GCSE Science: Physics

For Examination From June 1998

Communications Booklet

This **Course Guidance** document is intended to provide the teacher with background material for the communications topic. It also contains some pupil assessment questions and answers.

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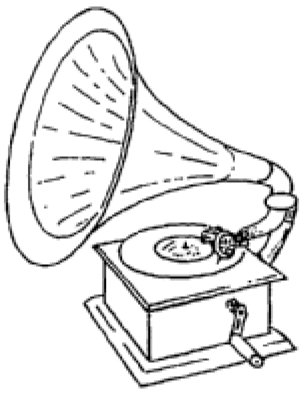
FOREWORD

This booklet has been written for ULEAC by Mr E Beales, Chief Examiner for syllabus 1524 Science: Double Award (Combined) and Principal Examiner for syllabus 1046, Science: Physics. It is not intended to be used as a pupil text but to provide the teacher with sufficient background material to be able to teach the communications topic in the syllabus with confidence. It is, however, entirely at the teacher's discretion as to how the booklet is used in practice.

Whatever use is made of the booklet, it is hoped that it proves helpful and informative.



1.0 COMMUNICATIONS

All communication methods involve making use of waves as the carrier to carry the signal from one place to another. For example:
- radio and television waves for transmitting coded audio and visual signals;
- infra-red waves for sending signals to the TV or video from the remote control unit;
- light waves for carrying signals through optical fibres to carry telephone messages;
- microwaves for carrying signals from the control tower to an aircraft.

Electrical currents in conductors also give rise to electromagnetic waves which travel through co-axial cables or along wires. Clearly, if we are to understand communication systems, we need to understand basic wave behaviour and properties.

WAVES CHECKLIST

- Waves can reflect, refract, interfere and diffract
- The wave equation is given by

$v = f \times \lambda$

- where v = wave speed, f = frequency, λ = wavelength
- the amplitude of a wave is the maximum displacement of the wave
- all electronic waves travel in air or space at the speed of light in a vacuum
- the power of an elenctromagnetic wave of fixed amplitude depends on its frequency

We have already seen that communication systems have a number of common features:
- all use waves as a means of carrying the signal from one place to another.
- all need some way of coding the message and then decoding it when it arrives at its destination.

Other features are included on the following pages.

THINGS TO DO

The significance of waves is vital to the understanding of communication.
A useful assignment would be for pupils to research the range of different methods of communication and identify which waves are being used to carry the information.

It would seem appropriate to revisit some of the core syllabus work at this stage, perhaps having a practical circus, involving a number of different types of waves and designed to show the different properties of waves. Ultrasound, sound, light, 3 cm waves, water ripples and GHz waves are all useful waves to look at.

This could be reinforced with a homework assignment on using the wave equation and testing the understanding of the terms such as GHz, MHz, and kHz.

1.1 INTRODUCTION

Communications are concerned with sending information from one place to another. Although methods of communication have changed over time, all have a number of features in common.

To send any message:

- something has to be used to carry the message - the carrier;
- the message has to be placed on to the carrier;
- something has to be used to detect the message - the receiver.

North American Indians developed a system of sending messages by using smoke signals. In this method, light was used to carry the message, smoke to encode the message and the eye and brain to detect and interpret it. Of course, the sequence of smoke signals would have been of no use to anyone who did not know the code being used to send the signals.

This example highlights two further features that are common to communications systems:

- the message has to be coded in some way before it can be sent;
- when the coded signal is received it has to be decoded so that it makes sense.

You might think that this does not apply to everyday speech, but a little thought shows that it does. In order for people to understand each other a common code is needed (in our case the English language), a means of carrying the message (the sound wave) and a means of receiving and decoding the message (the ear and the brain).

Most of the early methods of communication used light waves to carry the signal. In general, they were known as line of sight methods, for example, smoke signals, semaphore, Aldis lamp and so on. This meant that usually the sender and receiver had to be within sight of each other. However, there are a number of disadvantages with line of sight methods, for example:

- poor weather limits the distance over which the signal can be received;
- the natural curvature of the Earth, together with the fact that light travels in straight lines, limits the range;
- signals could only be sent from places high up, to avoid geographical features;
- the messages could easily be intercepted by others.

THINGS TO DO

A useful starting point would be to invite pupils to think of a number of different ways of sending messages across the laboratory. This might involve using light, sound or electrical currents.

The outcome of the exercise would be to identify the need for a method of conveying a signal (the carrier) and a means of placing the signal on to the carrier (modulation). It should also be apparent that establishing a common code is important if the signal is to be understood by others.

This could be related to the experience of visitors to foreign countries where they do not have knowledge of the particular code being used and are therefore unable to understand the signals (messages) being sent.

The idea of limitations should have arisen from the practical work earlier.

2.0 THE TECHNICAL LANGUAGE OF COMMUNICATIONS - LEARNING THE LINGO

ENCODER
The method by which the message to be sent is produced in the form of a code. For example this would be the Morse code in telegraphy and a digital code in optical fibres.

DECODER
The method by which the coded message is decoded once it has been received. For example, this would involve changing the dots and dashes in Morse to meaningful letters using a code book to decipher the encoded signal.

MODULATION
The method by which the coded message is placed on to the carrier wave. For example, in fibre optics this is achieved by turning a light on and off to represent the binary code used for transmission.

TRANSDUCER
A device which can be used to change from one type of signal to another. This is useful where, for example, sound signals have to be changed to electrical signals before being used to modulate the carrier wave. In this case the appropriate transducer would be a microphone (see page 38).

TRANSMITTER
The device which is used to radiate the waves which carry the signal into the surroundings. The carrier wave radiates from an aerial and the power of the transmitter determines the area of coverage of the carrier wave.

RECEIVER
A device used to detect the transmitted signal. It is usually combined with the decoder so that the message can be separated from the carrier wave.

ATTENUATION
All waves that travel through air, conductors or cables lose energy, which results in the signal strength decreasing with distance travelled. This loss of energy is known as attenuation. The signal strength also decreases as waves spread out in three dimensions. In this case, the signal strength falls to a quarter when the distance from the transmitter is doubled.

AMPLIFIER
The amplifier is used to boost the signal as it travels or once it has been received. For example, in transatlantic cables there is a series of repeater stations which amplify the signal. These repeater stations are used to replace energy losses which result from the electrical resistance of the cable. A satellite dish has an amplifier placed at its focus so that the very weak signals from outer space are boosted before being decoded by the receiver.

THINGS TO DO

It would be useful to have available a number of different devices, together with circuit diagrams, so that reference can be made to them when teaching the technical terms used.

The idea of encoding, modulation and decoding can easily be demonstrated using a light beam which is turned on/off using a particular code, or using electrical signals to open and close relay switches. The person operating the system would be the transmitter and the person at the other end the receiver. It would perhaps be appropriate to highlight the limitations of these methods.

Attenuation can readily be shown by looking at the power loss along electrical wires and it is possible, using op-amps, to set up elementary voltage amplifiers and display the output to a oscilloscope. If this is done, it is possible to introduce the idea of signal distortion and noise.

STORAGE
This is the method used to keep a hard copy of the message which has been sent. There are a number of different ways of doing this. For example, the vinyl disc (record) has grooves etched into its surface which a stylus can 'read'; the CD has a sequence of pits on its surface which a laser can 'read'; and a magnetic tape has small magnetic particles on its surface which the head can 'read'.

SIGNAL-TO-NOISE RATIO
Noise is the result of picking up unwanted signals. It can be caused either by electrical machinery nearby which the receiver detects or when the receiver picks up more than one transmitter at a time so that the signals interfere with each other. Ideally, the signal-to-noise ratio should be high since it is the signal which needs detecting and not the noise.

DIGITAL AND ANALOGUE SIGNALS
An analogue signal is one represented by voltages whose amplitude varies continuously with time. For example, a microphone produces a voltage which replicates the speech waveform.

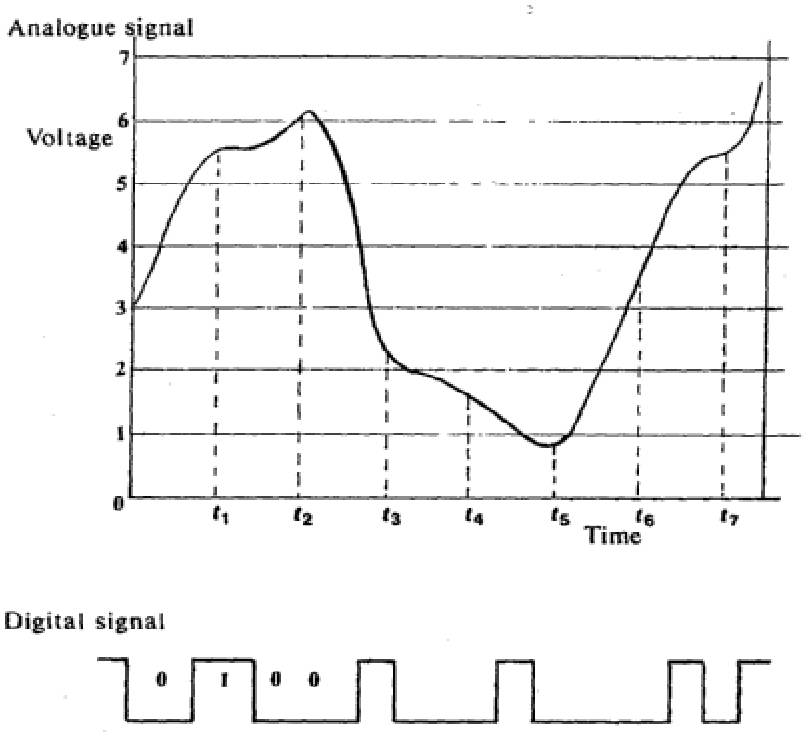
Digital signals do not vary continuously but generally consist of two voltage levels. The combination of these voltage levels is used to represent the signal being sent. For example, in Morse code the message is broken into on and off pulses by using an electrical switch. When the switch is open the voltage level is zero (usually represented by a 0) and when the switch is closed the voltage level is high (represented by a 1).

THINGS TO DO

Examine the surfaces of a CD and a vinyl disc. CD's, LP's and tape recorders afford the opportunity to consider the different methods of storage.

Most school laboratories have ready access to microphones and speakers and practical work can be arranged to examine their performance.

An A to D converter is an electronic device which is able to convert an analogue signal to a digital signal, whilst a D to A converter carries out the opposite process. The diagrams below show an analogue signal from a microphone and a digital signal from an analogue to digital converter.



THINGS TO DO

If schools offer electronics they will probably have available A to D and D to A converters which could be shown as a demonstration. It would be beyond the brief of the syllabus to go into details of how these devices carry out their function.
The idea of analogue and digital signals can easily be demonstrated using the output from a microphone connected to a cathode ray oscilloscope and the square wave output from an AFO can be used to illustrate the meaning of 0 and l's.
Pupils who have a particular interest might have their work extended by designing logic circuits and examining how they perform when square waves pulses are sent through them.

DIGITAL VERSUS ANALOGUE SIGNALS

Earlier, the difference between digital and analogue signals was explained. With analogue signals a continuously varying voltage is produced whereas with a digital signal there are only two states, generally represented by 0 and 1.

One of the advantages of using digital signals is that they can be boosted to compensate for attenuation, without any loss of quality of the signal. When analogue signals are amplified (at a repeater station) any noise associated with the signal is also amplified. This can distort the signal being transmitted. The same is not true for a digital signal, the equivalent amplification stage is called a regenerator which, as the name suggests, re-establishes the sequence of 0 and l's. Because the amplitude of the signal is not being amplified any noise present will not affect the digital signal. This leads to less signal distortion and better quality being produced.

3.0 PIONEERS IN COMMUNICATION

3.1 Morse, Samuel Finley Breese (1791-1872)

American artist and inventor, known for his invention of the electric telegraph and the Morse code. Morse was born in Charleslown, Massachusetts, on 27 April, 1791 and educated at Yale University.

In 1837, he invented the first electrical instruments for telegraphic transmission. Morse used a simple code in which messages were transmitted by electric pulses passing over a single wire. Morse's apparatus, which sent the first public telegram in 1844, resembles a simple electric switch. It allowed current to pass for a prescribed length of time and then shut if off, all at the pressure of a finger. The original Morse receiver had an electromagnetically controlled pencil that made marks on paper tape moving over a clockwork-operated cylinder. The marks varied with the duration of the electric current passing through the wires of the electromagnet and took the written form of dots and dashes.

While experimenting with his instrument, Morse found that signals could be transmitted successfully for only about 32 km (20 miles). Beyond that distance, the signals grew too weak to be recorded. Morse and his associates therefore developed a relay apparatus that could be attached to the telegraph line 32 km from the signal station to repeat signals automatically and send them an additional 32 km. The relay consisted of a switch operated by an electromagnet. An impulse entering the coil of the magnet caused an armature to rotate and close an independent circuit actuated by a battery. This action sent a fresh pulse of current into the line, and this pulse in turn activated successive relays until the receiver was reached. A few years after Morse developed his receiving instrument and demonstrated it successfully, telegraph operators discovered that it was possible to distinguish dots and dashes by sound alone, and the Morse recording apparatus was then discarded. The other fundamental principles of the Morse system continued in use in wire-telegraph circuits, however.

Because telegraphy was too expensive for widespread use, several means of sending several messages simultaneously over a single line were developed. In duplex telegraphy, the earliest advance of this kind, one message can be transmitted simultaneously in each direction between two stations. In quadruplex telegraphy, invented in 1874 by the American engineer Thomas Edison, two messages were transmitted in each direction simultaneously. Because of this, and the development of teleprinting machines during the mid-1920's, the Morse manual telegraph system of code and key was gradually discontinued for commercial use and replaced by automatic wire and wireless radio wave methods of transmission.

THINGS TO DO

A model telegraph system can be easily set up in the lab and pupils might like to see how well they can transmit and receive Morse code.

Using a set of relay switches it is possible to set up in the lab a model of the repeater stations.
Pupils may notice that each additional relay used causes the signal to be delayed. This illustrates the limitation of mechanical switching methods on the speed of communication. It could be worthwhile pointing out that most switching is now done electronically, often making use of logic gates for the function.

