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DOCUMENT TITLE
RADIO NAVIGATION

CHAPTER 1 – BASIC RADIO PRINCIPLES

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CONTENTS .... PAGE

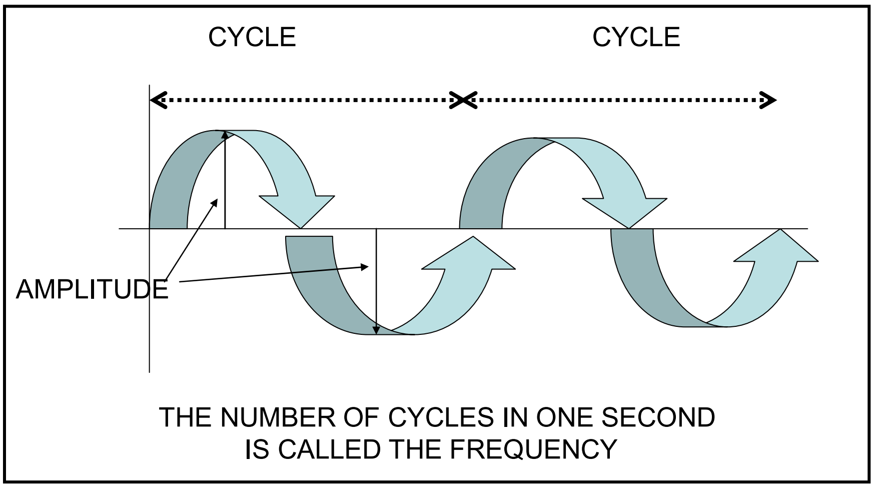
CHAPTER 1: BASIC RADIO PRINCIPLES

THE PROPAGATION OF RADIO WAVES

TERMINOLOGY

If a suitable alternating current is connected to an aerial, the energy will not be confined to the aerial but will radiate out into space in the form of radio waves. These radio waves are described as electromagnetic as they consist of electrical and magnetic fields. Radio waves travel at the speed of light which has a mean value of 299 792 500 metres per second or approximately 300,000 kilometres per second. For the purposes of radar, it is useful to consider this speed to be 300 metres per microsecond. The following radio terminology is related to alternating current:

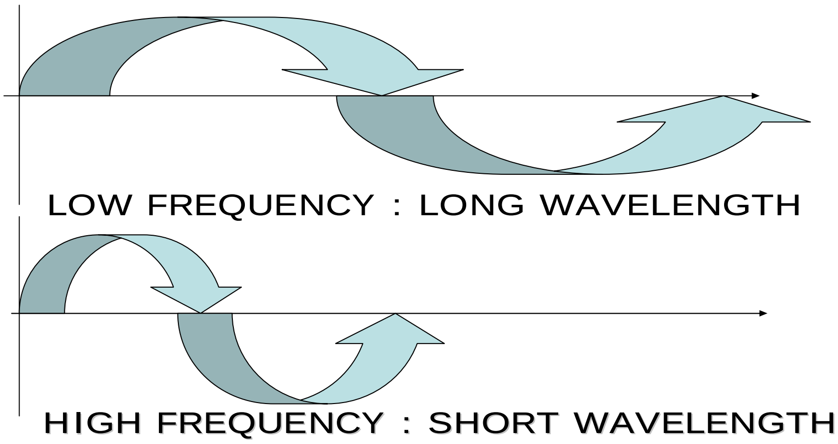
Cycle. One complete series of values.
Hertz. The number of cycles per second.
Amplitude. The maximum displacement from the mean.



Frequency. The number of cycles per second expressed in Hertz.

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

Wavelength. The distance travelled by a radio wave in one complete cycle.



