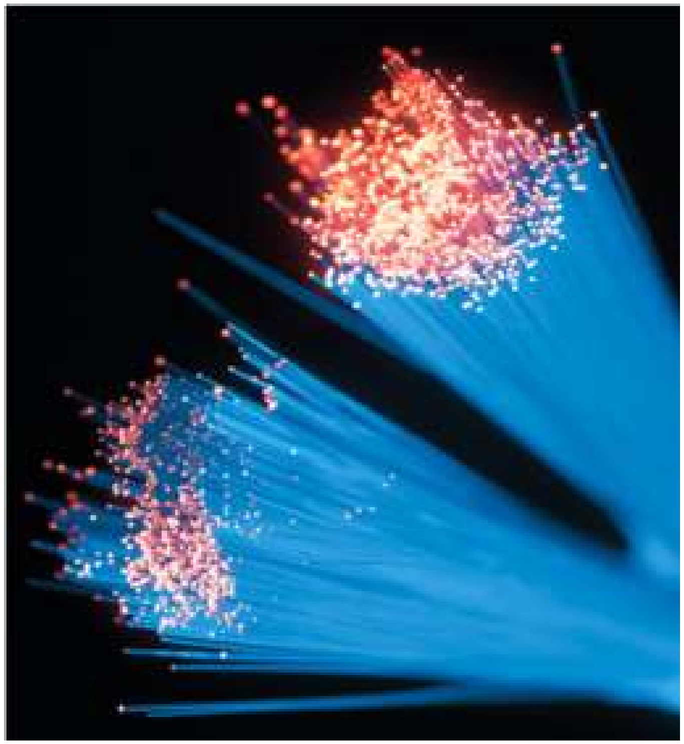


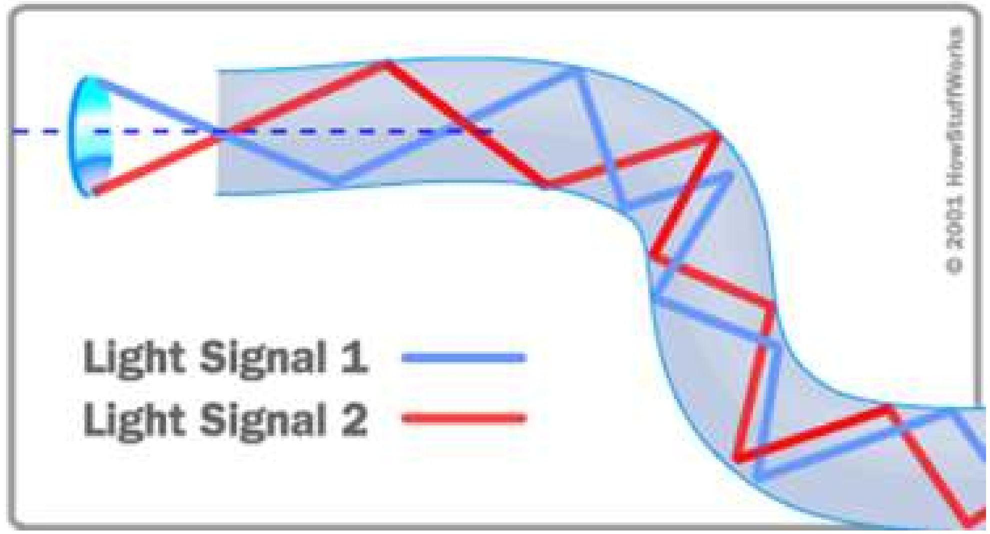
4.) Microwave Link

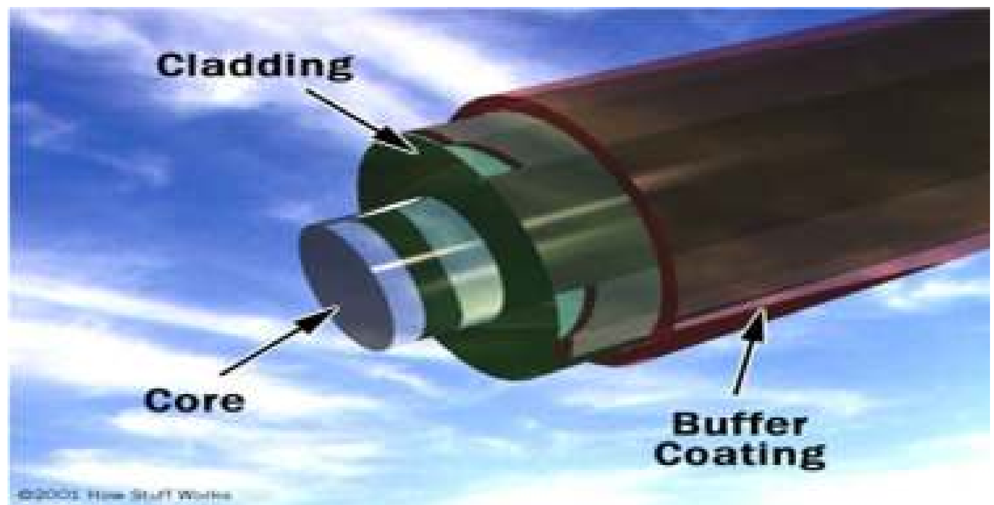
- Microwaves are also electromagnetic waves but they are in the range of 3 GHz to 30 GHz and are generally used for point to point communications as the range of transmissions is limited to line of sight.
- For long distance transmission, many repeater stations are required.
- Reflecting parabolic dishes are used so that the transmission is in the form of a parallel beam and so that as much wave power as possible can be focused onto the receiving aerial.
- The reflecting parabolic dishes at the transmitter or the receiver are not the aerials. The aerial is found at the focus of the transmitting or reflecting dish.
- The bandwidth of a microwave link is of the order of 1 GHz which means that the microwave beam has a large capacity for transmitting information.