3.2 Edison, Thomas Alva (1847-1931)

Born in Milan, Ohio, on I February, 1847. For saving the life of a station official's child, he was rewarded by being taught telegraphy. While working as a telegraph operator, he made his first important invention, a telegraphic repeating instrument that enabled messages to be transmitted automatically over a second line without the presence of an operator. Edison's major achievement in telegraphy was his invention of machines that made possible simultaneous transmission of several messages on one line and thus greatly increased the usefulness of existing telegraphy lines. Equally important was Edison's invention of the carbon microphone for use in telephones.

In 1888, he invented the kinetoscope, the first machine to produce motion pictures by a rapid succession of individual views. Among his later noteworthy inventions was the Edison storage battery (an alkaline, nickel-iron storage battery), the result of many thousands of experiments. The battery was extremely rugged and had a high electrical capacity per unit of weight. He also developed a phonograph in which the sound was impressed on a disk instead of a cylinder. This phonograph had a diamond needle and other improved features. By synchronizing his phonograph and kinetoscope, he produced, in 1913, the first talking moving pictures.

3.3 Bell, Alexander Graham (1847-1922)

Born on 3 March, 1847, in Edinburgh, Scotland, and educated at the Universities of Edinburgh and London. From the age of 18, Bell worked on the idea of transmitting speech. In 1874, while working on a multiple telegraph, he developed the basic ideas for the telephone. His experiments with his assistant, Thomas Waton, finally proved successful on March 10, 1876, when the first complete sentence was transmitted "Waton, come here; I want you." Subsequent demonstrations, particularly one at the 1876 centennial Exposition in Philadelphia, Pennsylvania, introduced the telephone to the world and led to the organisation of the Bell Telephone Company in 1877. He founded the Volla Laboratory in Washington, DC, where he and his associates invented the photophone, which transmits speech by light rays. Other inventions include the audiometer, used to measure acuity in hearing; the induction balance, used to locate metal objects in human bodies; and the first wax recording cylinder, introduced in 1886. The cylinder, together with the flat wax disc, formed the basis of the modern phonograph.

THINGS TO DO

Pupils could be set a research task to see if they can find out how Edison solved the problem of simultaneous transmission.

The phonograph was the precursor of the tape recorder and it should be possible for pupils to find further information about it, perhaps producing a wall display of their findings.

If an old telephone can be located it is a useful teaching aid. By taking the mouth and ear piece it is possible to construct a simple telephone line across the laboratory. Most pupils find it an enjoyable and worthwhile exercise.

Examining the dial of the telephone is also a useful leaching aid on opening and closing switch contacts.

3.4 Hertz, Heinrich Rudolf (1857-1894)

German Physicist; born in Hamburg, and educated at the University of Berlin. From 1885 to 1889, he was professor of physics at the technical school in Karlsruhe and after 1889, a professor of physics at the University of Bonn. Hertz clarified and expanded the electromagnetic theory of light that had been put forward by the British physicist James Clerk Maxwell in 1864. Hertz proved that energy can be transmitted in electromagnetic waves, which travel at the speed of light. His experiments with these electromagnetic waves led to the development of the wireless telegraph and the radio. The unit of frequency, cycles per second, was renamed the hertz; it is commonly abbreviated Hz.

3.5 Marconi, Guglieimo Marchese (1874-1937)

Italian electrical engineer and Nobel laureate, known as the inventor of the first practical radio-signalling system. He was born in Bologna and educated at the University of Bologna. By 1895, he had developed apparatus with which he succeeded in sending signals by means of a directional antenna to a point a few kilometres away. After patenting his system in Great Britain, he formed Marconi's Wireless Telegraph Company Ltd (1897), in London. In 1899, he established communication across the English Channel between England and France, and in 1901 he communicated signals across the Atlantic Ocean between Poldhu in Cornwall and Saint John's in Newfoundland, Canada. His system was soon adopted by the British and Italian navies and, by 1907, had been so much improved that a transatlantic wireless telegraph service was established for public use. Marconi was awarded honours by many countries and received, jointly with the German physicist Karl Ferdinand Braun, the 1909 Nobel Prize in physics, for his work in wireless telegraphy. During World War I he was in charge of the Italian wireless service and developed shortwave transmission as a means of secret communication. In the remaining years of his life, he experimented with shortwaves and microwaves.

3.6 Appleton, Sir Edward Victor (1892-1965)

British physicist, who received the Nobel prize in physics in 1947 for his discovery of the Appleton layer of the ionosphere, which reflects high-frequency radio waves. Appleton was born in Bradford, Yorkshire, England, and educated at St John's College, University of Cambridge. He was a captain in the Signal Corps during World War 1. From 1918 to 1939, he taught physics at Cambridge and at the University of London, where he began a series of experiments with radio waves that led to his discovery of the Appleton layer. He was secretary of the Department of Scientific and Industrial Research of the British Government from 1939 to 1949. This position gave him overall charge of British research during World War 2 and brought him into close cooperation with American scientists, particularly in connection with the development of radar. For this work, he received the United States Medal of Merit.

THINGS TO DO

The work on the electromagnetic spectrum will have been covered in the core syllabus but could be revisited here to reinforce some of the basic characteristics.

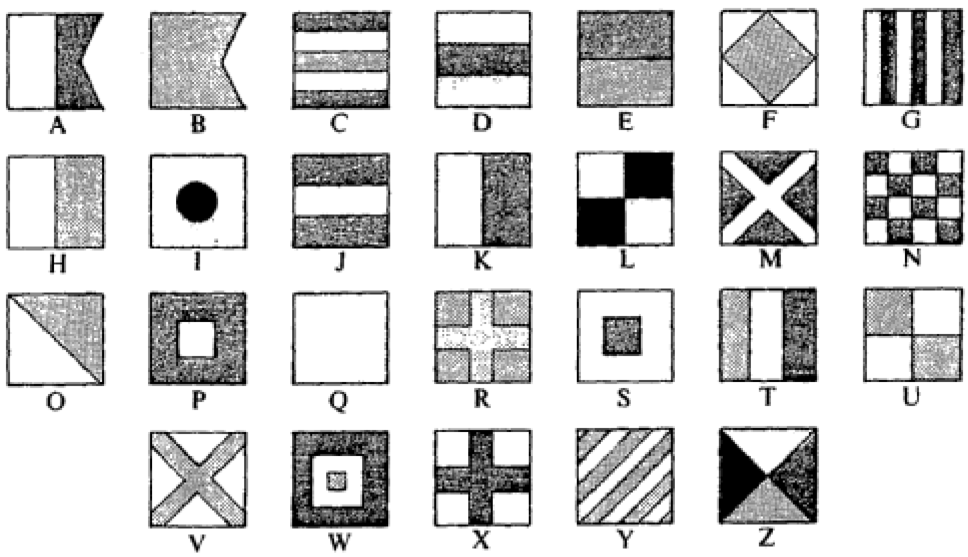
Using a spark generator and a simple radio receiver it is possible to detect the electro magnetic radiation emitted. Pupils will appreciate that the range is limited and that to extend this range a much higher power transmitter would be needed. Unilab market a GHz oscillator and aerial system which would give some scope for investigations into the range and design of aerials. It is possible to show polarisation and directional properties of a multiple dipole aerial.

Experiments with 3 cm waves and reflectors have already been suggested.

3.7 EXAMPLES OF CODES

A	·–	S	···
B	–···	T	–
C	–·–·	U	··–
D	–··	V	···–
E	·	W	·––
F	··–·	X	–··–
G	––·	Y	–·––
H	····	Z	––··
I	··	1	·––––
J	·–––	2	··–––
K	–·–	3	···––
L	·–··	4	····–
M	––	5	·····
N	–·	6	–····
O	–––	7	––···
P	·––·	8	–––··
Q	––·–	9	––––·
R	·–·	0	–––––

The Morse Code



International shipping flag code

THINGS TO DO

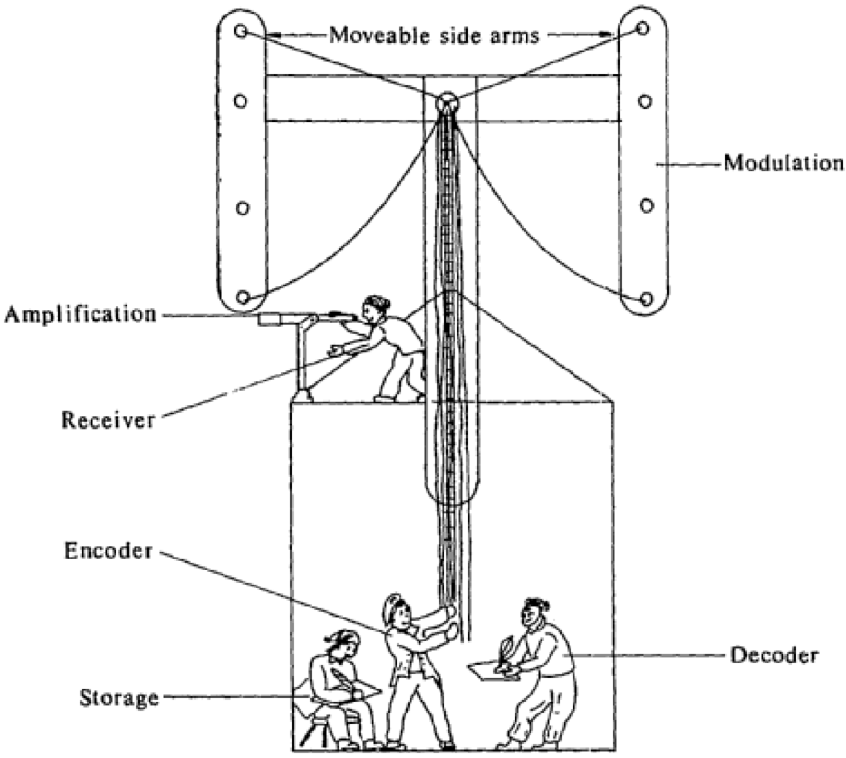
Pupils may enjoy designing their own code and using it to send messages across the lab.

They could research into other international codes, for example the sign language for the hearing impaired or that used in semaphore.

They could analyse each in terms of their limitations, viz. speed and accuracy.

4.0 EARLY COMMUNICATION SYSTEMS

The sketch below shows a method of communication used in the 1700's for sending signals from one place to another. It is possible to identify a number of basic building blocks for this method of communication.



Using a semaphore code

The signal was encoded by placing the large side arms in various positions. We can see from the illustration that the inventor had considered the limitations of this line of sight method. The large arms and the telescope increased the distance over which the method could be used. The following building blocks can be identified:

the **encoding** and **modulation** was achieved by the man operating the ropes to the side arms;
the **carrier wave** (light) was modulated by the position of the side arms; the **receiver** was the man with the telescope; **amplification** was achieved by the use of the telescope; the **decoding** was carried out by the man standing bottom right; the **hard copy** was produced by the scribe towards the bottom left.

Compared with modern systems which also use light, this method is slow and cumbersome. The fact that light travels at an exceptionally high speed has not been utilised. The speed of transmission is restricted by the manpower used to encode, transmit, receive and decode the signal.

THINGS TO DO

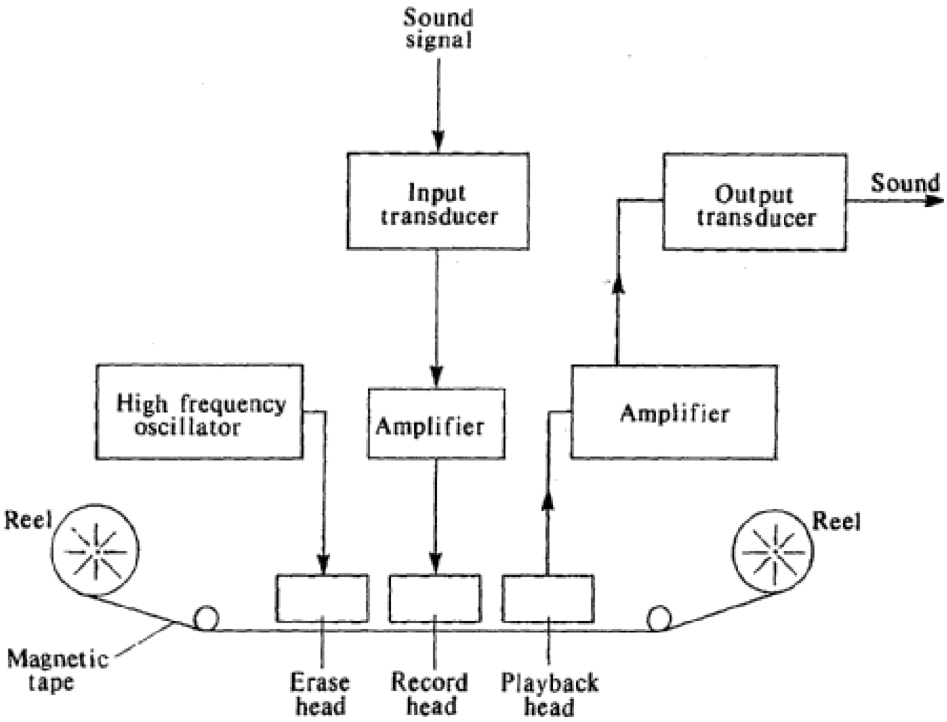
This part of the work could be tied in with looking at the historical development of communications and offers the opportunity for pupils to research and produce reports for the rest of the class.

It is a useful exercise for the pupils to consider the limitations of the methods which they have researched. So, for example, they may discuss the limitation imposed by the curvature of the Earth, of the loss of clarity along a telephone line etc.

The method illustrated here allows comparisons to be made with more recent developments and how these have gone some way in to resolving the difficulties identified.

Use circuit diagrams produced by manufacturers to identify the various building blocks which make up a system.

The diagram below shows a more modern method of storing and retrieving information, the tape recorder. This too can be broken down into some of the basic building blocks mentioned previously.



THINGS TO DO

Since the more modern methods are difficult to understand it is perhaps better to reserve these two examples for class discussion. Generally, pupils will have an interest but need guided discovery to identify the various building blocks which are used.

The first thing to notice is the use of transducers. At the input stage, a sound signal causes an analogue voltage using a microphone. The output from the playback head makes use of a second transducer to convert the analogue voltage back to a sound wave.

There are two amplifiers. The first takes the analogue voltage from the input transducer and increases its amplitude before sending it to the record head. This consists of a coil wrapped round an iron core which produces a magnetic field. As it passes beneath the record head, the tape becomes magnetised. The strength of the magnetic field is related to the amplitude of the signal received from the input transducer. In this way, a hard copy of the signal, in the form of the degree of orientation of magnetic particles in the tape, is produced.

