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DOCUMENT TITLE

CPL NAVIGATION 2 (AUSTRALIA)

CHAPTER 3 – BASIC RADIO PRINCIPLES

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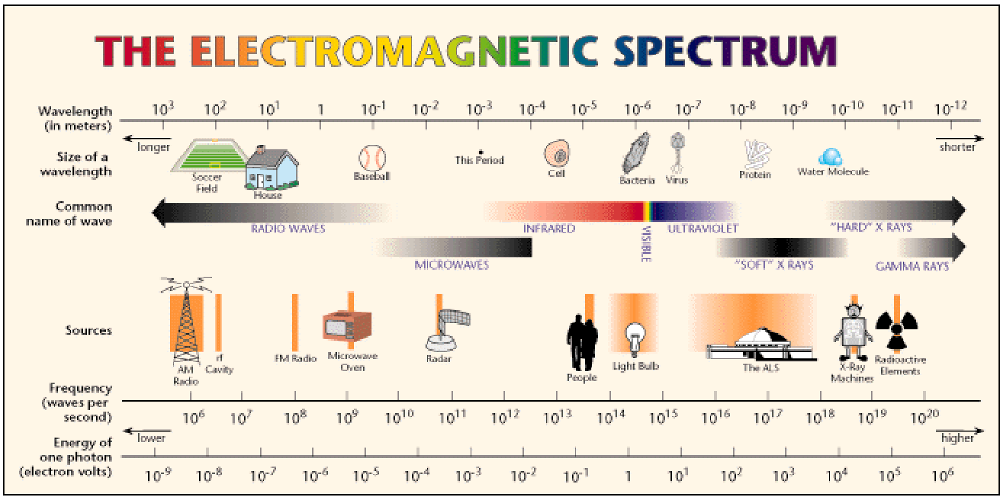
BASIC RADIO PRINCIPLES

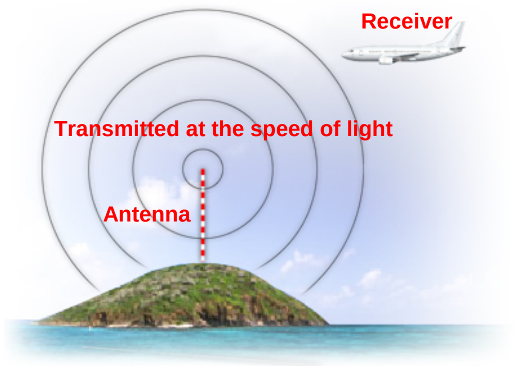
3.1 An Introduction to Electromagnetic Waves

Electromagnetic waves appear in many forms with widespread applications. Our ability to create, employ and manipulate electromagnetic waves forms one of the reasons that communication plays such an important role in society.

Electromagnetic waves are waves that travel at the speed on light. The spectrum of their frequencies results in waves that are used in many of our useful devices (microwave ovens, television and mobile phones).

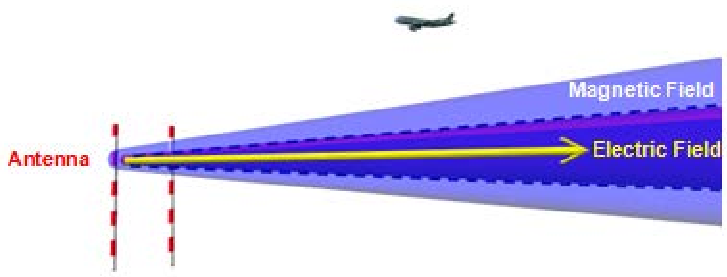


An electromagnetic wave **(such as a radio wave)** propagates outwards from the source **(an antenna, perhaps)** at the speed of light. Devices are designed to extract information from electromagnetic waves through the detection of the wave **(e.g. Television, aircraft radio receiver and mobile phones)**.

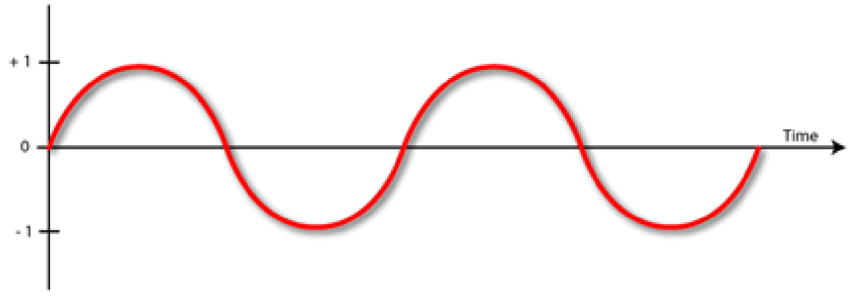


3.2 Properties and Characteristics of a Wave

If a source of alternating current (**AC**) is connected to a wire, **(i.e. an antenna)** an oscillating current will flow in the antennae. This produces an electric field in the wire accompanied by a magnetic field and both these fields radiate outwards from the wire in the form of electromagnetic-, or radio waves.



An alternating current (AC) in a wire reverses its direction a number of times every second. Consequently, if a graph of the current in the wire is plotted against time, it will be found that it is a sine wave. Conventional current flow is from positive to negative.

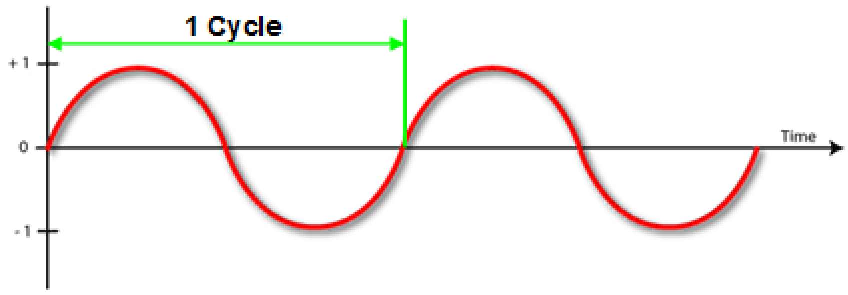


3.2.1 Properties of a Sine Curve

The following are properties and characteristics of a sine curve.

3.2.1.1 Cycle

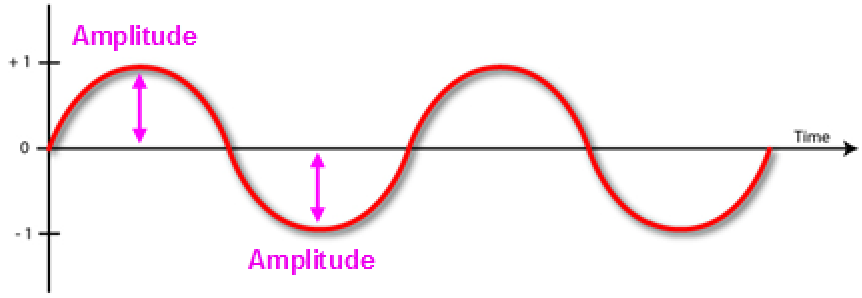
A cycle is one complete series of values, or one complete process.



Hertz (Hz) One hertz is one cycle per second. (The number of cycles per second is expressed in hertz –Hz).

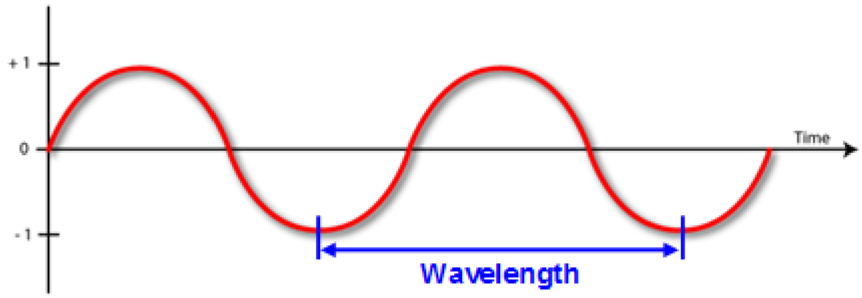
3.2.1.2 Amplitude

This is the maximum displacement, or the maximum value attained from the mean position during a cycle. For our purposes we say it is both positive and negative.



