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RADIO NAVIGATION

ATPL GROUND TRAINING SERIES

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Introduction

Chapter

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Properties of Radio Waves

1 Properties of Radio Waves

Introduction

Radio and radar systems are now an integral and essential part of aviation, without which the current intensity of air transport operations would be unsustainable. In the early days of aviation aircraft were flown with visual reference to the ground and flight at night, in cloud or over the sea was not possible. As the complexity of aircraft increased it became necessary to design navigational systems to permit aircraft to operate without reference to terrain features.

The early systems developed were, by modern standards very basic and inaccurate. They provided reasonable navigational accuracy for en route flight over land, but only a very limited service over the oceans, and, until about 40 years ago, flight over the oceans used the traditional seafarer's techniques of astro-navigation, that is using sights taken on the sun, moon, stars and planets to determine position. Developments commenced in the 1910s, continued at an increasing rate during the 1930s and 1940s and up to the present day leading to the development of long range systems which by the 1970s were providing a global navigation service.

It is perhaps ironic that, having forsaken navigation by the stars, the most widely used navigation systems in the last few years are once again space based, that is the satellite navigation systems we now take as being the norm. Whilst global satellite navigation systems (GNSS) are becoming the standard in aviation and many advocate that they will replace totally all the terrestrial systems, the ICAO view is that certain terrestrial systems will have to be retained to back up GNSS both for en route navigation and runway approaches.

The development of radar in the 1930s allowed air traffic control systems to be developed providing a control service capable of identifying and monitoring aircraft such that aircraft operations can be safely carried out at a much higher intensity than would be otherwise possible. Modern satellite technology is being used to provide a similar service over oceans and land areas where the provision of normal radar systems is not possible.

The Radio Navigation Syllabus

The syllabus starts by looking at the nature of radio waves and how they travel through the atmosphere. This is essential to understand why different radio frequencies are selected for particular applications and also the limitations imposed. The introductory chapters also cover how radio waves are produced, transmitted, received and how information is added to and recovered from radio waves.

Electromagnetic (EM) Radiation

If a direct electric current (DC) is passed through a wire then a magnetic field is generated around the wire perpendicular to the current flow.

If an alternating electric current (AC) is passed through the wire then, because the direction of current flow is changing, the polarity of the magnetic field will also change, reversing polarity as the current direction reverses. At low frequencies the magnetic field will return to zero with the current, but as frequency increases the magnetic field will not have collapsed completely before the reversed field starts to establish itself and energy will start to travel outwards from the wire in the form of electromagnetic radiation i.e. radio waves.

The resulting EM energy is made up of two components, an electrical (E) field parallel to the wire and a magnetic (H) field perpendicular to the wire.