The reverse process takes place at the playback head where the varying magnetic field from the tape creates an induced voltage in the coil of the playback head. This voltage in turn is amplified before being sent to the output transducer, the loudspeaker.

We can see here that the record head is the method by which the signal is encoded whereas the playback head decodes any signal on the tape. In this example, it is the arrangement of the magnetic particles on the tape which represents the modulation of the carrier (in this case, the tape).

A useful exercise is to encourage the pupils to mount a wall display in which the various building blocks are identified for a number of devices. The more artistic will enjoy the opportunity of producing exploded views of the devices.

Investigate the alignment of plotting compasses in magnetic fields.

Investigate moving magnetic tape at different speeds past the playback head.

The purpose of the high frequency oscillator is to disorientate the magnetic particles on the tape so that any signals previously placed on the tape are erased. The conventional understanding of transmitter and receiver do not apply in this particular context, other than in the sense that a tape could be physically sent (transmitted) to a third person (receiver) who then uses a second tape machine (decoder) to listen to the tape (receiving the information).

In this context, it is clearly important that the transmitter and receiver use machines that operate at the same tape speed if sense is to be made of the signal carried on the tape.

The transmission and reception of television pictures and sounds is much more complex than the previous two examples. A simplified block diagram of the arrangement is given opposite. As with the other two examples, the basic building blocks can be readily identified.

At the television studio, the microphone and television camera are transducers which allow the sound and visual signals to be represented as voltage variations. The information, encoded in the form of voltage variations, is then amplified before being used to modulate a carrier signal at the transmitting station. The sound and visual signals modulate electromagnetic wave carriers at different frequencies, before being further amplified and sent to the transmitting aerial. The power amplifier ensures that the two modulated waves have sufficient energy to travel considerable distances (remember that the intensity of electromagnetic waves follows an inverse square law and therefore the energy decreases with distance).

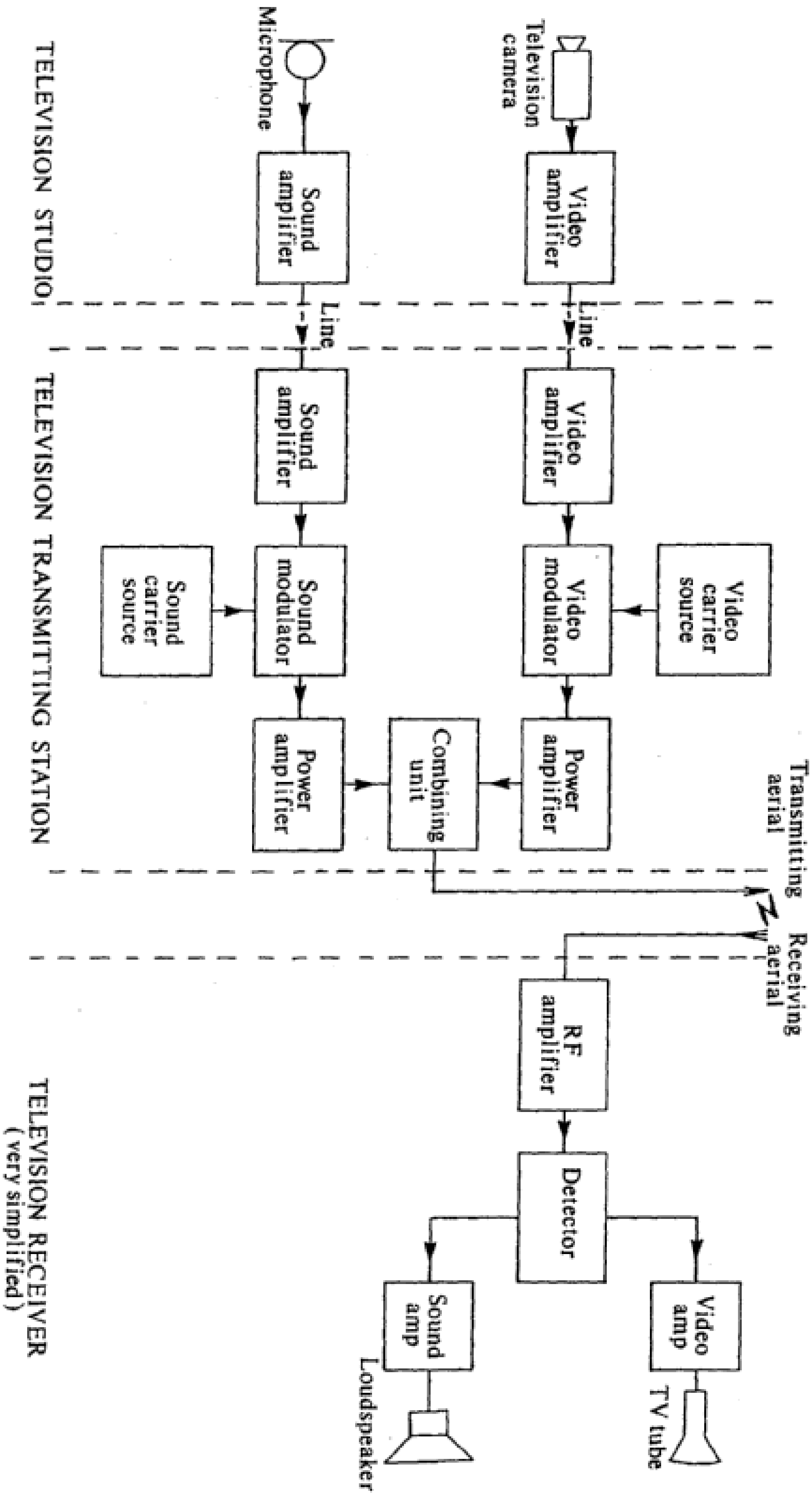
The first part of the receiver is the aerial in which the electromagnetic waves produce a varying voltage. When the receiver is tuned, resonance occurs and a particular carrier wave i.e. television station will be detected. The signal at the aerial is often weak and is therefore amplified by the radio frequency amplifier on reception. The detector in the television receiver is then used to separate the audio and visual signals; it decodes the information carried by the transmitted wave. These signals are then sent to the loudspeaker (the output transducer and decoder of the audio signal) and the television tube (the output transducer and decoder for the visual signal).

THINGS TO DO

If the school posses the UNILAB TV teaching equipment, this is an ideal piece of apparatus for illustrating the various aspects of the TV. Failing this, it is not uncommon to come across old television sets which can be dismantled* to show the various parts that make them up.

***Safety note** - TV should not be capable of being plugged in. Teacher supervision is essential.

Likewise for radios and tape recorders.


TELEVISION STUDIO
Television camera
Video amplifier
Microphone
Sound amplifier
Line
Line
TELEVISION TRANSMITTING STATION
Video amplifier
Sound amplifier
Video carrier source
Video modulator
Sound modulator
Sound carrier source
Power amplifier
Combining unit
Power amplifier
Transmitting aerial
Receiving aerial
RF amplifier
Detector
Video amp
Sound amp
TV tube
Loudspeaker
TELEVISION RECEIVER
(very simplified)

5.0 TRANSMITTING AND RECEIVING RADIO WAVES

THINGS TO DO

The majority of the world's communication systems use radio waves as the carrier wave for signals. Radio waves form part of the electromagnetic spectrum and generally have frequencies between 3 kHz and 300 GHz. Being electromagnetic waves, they have a number of characteristics which are common to all electromagnetic waves, knowledge of which helps us to understand how they can be used as carrier waves.

The important properties of electromagnetic waves are given below:

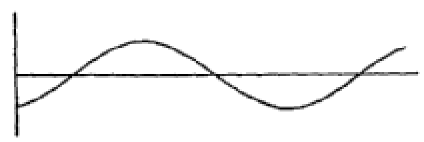
- **they travel in air or space at the speed of light in a vacuum;**
- **they consist of oscillating electric and magnetic fields at right angles to each other and can be polarised;**
- **they can be reflected, refracted and diffracted;**
- **they obey the principle of superposition and produce interference patterns;**
- **the variation of intensity with distance follows an inverse square law.**

Useful opportunity to revisit some of the core syllabus material, perhaps making use of a practical circus to illustrate various aspects of electromagnetic waves.

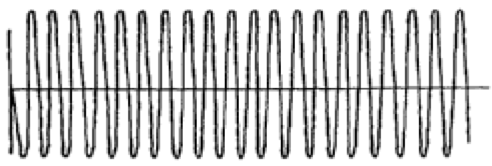
There are two ways of modulating a carrier wave. These are described below.

5.1 Amplitude Modulation (AM)

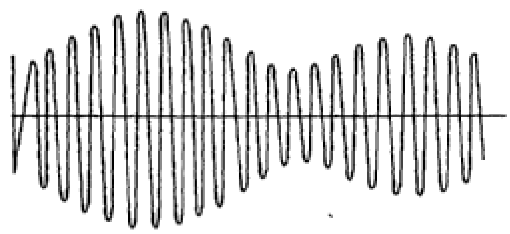
In this method, the varying amplitude of an audio signal is used to vary the amplitude of the radio frequency carrier wave. The signal is generally an analogue one whose voltage variation follows the changing amplitude of the original signal. The amplitude of the radio frequency carrier follows the changes in amplitude of the modulating signal. This can be seen below where the various stages are illustrated.



Signal frequency



Carrier wave



Modulated carrier

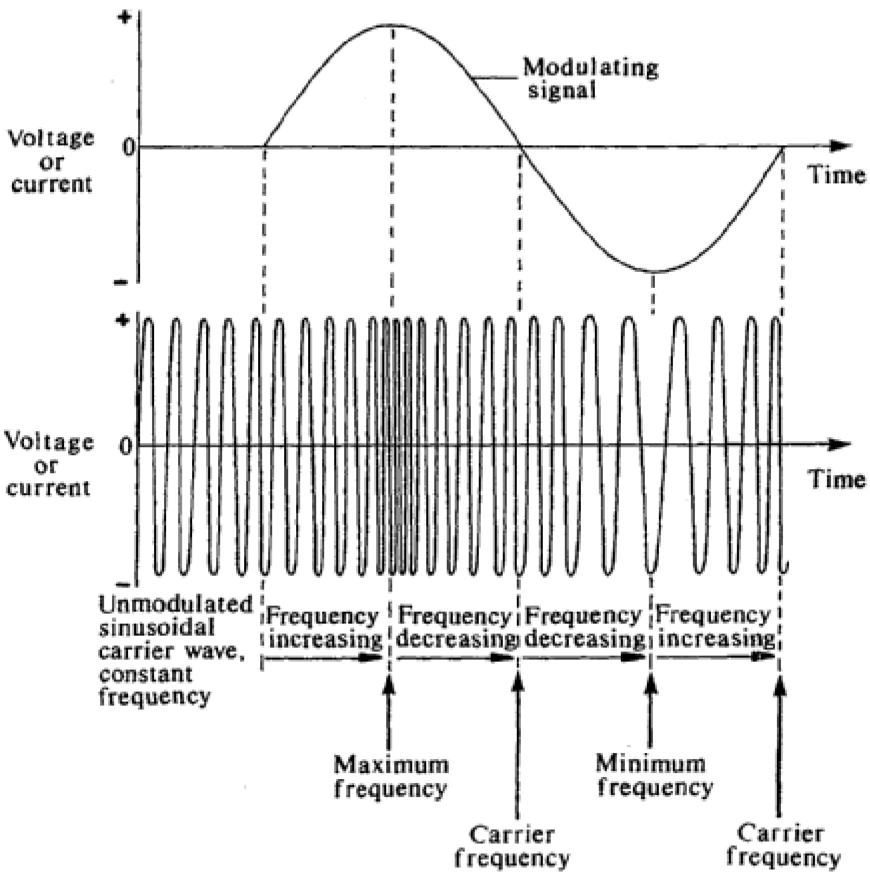
THINGS TO DO

Although the carrier wave has one particular frequency (the frequency of transmission), when amplitude modulated it behaves as though it has a range of frequencies. This range of frequencies is called the bandwidth. Too large a bandwidth would restrict the frequencies available for the different radio stations for transmission. For this reason it is normal practice in the UK to limit the range of audio frequencies which can be transmitted on the long and medium wave from 50 Hz to 4.5 kHz. With this range it can be shown that the bandwidth of each AM signal is 9 kHz. Limiting the range does have implications for the quality of the signal received since the normal speech and music frequencies can range from 20 Hz to 20 kHz. This means that, with this particular bandwidth, the upper and lower frequencies, particularly the latter, are not transmitted.

5.2 Frequency Modulation (FM)

With this method, the carrier wave frequency is modulated (changed) by the signal but its amplitude does not alter. It works by varying the frequency according to the amplitude of the signal. For positive amplitudes, the frequency is increased and for negative amplitudes, the frequency is decreased. The size of the change being determined by the displacement of the signal wave at that time, the greater the displacement the greater the change in frequency. This principle is illustrated by the diagram below.

Use an oscilloscope and a signal generator to illustrate the difference between AM and FM.



The signal bandwidth for FM is normally about 200 kHz which allows for a greater range of audio frequencies to be transmitted than with AM waves. However, because a VHF carrier wave is used for FM, the straight line range of FM waves is limited to 100 km. The disadvantage of this is that FM has a limited area of coverage compared with AM waves and so requires more transmitters to cover the same area as an AM wave.

5.3 AM or FM?

There are advantages and disadvantages with both methods. With AM, the chosen bandwidth is narrow and so may distort the signal being sent, whereas FM has a wide bandwidth and is therefore more likely to produce a better quality signal at the receiver. AM is more susceptible to noise than FM because stray noises affect the amplitude of the signals and (they become distorted, whereas with FM the signals are unaffected by changes in amplitude due to noise since the signal is encoded as changes in frequency. As already indicated, the area of coverage of AM is much greater than that of FM because of the different carrier wave frequencies used. In addition, AM is cheaper to produce since there are fewer electronic components required and, for the same area of coverage, uses fewer transmitters than FM.