3.2.1.3 Wavelength

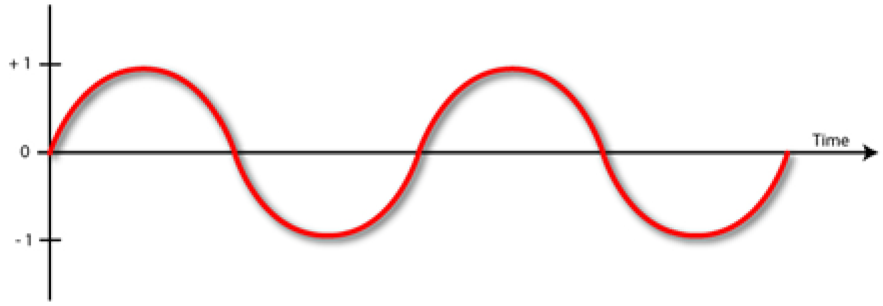
The wavelength is the physical distance travelled by a radio wave during one complete cycle. The symbol for wavelength is **λ** (lambda).



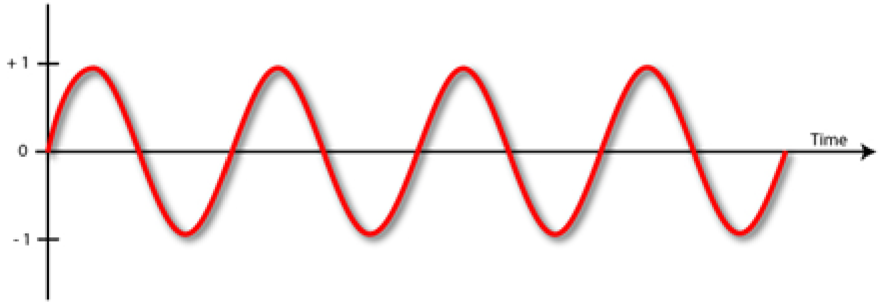
3.2.1.4 Frequency

Frequency is the number of cycles occurring in one second, expressed in hertz (Hz). Since the number of cycles per second of normal radio waves is very high it is usual to refer to them in terms of kilohertz, megahertz and gigahertz as follows:

- 1 cycle per second = 1 Hz
- 1000 Hz = 1 kHz (kilohertz)
- 1000 kHz = 1 MHz (megahertz)
- 1000 MHz = 1 GHz (gigahertz)



The frequency of this wave is double that of the wave above, and also note that the wavelength has halved.



Wavelength and Frequency can be determined mathematically by means of a formula (discussed below). Wavelength and Frequency are inversely proportional. This means that if a wave's frequency increases (more cycles per second), then the wavelength will decrease and vice versa.

3.2.1.5 <u>Speed</u>

In the earth environment, radio waves travel at approximately the speed of light, i.e:

- **186,000 Statute miles per second or**
- **162,000 Nautical miles per second or**
- **300,000,000 Metres per second**

The speed of radio waves is considered to remain constant and the frequency and wavelength are inversely proportional. The relationship can be illustrated mathematically as follows:

$$\text{Wavelength } (\lambda) = \frac{\text{Speed (C)}}{\text{Frequency (f)}}$$

3.2.2 Properties of Radio Waves

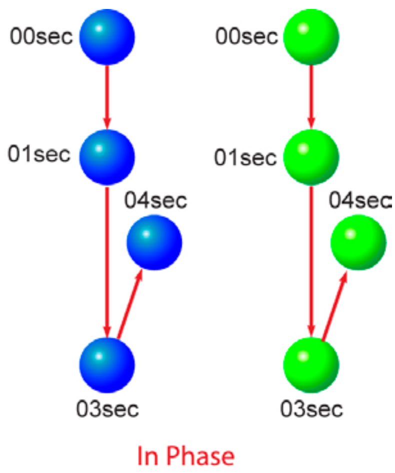
Radio waves have the following properties:

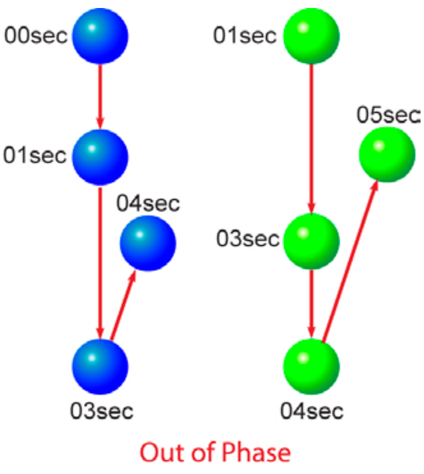
- In a constant medium, radio waves travel at a constant speed.
- When passing from one medium to another (e.g. air to water), radio waves may change speed and wavelength, but the frequency will remain constant.
- Radio waves can be reflected.
- Generally waves travel in a straight line.
- Surface waves follow the shortest distance over the surface of the Earth which is a great circle path and not a straight line in space.

3.3 Electromagnetic Wave Phases

If two balls that share the same characteristics are released from the same height at the same time, they will bounce off a surface at the same time. If they should reach the top of their upward movement at the same time, and then bounce again at the same time, they are said to be in phase.

If however at any time there is a fraction of a delay between the balls bouncing, they will not reach any given point at the same time, and are said to be out of phase.

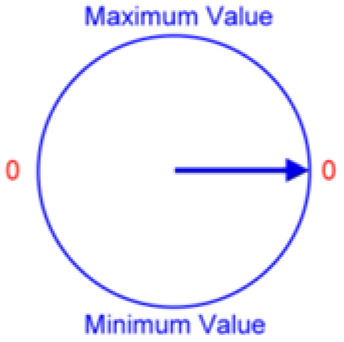




The same can be said of two electromagnetic waves travelling through space, should one wave reach its maximum value before the other, (or any other point) they will be travelling out of phase.

Two waves can be made to travel in, or out of phase, depending on the requirement. In some instances it is desirable to create an “out of phase” wave, and some navigational instruments are designed to operate on this principle i.e. VOR.

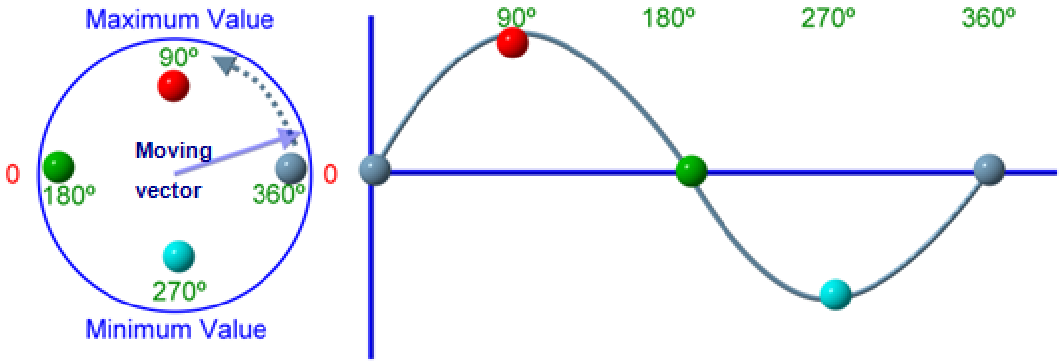
3.3.1 Representation of Phase in Electromagnetic Waves



In order to illustrate this principle, let us assume that an alternating current (AC) is being produced by a rotating vector.

One cycle of AC will have a single maximum value, a single minimum value and two zero values.

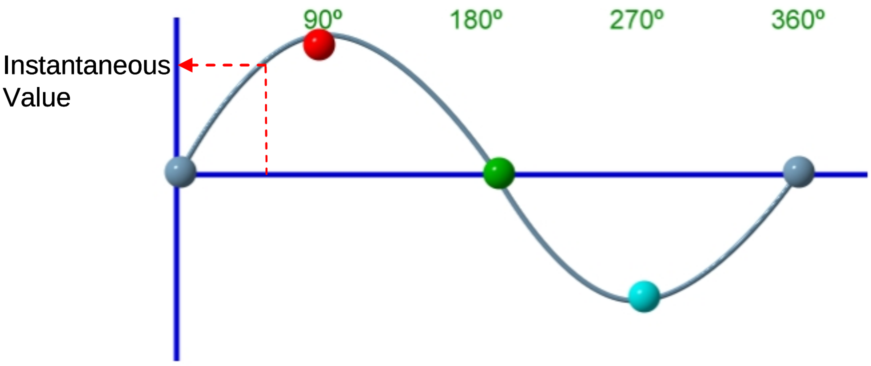
This cycle can be plotted on a horizontal axis, representing 360° and is represented by a sine curve.



If two waves are sent at the exact same time and at the same frequency, they will lie over each other ***(superimposed)***, and no phase difference will be seen. They will be "in-phase". Waves that are in-phase strengthen each other.