5.) Optic fibres







Optic fibres

- An optic fibre consists of a fine strand of very pure glass(thinner than hair) surrounded by protective covering.
- Pulses of light or infra-red radiation carrying digital data travel along the fibre as a result of total internal reflection.
- The radiated pulses are provided by lasers (light amplification by stimulated emission of radiation) and have very high frequencies of the order of 10^8 MHz (i.e.10^{14} Hz)
- In theory a single pulse need only last for 10^{-14} seconds; such high frequencies mean a large bandwidth. This would allow hundreds of thousands of individual telephone calls to share the same optic fibre.

- The advantages of transmission using optic fibres are indicated below.

  1.) Optic fibres have a wide bandwidth. This gives rise to a large transmission capacity.

  2.) Signal power losses in optic fibres are relatively small. This allows for longer uninterrupted distances between regenerator amplifiers and reduces the costs of installation.

  3.) The cost of optic fibre is much less than that of metal wire.

Optic fibres

- Continue…

  4.) The diameter and weight of fibre optic cables is much less that that of metal cables. This implies easier handling and storage.

  5.) Optic fibres have very high security since they do not radiate energy and thus there is negligible ‘cross-talk’ between fibres.

  6.) Optic fibres do not pick up electromagnetic interference. This means they can be used in electromagnetically ‘noisy’ environments, for example alongside electric railway lines.

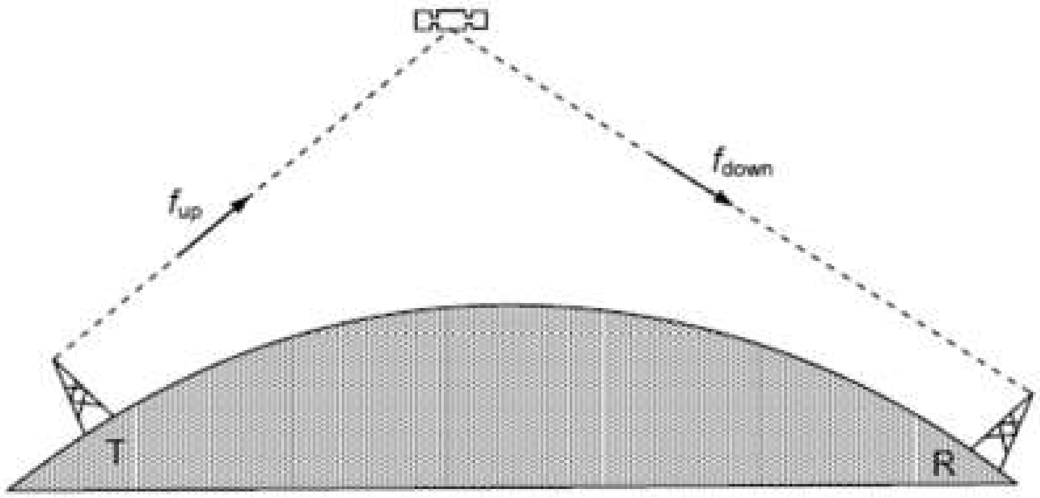
  7.) Optic fibre is ideal for digital transmissions since the light is obtained from lasers that can be switched on and off very rapidly.

Satellite Communication

- Although long distance communication using radio waves is possible on the MW waveband (as surface waves) and the SW waveband (as sky waves), for modern communication systems, there are some disadvantages:
  1) Long distance communication using sky waves is unreliable as it depends on reflection from layers of ions in the upper atmosphere which vary in height and density. This gives rise to variable quality of signal.
  2) Surface waves are also unreliable because there is poor reception in hilly areas.
  3.) The wavebands available on MW and SW are already crowded.
  4.) The bandwidths that are available are narrow and completely unable to carry large amounts of information.

- Satellite communication enables more wavebands to be made available and at much higher frequencies, thus giving rise to a much greater data carrying capacity.