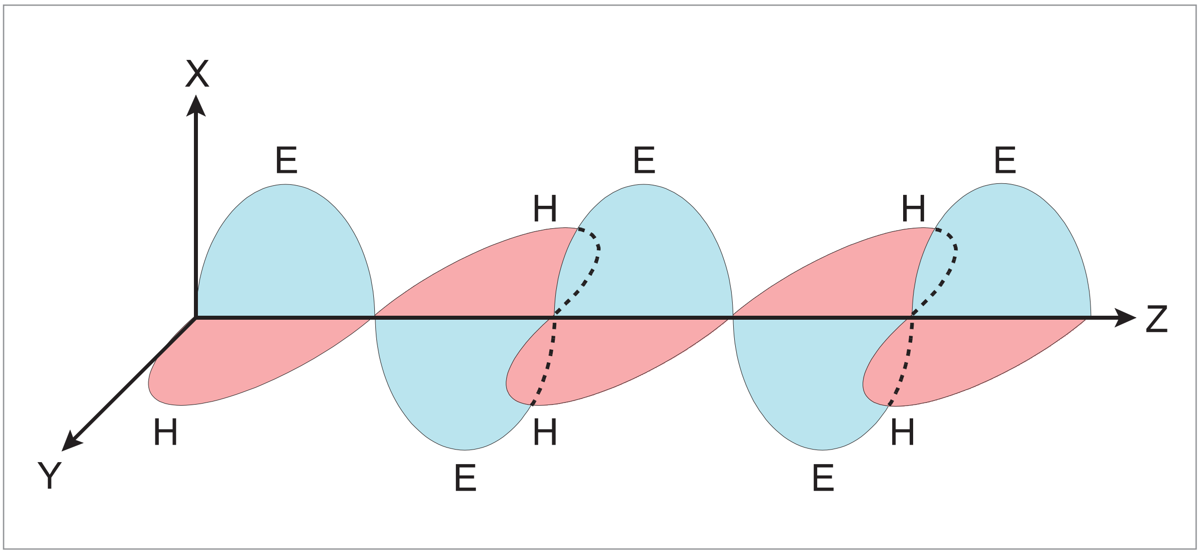


Figure 1.1 Vertical polarization

Polarization

The polarization of radio waves is defined as the plane of the electric field and is dependent on the plane of the aerial. A vertical aerial will emit radio waves with the electrical field in the vertical plane and hence produce a vertically polarized wave, and a horizontal aerial will produce a horizontally polarized wave.

To receive maximum signal strength from an incoming radio wave it is essential the receiving aerial is in the same plane as the polarization of the wave, so a vertically polarized radio wave would require a vertical aerial.

Circular polarization can be produced in a variety of ways, one of which is using a helical antenna. In circular polarization the electrical (and hence magnetic) field rotates at the frequency of the radio wave. The rotation may be right handed or left handed dependent on the orientation of the aerial array.

For reception of a circularly polarized wave an aerial of the same orientation is required, or a simple dipole aerial. There are two significant advantages. Firstly in radar systems, if circular polarization is used, when the energy is reflected from water droplets the circularity is reversed and therefore the 'clutter' caused by precipitation can be eliminated. Secondly, if a dipole aerial is used the orientation of the aerial is no longer critical, as it is with linear polarization, and, clearly, this will be a major advantage in mobile systems, such as cellular phones and satellite communication and navigation systems.

Radio Waves

The length of time it takes to generate one cycle of a radio wave is known as the period and is generally signified by the Greek letter tau (τ), and measured in microseconds (μs). (1 μs = 10^{-6} second).

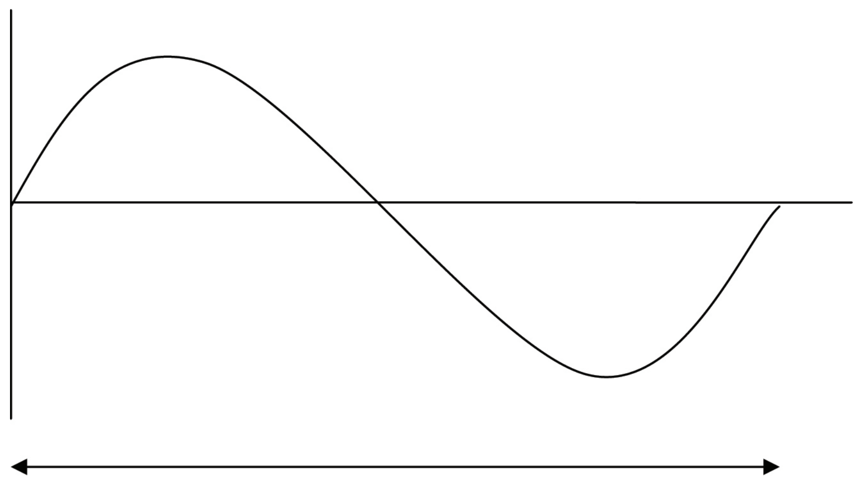


Figure 1.2 Sinusoidal wave - period

If, for example, the period of one cycle of a radio wave is 0.125 μs then the number of cycles produced in one second would be the reciprocal of this giving:

$$\frac{1}{\tau} = \frac{1}{0.125 \times 10^{-6}} = 8\,000\,000$$ cycles per second which are known as hertz (Hz)