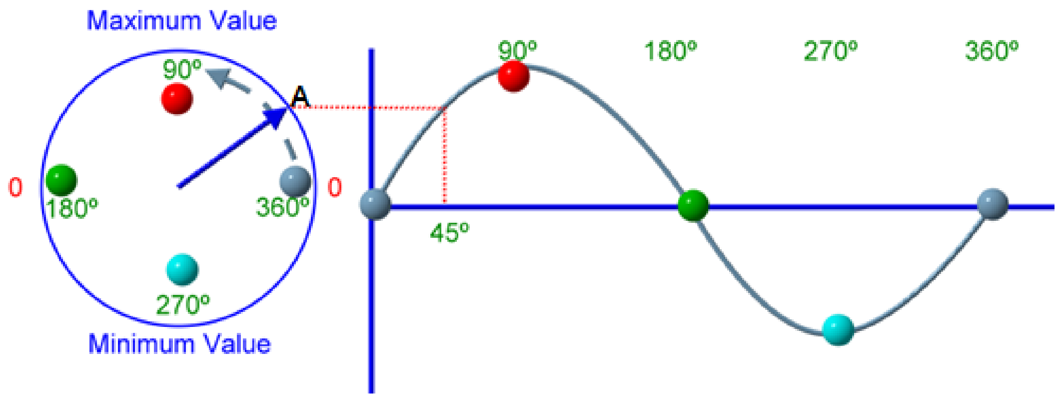
3.3.2 Instantaneous Value

The instantaneous value of a sine wave of alternating voltage or current is the value of voltage or current (indicated on the y-axis of the wave diagram below) at one particular instant of time (any point along the x-axis of the wave diagram below). There are an infinite number of instantaneous values between zero and the peak value.



3.3.3 How Phase Difference is Measured

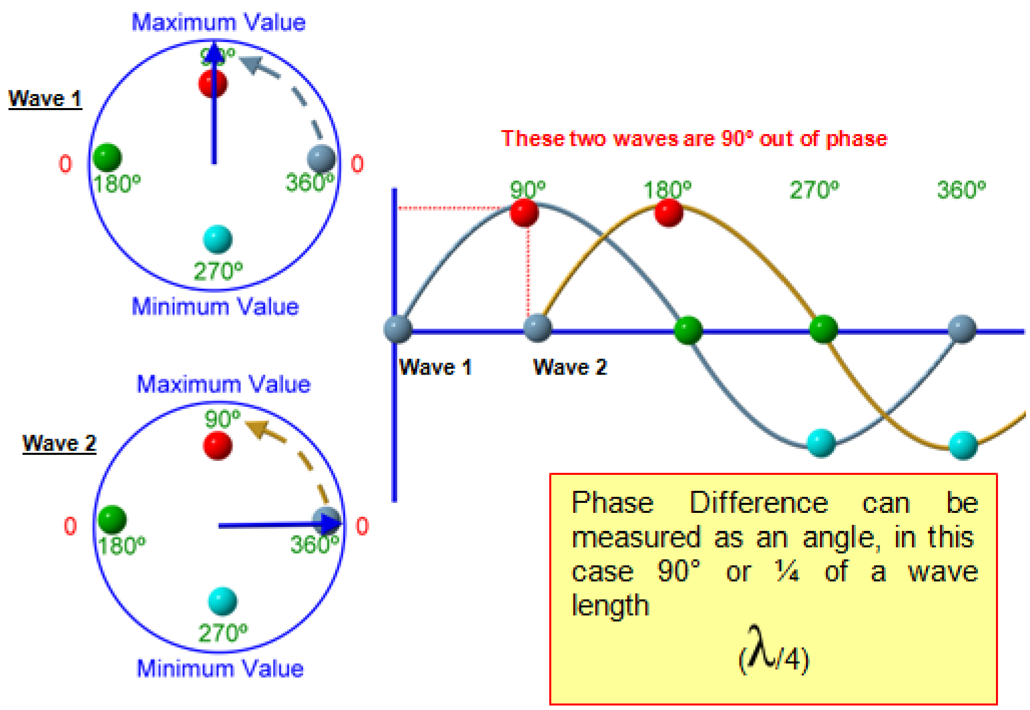
If the vector is stopped at some stage of its revolution, say at point A (45° anti-clockwise from the starting point), it would have traced the cycle from the zero (360°) position on the horizontal axis up to point midway between 0° and 90°.



If at this instant (45°), another wave were to be transmitted, the two waves would have a phase difference of 45°. This is termed the instantaneous phase of the wave cycle - instantaneous, because it is the phase difference at that instant. The instantaneous value of a cycle can be found along any point on the wave's cycle.

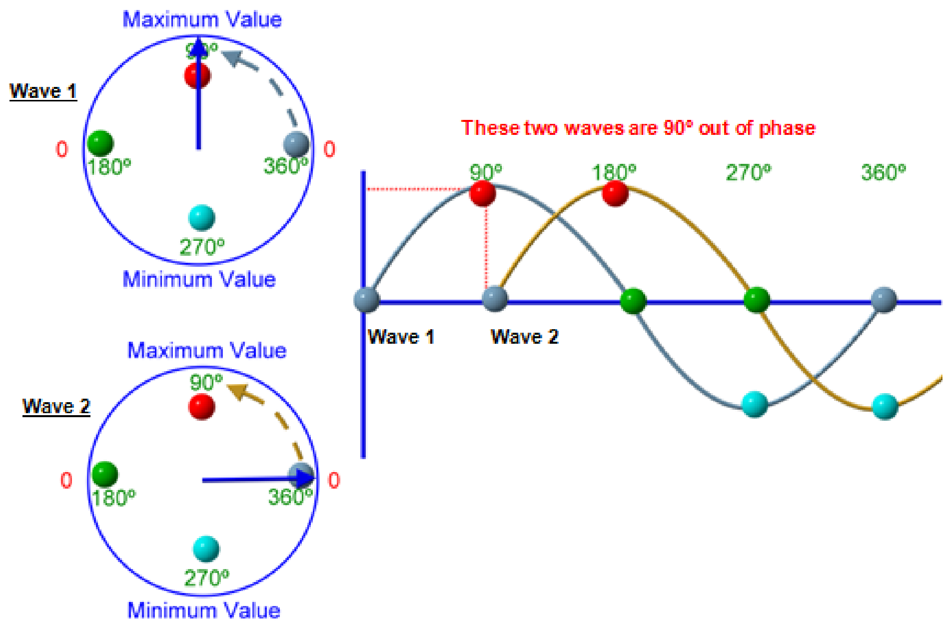
A delay in sending off one transmission before another would cause them to be out of phase. Therefore, if two radio waves of the same frequency **(their amplitudes need not be the same)** do not reach the same value at the same time, they are out of phase.

Phase Difference is the angular difference between corresponding points on the waveform and is measurable.



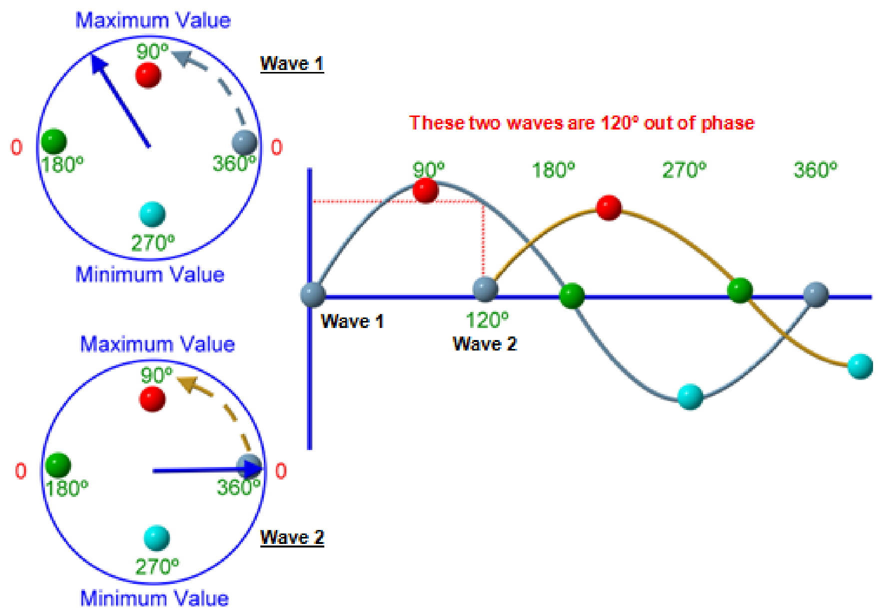
By convention the starting point for counting degrees in a wave is the zero point as the voltage or current begins the positive half cycle. Phase difference is the measurement of degrees between starting points of two waves.