WAVELENGTH-FREQUENCY RELATIONSHIP

For a transmission of frequency of 1 Hz, a wave will travel a distance of 300,000 kilometres. The relationship between frequency, wavelength and the speed of radio waves is as follows:

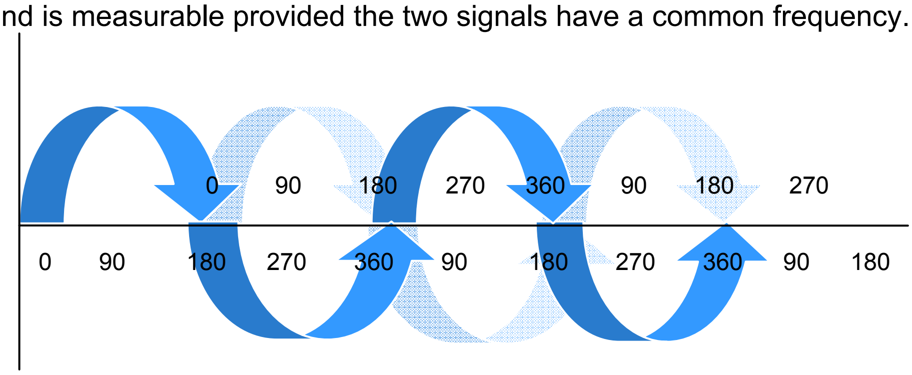
$$\text{WAVELENGTH} = \frac{\text{SPEED OF RADIO WAVES}}{\text{FREQUENCY}}$$

$$\text{FREQUENCY} = \frac{\text{SPEED OF RADIO WAVES}}{\text{WAVELENGTH}}$$

PHASE AND PHASE DIFFERENCE

Phase defines a particular point in a cycle. If two alternating currents of the *same frequency* do not reach the same value at the same instant of time, they are out of phase.

The phase difference is the angular difference between the corresponding points on the waveform and is measurable provided the two signals have a common frequency.



THESE SIGNALS ARE 180° OUT OF PHASE

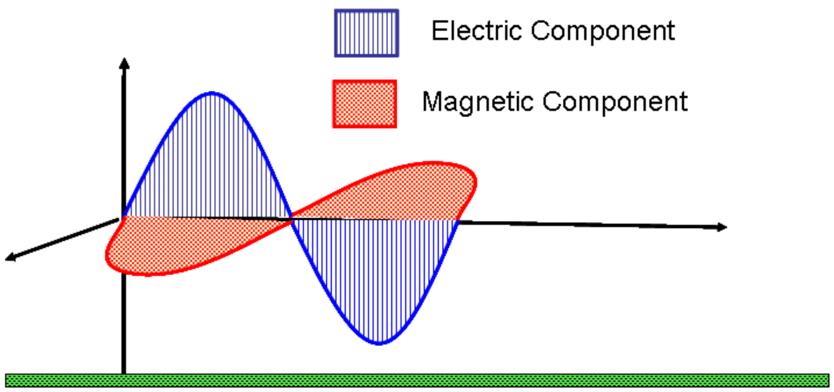
It is essential for the two signals to be on the same frequency if there is to be a fixed, measurable phase difference between them. The navigation aid VOR relies on phase difference at a common frequency to provide a position line. Phase difference can create problems when radio waves at the same frequency arrive at a receiving aerial. The voltage induced by one radio wave may be cancelled by an opposite voltage created by the other, resulting in fading or complete loss of the signal.

POLARISATION

The electrical and magnetic components of the radio wave travel at right angles to each other and in the direction of propagation. The plane of polarisation is taken from the plane of the electrical component.

VERTICAL POLARISATION

When the transmission is made from a vertical aerial, the electrical component travels in the vertical plane and the magnetic component in the horizontal plane. The radiation from a NDB is vertically polarised.