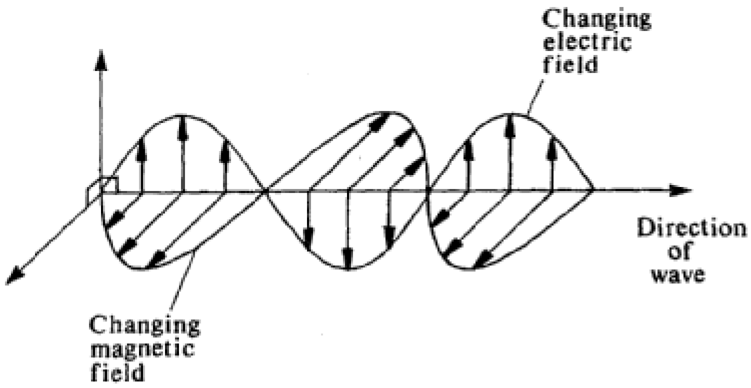
THINGS TO DO

To understand this work pupils will need a knowledge of electromagnetic waves and their properties. It presents another opportunity to reflect and review earlier work covered in the core syllabus content. The two main sources of electromagnetic waves likely to be found in the school laboratory are light and 3 cm wave apparatus. The processes of refraction, reflection, diffraction and interference can easily be demonstrated with these. There are also on the market speed of light methods, which could be usefully used in this context to measure the speed of light through a fibre optic cable.

The inverse square law for light can be examined using a Filament light source and a light intensity meter. If solar cells which give a linear output are available then it is possible to use these as well. LDR’s are not practical since there is not a linear relationship between light intensity and resistance.

6.0 DIRECTION OF RADIO FREQUENCY CARRIER WAVES

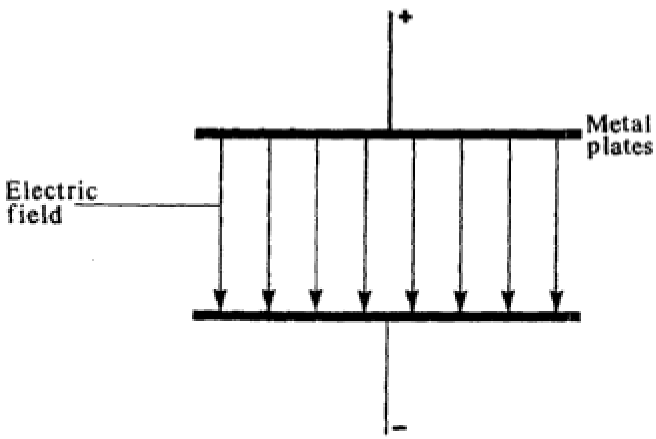
To understand how this is done, we need first to recall that an electromagnetic wave consist oscillating electric and magnetic fields at right angles to each other. This is shown below:



The second thing we need to remember is how an electric field can affect a charged particle (like an electron) and also what effect a changing magnetic field has on a coil.

It is easy to see that an electric field can produce a force on an electron which makes the electron move.

The diagram shows two parallel plates which have a voltage across them. This produces an electric field between the plates which is shown by the parallel lines running from the positive to the negative plate.



THINGS TO DO

Polarisation of light can be easily demonstrated using crossed Polaroids and with 3 cm waves using an aluminium grid with the spacing between the bars about 1.5 cm.

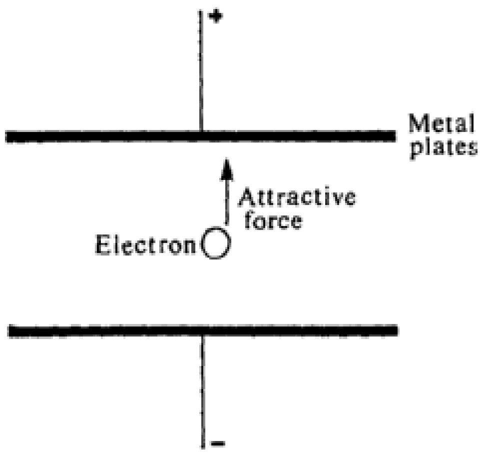
Electromagnetic induction forms part of the core syllabus and this would be an opportunity to revisit this area.

The experiment can be readily set up in the lab and the basic principles established.

In addition, the work on cathode rays can be looked at again here to establish the principle that charges can be made to move by an applied electric field.

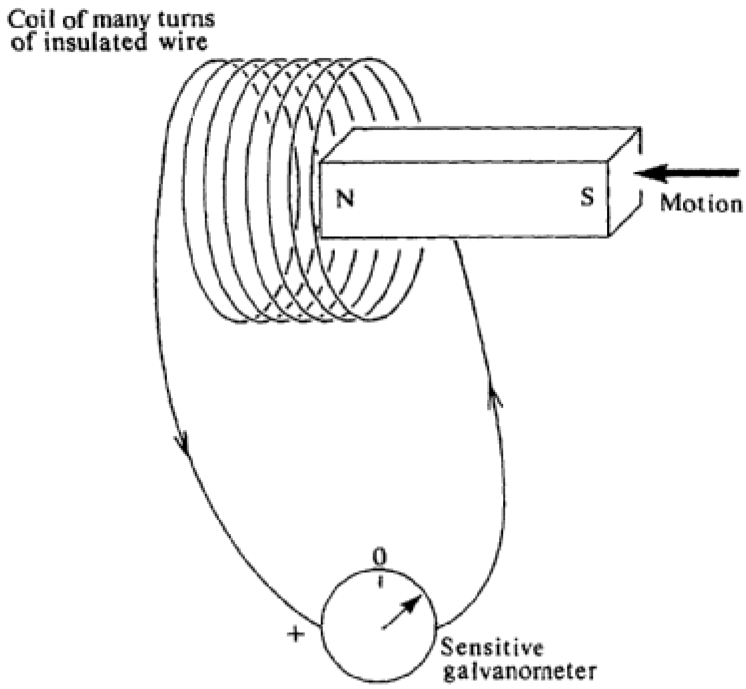
Both the action of a changing magnetic field and a changing electric field are important for understanding the action of aerials and receiving coils.

The second diagram shows the effect of this electric field on an electron placed between the plates. The electron is moved in the upward direction because of the attraction to the top plate. The field has produced a force which causes the electron to accelerate upwards.



If the voltage across the plates is reversed, the force acting is now downwards and the electron accelerates in that direction. It should be recalled from the work on the cathode ray oscilloscope that this is how the position of the electron beam on the screen is controlled.

The third diagram shows a magnet being brought towards a coil which is connected to a sensitive meter, capable of measuring very small currents.



As the magnet is moved towards the coil, a reading is produced on the meter. This tells us that a current is passing and that a voltage has been produced. When the magnet stops moving, the current drops to zero. Moving the magnet away from the coil also produces a current but in the opposite direction. If, instead of moving the magnet, the coil is moved, exactly the same observations are made. The name given to the voltage produced in this way is the induced voltage and the current is called the induced current.

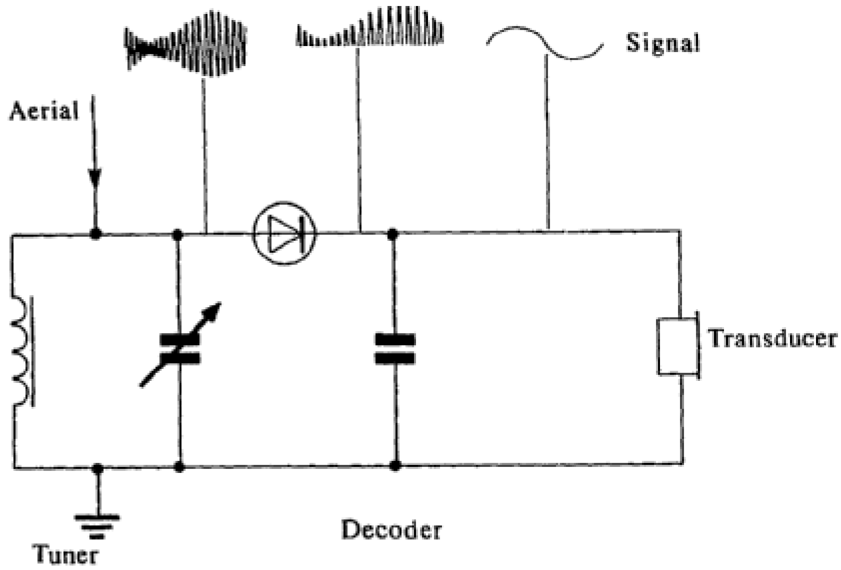
The effects of electric and magnetic fields on a charge and a coil can be summarised as follows:

- **electric fields produce forces on charges which can accelerate the charges;**
- **changing magnetic fields inside a coil produce an induced voltage across the coil.**

Each of these effects is used in the detection of radio frequency waves.

6.1 A simple radio receiver

The circuit below shows a simple radio receiver which can be used to detect different radio stations transmitting at different frequencies. The receiver can be divided into the three sections shown - the tuner, the decoder and the output transducer. The diagram shows the various wave shapes produced at the different sections of the radio.



THINGS TO DO

There are a number of kits on the market which will allow the opportunity for pupils to make their own simple receiver. Ready-made ones are also available.
It is worth using an oscilloscope to explore the various waveforms at different places in a simple receiver. It may be possible to explore the effect on reception of changing the aerial parameters or its orientation.

Use a simple radio receiver and spark generator to demonstrate noise.

6.2 The tuning circuit

This part of the circuit is tuned to the frequency of the carrier wave. The electric field part of the radio frequency carrier acts on the free electrons in the aerial, making them oscillate up and down it. This produces an alternating current of a particular frequency. If the frequency of this current equals the natural frequency of the tuning circuit, then the radio station transmitting will be detected. The tuning circuit can detect different radio stations by having its natural frequency changed using the variable capacitor. A radio is tuned by varying the capacitance of a capacitor by turning the tuning control.

6.3 The decoder

This part of the circuit is designed to extract the signal from the carrier wave. In it, a diode (a radio frequency diode) makes sure that the average of the wave detected is not zero. There is also a capacitor which is able to block the very high frequency radio waves whilst at the same time allowing the low frequency audio signals to pass to the transducer.

6.4 The transducer

THINGS TO DO

The transducer produces sound when there is a changing electric current in it. This is generally a loudspeaker or earpiece. In a more advanced radio receiver there would be an amplifier before the transducer to boost the received signals. This would require the use of a power supply as energy is being fed to the signal. On radios, the volume control is connected to the amplifier part of the circuit.

It has already been mentioned that the carrier wave consists of oscillating electric and magnetic fields. In the simple radio shown above the aerial detects the changing electric field of the carrier wave. It would be possible instead to detect the changing magnetic field. This could be done by lining the coil up with the changing magnetic fields so that the magnetic field ran along the axis of the coil. This would produce a changing induced voltage across the ends of the coil with a frequency equal to the carrier wave frequency. If this frequency equalled the natural frequency of the tuning circuit then the radio station would be picked up by the receiver as previously.

6.5 Polarisation of the Carrier Wave

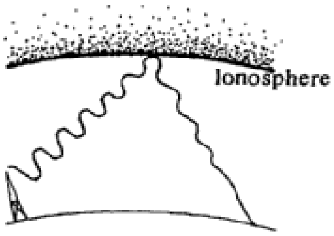
At the transmitter, radio waves are normally produced so that electronic fields each oscillate in only one plane. The diagram on page 21 shows the electric field oscillating in the vertical plane and the magnetic field in the horizontal plane. The radio wave is described as being plane polarised. The implication of this is that the aerial coil of the receiver must be placed with the correct orientation if a radio wave is to be detected. For example, if the electric field is polarised in a vertical plane then the aerial must also be vertical if electric currents are to be induced in it.

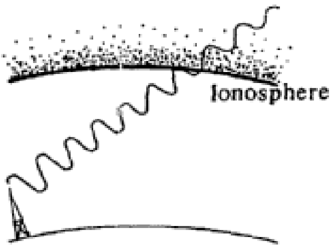
If the aerial were placed on a horizontal plane then detection would be difficult. The advantage of having the electric field polarised in a vertical plane is that a vertical aerial would be able to detect the radio wave even if the radio were tuned through a vertical axis. The same would not be true for the magnetic field which is polarised in a horizontal plane, since rotating the receiver through 360° about a vertical axis would cause the strength of the received signal to fluctuate as the axis of the coil lined up with the magnetic field.

Polarisation can be shown in the lab both with 3 cm waves and with pieces of Polaroid (for light). This can lead to the significance of the orientation of the coil or the aerial in a simple radio receiver. It may be worth reinforcing that only transverse waves can be plane polarised, which means sound waves cannot.

6.6 How do radio waves travel?

There are three main ways by which radio waves arrive at the receiver from the transmitter. These are illustrated in the diagram below.





The first way is by ground waves which, as the name indicates, travel close to the surface of the Earth and the signal strength at the surface decreased with distance. The maximum transmission distance for these waves is about 1000 km. It is the main method of propagation for waves up to frequencies of 2 MHz. They require high powered transmitters to obtain useful areas of coverage and are restricted to the medium, long and very long waves (known as MF, LF, VLF). Ground waves are not affected by atmospheric effects or time of day, particularly at frequencies below about 500 kHz. They are able to follow the curvature of the Earth because of a process of diffraction.

The second method is by sky waves which are important for the 3-30 MHz frequency range (known as HF). They are reflected by the ionosphere so may be heard half-way round the world. The layers which make up the ionosphere are not entirely stable and move up and down from hour to hour and from season to season. so that short wave communication is

THINGS TO DO

Using a metal reflector in conjunction with 3 cm waves or a GHz oscillator can introduce pupils to the idea of reflection from the ionosphere.