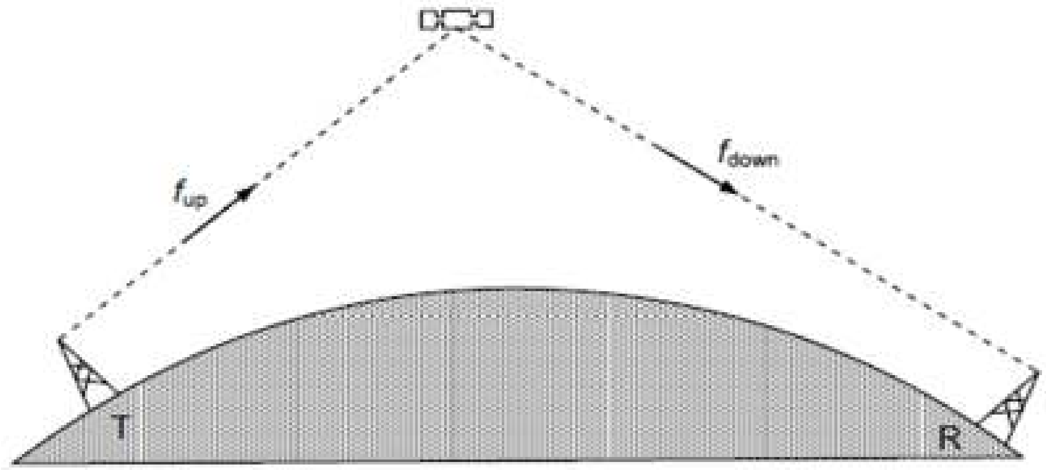
Basic principle of satellite communications



Procedure

1) ***A carrier wave of frequency f_{up} is sent from a transmitter T on Earth to a satellite***
2) ***The satellite receives the signal greatly attenuated***
3) ***The signal is amplified***
4) ***The carrier frequency is changed to a lower frequency f_{down}***
5) ***The carrier wave of f_{down} is then directed back to a receiver R on Earth***

Basic principle of satellite communications



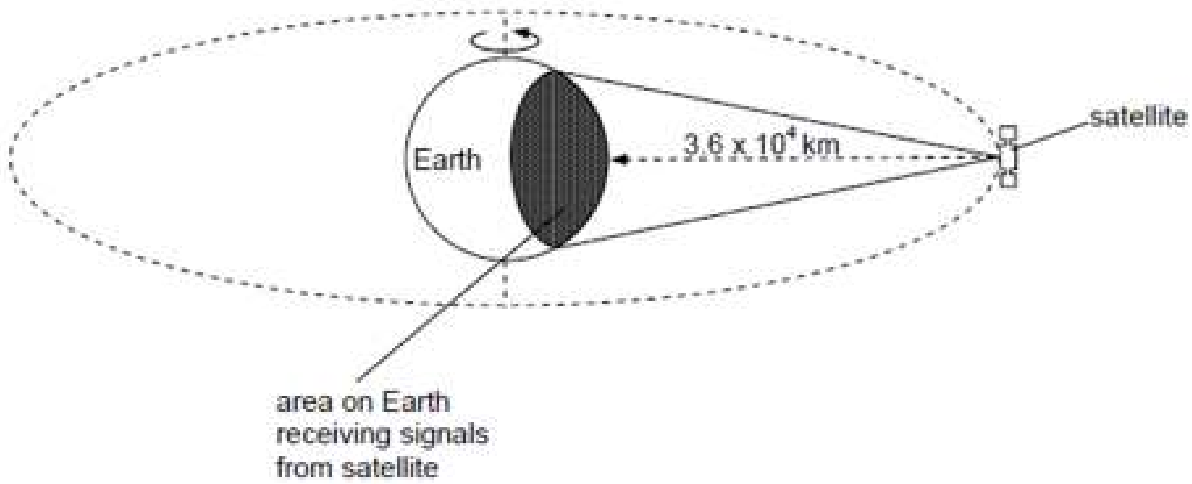
- The 'uplink' and 'downlink' carrier frequencies f_{up} and f_{down} respectively are different so that the very low power signals received from Earth are not swamped by(i.e. can be distinguished from) the high power signal that is transmitted back to Earth
- Typical values of uplink/downlink are 6/4 GHz(6/4 GHz band), 14/11 GHz and 30/20 GHz

Geostationary Satellite

- The communication satellite may be in **geostationary orbit** which means that the satellite is above the equator, orbits the Earth with a period of 24 hours at a height of 3.6 x 10^4 km above the Earth’s surface and in the same direction as the rotation of the Earth which is from west to east.
- From the viewpoint of a person on Earth, the satellite remains above the same point on the Earth’s surface.
- The transmitting aerial and the receiving aerial on Earth both have large parabolic reflectors
- For geostationary satellites, these aerials can be in fixed positions and hence the satellite does not need to be tracked.
- This also means that a geostationary satellite can have a permanent link with a transmitting ground station hence maintaining communications with any point on the Earth’s surface that can receive the signal from the satellite.
- A number of satellites with overlapping areas allows for long distance communications removing the need for long distance submarine cables
- International television broadcasting is possible allowing for ‘live’ events in one country to be viewed by another.

Geostationary Satellite

- There are problems with geostationary satellites.
- Geostationary satellites are in equatorial orbits which means that *communication in polar regions (north & south) may not be possible because a satellite will not be in line-of-sight.*
- The height of the orbit may also pose a problem as between the transmission and receipt of the signal, the wave must travel at least twice the distance between the satellite and Earth i.e. 7.2×10^4 km for which the time to travel is 0.24 seconds.
- This delay may be increased where several satellites were involved and would not be acceptable for telephone conversation.
- To avoid these problems, geostationary satellites may be used in conjunction with optic fibres.