This is known as the frequency (*f*) of the wave; hence:

$$f = \frac{1}{\tau} \qquad (1)$$

The frequency of radio waves is expressed in hertz (Hz). Since the order of magnitude of the frequency of radio waves is very high, for convenience, the following terms are used to express the frequency:

Kilohertz (kHz)	=	10^3 Hz	=	1 000 Hz
Megahertz (MHz)	=	10^6 Hz	=	1 000 000 Hz
Gigahertz (GHz)	=	10^9 Hz	=	1 000 000 000 Hz

So in the example above the frequency would be expressed as 8 MHz.

Wavelength

The speed of radio waves (c) is the same as the speed of light (which is also EM radiation) and is approximately:

300 000 000 ms^{-1} (= 300 × 10^6 ms^{-1}), or 162 000 nautical miles per second

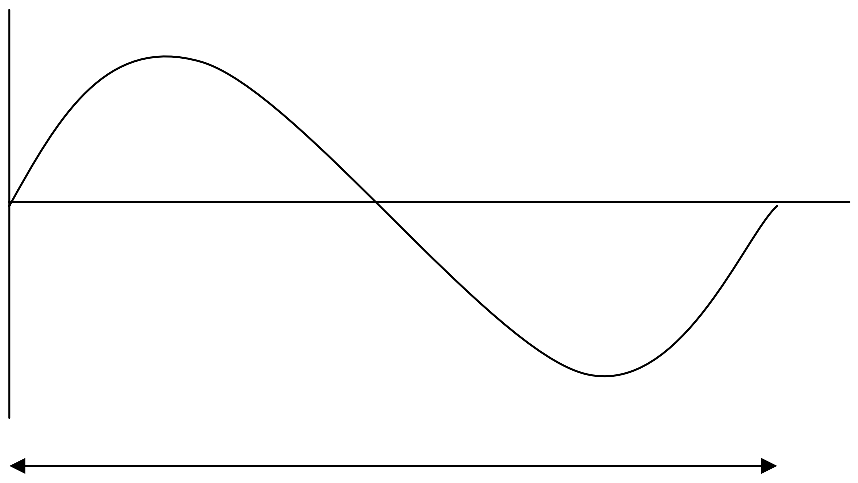


Figure 1.3 Sinusoidal wave - wavelength

If a radio wave travels at 300 × 10^6 ms^{-1} and the period is 0.125 μs, then the length (λ) of each wave will be:

$$\lambda = c.\tau \qquad (2)$$

$$300 \times 10^6 \times 0.125 \times 10^{-6} = 37.5 \text{ m}$$

This is known as the wavelength. From equation (1) this can also be stated as:

$$\lambda = \frac{c}{f} \qquad (3)$$

Giving:

$$\lambda = \frac{300 \times 10^6}{8 \times 10^6} = 37.5 \text{ m}$$

Hence if the frequency is known then the wavelength can be determined and if the wavelength is known then the frequency can be calculated from:

$$f = \frac{c}{\lambda} \qquad (4)$$

Examples:

1. If the frequency of a radio wave is 121.5 MHz calculate the wavelength.

$$\lambda = \frac{c}{f} = \frac{300 \times 10^6}{121.5 \times 10^6} = 2.47 \text{ m}$$

2. If the wavelength is 1515 m, what is the corresponding frequency?

$$f = \frac{c}{\lambda} = \frac{300 \times 10^6}{1515} = 198\,000 \text{ Hz} = 198 \times 10^3 \text{ Hz} = 198 \text{ kHz}$$

For ease of calculation we can simplify the formulae:

$$f = \frac{300}{\lambda\ \mathbf{(m)}}\ \mathbf{MHz}$$

$$\lambda = \frac{300}{f\ \mathbf{(MHz)}}\ \mathbf{m}$$

But we must ensure that our input arguments are correct, i.e. to calculate the frequency the wavelength must be in metres and to calculate the wavelength the frequency must be input in MHz.