Example 1: By comparing the instantaneous values of these two vectors, **(same frequency and amplitude)**, it can be seen that their phase difference will be 90°.

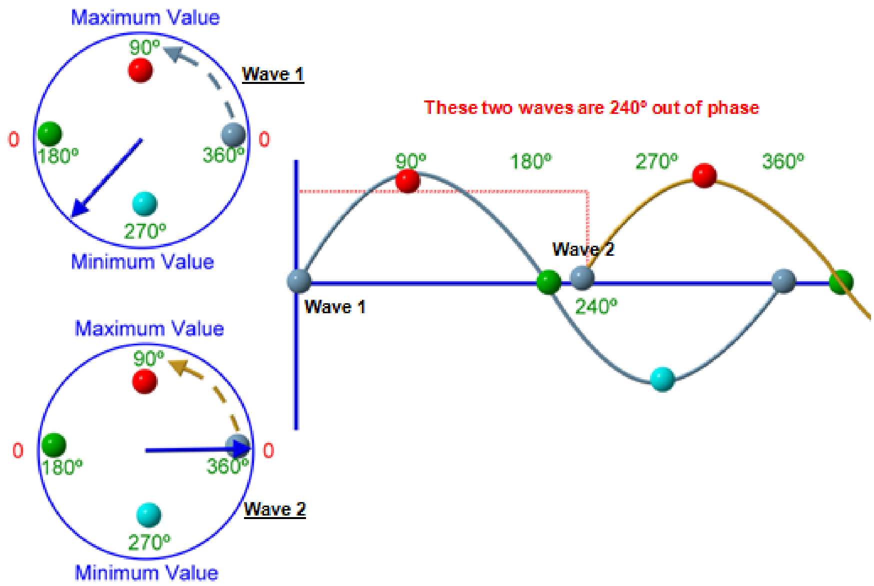


The VOR is able to calculate magnet bearings between the station and the aircraft, measuring the phase difference between two signals.

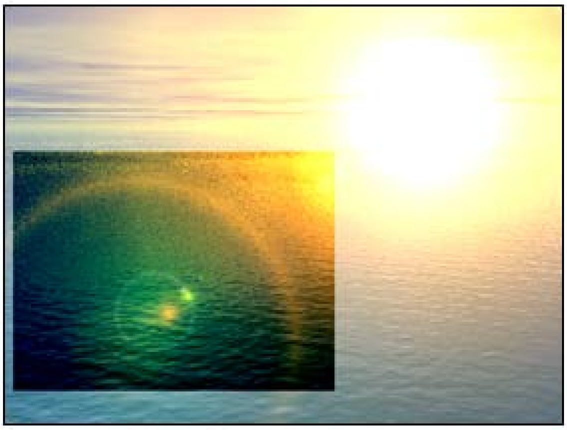
<u>Example 2</u>: By comparing the instantaneous values of these two vectors, **(same frequency and different amplitude)**, it can be seen that their phase difference will be 120°.



<u>Example 3</u>: By comparing the instantaneous values of these two vectors, **(same frequency and amplitude)**, it can be seen that their phase difference will be 240°.



3.4 Electromagnetic Wave Polarisation



Polarisation is simply the orientation of a wave. Sun film and many sun glasses make use of polarisation to prevent certain waves entering the eye. Therefore a specific lens may only allow vertical waves to enter, and omit horizontal waves.

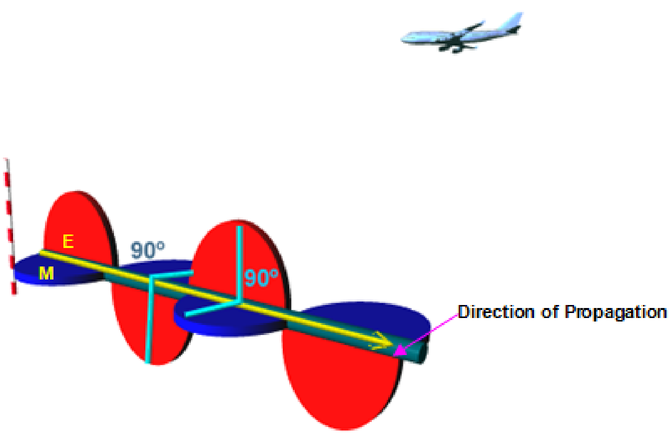
By excluding waves entering the eye, images are sharper and glare is reduced.

Experiment: Take two pieces of polarised film (or lenses from polarised sunglasses), places it together and rotate one piece. As it rotate, more or less light will be allowed through.

3.4.1 Polarised Waves

An electric field in an aerial is accompanied by a magnetic field and both these fields radiate efficiently outwards in the form of electromagnetic-, or radio waves. Electromagnetic (radio) waves therefore consist of two components - electric (E) and magnetic (M).

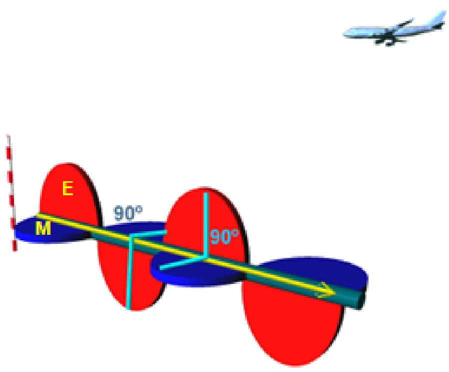
Both components travel at right angles to each other and at right angles to the direction of propagation.



Polarisation refers to the orientation of the electrical component of the radio signal.

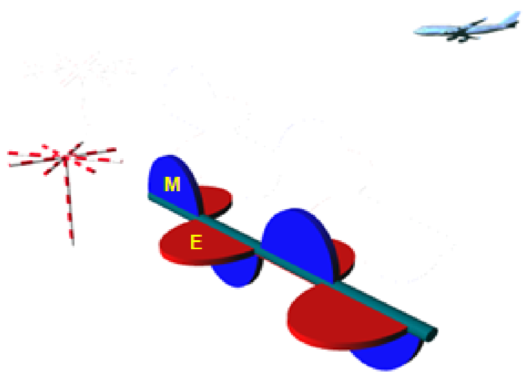
3.4.1.1 Vertical Polarisation

When a transmission is made from a vertical aerial the electrical component, **E**, travels in the vertical plane. The magnetic component, **M**, will travel in the horizontal plane and this emission is said to be **vertically polarised**.



The radiation from a NDB is vertically polarised.

3.4.1.2 Horizontal Polarisation

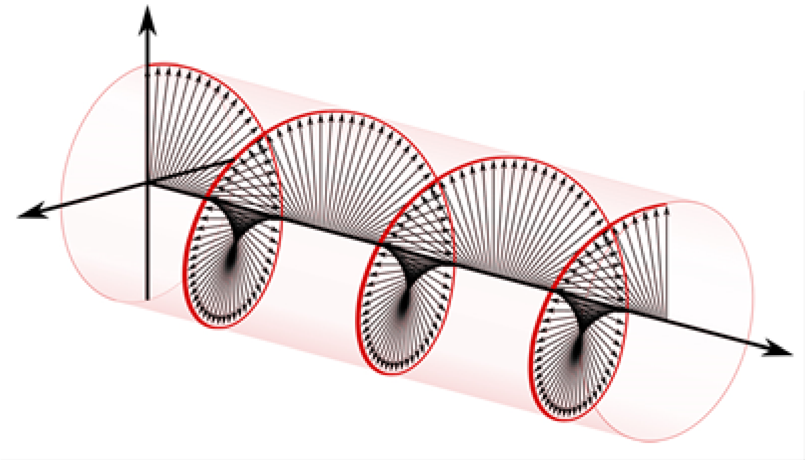


The reverse is also true. When a transmission is made from a horizontal aerial the electrical component, **E**, travels in the horizontal plane and the magnetic component, **M**, travels in the vertical plane. This emission is said to be **horizontally polarised**.

The radiation from VOR and ILS is horizontally polarised.

3.4.1.3 Circular Polarisation

The electrical and horizontal components spin about the axis of advance, at a rate equal to the frequency.



This technique is used in reducing rain clutter in radar.

The importance of knowledge of polarisation lies in the orientation of the receiver aerial. The receiver aerial must be similarly polarised to the transmitter aerial for maximum reception efficiency.

A vertical antenna will receive a vertically polarised signal, while a horizontal antenna can receive a vertical signal only because reflections change the polarisation of the waves.

