Cambridge

A2 Level

Physics

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Chapter 20

Chapter 20 -Communications systems

Radio waves

Sound waves and radio waves are completely different types of wave:

■ ■ Sound waves travel as mechanical vibrations. Their speed is typically 330 m s−1 in air, and audible frequencies lie between 20 Hz and 20 kHz.

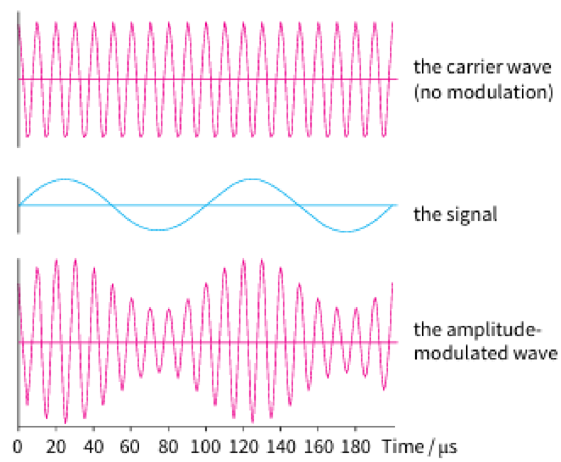
■ ■ Radio waves are electromagnetic waves which travel at the speed of light (3.0 × 106 m s−1 in a vacuum). Their frequencies are much higher than those of sound waves.

To allow several radio stations to broadcast, each signal has a different **carrier wave** frequency

Modulation is the variation of either the **amplitude or the frequency** of the carrier wave. The modulated wave is the actual wave transmitted. The signal is present in either the changing amplitude or the changing frequency of the modulated wave.

Amplitude modulation

Figure 20.3 shows amplitude modulation (AM). The three diagrams show the carrier wave, the signal and the modulated wave. In each case, the horizontal axis represents time, shown on the axis at the bottom.



The amplitude of a signal must be less than half of the carrier wave's amplitude to avoid confusion. For example, a radio station transmitting music has a more complex wave pattern with changing frequencies. The carrier wave frequency remains constant, but the amplitude of the trace changes with time. Amplitude modulation (AM) maintains the same frequency.

Frequency modulation

In frequency modulation (FM) the frequency of the modulated wave varies with time. Without any signal, the frequency of the modulated wave is equal to the frequency of the carrier wave. The size of the input signal at any instant causes the frequency of the modulated wave to change. When the input signal is positive, the frequency of the modulated wave is increased so that it is larger than the frequency of the carrier wave.

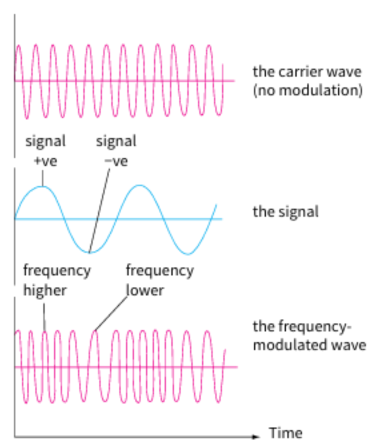


Figure 20.4 Frequency modulation.

Sidebands and bandwidth

When music or speech is transmitted, the carrier is modulated by a range of frequencies which change with time. Each frequency fm present in the signal gives rise to an extra pair of frequencies in the modulated wave. The result is a band of frequencies, called the **upper** and **lower sidebands**, stretching above and below the carrier frequency by the value of the highest modulating frequency.

The actual shape of the sidebands in Figure 20.6 will vary at any instant as the signal changes. The maximum and minimum values are important, as these must not overlap the sidebands from any other radio station.

You can see that the modulated carrier wave occupies a region of the spectrum from 0.985 MHz to 1.015 MHz. The **bandwidth** of a signal is the range of frequencies that the signal occupies. In other words, it is the difference between the highest-frequency signal component and the lowest frequency signal component.