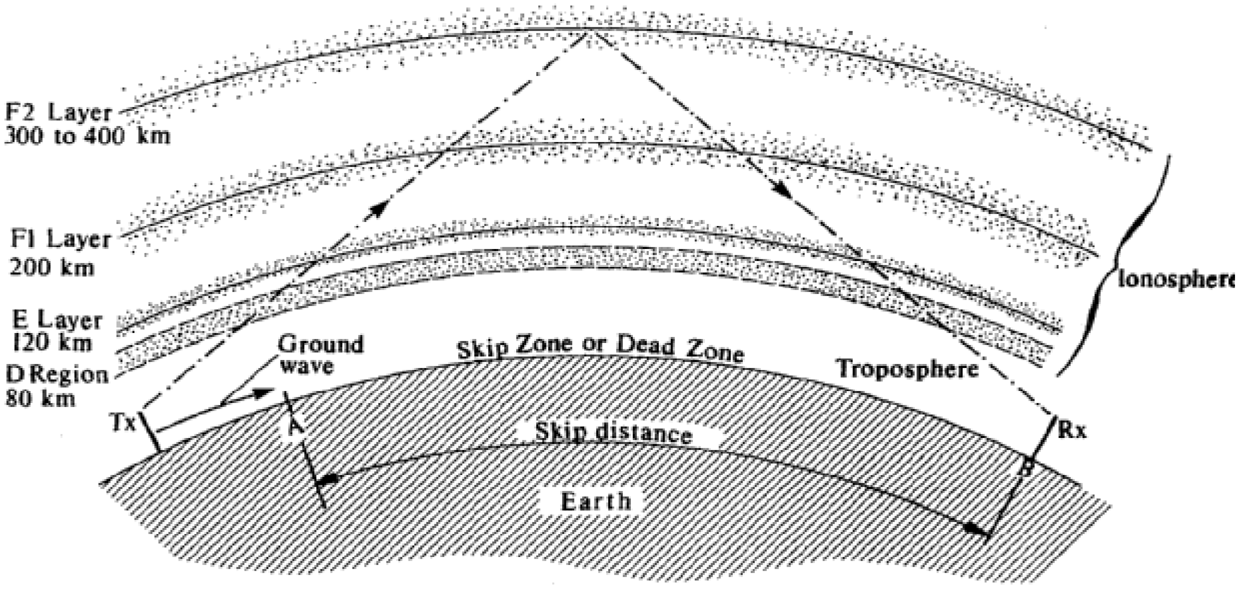
Movement of the reflector can be used to illustrate fading when the ionosphere layers moves. Some text books contain details of the variation with day and season.

Read historical accounts of the contributions made by pioneers such as Hertz and Marconi.

Read historical accounts of the discovery of the Appleton layer and Heavyside layer.

THINGS TO DO

The ionosphere consists of four distinct layers, the D, E, Fl and F2 layers. These are shown below.



The ionised layers are the result of the ionisation of the oxygen, nitrogen and nitric oxide by X-rays and ultraviolet radiation of various wavelengths which come from the Sun. The solar radiation which causes the ionisation is continually varying and consequently the degree of ionisation varies considerably according to the season and time of day.
It is believed it is also affected by the number of sunspots. The maximum frequency which is reflected in the ionosphere is known as the maximum usable frequency (MUF) which varies from season to season and day to day. These changes can be summarised as follows:

- the peak value of MUF generally occurs between 1100 and 1600 hours;
- peak values increase with sunspot activity;
- peak values are much higher in winter than the summer;
- there is a greater variation over the day in winter than in summer.

The D-layer shown on the diagram only exists during daytime. Since it is furthest from the Sun, it contains relatively few ion pairs and does not adversely affect the direction of the radio waves but does attenuate waves that travel through it. MF waves are completely absorbed by the D layer therefore limiting them to ground wave propagation during daylight hours. At night, when the D layer disappears it is then possible to transmit MF over long distances via sky wave propagation.

The movement of the layers in the ionosphere can often result in the fading of a signal. The signal received is rarely constant because of the continually changing conditions in the ionosphere.

Pupils can use sources of secondary data for finding out the various frequencies that are used for transmission and reception. For example, ‘The Radio Communication Handbook’ produced by the Radio Society of Great Britain is a useful source of data.

The third method of propagation is space waves, which mainly apply to radiation waves above 30 MHz. Waves of this frequency are not reflected by the ionosphere and appear to behave more like light because they travel in straight lines - that is they follow a line of sight path. They are basically short range and will not pass through solid ground and are generally cut off by the horizon due to the curvature of the Earth. The space wave is however excellent for communication to aircraft, satellites or space craft so long as they are in the line of sight. Provided the line of sight rule is obeyed, relatively low transmitter powers provide excellent communication. Since VHP and UHF wavelengths are very short,
e.g. 30 cm, many objects reflect the signals so that they can be received in built up areas apparently breaking the line of sight rule.

THINGS TO DO

6.7 Diffraction of waves

Experiments with microwaves of wavelength about 3 cm show that when they are sent through an opening they spread round after passing through it. Similar experiments with other waves show that all waves spread when passing round objects and spread out after passing through openings. The degree of spreading depends very much on the relationship between the wavelength and the size of the opening. For example, with light, the effect is only observable when the opening is very small, much less than a tenth of a millimetre. This explains why, under normal circumstances, we do not notice the diffraction of light. Sound waves, on the other hand, travel round the corners of buildings - we know this because we can hear conversations round the sides of buildings - they have a much greater wavelength than light and so the effect of diffraction becomes more noticeable.

Diffraction can be illustrated in the lab using a number of different types of waves. Sending light through small slits, sound waves for larger openings, 3 cm waves through smaller gaps and so on. Most pupils will understand that as the waves are diffracted they are spread round as they pass through the opening.

As with other waves, radio waves can be diffracted. This helps explain why long wave radio waves, e.g. Radio 4 at 1500 m, can follow the curvature of the Earth. They diffract round the mountains, accounting for the greater area of coverage than FM waves.

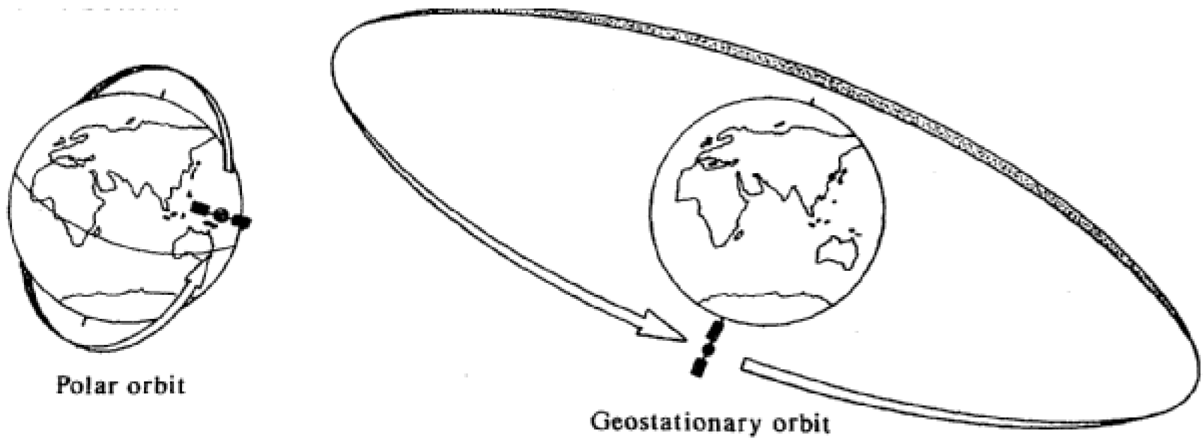
The wavelengths associated with FM are too short to observe any noticeable diffraction by the Earth's surface and hence they tend to follow a line of sight path. This does not mean they cannot be diffracted. Satellite dish reflectors will diffract FM waves, so that they spread out on leaving the dish. This is because their wavelengths are more compatible with the dish diameter than with the curvature of the Earth. As will be seen later, this has important implications for the intensity of radiation received at the Earth's surface from a satellite in orbit and also limits the number of satellites which can be usefully deployed in a particular orbit.

Reception in valleys or in the shadow of large buildings is often better with long wave radio waves than short wave radio waves; the longer wavelength waves being diffracted more by the large buildings or land forms than the short wave radio waves.

In general, the angular spread of a wave by an object or opening depends on the ratio of the size of the opening/object to the wavelength of the wave. The longer the wavelength in relation to the size of the object the less the angular spread of the wave due to diffraction.

7.0 COMMUNICATIONS SATELLITES

There are two main types of satellite used for communication purposes. These are in polar orbits and geostationary orbits, both of which are shown below:



The polar orbit has a path which goes over the North and South poles and is normally between 100 and 6400 km above the Earth's surface. The geostationary orbit has a much greater radius and follows a path on a plane through the Earth's equator. Both types of orbit are designed for specific functions: the polar orbit generally for gathering information about the Earth's surface, such as temperatures, whilst the geostationary orbit is specifically designed for relaying radio signals across the world for communication purposes. It is a geostationary orbiting satellite which is responsible for beaming TV pictures across the Atlantic to the UK.

One distinguishing feature of the geostationary orbit is that the position of the satellite relative to the Earth's surface is always the same. This means that it has a period of orbit of 24 hours and therefore can be used at all times for communication purposes. The main feature of the satellite in polar orbit is that, as it orbits the Earth, it is possible to view all points on the Earth's surface over a few days. For this reason, this type of satellite is extremely useful for surveillance or weather forecasting.

All satellites are kept in orbit by the pull of the Earth. This provides the necessary centripetal force for circular motion. We can think of the satellites as being under constant free-fall inwards towards the centre of its orbit. The condition needed to be satisfied for the satellite to stay in a circular orbit is that the centripetal acceleration must be equal to the acceleration due to gravity at that particular height above the Earth's surface.

A passive satellite does not process the transmitted signal but simply reflects it. An active satellite is able to pick up a signal from the Earth, another satellite or outer space, amplify it and re-transmit it back to Earth. Solar cells mounted on large panels attached to the satellite provide power for reception and transmission.

THINGS TO DO

There are a number of books, which give details of the use of satellites and their radii of orbit. This could present the opportunity for pupils to research the history and report back on their findings to the rest of the class. A suitable wall-chart could be developed which mapped out the time scale and the particular uses of the satellites concerned.

Read historical accounts of the early satellites.

Use secondary data to find the uses of a range of polar orbiting satellites.

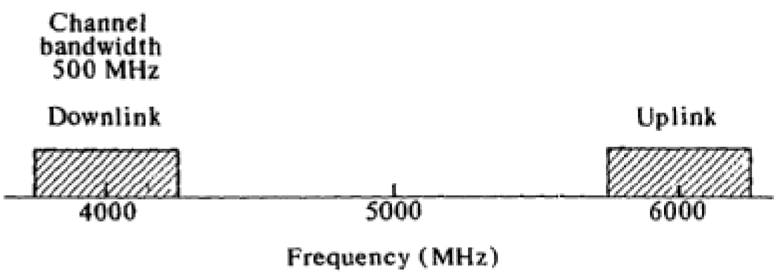
Make use of data from weather satellites e.g. METEOSAT. Investigate the growing contribution of satellite and cable communications systems.

7.1 History of Satellite Development

Some of the first communications satellites were designed to operate in a passive mode. Instead of actively transmitting radio signals, they served merely to reflect signals that were beamed up to them by transmitting stations on the ground. Signals were reflected in all directions, so they could be picked up by receiving stations around the world. Echo I, launched by the United Stales in I960, consisted of an aluminized plastic balloon 30 m in diameter. Launched in 1964, Echo 2, was 41 m in diameter. The capacity of such systems was severely limited by the need for powerful transmitters and large ground antennae.

Satellite communications currently make exclusive use of active systems, in which each satellite carries its own equipment for reception and transmission. Score, launched by the United States in 1958, was the first active communications satellite. It was equipped with a tape recorder that stored messages received while passing over a transmitting ground station. These messages were retransmitted when the satellite passed over a receiving station. Telstar 1, launched by American Telephone and Telegraph Company in 1962, provided direct television transmission between the United States, Europe and Japan and could also relay several hundred voice signals. Launched into a low elliptical orbit inclined 45° to the equatorial plane, Telstar could only relay signals between two ground stations for a short period during each revolution, when both stations were in its line of sight.

Hundreds of active communications satellites are now in orbit. They receive signals from one ground station, amplify them, and then retransmit them at a different frequency to another station. One frequency band used, 500 MHz wide, is divided into repeater channels of various bandwidths (located at 6 GHz for upward, or uplink, transmission and 4 GHz for downward, or downlink, transmission). This is shown below.



Within each channel there is room for many signals each with a bandwidth of a few MHz. For example, to carry TV signals, an agreed bandwidth of 8 MHz is used. An 80 MHz-wide band at about 1.5 GHz (up and downlink) is used with small, mobile ground stations (ships, land vehicles, and aircraft).

THINGS TO DO

Whilst there is limited scope for experimental work there is plenty of project work involving research and data analysis.

Pupils could perhaps find the radii of orbit for some of the satellites mentioned and determine by calculation what the time period should be, comparing the calculated value with the published data.

From our previous work on the ionosphere it is clear that, in order to communicate with a satellite in orbit, the frequency of the transmitted wave carrier will need to be greater than 30 MHz if it is to penetrate the ionosphere. There are a number of difficulties which need to be addressed when transmitting to and receiving from satellites in orbit.

There is the problem of the intensity of the signal decreasing with distance due to its attenuation when travelling through the atmosphere and diffraction effects. Consequently by the time the signal reaches the receiving dishes at the Earth the power received is going to be very small.