The horizontal antenna will thus be less efficient in receiving vertically polarised signals and best suited to transmissions originating from a horizontal transmitting antenna.

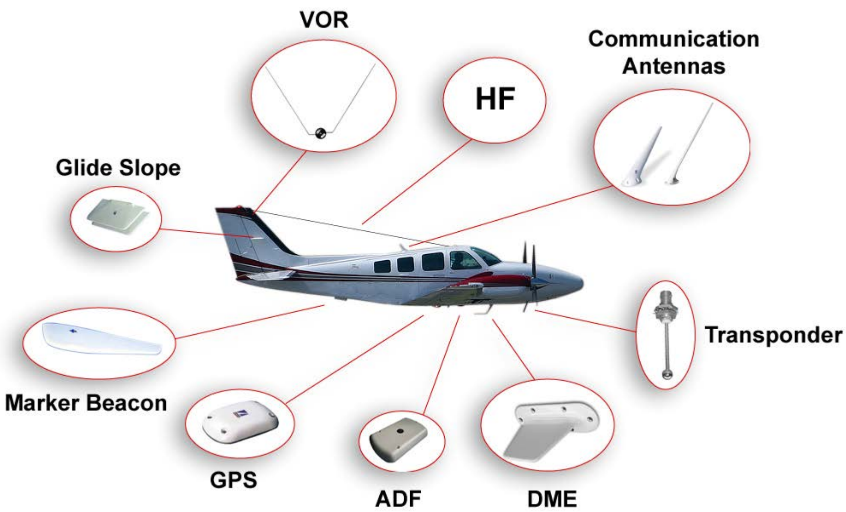
3.5 Antennas (Aerials)

An antenna is that part of a radio system from which energy is transmitted into, or received from, space. An optimum antenna would be exactly as long as the wavelength it transmits or receives but if this is not possible, a fraction such as ½ wavelength or ¼ wavelength may be used. It is a general rule that antenna size relates to wavelength so for example, a radar operating on a very high frequency will be likely to have a very small antenna.

Vertically Polarised VHF Antenna

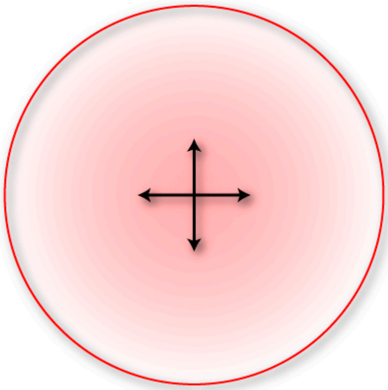
The orientation of antennas takes into account the polarisation of the radio waves which they are designed to receive or transmit. ADF signals are vertically polarised whereas VOR and ILS Localizer signal are horizontally polarised and so their receiving antennas have the same orientation, when placed on the aircraft's fuselage. In practice, antennas on the aircraft must also be designed for minimum drag as well as for optimum radio efficiency.

Not all aircraft are fitted with the same types of avionic systems, so not all aircraft have the same antennas on their fuselages. The diagram below illustrates some of the more common antennas fitted to light civilian aircraft.

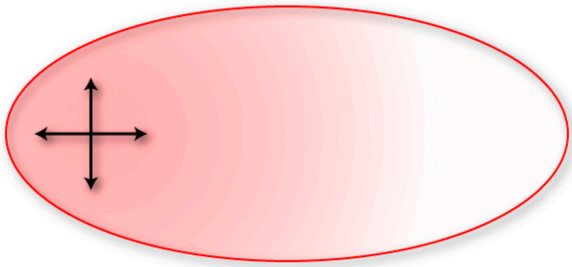


3.5.1 Polar Diagrams

A polar diagram is a representation of the radiation pattern of a transmitting aerial or reception of a receiving aerial. All points on the polar diagram represent the same values of either field strength or power.



Omni-directional aerial



Directional aerial

An omni-directional antenna is capable of transmitting or receiving signals in all directions whereas a directional antenna is designed to only transmit or receive signals in a single direction. Often directional antennas are rotated by means of a motor, if coverage in all directions is required.

3.6 Electromagnetic Wave Modulation

An electromagnetic radio wave alone does not contain any information - it is merely a carrier for information. Information or data must be impressed on it, which can be retrieved and decoded by the receiver. A radio wave is similar to a blank page (carrier), with no print (information) on it.

The process of altering the carrier wave to include information is termed modulation. Once modulation has taken place the carrier wave is called the modulated wave.

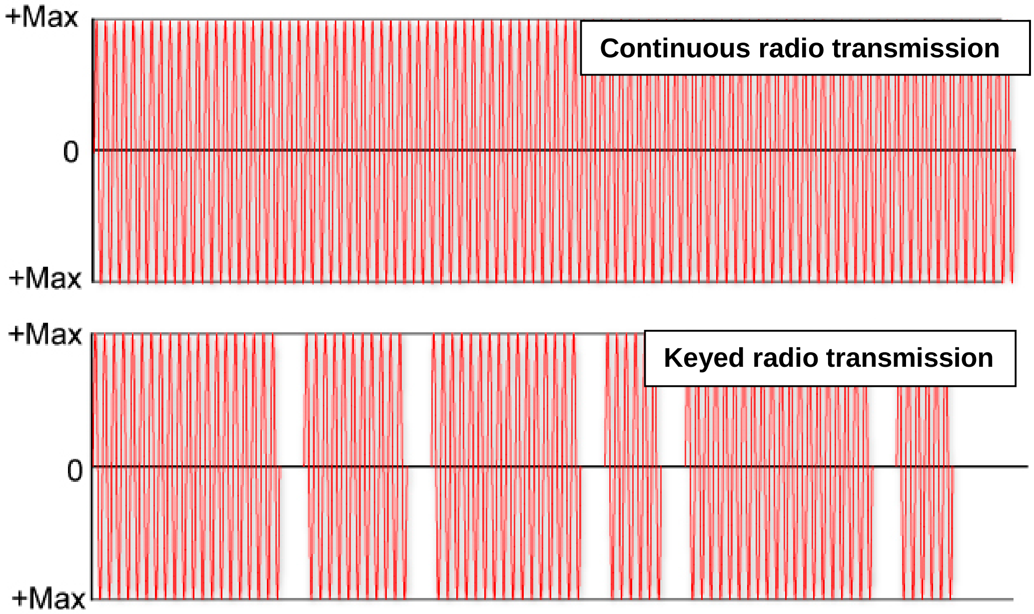
3.6.1 Methods of Modulation

There are many ways in which a carrier wave can be modulated. We will examine the following methods of modulation:

- Keying
- Amplitude Modulation
- Frequency Modulation
- Pulse Modulation

3.6.1.1 <u>Keying</u>

This is radiotelegraphy or Morse code. It consists of starting and stopping the continuous carrier so as to break it up into the form of dots and dashes.



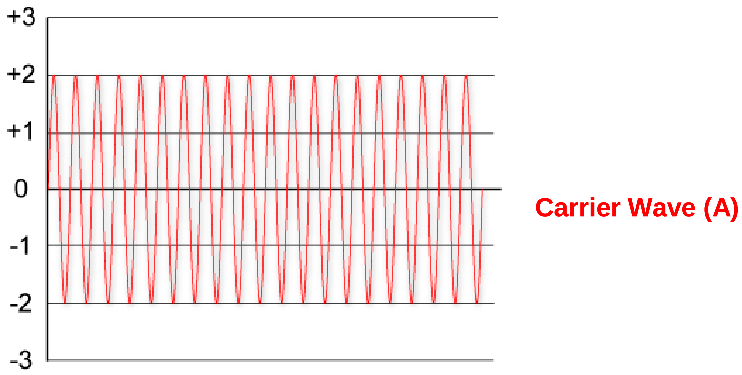
The receiver requires a beat frequency oscillator ***(BFO)*** facility to make the radio signals audible.