Comparing AM and FM transmissions

These radio waves produce unwanted electrical interference and change the amplitude of the radio wave received by a radio. Since the **amplitude** of the wave carries the signal, when amplitude modulation is used the output of the radio is affected. Most electrical interference does not affect the **frequency** of the radio wave received by a radio and thus electrical interference affects FM less than AM.

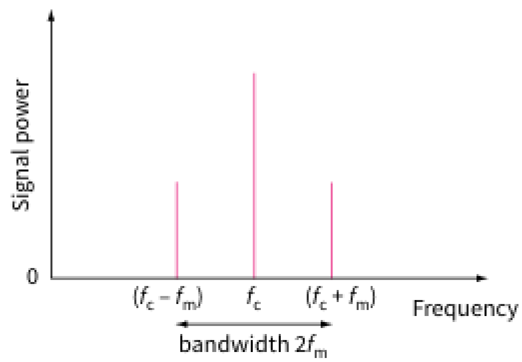


Figure 20.5 The frequency spectrum of a carrier wave modulated in amplitude by a signal of one frequency.

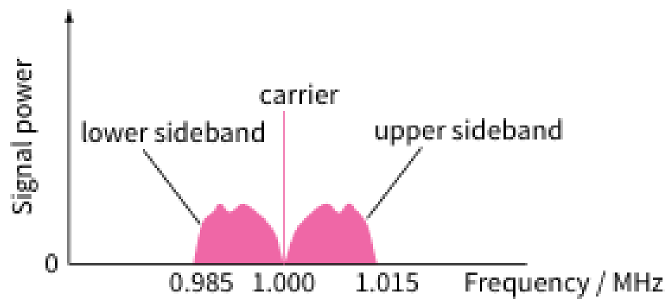


Figure 20.6 The frequency spectrum for an amplitude-modulated wave.

However, AM transmission has a number of advantages.

Advantages of FM	Advantages of AM
less electrical interference and noise	greater area covered by one transmitter
greater bandwidth produces a better quality of sound	smaller bandwidth means more stations available in any frequency range
	cheaper radio sets

Table 20.1 The relative advantages of FM and AM broadcasting.

Analogue and digital signals

An analogue quantity is one that can have any value, for example the height of a person. So far, the signals we have dealt with in this book have been **analogue signals**. **A digital signal**, on the other hand, looks completely different and consists of a series of zeroes (0) and ones (1).

Figure 20.8 shows an analogue and a digital signal. The digital signal is the number 0101001101, which is actually a pulse of 0 V followed by a pulse of 3 V and so on.

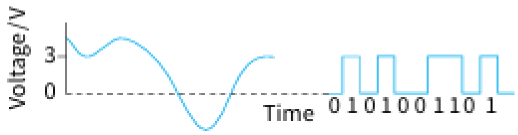


Figure 20.8 Analogue and digital signals.

Advantages of digital signals

Most devices such as microphones or thermistors produce analogue voltage signals. However, digital signals have advantages and it is often worthwhile to change an analogue signal into a digital signal.

Noise is the random, unwanted signal that adds to and distorts a transmitted signal. Amplification of a signal amplifies the noise at the same time as the signal

There is little improvement possible for an analogue signal; amplification will not remove the noise. However, **regeneration** will remove the noise from a digital signal. The signal is 'cleaned' of the noise and returned to its initial shape.

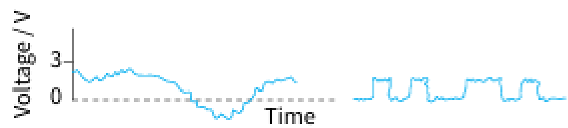


Figure 20.9 Weakened and noisy signals.

Other advantages of using digital signals are:

■ ■ Digital signals are compatible with modern technology and can be stored and processed more easily, for example in a computer or on a compact disc (CD).

■ ■ Digital electronic systems are, in general, more reliable and easier to design and build.

■ ■ Digital signals build in safeguards so that if there is an error in reception it is noticed and parts of the signal can be sent again.