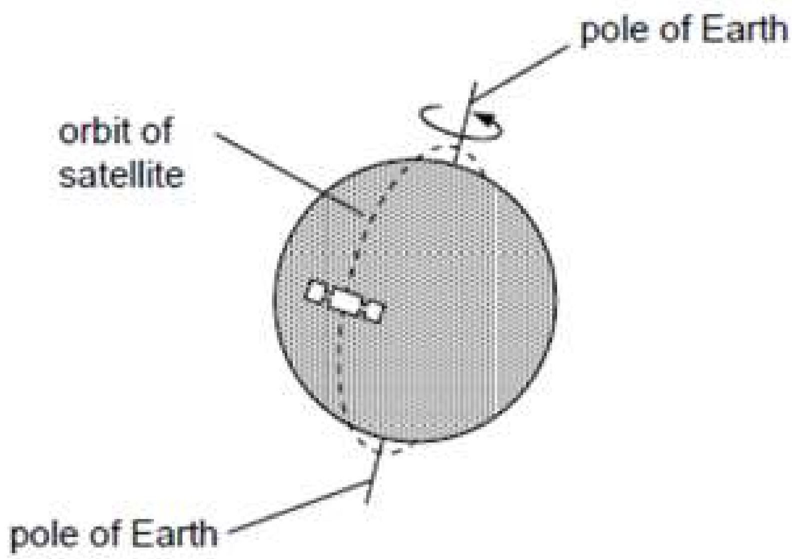


Polar Satellite

- Polar orbits are relatively low with a period of rotation of the order of 90 minutes.
- Such satellites will, as a result of the rotation of the Earth, at some time each day orbit above every point on the Earth's surface.
- For a satellite having a period of 90 minutes, each orbit crosses the Equator 23° to the west of the previous orbit.
- It is not possible to have continuous communication links with one such satellite because, from Earth, the satellite appears to move rapidly across the sky and, for part of the time, is below the horizon.
- Polar orbiting satellites are used for communications, for monitoring the state of the Earth's surface, weather forecasting, spying etc.

Polar Satellite

- Polar orbiting satellites are used for communication since they are in low orbits, resulting in short time delays between transmission and receipt of a signal.
- Furthermore, total global coverage is possible. However, a network of such satellites is required in order to maintain continuous links.
- The satellites must be tracked and the link switched from one satellite to another.
- Geostationary satellites have the advantage that they do not need to be tracked.



Signal attenuation

- When an electrical signal is transmitted along a metal wire, it gradually loses power, mostly as thermal energy in heating the wire.
- Similarly, a light pulse travelling along an optic fibre loses power, mostly by absorption due to impurities in the glass and by scattering due to imperfections. Electromagnetic waves lose power by absorption and dispersion.
- A reduction in signal power is referred to as *attenuation*.
- In order that a signal may be detected adequately, its power must be a minimum number of times greater than the power associated with noise. Typically, this signal-to-noise ratio could be 100.
- Repeater amplifiers may be required to increase the power of a signal that is being passed along a transmission line. The gain of such an amplifier (the ratio of the output power to the input power) could be 100000.
- For a radio link between Earth and a geostationary satellite, the power received by the satellite may be 10^{19} times smaller than that transmitted from Earth.

Signal attenuation

- It can be seen from the above examples that the ratio of the two powers may be very large.
- Consequently, an extremely convenient unit by which power levels, or any other quantities, may be compared is the bel (B). The number of bels is related to the ratio of two powers P_1 and P_2 by the expression

$$\text{number of bels} = \lg(P_1/P_2)$$

- In practice, the ratios are usually expressed in decibels (dB), where 10 dB = 1 B. Consequently,

$$\textbf{number of decibels} = \mathbf{10\ lg}(\boldsymbol{P_1/P_2})$$

- If $P_2 > P_1$ ***the dB number is negative***
- If $P_2 < P_1$ ***the dB number is positive***

Signal attenuation

Example

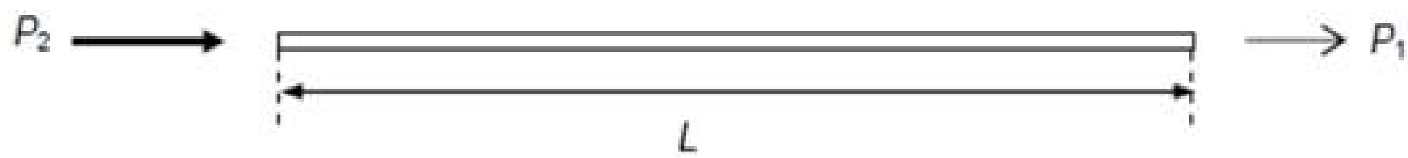
The gain of an amplifier is 45 dB. Calculate the output power P_{out} of the amplifier for an input power P_{in} of 2.0 μW.

$$\text{number of decibels} = 10\,\lg(P_1/P_2)$$

$$
\begin{aligned}
45 &= 10\,\lg(P_{out} / 2.0 \times 10^{-6}) \\
4.5 &= \lg(P_{out} / 2.0 \times 10^{-6}) \\
10^{4.5} &= (P_{out} / 2.0 \times 10^{-6}) \\
P_{out} &= 10^{4.5} \times 2.0 \times 10^{-6} \\
P_{out} &= 6.3 \times 10^{-2}\ \text{W}
\end{aligned}
$$

Signal attenuation

A transmission line has an input power P_2 and the power at a point distance L along the line is P_1 as illustrated in Fig. 3.17.