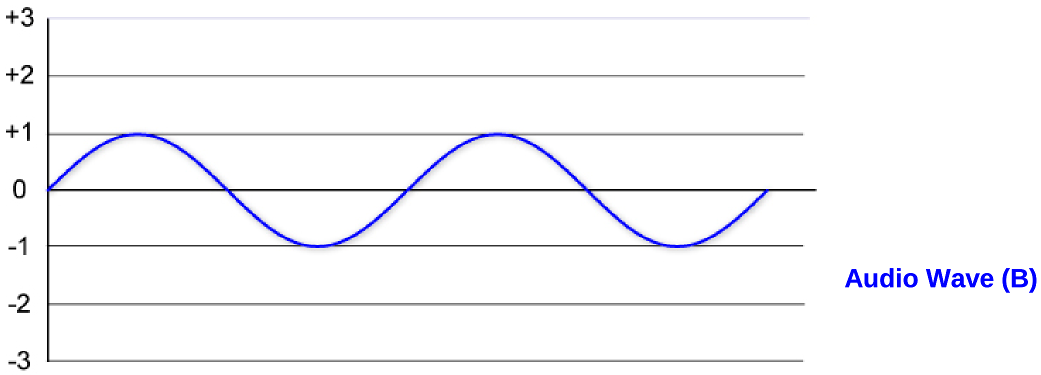
> Radio frequencies are inaudible to the human ear. The BFO generates a frequency close to the CW frequency – say 2 kHz off then takes the difference (2 kHz) which can be heard by the human ear. This is called the beat frequency.

3.6.1.2 Amplitude Modulation (AM)

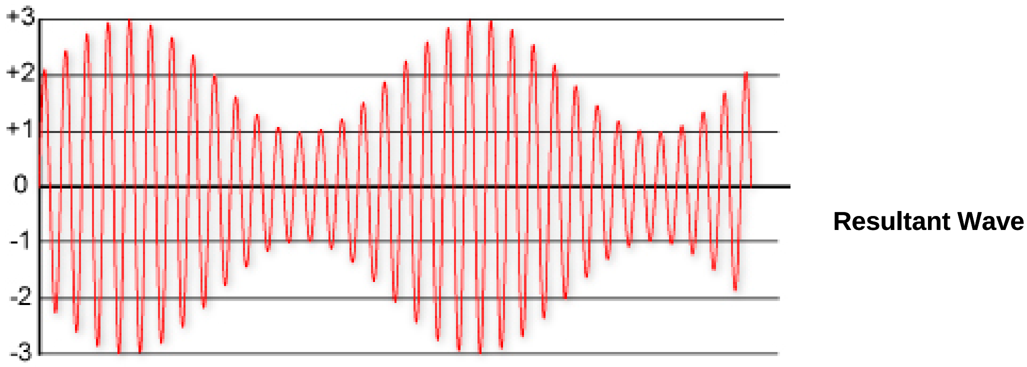
Amplitude modulation may be used to transmit data and messages, often at audio frequencies (AF), and also speech and music. The audio signal is impressed on the radio frequency by changing the amplitude of the Carrier wave (CW).

Modulating the Audio Wave





In the above diagrams, the carrier is represented by A, and the audio wave by B. The carrier wave has amplitudes between +2 and -2 (including 0) and the audio wave has amplitudes of between +1 and –1 (including 0).



After modulation, the resultant amplitude varies between the sum of the original amplitudes and the difference between the original *amplitudes* **(in this case between ±3 and ±1)**.

This resultant amplitude is a measure of the modulation depth, which is a percentage measurement of the degree to which the wave is modulated.

It is the ratio: $\boxed{\dfrac{\text{Amplitude of A} \times 100}{\text{Amplitude of B}}}$

Therefore in the above example, the modulation depth would be 50%.

The higher the modulation depth of the wave, the stronger the signal and the more power required to send an amplitude-modulated signal.

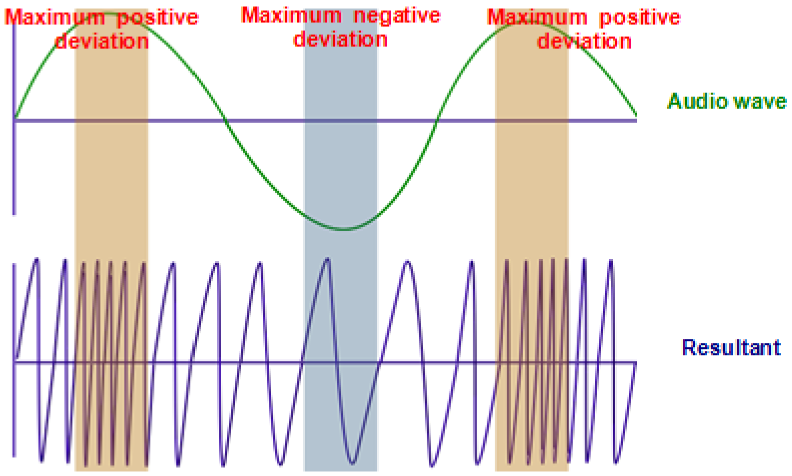
In practice signals are modulated to approximately 85%, in order to prevent over modulation, which causes distortion in reception. The power required to send a modulated signal a given distance increases by approximately 50% compared to transmitting the carrier wave only, or at a specific transmission power the carrier wave alone will travel further than the modulated wave.

Aviation makes use of amplitude modulated signals for VHF radio telephony.

3.6.1.3 Frequency Modulation (FM)

Here, the **frequency** of the CW is varied in accordance with the change in the amplitude of the audio frequency, while keeping the amplitude of the CW constant.

This is achieved by varying the frequency of the carrier in accordance with the change in amplitude of the audio. The amplitude of the carrier is kept constant. The degree of frequency variation depends on the amplitude of the modulating audio signal. When the amplitude is positive, the frequency will be greater than the mean carrier frequency. The frequency of the audio signal (the pitch of the sound) is conveyed by the rate at which the frequency of the carrier is varied.



Advantages of FM Over AM

- FM transmitters are simpler and cheaper.
- Modulation power required is lower.
- Reception is practically static free due to operation in the VHF band.

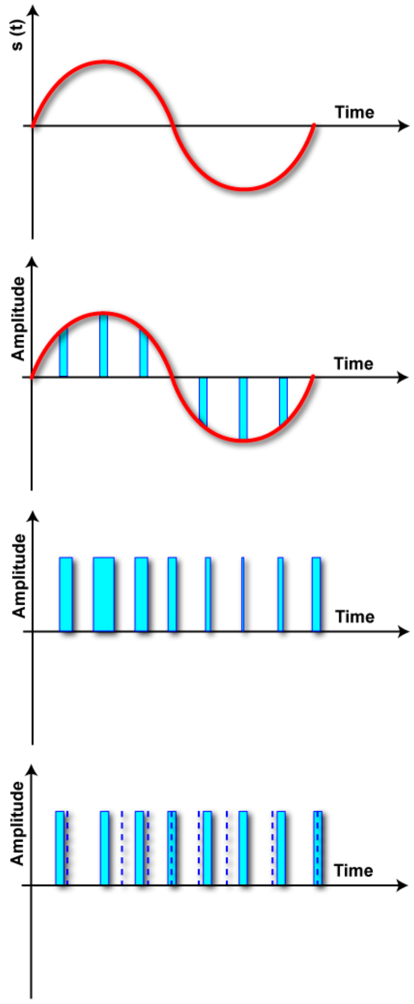
- As the transmission is usually horizontally polarised, it suffers less from weather induced static which is vertically polarised.

Disadvantages of FM

- FM receivers are more complex.
- Modulated transmission calls for a wider frequency band. As congestion in the lower frequency bands would not provide the necessary bandwidth, FM broadcasts operate in the VHF band.

3.6.1.4 Pulse Modulation

Pulse modulation is used in radar and there are a variety of forms of pulse modulations in current use. The modulating pulses, in the simplest form, amplitude-modulate the carrier, giving it the shape of the pulses.

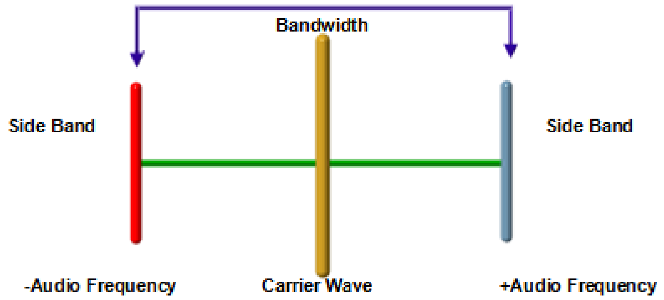


3.7 Sidebands

Sidebands are additional frequencies which occur whenever a carrier is modulated by a frequency lower than itself, particularly audio frequencies.

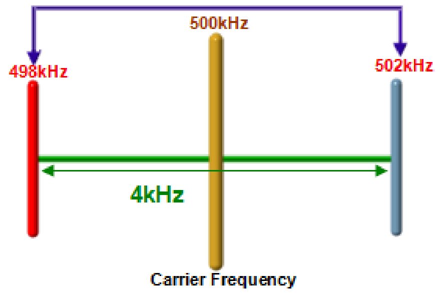
When a carrier wave is amplitude-modulated, the resultant radiation consists of three frequencies made up as follows:

- **Carrier frequency**
- **Carrier frequency + Audio frequency**
- **Carrier frequency - Audio frequency**



All these frequencies travel together and the new frequencies are called **'sidebands'**.