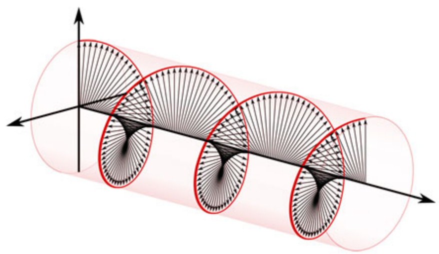


HORIZONTAL POLARISATION

When the transmission is made from a horizontal aerial, the electrical component travels in the horizontal plane and the magnetic component in the vertical plane. The radiation from VOR and ILS is horizontally polarised.

CIRCULAR POLARISATION

The electrical and magnetic components spin about the axis of advance at a rate equal to the frequency. This technique is used in reducing rain clutter in radar.



CHOICE OF POLARISATION

For communication in the bands up to VHF, vertical polarisation is preferred because horizontally polarised signals suffer severely from ground attenuation.

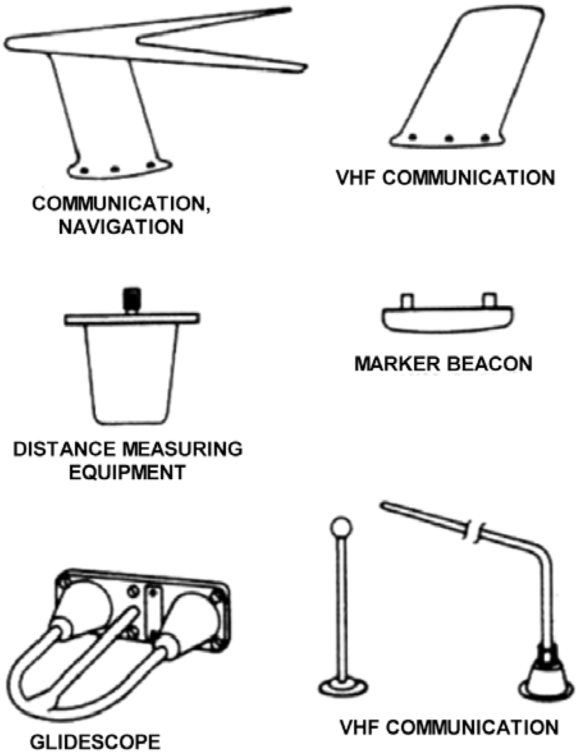
At VHF and above, either type of polarisation may be used. However in situations where reflections from the ground could generate space waves (see section 2) and cause problems due to phase difference, horizontal polarisation is preferred.

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 half as long as the wavelength it transmits or receives but if this is not possible, a fraction such as $^{1}/_{4}$ wavelength may be used. It is a general rule that antenna size relates to wavelength so for example, a radar operating on a higher frequency will be likely to have a smaller antenna.

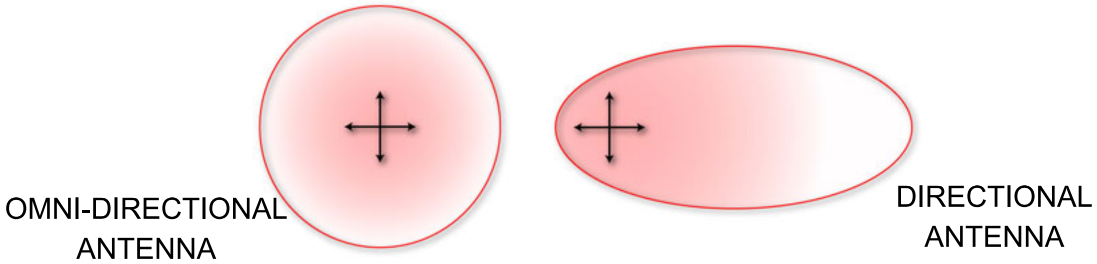
The orientation of antennas takes into account the polarisation of the radio waves which they are designed to receive or transmit. Transmissions from NDBs are vertically polarised whereas VOR and ILS Localizer signal are horizontally polarised and so their receiving antennas have the same orientation.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

The following diagram illustrates some antennas in common use:


COMMUNICATION,
NAVIGATION
VHF COMMUNICATION
DISTANCE MEASURING
EQUIPMENT
MARKER BEACON
GLIDESCOPE
VHF COMMUNICATION

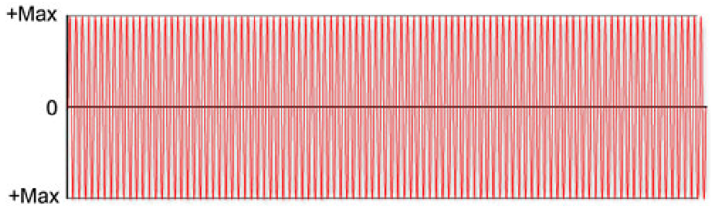
POLAR DIAGRAMS (ALSO KNOWN AS ANTENNA OR RADIATION DIAGRAMS)

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.



MODULATION

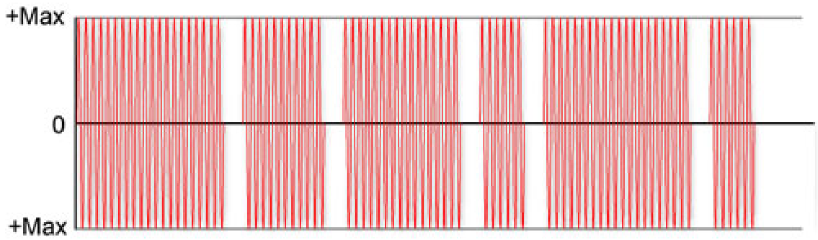
THE PURPOSE OF MODULATION



As radio waves simply act as a vehicle for information, they are called "carrier waves". Modulation is the process of impressing intelligence upon such a wave. Carrier waves may be changed to transmit information in the following ways:

KEYING

Keying consists of starting and stopping the continuous carrier wave so as to break it up in the form of dots and dashes. A radio navigation facility such as an NDB may break its carrier to identify itself by means of dots and dashes.



AMPLITUDE MODULATION

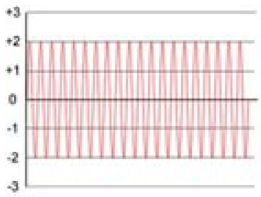
The amplitude of the carrier wave is varied in accordance with the amplitude of the audio modulating signal, keeping the carrier's frequency constant. When a signal is amplitude modulated, its resultant amplitude varies between the sum and difference of the amplitudes of the two waves.

Modulation depth is the extent to which a carrier is modulated and is expressed as a percentage.

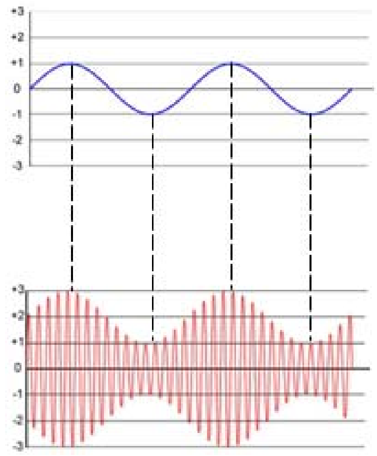
$$\frac{\text{AMPLITUDE OF THE AUDIO FREQUENCY}}{\text{AMPLITUDE OF THE CARRIER WAVE}} \quad \text{X} \quad 100$$

In practice, modulation is kept just below 100% as over-modulation causes distortion. Extra power is required to amplitude-modulate a carrier. For a given power output and all other conditions being equal, an amplitude-modulated signal will not travel as far as an unmodulated signal. To achieve the same range with an amplitude-modulated signal, approximately 50% more power will be required.

Broadcasters in the LF and MF bands as well as civil aviation in VHF RT employ amplitude modulation. To transmit coded information e.g. ident of a navigation facility, breaks must be made in the audio. This is done by either keying just the audio tone, or both the audio and the carrier.