Then, attenuation in the line = $10 \lg (P_2 / P_1)$ dB.

Since a transmission line may vary in length, an important feature of a transmission line is its attenuation per unit length.

$$\text{attenuation per unit length} = \frac{1}{L} 10 \lg \frac{P_2}{P_1}$$

Example

The input power to a cable of length 25 km is 500 mW. The attenuation per unit length of the cable is 2 dB km^{-1}. Calculate the output power of the signal from the cable.

signal loss in cable $= 2 \times 25 = 50$ dB

$50 = 10 \lg(500 \times 10^{-3} / P_{out})$, where P_{out} is the output power.

$P_{out} = 500 \times 10^{-3} \times 10^{-5} = 5 \times 10^{-6}$ W.

Signal attenuation

The signal cannot be allowed to travel indefinitely in the cable because, eventually, it will become so small that it cannot be distinguished from background noise. An important factor is the minimum *signal-to-noise ratio* that effectively provides a value for the lowest signal power allowed in the cable.

In the above example, the background noise is 5×10^{-13} W and the minimum signal-to-noise ratio permissible is 20 dB. Then if P_M is the minimum signal power,

$$20 = 10 \lg(P_M / 5 \times 10^{-13})$$

$$P_M = 5 \times 10^{-13} \times 10^2 = 5 \times 10^{-11} \text{ W.}$$

This enables the maximum uninterrupted length of cable along which the signal can be transmitted to be determined.

Maximum loss in cable $= 10 \lg(500 \times 10^{-3} / 5 \times 10^{-11}) = 120$ dB

Maximum distance $= 120 / 2 = 60$ km.

Signal attenuation

Example:

The signal input to an optic fibre is 7.0 mW. The average noise power in the fibre is 5.5×10^{-19} W and the signal-to-noise ratio must not fall below 24 dB. The fibre has an attenuation of 1.8 dB km^{-1}.

Calculate:

a) the minimum effective signal power on the cable

b) the maximum uninterrupted length of the optic fibre through which the signal can be transmitted