Examples:

3. Determine the frequency corresponding to a wavelength of 3.2 cm.

Noting that 3.2 cm = 0.032 m the calculation becomes:

$$f = \frac{300}{0.032} = 9375 \text{ MHz } \mathbf{(or}\ 9.375 \text{ GHz}\mathbf{)}$$

4. Determine the wavelength corresponding to a frequency of 357 kHz.

Noting that 375 kHz = 0.375 MHz the calculation is:

$$\lambda = \frac{300}{0.375} = 800 \text{ m}$$

Frequency Bands

The radio part of the electromagnetic spectrum extends from 3 kHz to 300 GHz. For convenience it is divided into 8 frequency bands. These are shown below with the frequencies, wavelengths and the uses made of the frequency bands in civil aviation. Note that each frequency band is related to its neighbouring band(s) by a factor of 10.

Frequency Band	Frequencies	Wavelengths	Civil Aeronautical Usage
Very Low Frequency (VLF)	3 – 30 kHz	100 – 10 km	Nil
Low Frequency (LF)	30 – 300 kHz	10 – 1 km	NDB/ADF
Medium Frequency (MF)	300 – 3000 kHz	1000 – 100 m	NDB/ADF, long range communications
High Frequency (HF)	3 – 30 MHz	100 – 10 m	long range communications
Very High Frequency (VHF)	30 – 300 MHz	10 – 1 m	Short range communication, VDF, VOR, ILS localizer, marker beacons
Ultra High Frequency (UHF)	300 – 3000 MHz	100 – 10 cm	ILS glide path, DME, SSR, Satellite communications, GNSS, long range radars
Super High Frequency (SHF)	3 – 30 GHz	10 – 1 cm	RADALT, AWR, MLS, short range radars
Extremely High Frequency (EHF)	30 – 300 GHz	10 – 1 mm	Nil

Phase Comparison

Some radio navigation systems use the comparison of phase between two signals to define navigational information. The first important point is that the two signals being compared must have the same frequency, otherwise any phase comparison would be meaningless. The second point is that one signal will be designated the reference signal and the other a variable signal and that the comparison must yield a positive result.