Communications Satellites

1958	Dec 18	Project Score	Broadcast first voice message from space
1962	Jul 10	Telstar 1	First satellite to relay television programmes between USA and Europe
1963	Jul 26	Syncom 2	First synchronous satellite
1965	Apr 6	Early Bird	First commercial satellite
1967	Jan 11	INTELSAT 2B	First of a series of satellites in stationary orbit, used for television, data and voice
1971	Jan 26	INTELSAT 4A	First high capacity international communication satellite
1972	Nov 9	ANIK 1	First Canadian communications satellite
1977	Dec 14	CS	First Japanese communications satellite
1981	Feb 21	Comstar D	Synchronous satellite, part of world wide communication system
1988	Jun 15	Pan American	First privately owned international satellite telecommunications satellite

Weather Satellites

1959	Feb 17	Vanguard 2	First satellite to send weather information back to Earth
1960	Apr 1	Tiros 1	Took first detailed weather pictures of the Earth
1974	May 17	SMS –1	First full-time weather satellite in synchronous orbit
1975	Oct 16	GEOS – 1	First weather satellite with enough speed to maintain same observational position over the Earth
1978	Jun 16	GEOS – 3	Equipped to provide day and night pictures of Earth's weather patterns
1980	Sep 9	GOES – D	Designed to help track storms
1984	Dec 12	NOAA – F	Weather observatory equipped with instruments to aid in Search and rescue missions world-wide

Navigation Satellites

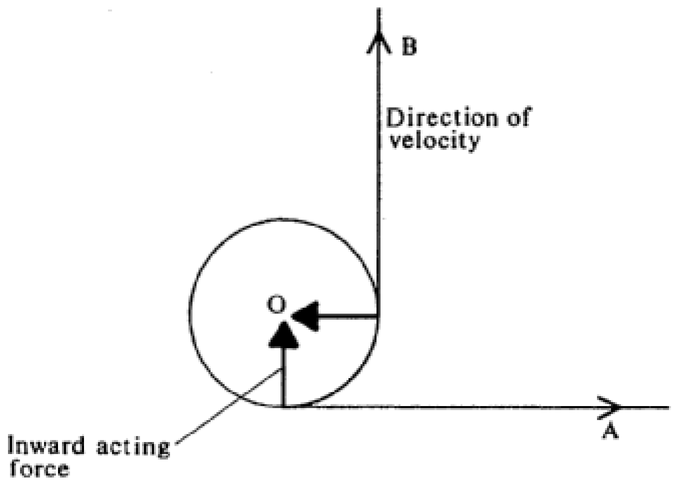
1960	Apr 13	TRANSIT 1B	First navigation satellite
1961	Jun 29	TRANSIT 4A	First satellite to use nuclear power
1961	Nov 15	TRANSIT 4B	Tested method of using Earth's gravity to keep satellites in proper position
1978	Feb 21	NAVSTAR	First satellite of a system designed to provide navigational positions on a continuous basis

Scientific Satellites

1958	Jan 31	Explorer 1	First US satellite, discovered Van Allen belts
1962	Mar 7	OSOI	First orbiting solar observational satellite
	Apr 26	Ariel	First UK satellite
	Sep 28	Alouette	First Canadian satellite
1963	Apr 2	Explorer 17	First satellite to study the atmosphere
1967	Sep 7	Biosalellile 2	Carried living cells, plants and animals into space and returned them to Earth
1968	Dec 7	OAO-2	First orbiting astronomical observatory
1972	Jul 23	Landsat-1	Photographed the Earth with different wavelengths of light to provide information about the Earth's natural resources
1976	May 4	Lageos	First satellite designed for high precision geographic measurements
1977	Aug 12	HEAO -1	Orbiting observatory used to locate objects in outer space that emitted X-rays
1978	0ct 24	Nimbus - 7	Collected data for studying the Earth's atmosphere and oceans
	Nov l3	HEAO - 2	Transmitted photographs of quasars and other cosmic objects that emitted X-rays
1979	Feb 18	SAGE	Primarily designed to measure fluorocarbon content of the Earth's stratosphere
	Sep 20	HEAO - 3	Monitored and analysed gamma rays and cosmic rays from deep oceans
1980	Feb 14	Solar Max	Designed to study solar flares
1983	Jan 25	IRAS	Collected information on the infra-red radiation given off by dust clouds, stars and galaxies
1984	Aug 16	AMPTE	Produced an artificial comet to collect information on the solar wind and the magnetosphere
1989	Nov 17	COBE	Designed to map cosmic background radiation and thereby test theories about the formation of the Universe
1990	Apr 24	Hubble Space Telescope	First optical telescope in orbit around the Earth

8.0 EXPLAINING SATELLITE ORBITS

Geostationary and polar orbits are both examples of circular motion. Most people experience circular motion as a passenger in a bus or car or on rides at theme parks. The sensation they experience when moving in a circle is to feel as if they are being thrown outwards. This is not actually the case as the diagram below shows:



As the object moves round the circle, we can see that the direction of motion is changing. In the diagram the directions of A and B are different. From Newton's laws, we know that to change a body's direction of motion a resultant force needs to act on the body. It is this resultant force that keeps the body moving in the circle - it is called the centripetal force. Without a centripetal force a body would keep going in a straight line at a tangent to the circle.

When a car travels round a corner, the centripetal force which makes the driver and passengers move in the circle is the push inwards of the interior side of the car or passenger seats. This creates the sensation of being thrown outwards and this is what most people will say is happening to them. Whirling a stone in a circle also requires an inward acting force, in this case provided by the pull of the string to which it is attached. In the case of satellites, it is the gravitational pull between the Earth and the satellite which provides the centripetal force on the satellite.

The centripetal force acts towards the centre of the circle and it follows from Newton's second law that this must also cause an inward acceleration - called the **centripetal acceleration.** This does not mean that the speed is increasing though. Since acceleration is rate of change of velocity (a vector) then an object can be accelerating because the direction is changing even though the speed is constant.

THINGS TO DO

This aspect of the work is very much more challenging, particularly for those who find difficulty in handling mathematical concepts. It can be a worthwhile challenge for the more able pupil.

All, however, should be able to carry out some investigation into circular motion which will bring out the point about a central acting force and that the size of the force depends on the radius, mass and speed.

If possible, it may be worthwhile trying to get some pupils to see if they can verify the centripetal force equation.

Although an object moving in a circular path has a centripetal acceleration, it does not follow that it is moving closer to the centre of the circle. In this case, the force is exactly enough to produce the change of direction needed to stay in the circle and no more or less. The size of the centripetal force depends on:

- the speed of the object;
- the radius of the circle
- the mass of the object.

Experiments and mathematical treatment show that the equation for centripetal force is given by

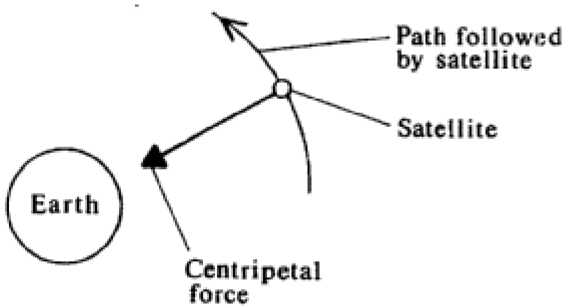
$$F=\frac{mv^2}{r}$$

where m = mass, r = radius and v = speed

It follows from $F = ma$ that the expression for centripetal acceleration is

$$a=\frac{v^2}{r}$$

The diagram below shows the path followed by a satellite in orbit round the Earth.



As with the car and the stone, a centripetal force is needed to keep the satellite in orbit. In this case, it is provided by the gravitational pull of the Earth at that distance. The condition needed for a circular orbit is

gravitational field strength at that distance = centripetal acceleration

$$g=\frac{v^2}{r}$$

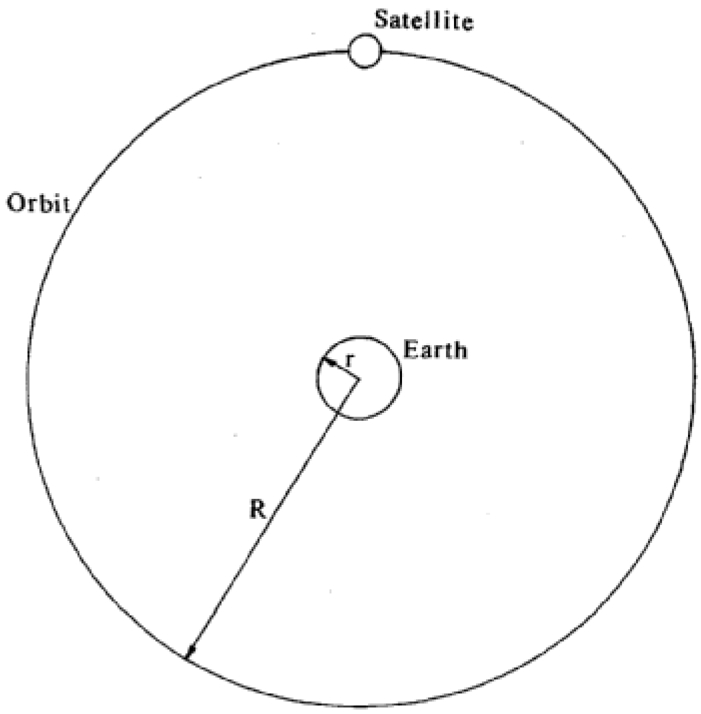
The gravitational field strength decreases with distance from the Earth and it follows an inverse square law. This means that if the distance from the Earth's centre is two Earth radii the gravitational field strength will be one quarter that at the Earth's surface: treble the distance and the strength will be one ninth and so on. We can make use of this fact, together with the expression for the centripetal acceleration, to calculate the height of a geostationary orbit above the Earth's surface.

9.0 FINDING THE HEIGHT OF A GEOSTATIONARY ORBIT

The data which we have is:

time period of orbit = 24 hours;
Earth's radius = 6400 km;
value of *g* at the Earth's surface = 9.81 N/kg or 9.81 m/s^2.

The diagram shows the orbit of the satellite.
In this diagram *R* is the radius of orbit and *r* the Earth's radius.



Since the gravitational field strength follows an inverse square law the value at a radius R is given by:

$$g' = \left[\frac{r}{R}\right]^2 g$$

and the condition for the circular orbit is that this should equal the centripetal acceleration. This is summarised by the following equation

$$\frac{v^2}{R} = \left[\frac{r}{R}\right]^2 g$$

THINGS TO DO

Investigate circular motion by a variety of methods.

Use secondary data of time of orbit and distance to calculate speeds of satellites.

THINGS TO DO

Compare calculated values with, and evaluate published data of, satellite launches and orbital data.

Use computer programmes to simulate how the weight of an object varies with its distance from the earth.

The speed can be determined by making use of distance/time and the height determined as shown below.

$$v = \frac{2\pi R}{T} \text{ where } T = \text{period of orbit}$$

and now the value of *R* can be expressed in terms of the data which we have:

$$\therefore \left[\frac{2\pi R}{T}\right]^2 \times \frac{1}{R} = \left[\frac{r}{R}\right]^2 \times g$$

$$\frac{4\pi^2 R^2}{T^2} \times \frac{1}{R} = \frac{r^2}{R^2} \times g$$

$$R^3 = \frac{T^2}{4\pi^2} \times r^2 \times g$$

$$R^3 = \frac{[24 \times 3600s]^2}{4\pi^2} \times [6400 \times 10^3 m]^2 \times 9.81 \ m/s^2$$

R = 42354000 m ≈42400 km

So the height of the geostationary orbit above the Earth's surface must be R-*r* = (42400 - 6400) km = 36000 km.

As can be seen from the above calculation there is only one radius of orbit which satisfies the condition for a geostationary orbit. This is not the case for polar orbits since they are not tied to one specific time period, which means they can have different radii. Their time period will determine the number of sweeps they make over the Earth in a 24 hour period, the choice of radii being largely determined by the particular function of the satellite.

The fact that the geostationary orbit is 36000 km above the Earth's surface means that it has a number of advantages and disadvantages. Firstly, it can be communicated with 24 hours a day, from any place which can 'see' it, as it appears to stay in one place in the sky. This means that it is possible to communicate with the whole world with just three geostationary orbiting satellites.

However, being 36000 km away causes difficulty with receiving signals back on Earth. The electromagnetic radiation transmitted to the Earth decreases in intensity with distance. It can be shown that for each 100 W transmitted, the intensity at the Earth will be about 10^{-12} W/m^2. This means that receivers have to be sensitive to extremely low intensity signals.

When waves are transmitted from the dish aerial they spread due to diffraction. The amount of diffraction depends very much on the size of the dish and the wavelength of the wave being used for transmission. This angular spreading due to diffraction also tends to reduce the intensity of the received signal.

An additional problem with the spreading is that the transmissions from neighbouring satellites could overlap and interfere with each other. This can largely be avoided by using frequencies of transmission that are far apart. However this is limited because of the limited channel widths available for transmission.

These factors limit the total number of geostationary satellites that can be placed in orbit. The advantage of the spreading of the waves is that a greater surface area of the Earth is covered and therefore many more people have access to the information being transmitted at one time.

THINGS TO DO

The inverse law of radiation can be examined using both light and 3 cm waves

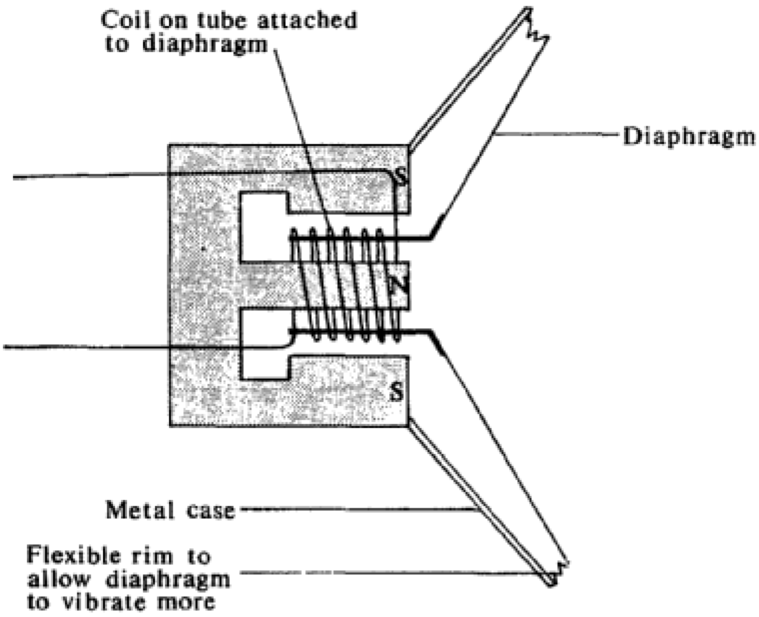
Diffraction has already been mentioned but could be reinforced again here with relevant demonstrations.

Interference effects with light, sound and 3cm waves are possible in the school lab.

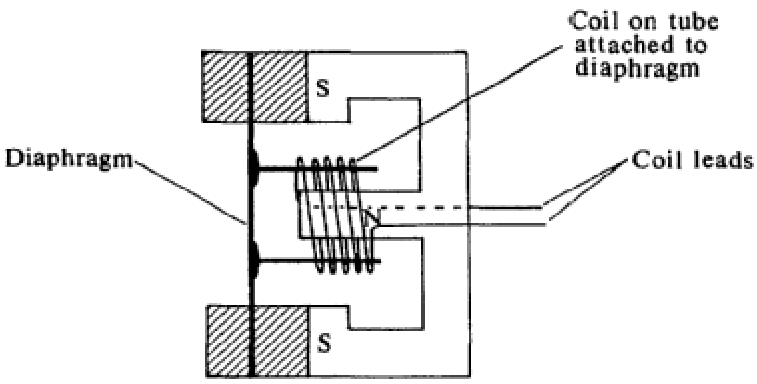
10.0 MORE ABOUT TRANSDUCERS

10.1 The loudspeaker and microphone

The loudspeaker makes use of the catapult effect for its operation. It is a transducer which converts electrical voltages to audio sound waves. This is achieved by sending the voltage signal through the coil in the speaker. This produces a changing magnetic field which interacts with the permanent magnetic field to produce a force which moves the speaker, which in turn moves the air causing compression waves to reach the ear.