Carrier Wave

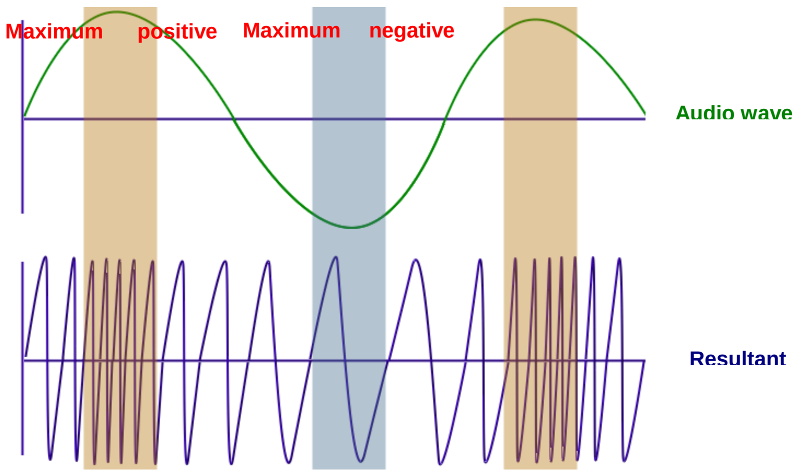


Audio Modulating Signal

Amplitude Modulating Signal

FREQUENCY MODULATION

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.



COMPARISON BETWEEN AM AND FM

Characteristics of the impressed intelligence	Type of Modulation	
	AM	**FM**
Loudness	Modulation Depth	Change of CW frequency
Pitch	Modulation Frequency	Rate of Change of CW frequency

Advantages of FM over AM:

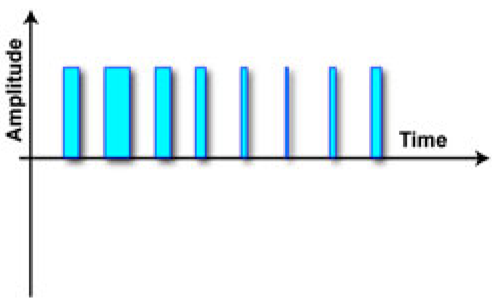
- FM transmitters are simpler and cheaper.
- Modulation power required is lower.
- Reception is practically static free due to operation in the VHF band.
- As the transmission is usually horizontally polarised, it suffers less from weather induced static which is vertically polarised.

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.

PULSE MODULATION

Pulse modulation is used in radar. The modulating pulses, in the simplest form, amplitude modulate the carrier giving it the shape of the pulses



Number of cycles in each pulse is equal to the frequency X the pulse length.