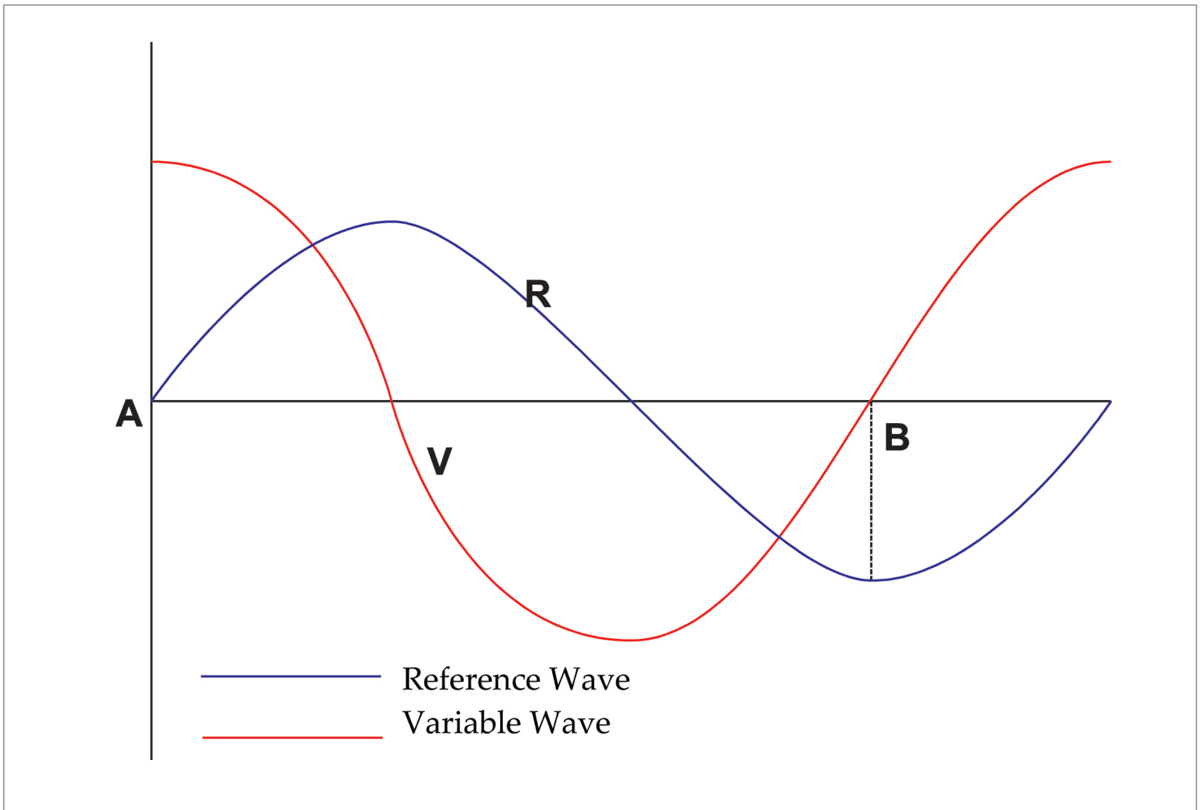


Figure 1.4 Sinusoidal wave - phase comparison

To determine the phase difference between 2 signals, first identify the position of (for example) zero phase on each of the waves, then move in the positive direction from the chosen point on the reference wave to measure the phase angle through which the reference wave has travelled before zero phase is reached on the variable wave.

In this example, starting at zero phase on the reference wave (point A), we observe that the reference wave has travelled through a phase angle of 270° before zero phase is reached on the variable wave (point B), hence the phase difference is 270°.

The relationship can also be found mathematically. At the origin the phase of the reference wave is 0° (= 360°) and the phase of the variable wave is 090°. Subtracting the instantaneous phase of the variable wave from the instantaneous phase of the reference wave gives the same result, note the result must always be positive.

Reference – variable = 360° – 90° = 270°

Note: The phase difference must be positive, so if the calculation yields a negative result simply add 360° to get a positive answer.

Practice Frequency (*f*) - Wavelength (λ) Conversions

In each of the following examples, calculate the frequency or wavelength as appropriate and determine in which frequency band each of the frequencies lies.

	Wavelength	Frequency	Frequency Band
1		198 kHz	
2	2.7 m		
3		5.025 GHz	
4	137.5 m		
5		137.5 MHz	
6	3 km		
7		329 MHz	
8	29 cm		
9		500 kHz	
10	5 cm		

Answers to Practice Frequency (*f*) - Wavelength (λ) Conversions

	Wavelength	Frequency	Frequency Band
1	**1515 m**	198 kHz	**LF**
2	2.7 m	**111.1 MHz**	**VHF**
3	**5.97 cm**	5.025 GHz	**SHF**
4	137.5 m	**2181.8 kHz**	**MF**
5	**2.18 m**	137.5 MHz	**VHF**
6	3 km	**100 kHz**	**LF**
7	**91.2 cm**	329 MHz	**UHF**
8	29 cm	**1034 MHz**	**UHF**
9	**600 m**	500 kHz	**MF**
10	5 cm	**6 GHz**	**SHF**

Questions

1. **A radio wave is:**

a. an energy wave comprising an electrical field in the same plane as a magnetic field
b. an electrical field alternating with a magnetic field
c. an energy wave where there is an electrical field perpendicular to a magnetic field
d. an energy field with an electrical component