Analogue-to-digital conversion

The key to the digital revolution has been the ability to change speech and music from analogue into digital form in **analogue-to-digital conversion (ADC**) and then convert them back again into analogue form in **digital-to-analogue conversion (DAC).**

Each digit in the binary number is known as a **bit**. The bit on the left-hand side of a binary number is the **most significant bit (MSB**) and has the highest value.

Decimal number	Binary number	Decimal number	Binary number
0	0	6	110
1	1	7	111
2	10	8	1000
3	11	9	1001
4	100	10	1010
5	101	11	1011

Table 20.2 Binary and decimal numbers.

Changing an analogue signal into a digital signal involves sampling. In analogue-to digital conversion (ADC), **sampling** is the measurement of the analogue signal at regular time intervals.

The process is illustrated in Figure 20.10 where 4-bit binary numbers are produced.

Figure 20.11 shows the result of this conversion back into analogue form. The blue circles show the values of the voltage, which are each a decimal number formed from a 4-bit binary number. The black line drawn through the circles is the output signal. Some electronic systems contain extra filter circuits that are able to smooth the output, and they produce the blue line as the final output. The black line, the output, is clearly not exactly the same as the original signal.

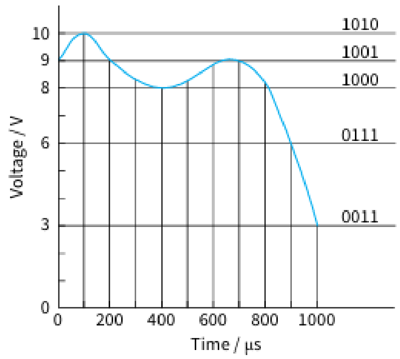


Figure 20.10 Analogue-to-digital conversion.

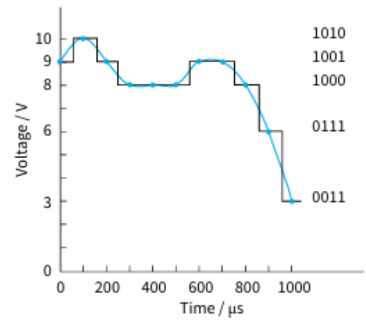


Figure 20.11 Digital-to-analogue conversion.

Channels of communication

The term **channel of communication** refers to the medium, the path or even the actual frequency range used to convey information from a transmitter to a receiver. When you listen to a radio, the radio signal may have travelled through the air by a number of different routes. When you talk to someone on a telephone in a different country then the signal may have passed along a **wire-pair, a coaxial cable**, through the air by a **microwave link** or been converted into pulses of light and then transmitted down an **optic fibre.**

Crosstalk

You may have experienced crosstalk or **crosslinking** when using a radio or a telephone. If you tune your radio set to one radio station, sometimes you can also hear another station.

Signal attenuation

Attenuation is the gradual decrease in the power of a signal the further it travels. The causes of energy loss depend on the type of signal:

■ ■ As an electrical signal passes along a wire, there is a voltage drop across the resistance of the wire itself. This reduces the voltage of the signal that arrives at the end of the wire. The energy loss in the wire causes electrical heating in the resistance of the wire (I 2Rt).

■ ■ A radio wave spreads out from a transmitter. On its own this spreading causes a decrease in intensity, but there is also a loss in signal strength because of the absorption of energy by the material through which the wave travels.

■ ■ Light travelling through an optic fibre may be scattered or absorbed by irregularities in the glass structure.

The logarithm to base 10 of the ratio gives us the number of bels (B). When multiplied by 10 we obtain the number of decibels (dB). Your calculator may show logarithms to base 10 as $\log_{10}$

They are written here as lg and must not be confused with logarithms to base e, which are usually written as ln.

$$\text{number of B} = \lg\left(\frac{P_2}{P_1}\right)$$

$$\text{number of dB} = 10\lg\left(\frac{P_2}{P_1}\right)$$

For example, suppose P_2 is 1000 times greater than P_1:

$$\text{number of dB} = 10\lg\left(\frac{1000}{1}\right) = 30$$

The number is positive because there is an increase in power – the signal is amplified. Attenuation produces a negative number of decibels; for example, an attenuation of −30 dB means that the received signal is 1000 times smaller than the signal transmitted.