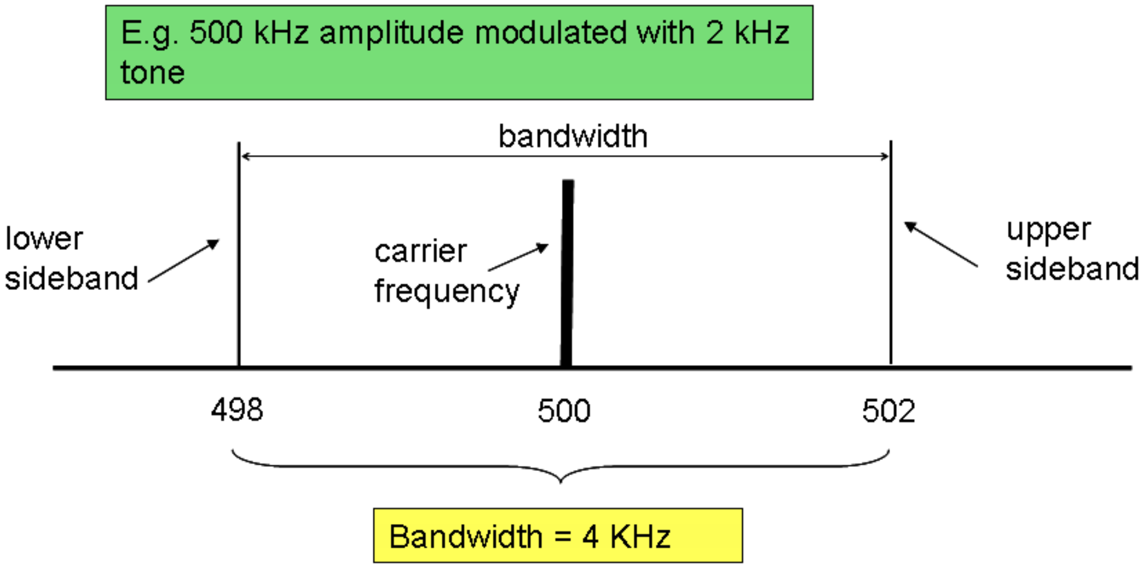
No of cycles = f x t

SIDEBANDS

Sidebands are additional frequencies which occur whenever a carrier is modulated by a frequency lower than itself. When the carrier is amplitude-modulated, two additional frequencies are created:

Carrier frequency
Carrier frequency + audio frequency
Carrier frequency - audio frequency

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



A carrier frequency of 500 kHz is amplitude-modulated by an audio tone of 2 kHz. The resultant side frequencies are 498kHz and 502 kHz resulting in a bandwidth of 4 kHz.

FM signals have multiple sidebands and have a greater bandwith. 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 transmissions, each sideband is a mirror image of the other and contains the same information. i.e. it is not possible to send different or additional information in the side bands.
With AM the range and clarity is less, but by transmitting only one sideband, power and bandwidth are saved.

DESIGNATION OF EMISSIONS

First Symbol - type of modulation of the main carrier

Examples

N	=	Unmodulated
A	=	Double sideband
H	=	Single sideband, full carrier
J	=	Single sideband, suppressed carrier
P	=	Unmodulated pulse transmission
F	=	Frequency modulated
G	=	Phase modulated
K	=	Amplitude modulated pulses

Second Symbol - nature of signal modulating the main carrier

Examples

0	=	Unmodulated CW
1	=	Unmodulated CW interrupted to give Morse
2	=	Modulated CW
3	=	Modulated CW for speech or music (AM)
8	=	Two or more channels containing analogue information
9	=	Composite system

Third Symbol - type of information transmitted

Examples

N	=	No information transmitted
A	=	Telegraphy for aural reception i.e. Morse code
B	=	Telegraphy for automatic reception
E	=	Telephony including sound broadcasting
D	=	Data transmission
W	=	Combination of above

Examples of Standard Emissions

NDB = NON A1A, NON A2A VHF R/T = A3E ILS = A8W

VOR = A9W HF SSB = J3E DME = PON

THE FREQUENCY SPECTRUM

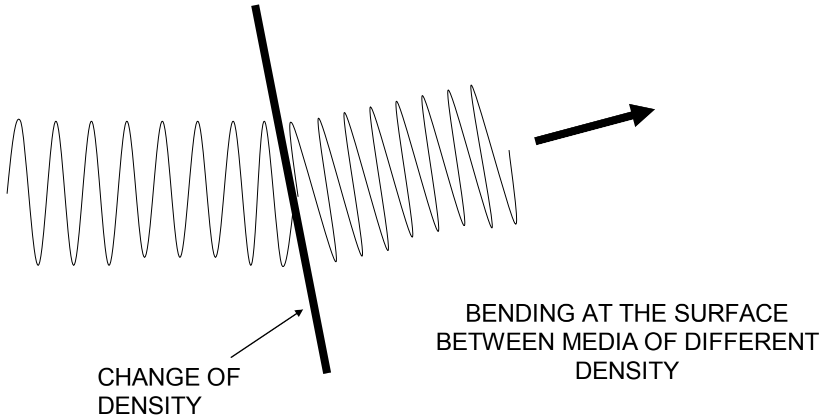
FREQUENCY BAND	ABBREV-IATION	FREQUENCY RANGE	WAVE-LENGTH	EXAMPLES OF USE
Very low	VLF	3-30 kHz	100-10 km	
Low	LF	30-300 kHz	10-1 km	NDB
Medium	MF	300-3000 kHz	1000-100 m	NDB
High	HF	3-30 MHz	100-10 m	HF R/T
Very High	VHF	30-300 MHz	10-1 m	VOR, ILS localiser, VHF R/T, ELT
Ultra High	UHF	300-3000 MHz	100-10 cm	DME, ILS GS, SSR, TCAS, GNSS
Super High	SHF	3-30 GHz	10-1 cm	ASR, AWR, Doppler, MLS, Radio Alt.
Extremely High	EHF	30-300 GHz	1-.1 cm	