2. **The speed of radio waves is:**

a. 300 km per second
b. 300 million metres per second
c. 162 NM per second
d. 162 million NM per second

3. **The plane of polarization of an electromagnetic wave is:**

a. the plane of the magnetic field
b. the plane of the electrical field
c. the plane of the electrical or magnetic field dependent on the plane of the aerial
d. none of the above

4. **If the wavelength of a radio wave is 3.75 metres, the frequency is:**

a. 80 kHz
b. 8 MHz
c. 80 MHz
d. 800 kHz

5. **The wavelength corresponding to a frequency of 125 MHz is:**

a. 2.4 m
b. 24 m
c. 24 cm
d. 24 mm

6. **The frequency which corresponds to a wavelength of 6.98 cm is:**

a. 4298 GHz
b. 4.298 GHz
c. 429.8 GHz
d. 42.98 GHz

7. **The frequency band containing the frequency corresponding to 29.1 cm is:**

a. HF
b. VHF
c. SHF
d. UHF

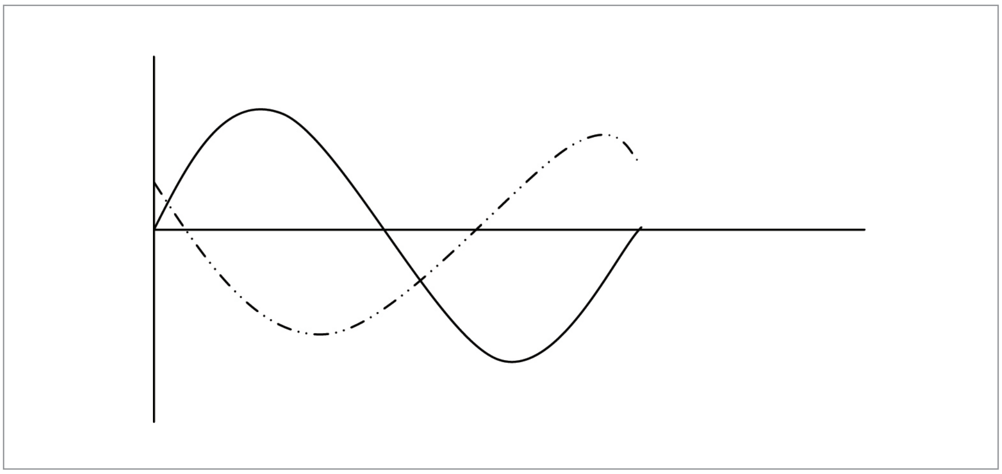
8. **To carry out a phase comparison between two electromagnetic waves:**

a. both waves must have the same amplitude
b. both waves must have the same frequency
c. both waves must have the same amplitude and frequency
d. both waves must have the same phase

9. **The phase of the reference wave is 110° as the phase of the variable wave is 315°. What is the phase difference?**

a. 205°
b. 025°
c. 155°
d. 335°

10. **Determine the approximate phase difference between the reference wave and the variable wave:**
(The reference wave is the solid line and the variable wave is the dashed line)



a. 045°
b. 135°
c. 225°
d. 315°

11. **The wavelength corresponding to a frequency of 15 625 MHz is:**

a. 1.92 m
b. 19.2 m
c. 1.92 cm
d. 19.2 cm

12. **Which frequency band is a wavelength of 1200 m?**

a. UHF
b. LF
c. HF
d. MF

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	b	b	c	a	b	d	b	c	c	c	b

Chapter

2

Radio Propagation Theory

Introduction

In the context of radio waves the term propagation simply means how the radio waves travel through the atmosphere. Different frequency bands use different propagation paths through the atmosphere; the propagation path often determines the uses to which a particular frequency band can be put in either communication or navigation systems. The different propagation paths associated with particular frequencies can also impose limitations on the use of those frequencies.