Solution

a) number of decibels(dB) $= 10 \lg(P_2/P_1)$

$$24 = 10 \lg(P_{min}/(5.5 \times 10^{-19}))$$

$$\mathbf{P_{min} = 1.38 \times 10^{-16}\ W}$$

b) total attenuation of signal to reach minimum $= 10 \lg(P_{input}/P_{min})$

$$= 10 \log((7.0 \times 10^{-3})/(1.38 \times 10^{-16}))$$

$$= 137 \text{ dB}$$

maximum uninterrupted length = total attenuation / attenuation per unit length

$= 137/1.8 =$ **76 km**

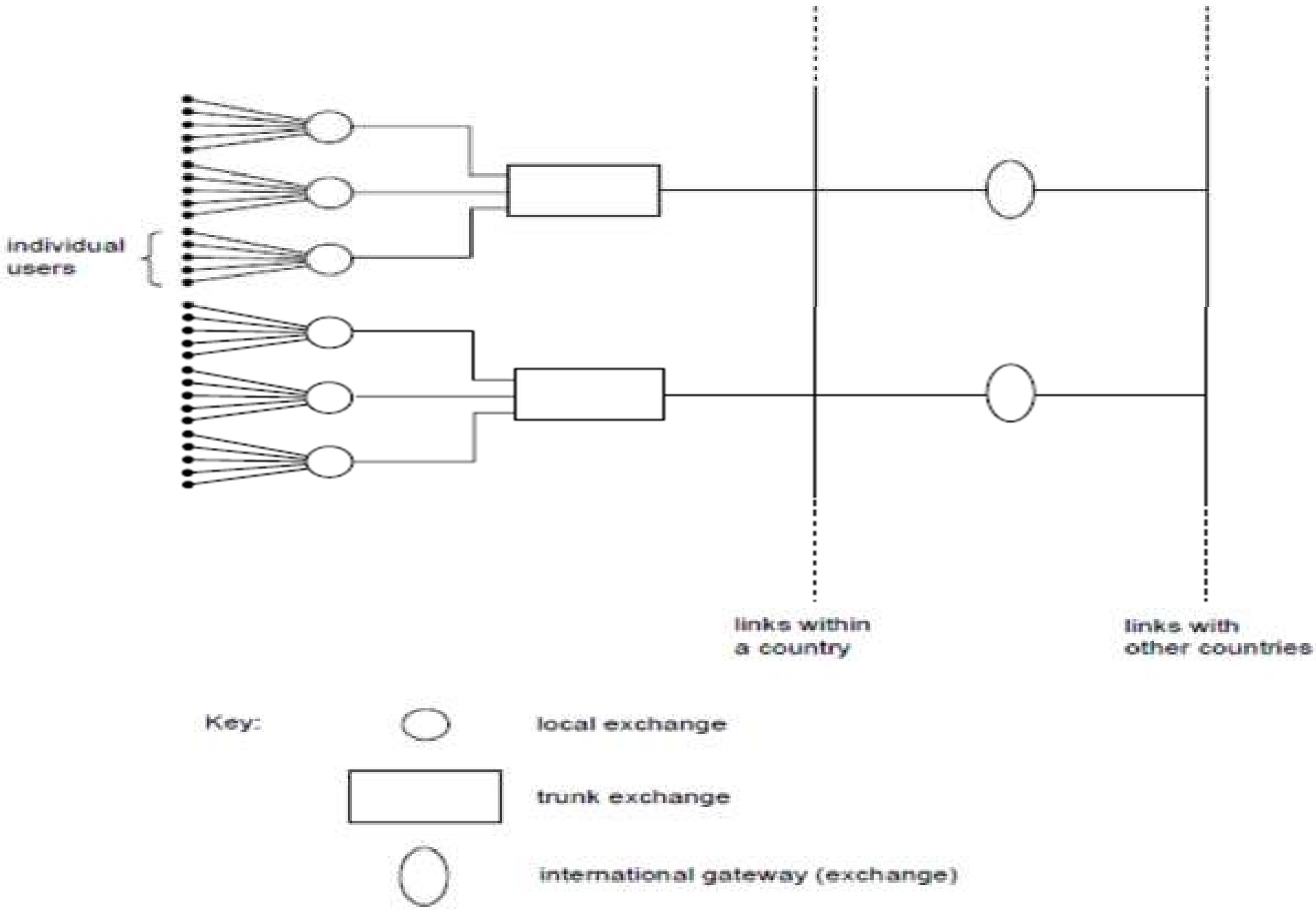
The Mobile Phone Network

The mobile phone system & PSTN

- In the early days of telephones, each telephone user was connected to all other users by their own cables. This was feasible only where the number of users was small as in, for example, a single building.
- As telephones became more popular and widespread, connections between individual users became impractical.
- Consequently, the telephone exchange was developed. The caller would contact the telephone exchange and, at the exchange, the connection to the other user would be made by a person known as an ‘operator’.
- If the call was not a local call served by that particular exchange, then the local exchange would contact the other user’s local exchange via a trunk exchange. Trunk exchanges were connected via trunk lines and hence the expression ‘trunk call’ for any long-distance call.
- In essence, the Public Switched Telephone Network (PSTN) uses the same principles of exchanges but has developed with modern technology and the number of users. For example, switching is no longer achieved using operators. Electromagnetic relays have been replaced by solid-state devices and international ‘exchanges’, or gateways, have been introduced.

The mobile phone system & PSTN

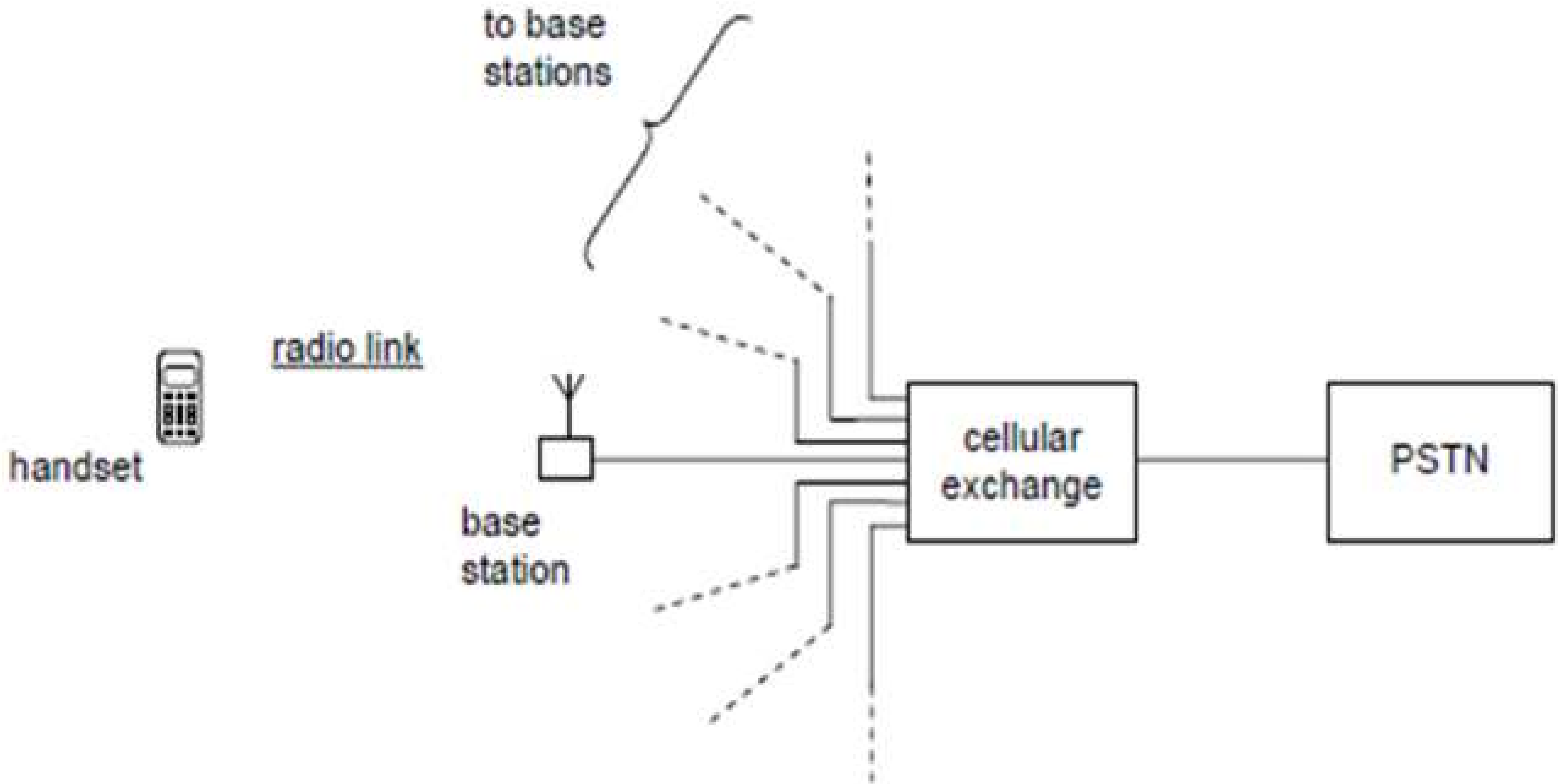
- The PSTN is illustrated as below.