RADAR FREQUENCY BANDS

RADAR BANDS	FREQUENCY RANGE	COMMENT
L	1-2 GHz	
S	2-4 GHz	
G	4-8 GHz	previously called C band
I	8-12.5 GHz	previously called X band

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 - 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.

ATMOSPHERIC REFRACTION - 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.

IONOSPHERIC REFRACTION - 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.

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 of temporary loss of signals.

DIFFRACTION

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.

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 are explained in later chapters:

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 pass. 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.

RADAR ATTENUATION

Radar attenuation is affected by water droplets which:

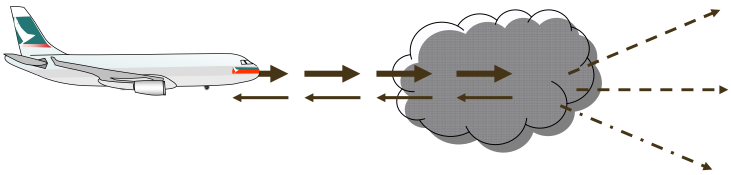
absorb and therefore attenuate the signal and

also reflect energy back to the radar receiver.

The shorter the wavelength the smaller the object that has the above effect.

At wavelengths below 0.5 cm (which is equivalent to a frequency of 60 GHz) radar is attenuated by atmospheric gases including water vapour.

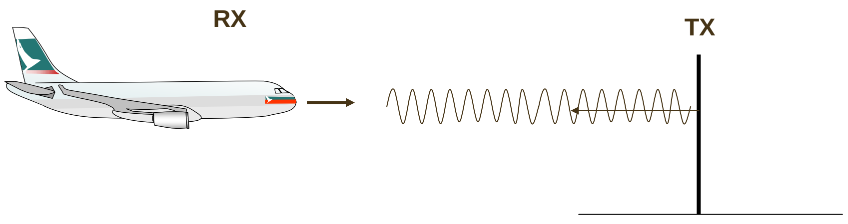
Remember the general rule: The higher the frequency the greater the attenuation.



WHEN RADAR ENERGY STRIKES WATER DROPLETS SOME ENERGY IS ABSORBED AND THEREFORE ATTENUATED

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 reduced, more radio waves arrive at the RX in unit time so the received frequency is greater than that transmitted. Similarly, if the distance is increased the received frequency is lower.



An aircraft flying towards a transmitter will capture extra waves in each second with the result that the received frequency is higher than the transmitted frequency. The change of frequency is known as the Doppler shift.

The change in received frequency is illustrated by the following formulae:

$f_R = f_T + DS$ (distance reducing between transmitter and receiver)

$f_R = f_T - DS$ (distance increasing between transmitter and receiver)