Example: A carrier wave of 500kHz, is amplitude modulated by an audio wave of 2kHz.

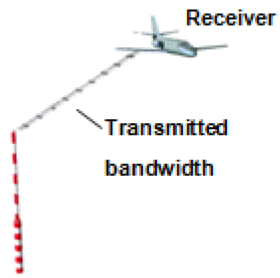


The resultant side frequencies (Carrier frequency +Audio frequency and Carrier frequency -Audio frequency) are therefore :

498 kHz (lower sideband) and 502 kHz (upper sideband). The complete range, from 498 kHz to 502 kHz, is called 'bandwidth', which is 4 kHz in the example given.

Unlike AM, an FM signal has multiple of sidebands and consequently its bandwidth is greater.

This is only possible in the VHF band (or a higher band) which is less congested and therefore able to cover the full span of human audio frequencies of up to 15 kHz. A voice transmission consists of many different audio frequencies impressed on the carrier wave and so there are many sidebands.



It is the sidebands and not the carrier that carry the information.

With AM transmission, each sideband is a mirror image of the other and contains the same information. With AM the range and clarity is less but by transmitting only one sideband, power and bandwidth are saved.

3.8 Emission Designation and Frequency Spectrum

3.8.1 ICAO Designation of Transmissions

ICAO designates all radio transmissions used in civil aviation according to their description and required bandwidth. This is done by making use of a three symbol designator. The table below indicates the symbols used. The system was introduced on 1 January 1982.

First Symbol		Second Symbol		Third Symbol	
Symbol	Meaning	Symbol	Meaning	Symbol	Meaning
N	Emission of an non-modulated carrier and for emissions in which the main carrier is amplitude modulated	**0**	No modulating signal	**N**	No information transmitted
A	Double Sideband	**1**	Single channel containing quantised or digital information without the use of a modulating sub-carrier	**A**	Telegraphy (Morse Code) – for aural perception
H	Single Sideband	**2**	Single channel containing quantised or digital information with the use of a modulating sub-carrier	**B**	Telegraphy – for automatic reception
J	Single sideband, suppressed carrier and for emissions in which the main carrier is angle-modulated	**3**	Single channel containing analogue information	**C**	Facsimile
F	Frequency modulation	**7**	Two or more channels containing quantised or digital information.	**D**	Data transmission, telemetry, tele-command
G	Phase modulation together with emission of pulses	**8**	Two or more channels containing analogue information	**E**	Telephony (Voice) - (including sound broadcasting)
P	Non-modulated sequence of pulses	**9**	Composite system comprising 1,2 or 7 above, with 3 or 8 above	**F**	Television (video)
K	Sequence of pulses modulated in amplitude	**X**	Cases not otherwise covered	**W**	Combination of the above
				X	Case not otherwise covered

Examples of aviation related radio signals in terms of ICAO signal classification

- VOR signals are classed as (A9W)
- NDB signals are classed as (N0N A1A or N0N A2A)
- DME signals are classed as (P0N)
- HF Communication is classed as (J3E) and VHF Communication is classed as (A3E)

3.8.2 Frequency Bands

Frequency Band	Characteristics	Application	Frequency Range	Wave Length
VLF (Very Low Frequency)	**Propagation:** Ground and Sky wave **Range:** 4000nm by surface wave **Static:** Severe **Aerials:** Very Large	Very long range navigation aids	3-30 kHz	100-10 km
LF (Low Frequency)	**Propagation:** Ground wave by day; ground wave and sky wave by night **Range:** 1500nm by surface wave **Static:** Less than VLF, but still a problem **Aerials:** Large	▪ NDB ▪ Radio Range ▪ Broadcast	30-300 kHz	10-1 km
MF (Medium Frequency)	**Propagation: Same** as LF **Range:** 300-500nm. 1000nm over water by day. By night the sky wave travels a little further, giving added range. **Static:** Present and troublesome	▪ NDB ▪ Broadcast ▪ Radio Range	300-3000 kHz	1000-100m
HF (High Frequency)	**Propagation:** Mainly by sky wave (day and night) **Range:** Ground wave 100nm, sky wave 3000 – 4000nm **Static:** Present and less troublesome	Long distance communications	3-30 MHz	100-10 m
VHF (Very High Frequency)	**Propagation:** Direct wave **Range:** Line of sight **Static:** Low	▪ VHF RT ▪ ILS localiser ▪ VDF ▪ VOR	30-300 MHz	10-1 m
UHF (Ultra High Frequency)	**Propagation:** Direct wave **Range:** Line of sight **Attenuation:** From water vapour above 1000MHz	▪ ILS Glide Path ▪ DME ▪ Surveillance Radar ▪ UHF RT ▪ GPS ▪ Satcom	300-3000 MHz	100-10 cm
SHF (Super High Frequency)	As for UHF, with increased attenuation	▪ Precision Approach Radar ▪ Surveillance Radar ▪ Doppler ▪ Airborne Weather Radar ▪ Radio Altimeter ▪ Satcom	3-30 GHz	10-1 cm
EHF (Extremely High Frequency)	As for SHF, with severe attenuation and very small aerials	▪ Airfield Surface Radar ▪ Experimental Radar	30-300 GHz	1-0.1 cm

3.9 Basic Principles of Propagation

3.9.1 Refraction

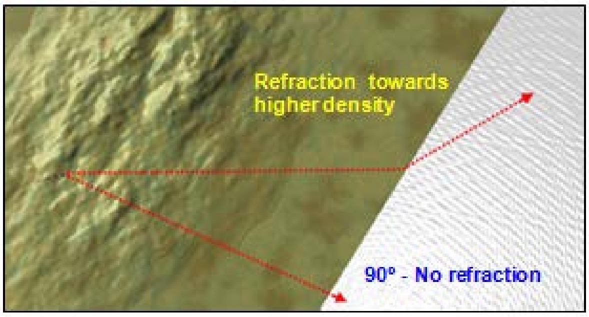
When a radio wave travels obliquely from a medium of one density to another of different density, it is bent or refracted at the surface separating the two media. The refraction occurs because radio waves travel at slightly different velocities in different media. Thus at the interface between the media there is a slight change of wavelength.

The following are well-known examples of refraction:

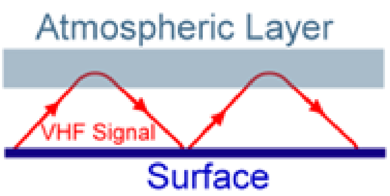
- Coastal Refraction
- Atmospheric Refraction
- Ionospheric Refraction

3.9.1.1 Coastal Refraction

This is where there is a change of direction when the radio wave crosses the coast. This is due to the different levels of attenuation and the different speed of radio waves over land and water.



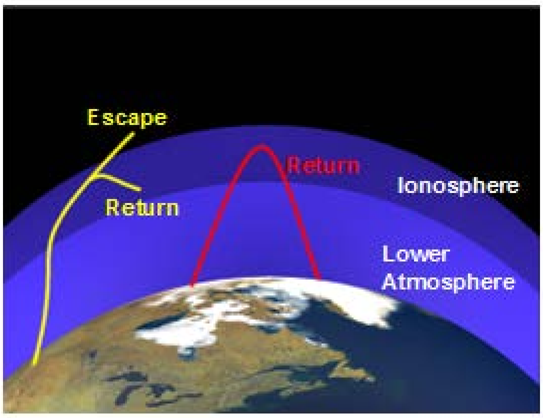
3.9.1.2 Atmospheric Refraction



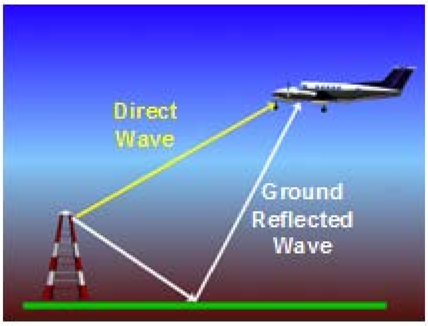
This is where changes in direction occur due to variations in temperature, pressure and humidity, particularly at low altitude. Normal levels of atmospheric attenuation cause the radio horizon to be different to the visual horizon. Exceptional levels of attenuation lead to Duct Propagation which is described in the next chapter.