The mobile phone system & PSTN

- In the system illustrated in previous slide, the user is connected to the PSTN via the local exchange. Each user has a ‘fixed line’ to the local exchange, resulting in the user having limited mobility whilst making the call.
- During the 1970s and 1980s, mobile phone systems were developed that did not have a permanent link to a local exchange.
- Basically, a mobile phone is a *handset* that is a radio transmitter and receiver. When a call is to be made, the user makes a radio-wave link with a nearby *base station*. This base station is connected by cable to a *cellular exchange*.
- The cellular exchange then allows connection to be made to the PSTN.
- This is illustrated in the following slide.

The mobile phone system & PSTN

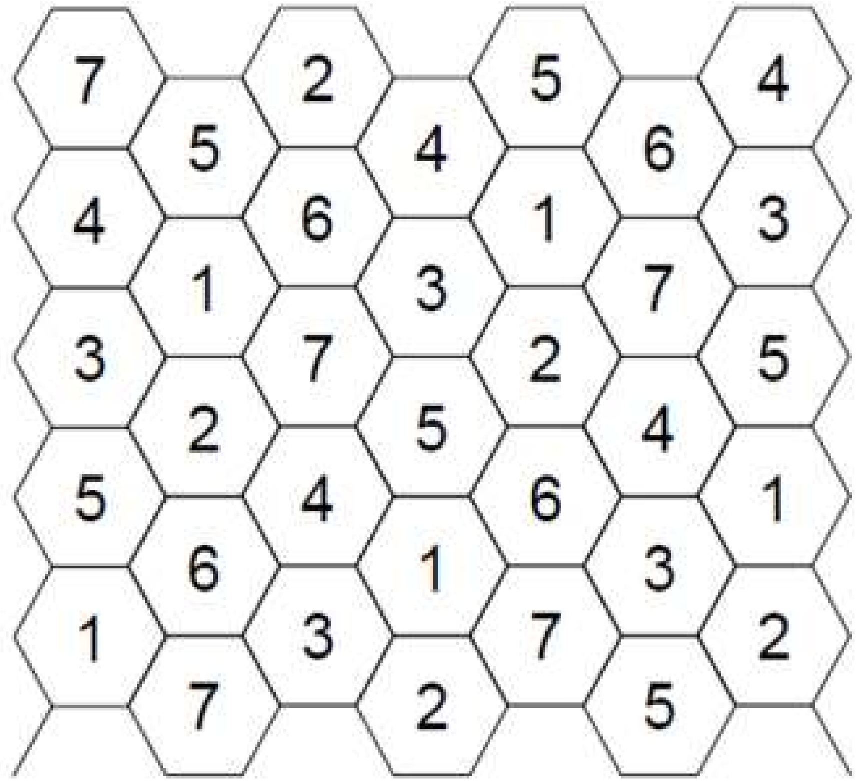


The mobile phone system & PSTN

- The popularity of mobile phones means that large numbers of people use a mobile phone system at the same time.
- However, the range of carrier-wave frequencies for linking between the mobile phone and the base station is limited.
- Consequently, each mobile phone cannot have its own carrier frequency. This means that the same carrier frequencies must be used by many mobile phones at the same time. This is achieved using a network of base stations.
- The base stations operate on UHF frequencies so that they have a limited range and are low-power transmitters. The UHF frequencies also mean that the aerial in the mobile phone is conveniently short!
- A country is divided into areas or *cells*, with each cell having its own base station, usually located near the centre of the cell. The aerial at the base station transmits in all directions so as to cover the whole cell, but not to overlap too far into neighbouring cells.
- In this way, the whole country is ‘covered’.
- Neighbouring cells cannot use the same carrier frequencies, otherwise interference would occur at the boundaries between cells. A possible arrangement of cells is shown in diagram in the next slide.