The moving coil microphone makes use of induced voltages for its operation. When the diaphragm is moved by the sound waves, it moves a coil so as to cut the magnetic field of the permanent magnetic field. This motion causes an induced voltage across the coil which follows the amplitude and frequency of the sound waves. In this way, energy from sound is transferred to electricity.



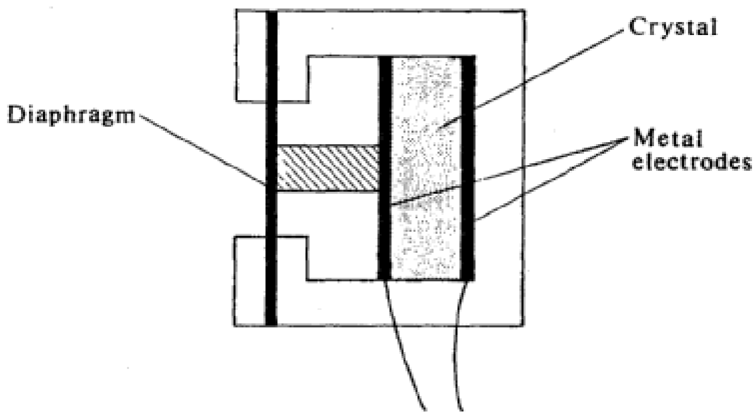
THINGS TO DO

It is possible to make a loudspeaker using a coil wrapped round a cardboard diaphragm and placing it between the poles of a magnet. It will probably manage to respond to a 50 Hz supply. With commercial loudspeakers it is possible to observe the movement of the diaphragm at low frequencies and look for resonance - this could be an extended investigation for the more able pupil.

Comparisons between woofers and tweeters can be made and if the circuits are set up pupils could investigate low and high pass filters, in particular examining the frequency response of the circuits.

Most school labs have access to crystal microphones and possibly capacitor microphones. They can both be used in conjunction with the CRO to look at their frequency responses. Pupils might like to find out why telephones no longer make use of crystal microphones.

The carbon granule microphone makes use of the fact that a changing electrical resistance in a circuit will cause changes in the current in it. When the diaphragm is moved the carbon granules are moved either closer together or further apart thereby altering the electrical resistance in sympathy with the sound waves arriving.



In this type of microphone, use is made of the piezo-electric effect. When a mechanical strain is placed across the crystal, a potential difference is produced across it. In this way, the sound signal can produce a varying voltage.

10.2 The LDR, LED and Photodiode

The LDR, LED and photodiode are three further examples of transducers used in communication systems.

10.3 The LDR (light dependent resistor)

The light dependent resistor makes use of the fact that when certain semiconductors have light shone on them their electrical resistance changes. In the dark, a cadmium sulphide LDR has a resistance of about I MΩ and in bright light it falls to about 400Ω. It is possible, therefore, to use an LDR to employ a light signal whose intensity is varying to produce a voltage variation using an appropriate circuit.

10.4 The LED (light emitting diode)

The light emitting diode only conducts in one direction and it emits light when it conducts. It is possible using this device to use pulsed voltages to produce a series of flashes of light, that is a modulated light beam can be produced to carry a signal. They are familiar in the use of LED's in numeric displays and as bar graph voltmeters on Hi-fi systems.

THINGS TO DO

The LDR and LED are common school components and they can be used in circuits to investigate their characteristics. Pupils could examine Radio Spares data sheets to see if their measurements agree with the published working characteristics.

It may be possible to design some light operated circuits making use of logic gates and relays which would highlight how the LDR can be put to practical use. Ideal for a challenge competition!

Amplified noise can be demonstrated using an op-amp and viewing the output on an oscilloscope.

10.5 The photodiode

A photodiode is able to produce a voltage output when a varying intensity light is shone on it. It is very similar to an LED but it works the other way round. When light falls on the photodiode in a circuit, there is a current which depends on the light intensity. In an optical fibre system, a modulated LED could be used as the source of light pulses which travel down the cable and a photodiode could be used at the far end to detect the incoming pulses. These could then be amplified and decoded to reveal the signal being sent.

10.6 Lasers

Lasers are capable of producing hundreds of millions of light pulses each second, of very precise wavelengths (and frequencies). The output from a laser is coherent and can be confined to a very small cross-sectional area. The range of wavelengths produced by a laser is very narrow, approximately 2 nm. This is small compared with an LED which produces a range of about 20 nm. For these reasons laser pulses are generally used in fibre-optic systems of communication.

RESOURCE MATERIAL

Telecommunications. University of Bath. Macmillan Science 16-19 Project. John Allen ISBN 0 333 476 27 1

Telecommunications Primer. G Langley. Pitman
ISBN 0 273 031 87 2

Electronics Made Simple. H Jacobiwitz. W H Allen

Radio Communications Handbook. Radio Society of Great Britain
ISBN 1872309 24 0

11.0 PUPIL ASSESSMENT TASKS

11.1 Test Yourself 1

Question I

When you speak to someone, you are using a communication system. Name the parts which carry out the following functions.

- Encoder
- Decoder
- The carrier wave

Outline the limitations of this system of communication.

Question 2

All communication systems use waves for carrying the signal. For each of the different systems listed below, identify the wave which is being used as the carrier.

- Sending signals through optical fibres
- Using the sign language for the hearing impaired
- Sending telephone messages through wires
- Communicating with a satellite in geostationary orbit

Question 3

Under the Atlantic Ocean, there are a number of transatlantic cables used for carrying telephone signals from Britain to America. A number of repeaters are built into each cable.

- How do you know that analogue signals are being used?
- Explain what causes the signal to lose energy as it travels along the cable
- What is the purpose of the repeaters?

Question 4

When a pupil listens to his radio, he sometimes hears a crackling sound which stops him from listening to the programme.

- What name is given to this type of interference?
- Explain how it can occur
- Why would turning up the amplitude on the radio not help?

11.2 Test Yourself 2

Question I

What. is the difference between an analogue and digital signal?

What advantage have digital signals over analogue signals when the attenuation of the signal has to be corrected for?

State which of the following use analogue and which use digital signals.

- Tape recorder
- CD player
- Optical fibres
- Record player

Question 2

What methods are used to store information in the following systems?

- Video recorder
- Cine film projector
- Tape recorder
- Hard disc on a computer

Question 3

Radio signals can be modulated in two different ways, AM or FM. What does the term ’modulation’ mean?

Draw diagrams to show the difference between AM and FM.

Label each diagram. Explain why the quality of voice transmission using AM is not as good as FM.

Question 4

FM is a line of sight method of propagation of radio waves. What is meant by line of sight?

Explain why FM waves travel in straight lines but AM can follow the curvature of the Earth.

11.3 Test Yourself 3

Question 1

A radio station transmits on a wavelength of 1500 m. If the speed of the carrier wave is 3×10^8 m/s, calculate the frequency of transmission.

The wave is transmitted from an aerial equally in all directions. How would the intensity arriving at a receiver I km away from the transmitter compare with that arriving at a receiver 10 km away?

Question 2

Most car aerials consist of a vertical length of aluminium rod. What does this suggest about the radio waves from the transmitter?

A car can tune into radio waves irrespective of its direction of motion. How does the answer to the question above help to explain this?

Explain why it might not be sensible to use the tuning coil in the car’s receiver for detecting the radio signals from the transmitter.

Question 3

The police service use short wave radio for communicating with policemen on the beat. Explain how it is possible for two towns which are within 15 miles of each other, to use the same frequency for transmission to their respective police forces. Why would this not be possible for long wave radiation?

Question 4

What is the ionosphere?

Explain how the ionosphere can be used to provide a world-wide radio link.

When the ionosphere is being used for this purpose, there are certain places around the world which are unable to detect the signal being sent. Suggest a reason for this.

Question 5

Explain how long wave reception can be better in valleys than short wave reception.

Microwaves are used for communications. Explain why they do not heat the air through which they travel.

11.4 Test Yourself 4

Question I

Explain the differences between a geostationary orbit and a polar orbit.

Explain why it is not possible to have a satellite orbit at a latitude of 50°N so that it stays roughly above Manchester.

A satellite moves from an orbit at a distance of two Earth radii to one at three Earth radii. What is the gravitational field strength at the new distance? (That at the Earth can be taken as 1ON/kg).

Question 2

A geostationary satellite is at a height of 36000 km above the Earth's surface and is transmitting 100W of radiation towards the Earth. Explain the two factors which could determine the intensity of radiation that arrives at the Earth's surface.

The frequency of the radio signals from the Earth to the satellite and that of the radio signals from the satellite back to the Earth are different. Explain why different frequencies are used.

Question 3

Explain the difference between an active and a passive satellite.
State THREE examples of the use of polar orbiting satellites.

A particular polar orbiting satellite has a time period of 90 minutes. Calculate its height above the Earth's surface, assuming that the gravitational field strength has not altered appreciably at that height and that the radius of the Earth is 6400 km.

Calculate the number of orbits that would be needed in order for the satellite to map out the whole of the Earth beneath it.

Question 4

The number of satellites that can be placed in geostationary orbit is limited. Explain TWO reasons for this.

Explain whether or not you think that a satellite in geostationary orbit is using energy in order to keep its orbit. What would be the effect on the orbit of the satellite slowing down?

11.5 Test Yourself 5

Question I

What is meant, by a transducer?

Identify the transducers used in the following communications systems,

- The input to the record head of a tape recorder
- The audio output from a television
- Optical Fibres

Question 2

A loudspeaker is able to produce sound signals from electrical signals. Explain the principles of how it does this.

In a modern hi-fi system, there are usually two loudspeakers, the woofer and the tweeter. The woofer is used for the low frequency sounds and the tweeter for the high frequency ones.
Explain why the woofer would only give a low amplitude output if high frequency sound were sent to it.
What would be effect of sending low frequency sounds to the tweeter?

Question 3

LED's and LDR's are both examples of transducers. Explain the difference between an LED and an LDR.

Explain where an LED would be used in a communication system.

State the disadvantage of an ordinary LED, which the laser diode has overcome.

Question 4

In a carbon microphone the sound waves incident on it cause changes in its electrical resistance. Suggest the limitations that this type of microphone has.

In the telephone, the mouthpiece is a crystal microphone. The microphone is connected in series with a battery and the primary coil of a transformer. The output from the secondary coil is connected to the transmission wires.
Explain how this system is able to work even though transformers are not designed for DC. What is the purpose of the transformer in this circuit?

11.6 Test Yourself 6

Use the words in the word list to complete the following passage. Each word may be used once, more than once or not at all.

In a simple radio, the (1) is used to detect the (2) wave. The carrier wave has been (3) by the signal. There are two ways of doing, this, (4) modulation and (5) modulation. In (6) modulation the carrier wave frequency is changed whereas in (7) modulation the amplitude of the carrier is changed. The aerial of the simple radio is vertical which indicates that the carrier wave is (8) in a vertical plane. Instead of using the electrical field of the carrier wave it is possible to detect the changing (9) field using the coil in the tuning circuit. The disadvantage of this is that the radio would no longer be omnidirectional but would have to have the coil orientated with its axis (10) to the changing magnetic field.

The (11) also picks up stray electromagnetic fields from electrical equipment nearby. This is called (12) and if the signal to (13) ratio is too small the signal can be swamped by these stray electromagnetic fields. Once the simple radio has been tuned into the carrier wave frequency the signal has to be extracted, this process is called (14), which is the reverse process of (15). In the simple radio, this is achieved using the radio (16) and capacitor. Firstly, the radio (17) rectifies the modulated carrier wave and then the capacitor blocks out the high frequency carrier, leaving the low frequency signal which can then be sent to an output (18), the loudspeaker or headphones. If the signal being detected is an (19) one, the range of signal frequencies is limited to a bandwidth of 9 kHz. This has implications for the quality of the signal received since normal speech and music frequencies can range from 20 Hz to 20 kHz, this means the upper and lower frequencies are restricted.

However, this is compensated for by the fact that (20) has a longer range than (21), which means fewer low power transmitters are required for a particular range. On the other hand, (22) is more susceptible to noise interference than (23). The (24) range is limited because of its (25) wavelength which causes it to travel in straight lines without being (26) by the Earth's surface. (27) because of its long wavelength is (28) and consequently can follow the curvature of the Earth's surface.

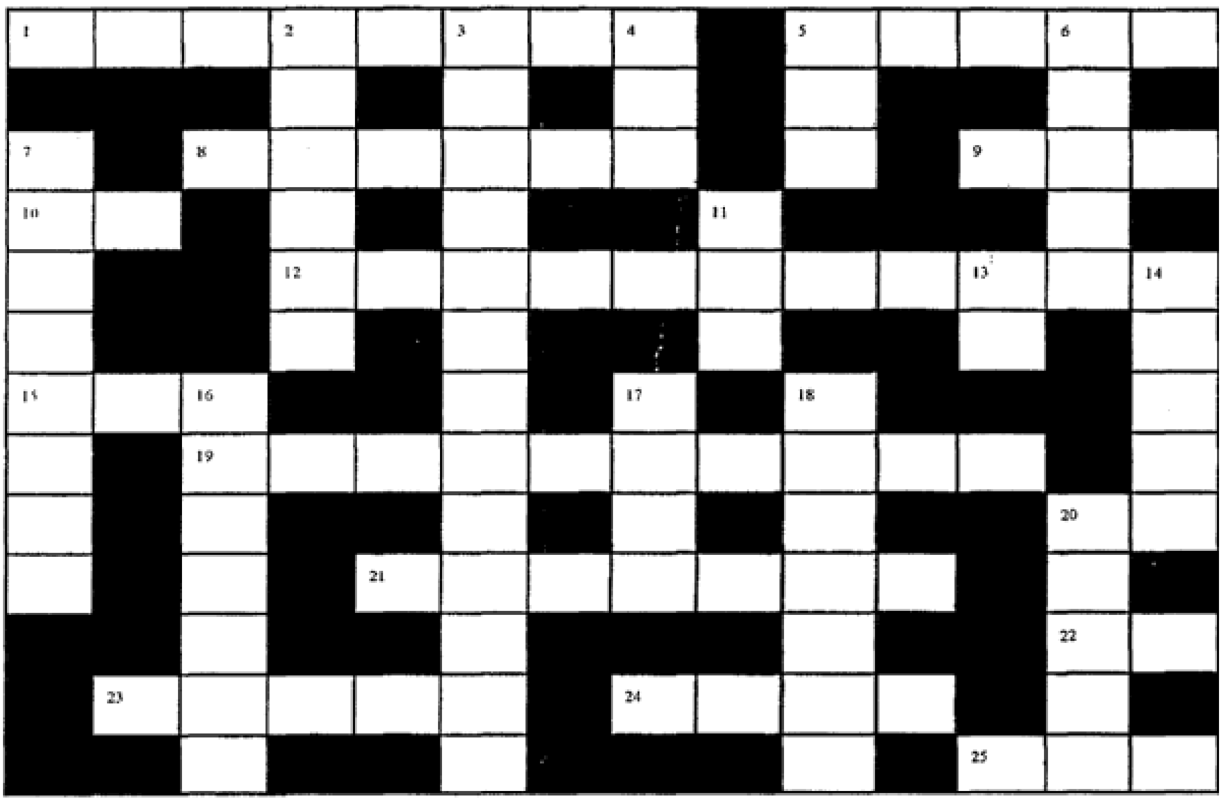
The output from the decoder of the simple radio is normally sent through an (29) before being sent to the output (30). The (31) boosts the signal so that its amplitude is increased. The disadvantage of this is that it can also amplify any (32) as well. The output (33) is normally a loudspeaker which makes use of the fact that a current carrying conductor in a (34) field will experience a force which can make it move. If the conductor is wrapped round the base of the diaphragm then it will make the diaphragm move in sympathy with the signal (35) variations. In this way a sound wave is produced in the air which replicates the original signal input to the (36) at the transmitting station.