You may be much more familiar with logarithms to base e than with logarithms to base 10. All logarithms obey the same rules; some, which you should know, are:

log of a product $\quad \log(ab) = \log(a) + \log(b)$

log of a ratio $\quad \log\left(\frac{a}{b}\right) = \log(a) - \log(b)$

log of a power $\quad \log(a^n) = n\log(a)$

Overcoming attenuation

In long-distance cables, the attenuation is given as attenuation per unit length, with units such as dB km^{-1}. The attenuation is found from the equation:

$$\text{attenuation per unit length (dB km}^{-1}) = \frac{\text{attenuation (dB)}}{\text{length of cable (km)}}$$

When a signal travels along a cable, the level of the noise is important. The signal must be distinguishable above the level of the noise. The signal-to-noise ratio, measured in decibels, is given by the expression:

$$\text{signal-to-noise ratio} = 10\lg\left(\frac{\text{signal power}}{\text{noise power}}\right)$$

At regular intervals along a cable, **repeaters** amplify the signal. If the signal is analogue then repeaters also amplify the noise. Multiplying both signal and noise by the same amount keeps the signal-to-noise ratio the same. Regeneration of a digital signal at the same time as amplification removes most of the noise. This ensures that the signal-to-noise ratio remains high.

Comparison of different channels

Each type of signal channel has its good points and its disadvantages, which we will now consider.

Wire-pairs and coaxial cables

The earliest telephones used a pair of wires strung on either side of a pole (Figure 20.13). As the use of electricity became more common, the amount of electrical interference increased, causing crackle and hiss on the line.

Wire-pairs are the cheapest transmission medium, but they have disadvantages such as electromagnetic fields, low bandwidth, and potential for crosstalk. They are often close together in telephone systems, making them easy to be tapped. Coaxial cables, made of a copper core and a finely woven copper wire or braid, reduce crosstalk and interference. The braid provides a screen or barrier, reducing interference that reaches the copper core. Ideal coaxial cables also prevent EM wave emission at radio frequencies and have less attenuation.

Figure 20.14 Twisted wire-pairs in a computer network.

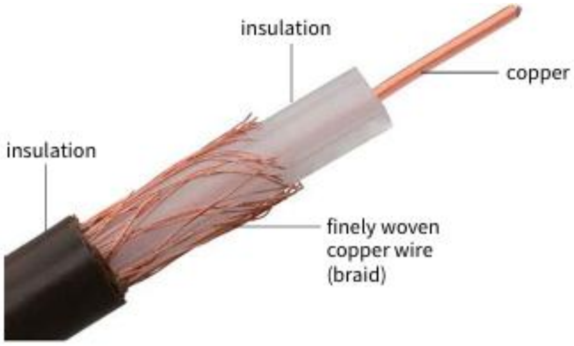


Figure 20.15 Coaxial cable.

Radio waves and microwave links

Radio waves can travel by a number of different paths from a transmitter to a receiver, as shown in Figure 20.16

Surface waves travel close to Earth's surface, with lower frequencies diffracting around the Earth's surface due to their long wavelengths. AM broadcasts in the medium-wave and long-wave bands travel efficiently as surface waves.

Radio waves travel in all directions, with absorption depending on frequency. Distance varies with frequency. Aerials can focus waves towards receivers using dishes, reducing signal strength with distance.

Satellites and optic fibres

Long-distance communication can be transmitted using a sky wave or a space wave and a satellite. Satellites receive a space wave from Earth's uplink, re-transmitting the signal as the downlink back to Earth. Different frequencies are used to accommodate the larger signal sent from Earth. The first communications satellites used 6 GHz for the uplink and 4 GHz for the downlink, but now even higher frequencies are used.

Wire-pairs	Coaxial cable
are cheap and convenient	is more expensive
strongly attenuate a signal	is less attenuating
have low bandwidth	has higher bandwidth
pick up some noise and interference	has less electrical interference and noise
suffer from crosstalk	has little crosstalk
have low security	is more secure

Table 20.3 Comparison of wire-pairs and coaxial cable.