The mobile phone system & PSTN

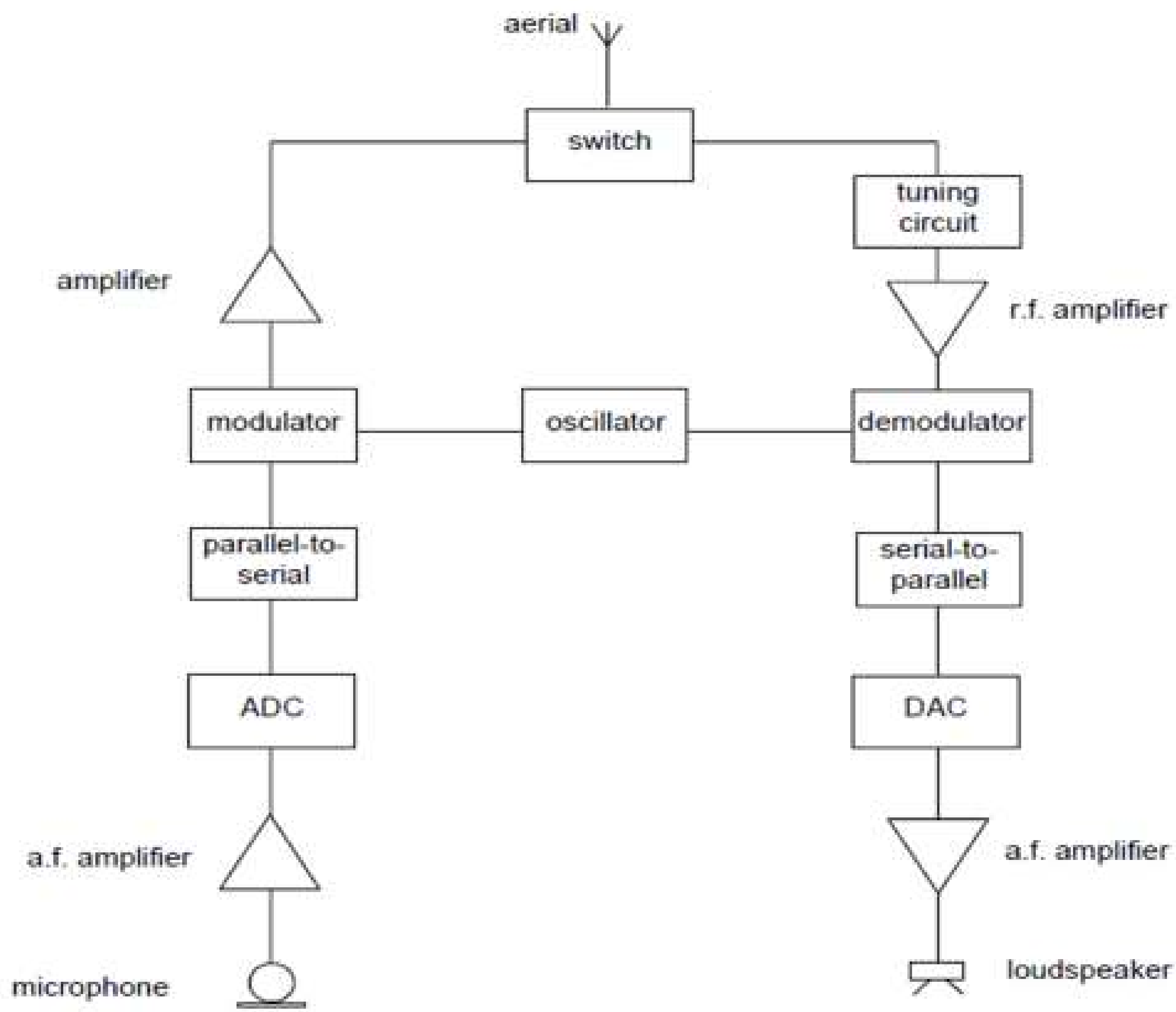
- Although each cell is approximately circular (depending on the flatness of the land), the cells are shown as a ‘honeycomb’ so that the cells fit together.
- The number in each cell represents a particular range of carrier frequencies that would be allocated to each cell. Neighbouring cells do not have the same range of carrier frequencies.
- When a handset is switched on, it transmits a signal to identify itself. This signal is received by a number of base stations, from where it is transferred to the cellular exchange.
- A computer at the cellular exchange selects the base station with the strongest signal from the handset. The computer also allocates a carrier frequency for communication between the base station and the handset.



- During communication between the handset and the base station, the computer at the cellular exchange monitors the signal from the handset. If the user of the handset moves from one cell to another, the signal strength changes. The call from the handset is then re-routed through the base station with the greater signal.

The mobile phone system & PSTN

- A mobile-phone handset is, in its simplest form, a radio transmitter and receiver. A simplified block diagram of its circuitry is shown in figure below.



The mobile phone system & PSTN

- The caller speaks into the microphone. This produces a varying signal voltage that is amplified and converted to a digital signal by means of the ADC.
- The parallel-to-series converter takes the whole of each digital sample voltage and then emits it as a series of bits. The series of bits is then used to modulate the chosen carrier wave.
- After further amplification, the modulated carrier wave is switched to the aerial where it is transmitted as a radio wave.
- On receipt of a signal at the aerial, the signal is switched to a tuning circuit that selects only the carrier-wave frequency allocated to it by the computer located at the cellular exchange.
- This selected signal is then amplified and demodulated so that the information signal is separated from the carrier wave.
- This information signal is in digital form. It is processed in a series-to-parallel converter to produce each sample digital voltage and then in a digital-to-analogue converter (DAC) to provide the analogue signal.
- After amplification, the analogue signal is passed to a loudspeaker.