WORD LIST

AM
Aerial
aluminium
amplifier
attenuation
carrier
crackling
current
decoding
deflected
diffracted
dispersed
diode
electronics
encoding
forty
frequency
FM
long
magnetic
magnetism
medium wave
microphone
middle
modulated
modular
noise
parallel
polarised
poles
reflected
refracted
right angle
short
sound
ten
thirty
transducer
transformer
transmitter
twenty
UHF
variation
VLF
voltage
wire

11.7 Test Yourself 7

COMMUNICATIONS CROSS-WORD



ACROSS

1. The output, is a continuous variable (8)
5. Cells for powering the satellite? (5)
8. Scramble that message! (6)
9. May respond to night or day (3)
10. Ton without the top (2)
12. Runs out of steam en route (11)
15. Could be a bit of a flasher! (3)
19. Sounds like pressing, one on the seat, for ages (10)
20. Initially reversed to give carrier waves (2)
21. Feeler for direction? (7)
22. High frequency carrier waves, initially (2)
23. Reals about (5)
24. Sounds like they are leaping over the box (4)
25. Need line of sight to do this (3)

DOWN

2. Could be straight line (6)
3. Of still Earth (13)
4. Visual receiver for the brain (3)

5 & 17 Flapping arms upwards? (3,4)

6. A signal to listen out for (5)
7. Connection made to below (8)
11. The upper limit for reflection (3)
13. Not out (2)
14. What's the message? I can't hear you. (5)
16. Of fingers, nearly everyone. Only two types (7)
17. See 5 (3,4)
18. The umpire gives an indication (7)
20. Dash it, I thought the 'I' was dotted (5)

11.8 Test Yourself 8

MIX 'N' MATCH

All the words/phrases in the left hand column belong to associated statements in the right hand column, unfortunately they have been mixed up. Draw lines between the two columns to show which word-phrases belongs with which statement. One has already been done for you.

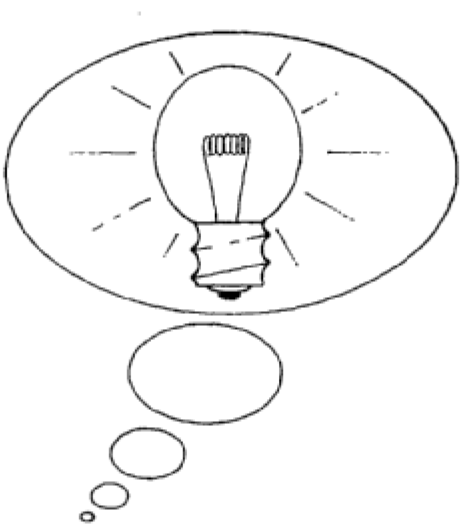
AMPLIFIER	Boosts the signal received by an input of energy
ANALOGUE	Can be used to communicate with satellites in orbit
ATTENUATION	Changes one type of signal into another
CENTRIPETAL FORCE	Describe the loss of energy between transmitter and receiver
DECODER	Has four layers and consists of charged particles
DIFFRACTION	Has speed but no motion relative to the Earth
DIODE	Is an attractive field following an inverse square law
ENCODER	Limits the number of satellites in geostationary orbit
GEOSTATIONARY ORBIT	Takes an audio signal and produces an analogue voltage
GRAVITATIONAL FIELD	The device used to code a signal before being placed on the carrier
IONOSPHERE	The force needed to keep an object in a circular path
LOUDSPEAKER	The output form a microphone can be described as this
MICROPHONE	The way in which a signal is placed on the carrier wave
MODULATION	This can reproduce a digital signal to compensate for power losses
POLAR ORBIT	This has the disadvantage that it will also increase the level of noise
REGENERATOR	Used for mapping weather patterns
REPEATER	Used to unscramble the received transmission
SPACE WAVE	Will only allow current to pass through it in one direction
TRANSDUCER	Works by making use of the catapult effect

11.9 Test Yourself 9

UNSCRAMBLE THE WORD

Each of the phrases listed are anagrams of words associated with communications. Can you work out what each is?

IS SLANG
KEV'S WAY
RAYS GO INTO EAT
ROB IT
SMART TIN
ONE IS
LOUT MADE
EVER RICE
RED CONE
DO DIE



11.10 Test Yourself 10

COMMUNICATONS WORD SEARCH

Q	S	I	G	H	T	S	E	V	A	W
Z	S	A	M	P	L	I	F	I	E	R
D	R	N	T	Z	E	G	M	A	D	A
I	E	A	R	E	D	N	Q	L	Z	R
G	K	L	T	E	L	A	Z	T	A	E
I	A	O	I	E	C	L	R	D	T	S
T	E	G	B	G	D	E	I	O	A	R
A	P	U	R	E	H	O	I	T	P	O
L	S	E	O	O	N	T	C	V	E	M
T	R	A	N	S	M	I	T	T	E	R

AM
Amplifier
Analogue
Code
Digital
Dot
FM
Geo
Hertz
LDR

Morse
Orbit
Radio
Receive
Satellite
Sight
Signal
Speakers
Tape
Transmitter Waves

11.11 Test Yourself Solutions

TEST I

1. Larynx or voice box is the encoder
The decoder is the brain
The carrier wave is a sound wave

2. Optical fibres use a modulated light wave
The deaf and dumb languages also use a light wave
For sending telephone messages, an electromagnetic wave is needed
Radio waves for communicating with satellites

3. Repeaters are only used with analogue signals, regenerators with digital signals.
The signal loses energy due to the electrical resistance of the cable.
The repeater's purpose is to replace the energy that is lost along the way.

4. The crackling sound is known as noise.
It can be produced by electrical equipment (such as motors) that are nearby.
Turning up the amplitude would also amplify the noise as well as the signal.

TEST 2

1. An analogue signal is a continuously variable signal whereas a digital signal can only exist in two states, 0 or 1.
Regenerators are used with digital signals which re-establishes the 0 or l's, the amplitude of the signal is not being amplified, thereby the noise is not amplified either. With analogue signals any noise is also amplified when sent through a repeater.

   Tape recorder - analogue
   CD player - digital
   Optical fibres - digital
   Record player – analogue

2. Video recorder - magnetic tape
Cine file - transparency, using light
Tape recorder - magnetic tape
Hard disc - logic states, 0 or l's

3. Modulation refers to the way in which the signal is added to the carrier wave.
AM has a restricted bandwidth and cuts off the higher and lower limits of the audio frequency range. FM accommodates a greater frequency range.

4. Travels in a straight line and cannot travel round objects.
AM has a longer wavelength and is diffracted by the curvature of the Earth and so can follow the Earth's surface and hence can be detected even if not in the line of sight FM has a much shorter wavelength and is not diffracted by the Earth's curvature and so is associated with a line of sight transmission.

TEST 3

1. 200 kHz
The signal at 1 km would be 100 x that at 10 km since it follows an inverse square law.

2. They are plane polarised in a vertical plane.
Whatever the direction of the car the aerial must always be parallel to the electric field vector.
To receive the maximum signal the magnetic field has to be parallel with the axis of the coil, clearly this will depend on the direction that the car is travelling.

3. If they use FM then it is a line of sight method and therefore it has a limited range when sent out horizontally. So long as the next town is beyond this range then the two towns can use the same frequency for transmission.

4. A region above the Earth's surface consisting of free ion pairs.
The ionosphere can be used to reflect radio waves back to Earth and so provide a path round the Earth.
This is known as a dead space and it is the region where the reflected waves cannot be detected as they over-shoot this region.

5. The long wavelength waves can be diffracted into the valleys by large geographical features such as mountains, whereas the short wave transmissions are mainly line of sight and are not diffracted as much.
Water molecules have a particular resonant frequency and the frequency used for micro-wave transmission is different to this frequency.

TEST 4

1. Geostationary orbits have no motion relative to the Earth, a lime period of 24 hours and are in orbit on a equatorial plane. Polar orbits can have a range of periods and orbit from N to S whilst Earth rotates beneath them.
For circular motion an inward acting force is needed for satellites this is provided by the pull of the Earth, which acts towards the Earth's centre. There is no resultant force at latitude of 50° towards the centre of the orbit, therefore it is impossible to have a geostationary orbit at this latitude.
The gravitational Field follows an inverse square law so at three Earth radii the field strength will be 1/9 of that at the Earth's surface.

2. The two factors are the diffraction effect of the transmitting dish and the inverse square law of radiation. This avoids constructive or destructive interference occurring between the two waves.

3. Passive merely reflects the signals but active will receive, amplify and re-transmit.
Three uses could be weather forecasting, the mapping of geographical features or looking at the Earth's areas of vegetation.
846 km
16

4. The diffraction of the waves by the transmitting dishes, interference caused by overlapping waves from close satellites.
No, work is not being done against the Earth's gravitational field.
If it slowed down the field strength at that height would be greater than that needed to keep it in orbit so it would move in towards the Earth and eventually burn up in the Earth's atmosphere.

TEST 5

1. A device which is able to convert from one type of signal to another.
Record head input microphone
TV audio output - loudspeaker
Optical fibres - input - LED/laser diode
- output - photodiode/LDR

2. Magnetic field in the coil interacts with the permanent magnetic field and produces a force which makes the coil-diaphragm move.
The woofer would be two massive to respond to the high frequency sounds so its amplitude would be restricted. With the tweeter, although it would move, the size of it would restrict the volume of air displaced and also result in low amplitude, this time at the low frequencies.

3. LED produces light whereas LDR responds to varying light intensity by changes in its electrical resistance.
LED could be used as the source of on/off pulses being sent down fibre optic cables.
The frequency range of the light from an LED is too wide, whereas the laser diode has a much narrower range.

4. Limited amplitude response and the time of response. If the intensity of sound is too low the movement of the diaphragm may produce an insignificant change in the resistance and therefore not be detectable. The inertia/mass of the diaphragm system will limit the frequency response at the top end of the frequency range.
Since movements of the diaphragm result in changes in the current in the circuit, there is a changing magnetic field in the primary of the transformer. Hence there will be an induced voltage across the secondary. One of the purposes will be to increase the voltage, that is a step-up transformer.

TEST 6

1.	aerial	2.	carrier	3.	modulated	4/5.	amplitude
5/4.	frequency	6.	frequency	7.	amplitude	8.	polarised
9.	magnetic	10.	parallel	11.	aerial	12.	noise
13.	noise	14.	decoding	15.	encoding	16.	diode
17.	diode	18.	transducer	19.	AM	20.	AM
21.	FM	22.	AM	23.	FM	24.	FM
25.	short	26.	diffracted	27.	AM	28.	diffracted
29.	amplifier	30.	transducer	31.	amplifier	32.	noise
33.	transducer	34.	magnetic	35.	voltage	36.	transducer

TEST 7

CROSS-WORD SOLUTION

A	N	A	L	O	G	U	E		S	O	L	A	R
			I		E		Y		K			U	
D		E	N	C	O	D	E		Y		L	D	R
O	N		E		S			M				I	
W			A	T	T	E	N	U	A	T	I	O	N
N			R		A			F			N		O
L	E	D			T		W		S				I
I		I	O	N	I	S	A	T	I	O	N		S
N		G			O		V		G			M	E
K		I		A	N	T	E	N	N	A		O	
		T			A				A			R	F
	L	A	S	E	R		V	O	L	T		S	
		L			Y				S		S	E	E

TEST 9

Signals
Sky wave
Geostationary
Orbit
Transmit
Noise
Modulate
Receiver
Encoder
Diode

TEST 10

Self evident

TEST 8

MIX 'n' MATCH

AMPLIFIER	Boosts the signal received by an input of energy
ANALOGUE	Can be used to communicate with satellites in orbit
ATTENUATION	Changes one type of signal into another
CENTRIPETAL FORCE	Describe the loss of energy between transmitter and receiver
DECODER	Has four layers and consists of charged particles
DIFFRACTION	Has speed but no motion relative to the Earth
DIODE	Is an attractive field following an inverse square law
ENCODER	Limits the number of satellites in geostationary orbit
GEOSTATIONARY ORBIT	Takes an audio signal and produces an analogue voltage
GRAVITATIONAL FIELD	The device used to code a signal before being placed on the carrier
IONOSPHERE	The force needed to keep an object in a circular path
LOUDSPEAKER	The output form a microphone can be described as this
MICROPHONE	The way in which a signal is placed on the carrier wave
MODULATION	This can reproduce a digital signal to compensate for power losses
POLAR ORBIT	This has the disadvantage that it will also increase the level of noise
REGENERATOR	Used for mapping weather patterns
REPEATER	Used to unscramble the received transmission
SPACE WAVE	Will only allow current to pass through it in one direction
TRANSDUCER	Works by making use of the catapult effect