Factors Affecting Propagation

There are several factors which affect the propagation of radio waves and need to be considered when discussing the propagation paths:

Attenuation

Attenuation is the term given to the loss of signal strength in a radio wave as it travels outward from the transmitter. There are two aspects to attenuation:

Absorption

As the radio wave travels outwards from a transmitter the energy is absorbed and scattered by the molecules of air and water vapour, dust particles, water droplets, vegetation, the surface of the earth and the ionosphere. The effect of this absorption, (except ionospheric) increases as frequency increases and is a very significant factor above about 1000 MHz.

Inverse Square Law

The EM radiation from an aerial spreads out as the surface of a sphere so the power available decreases with increasing distance from the transmitter. For example, if, at a certain distance from a transmitter, the field intensity is 4 Wm^{-2} at double the distance that energy will be spread over an area of 4 m^2 and the field intensity will be 1 Wm^{-2}. That is, power available is proportional to the inverse of the square of the range.

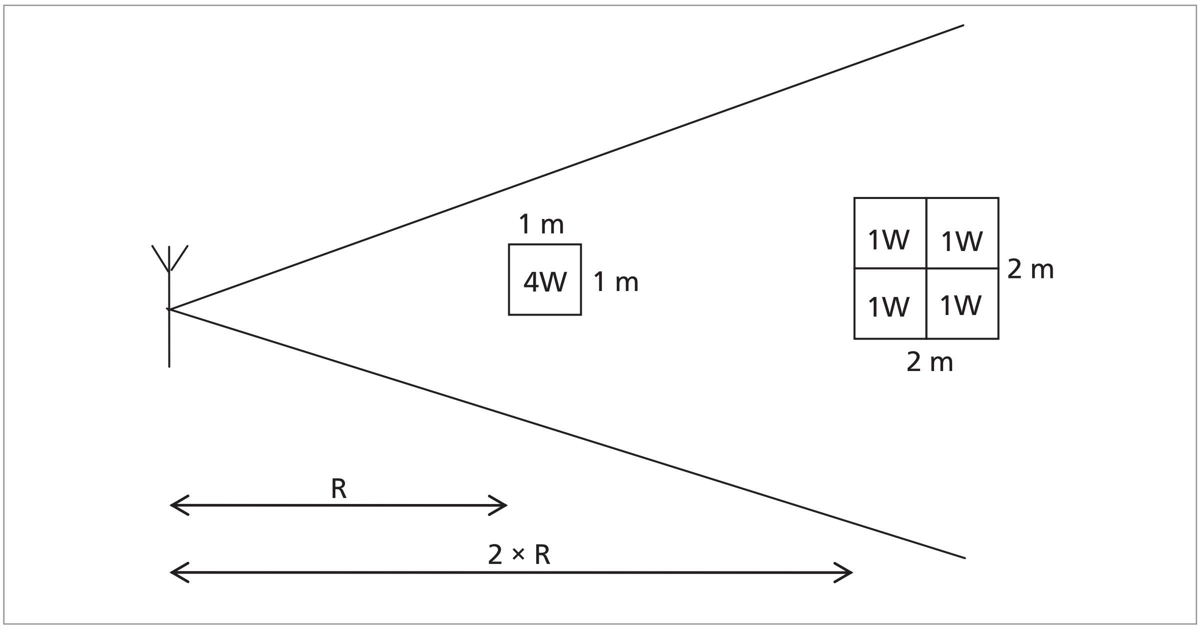


Figure 2.1 Inverse Square Law

$$P \propto \frac{1}{R^2}$$

The practical effect of this is that if it is required to double the effective range of a transmitter then the power would have to be increased by a factor of 4.

Static Interference

There is a large amount of static electricity generated in the atmosphere by weather, human activity and geological activity. The effect of static interference is greater at lower frequencies whereas at VHF and above the effect of interference is generally negligible. However, radio waves travelling through the ionosphere will collect interference at all frequencies. Additionally the circuitry in the receivers and transmitters also produces static interference. The static, from whatever source, reduces the clarity of communications and the accuracy of navigation systems. The strength of the required signal compared to the amount of interference is expressed as a signal to noise ratio (S/N) and for the best clarity or accuracy the unwanted noise needs to be reduced to the lowest possible levels.