	Frequency range	Communication method and waveband	Distance travelled
surface wave	up to 3 MHz	LW and MW radio in the LF band	up to 1000 km
sky wave	3–30 MHz	SW radio in the HF band	worldwide by reflection
space wave	30–300+ MHz	FM radio in the VHF band, TV and mobile phones in the UHF band	line-of-sight
microwave	1–300 GHz	microwave, satellite links and Wi-Fi in the super-high-frequency (SHF) and extra-high-frequency (EHF) bands.	line-of-sight except when retransmitted by satellite

Table 20.4 Data for radio and microwaves.

Here are some advantages of communication by satellite rather than by sky wave:

■ ■ The concentration of ions in the ionosphere is constantly changing and reflection of the sky wave is not always possible; sometimes layers in the ionosphere even absorb radio frequencies.

■ ■ The satellite boosts the signal for its return to Earth and provides a stronger signal than is obtained by reflection from the ionosphere.

■ ■ Satellite communication uses higher frequencies, which have higher bandwidth and can carry more information per second.

Figure 20.17 A microwave tower.

■ ■ Only a few frequencies in the MW and SW bands are available. More frequencies are available for communicating if a satellite uses higher frequencies.

The satellite does not rotate with the same **speed** as a point on the Earth because its orbit is far larger than the circumference of the Earth

Th e delay when communicating with a polar satellite is much smaller but you may have to wait until the satellite is overhead to transmit or receive. T h e features of a geostationary satellite are:

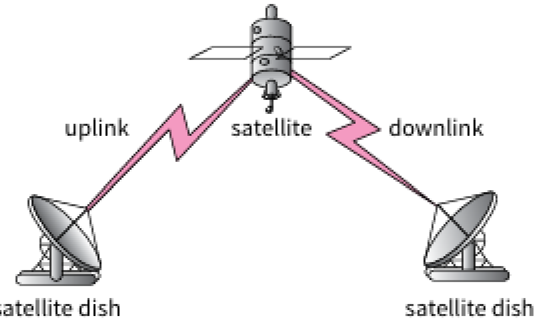


Figure 20.18 A satellite system.

■ ■ the satellite rotates with the same period as the Earth

■ ■ the satellite is in orbit above the equator with a period of 1 day

■ ■ the satellite appears to remain fixed in position above a point on the equator and so satellite dishes do not need to be moved.

Compared to a geostationary satellite, a satellite in polar orbit:

■ ■ travels from pole to pole, with an shorter period of orbit

■ ■ is at a smaller height above the Earth and can detect objects of smaller detail

■ ■ is not always in the same position relative to the Earth and so dishes must be moved

■ ■ has smaller delay times.

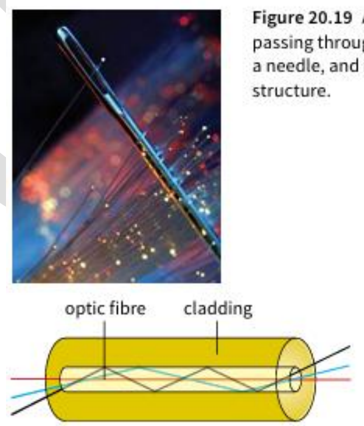


Figure 20.19 An optic fibre passing through the eye of a needle, and its internal structure.

Th e disadvantages of fibre optic cables are that an electrical signal must fi rst be converted to pulses of light and the optic fibres are difficult to connect to one another as two fibres cannot just be glued together. Compared to a metal cable, a fibre optic cable:

■ ■ has much greater bandwidth and can carry more information per second

■ ■ has less signal attenuation, so repeater and regeneration amplifiers can be further apart

■ ■ is more difficult to tap, making the data it carries more secure

■ ■ does not suffer from electrical interference and crosstalk

■ ■ weighs less and so large lengths can be handled more easily

■ ■ is immune to lightning and the effects of nearby power lines

■ ■ can be used in flammable situations as no sparks are produced

■ ■ is cheaper than the same length of copper wire.