3.9.1.3 Ionospheric Refraction

This is where changes in direction occur when the radio wave passes through the ionised layers of the earth's upper atmosphere. This results in skywave propagation described in the next chapter.



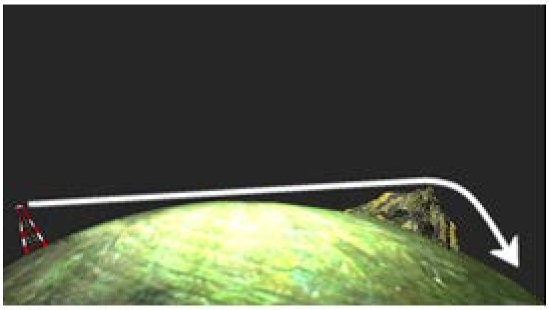
3.9.2 Reflection



The term reflection is used when a radio waves bounces off a solid surface. Reflection from targets causes radar pulses to return to the aerial from which they were transmitted but in some circumstances, there are adverse effects of reflection. The direct and ground reflected waves have followed different paths and are therefore likely to arrive at the receiving aerial out of phase. This can cause fading or temporary loss of signal reception.

3.9.3 Diffraction

This term is used to describe the ability of some radio waves to curve over obstacles. When a radio wave passes a solid object, it tends to scatter causing some of the energy to pass into the area of geometric shadow. This phenomena partly explains why radio waves in certain frequency bands are able to follow the curvature of the earth.

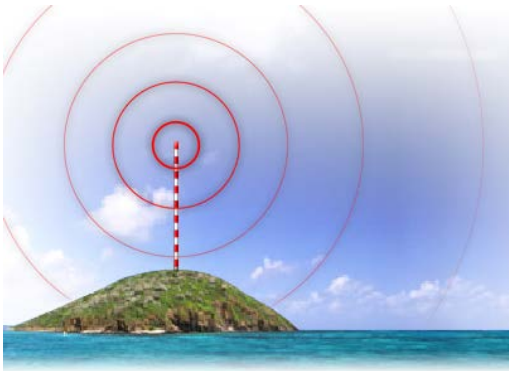


3.9.4 Attenuation

The term attenuation refers to the loss of power or signal strength suffered by radio waves as they pass through matter or over a surface.

The following general rules will be explained in the next chapter:

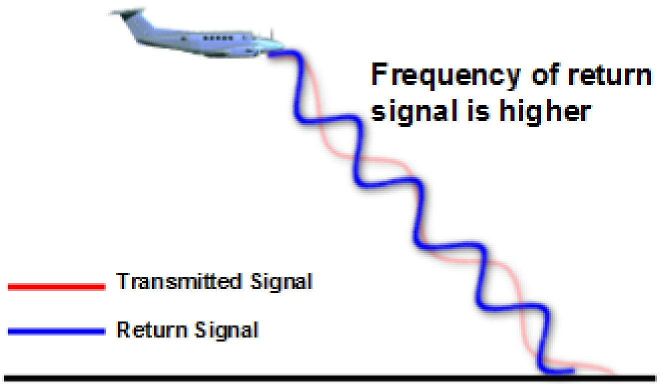
- Surface attenuation increases with increase in frequency.
- Ionospheric attenuation increases with decrease in frequency.
- Radar attenuation increases with increase in frequency.



Surface waves are to a greater or lesser extent absorbed by the surface over which the radio waves are passing. The ionosphere and particles in the atmosphere may to a greater or lesser extent block the passage of radio or radar energy. The processes of absorption and blocking are referred to as ATTENUATION.

3.9.5 Doppler Effect

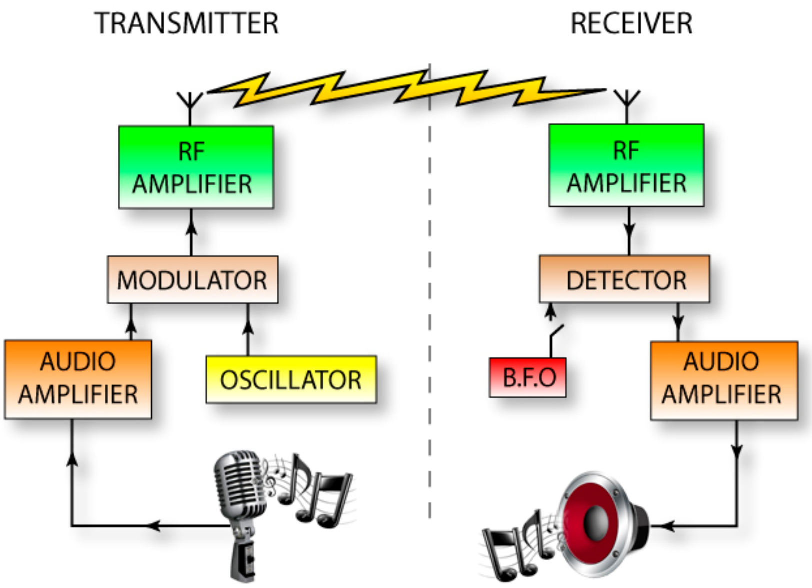
Doppler effect is the apparent change in the frequency of radio waves due to relative motion between the transmitter (TX) and receiver (RX).



If the distance between TX and RX is reducing, more radio waves arrive at the RX in unit time so the received frequency is greater than that transmitted. Similarly, if the distance is increasing the received frequency is lower.

3.10 Basic Radio Transmitter and Receiver

The basic components of a simple radio transmitter and receiver are shown in the following diagram.



- The MICROPHONE converts sound waves into weak electrical signals at audio frequencies. The human ear has a frequency range of about 50Hz to 15 kHz and these are known as audio frequencies.

- The weak signals are strengthened by the AUDIO AMPLIFIER and are then fed to the modulator.
- The OSCILLATOR produces radio frequencies which, by definition, are within the range 10 kHz to 100 GHz. The actual frequencies used will depend on the purpose of the radio equipment.
- The purpose of the MODULATOR is to superimpose the amplified audio signal on to the radio frequency produced by the oscillator which is referred to as the CARRIER WAVE.
- The modulated radio wave is now passed via the RF AMPLIFIER to the aerial. The choice of radio frequency will ensure that the signal can be efficiently radiated between transmitter and receiver aerials.
- The RF AMPLIFIER strengthens the weak radio signal which has been attenuated by the atmosphere or by the surface over which it has passed.
- The DETECTOR decodes the audio signal with which the carrier wave has been modulated.
- The weak audio signal passes through the AUDIO AMPLIFIER and then to the loudspeaker or headphones where it is heard as sound.
- The purpose of the BEAT FREQUENCY OSCILLATOR (BFO) is described in the ADF section.

3.11 Worksheet – Basic Radio Principles

1. A cycle of a radio wave refers to:
    a. The maximum displacement from the mean
    b. One complete series of values
    c. The physical distance travelled by the radio wave
    d. The orientation of the radio wave.

2. Frequency, wavelength and speed of radio waves have the following relationship:
    a. When frequency increases, wavelength decreases and speed is unchanged.
    b. When frequency decreases, wavelength decreases and speed is unchanged.
    c. When frequency increases, wavelength decreases and speed increases.
    d. When frequency decreases, wavelength increases and speed decreases.

3. What is phase difference?
    a. It is the process of imprinting audio information onto a carrier wave.
    b. It refers to the amount of cycles occurring in one second.
    c. It refers to the orientation of the electrical component of a radio wave.
    d. It refers to the angular difference between two points on a waveform and is measureable.

4. Which statement regarding antennas is true?
    a. An antenna must be at least equal to double the wavelength.
    b. Antenna length is inversely proportional to frequency.
    c. Antenna length is indirectly related to wavelength.
    d. Antennae need not consider signal polarisation to achieve best reception.

5. Which frequency band covers 3 to 30 MHz?
    a. VLF band
    b. MF band
    c. HF band
    d. VHF band.

6. Which frequency band has the longest wavelengths?

   a. HF band

   b. MF band

   c. UHF band

   d. VHF band.

7. Which one of the following statements is correct?

   a. Reflection is where there is a change in direction as a radio wave crosses the transition from one medium to another, like when crossing the coast from land to water.

   b. Diffraction refers to the loss of signal strength as a radio wave propagates.

   c. Attenuation is the ability of radio waves to curve over obstacles.

   d. Polarisation refers to the orientation of the electrical component of a radio wave.

3.11.1 Worksheet Answers

1B	2A	3D	4B
5C	6B	7D	