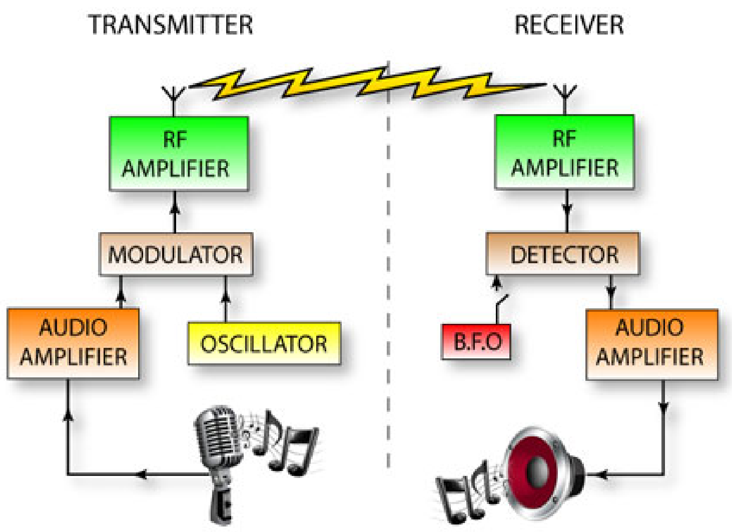
f_R = Frequency received

f_T = Frequency transmitted

DS = Doppler shift (Velocity/Wavelength i.e. V/λ)

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.

WORKSHEET – BASIC PRINCIPLES

1. A frequency of 2100 kHz lies in the _______ band and the corresponding wavelength is approximately ______.

   (a) HF / 14 metres
   (b) MF / 140 metres
   (c) HF / 140 metres
   (d) MF / 14 metres

2. For a constant phase difference to exist between two signals they must...........

   (a) both be amplitude modulated.
   (b) have the same amplitude.
   (c) both be frequency modulated.
   (d) have the same frequency.

3. A horizontally polarised radio wave has its magnetic component in the ______ plane and will be most effectively received by an antenna with a _____ orientation.

   (a) vertical / vertical
   (b) vertical / horizontal
   (c) horizontal / vertical
   (d) horizontal / horizontal

4. Frequency modulation, when compared with amplitude modulation, requires a _______ transmitter and _________ modulating power.

   (a) simpler / lower
   (b) more complex / higher
   (c) more complex / lower
   (d) simpler / higher

5. The term 'sideband' is used when referring to _______ and describes the additional ______ which occur when the carrier is modulated.

   (a) frequency modulation only / frequencies
   (b) amplitude modulation only / amplitudes
   (c) amplitude and frequency modulation / amplitudes
   (d) amplitude and frequency modulation / frequencies

6. Frequency modulation, when compared with amplitude modulation, requires a _________ receiver and the receiver needs a _______ passband.

   (a) simpler / wider
   (b) more complex / narrower
   (c) simpler / narrower
   (d) more complex / wider

7. The ICAO designator J3E refers to _______ which is a form of transmission that is ______modulated.

   (a) HF R/T Amplitude
   (b) HF R/T Frequency
   (c) VHF R/T Amplitude
   (d) VHF R/T Frequency

8. When a receiver is moving towards a stationary transmitter, at the receiver there will be .... as a result of Doppler effect.

   (a) a reduction in wavelength but no change in frequency
   (b) an increase in amplitude and frequency
   (c) a decrease in frequency and wavelength
   (d) an increase in frequency but no change in wavelength

9. At low frequencies an increase in wavelength will cause diffraction to _______ and surface attenuation to ________.

   (a) increase increase
   (b) decrease increase
   (c) decrease decrease
   (d) increase decrease

10. With frequency modulation, the amount of frequency deviation above and below the nominal carrier frequency depends on the ________ of the modulating audio wave. FM emissions have a _________ bandwidth than corresponding AM emissions.

   (a) amplitude narrower
   (b) amplitude broader
   (c) frequency narrower
   (d) frequency broader

11. Which of the following are characteristics of Single Sideband (SSB) transmissions when compared with Double Sideband?

    (i) Economy in the power requirements
    (ii) Multiple messages may be carried
    (iii) Bandwidth is effectively halved

    (a) All are true
    (b) Only (i) is true
    (c) Only (i) and (iii) are true
    (d) Only (ii) and (iii) are true