Fading

Transmissions following different paths can occur for a number of reasons, e.g. reflections, and can arrive at a receiver simultaneously; however, the two signals will not necessarily be in phase. In extreme cases the two signals will be in anti-phase and will cancel each other out. Signals going in and out of phase are indicated by alternate fading and strengthening of the received signal.

Power

An increase in the power output of a transmitter will increase the range, within the limits of the inverse square law. As noted above, to double the range of a radio transmitter would require the power to be increased by a factor of 4.

Receiver Sensitivity

If internal noise in a receiver can be reduced then the receiver will be able to process weaker signals hence increasing the effective range at which a useable signal can be received. However, this is an expensive process.

Directivity

If the power output is concentrated into a narrow beam then there will be an increase in range, or a reduction in power required for a given range. However the signal will only be usable in the direction of the beam.

Propagation Paths

There are four propagation paths of which four need to be considered for aviation purposes:

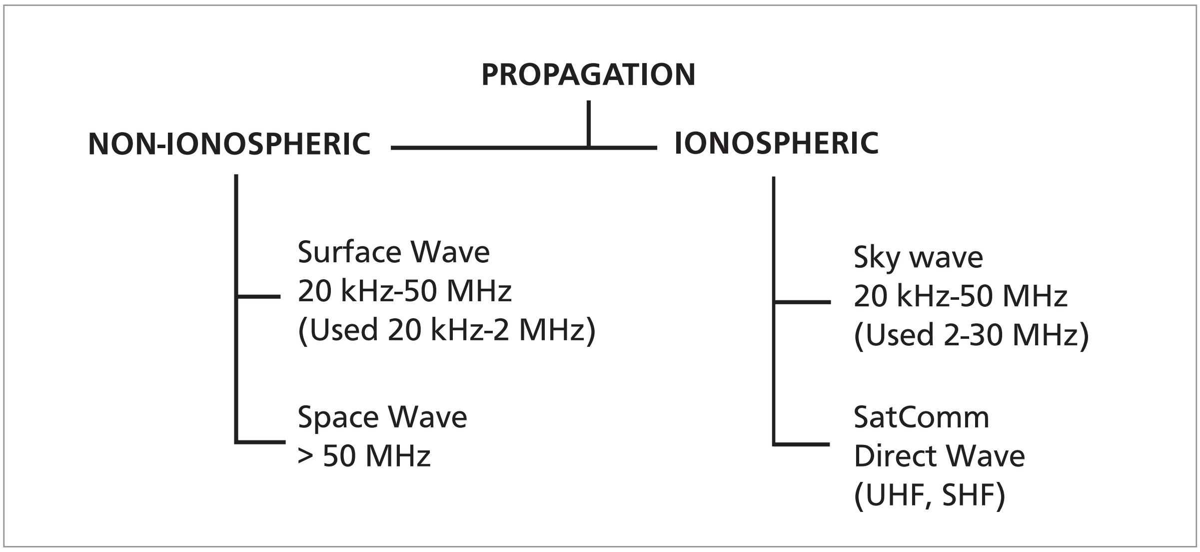


Figure 2.2

Ionospheric propagation is propagation affected by the properties of the ionosphere. At this stage it is only necessary to discuss sky wave, satellite propagation will be considered in conjunction with global navigation satellite systems (GNSS) in Chapter 18. Knowledge of propagation below 30 kHz is not required.

Non-ionospheric propagation covers the other propagation paths.

Non-ionospheric Propagation

Surface Wave

Surface wave propagation exists at frequencies from about 20 kHz to about 50 MHz (from the upper end of VLF to the lower end of VHF). The portion of the wave in contact with the surface of the earth is retarded causing the wave to bend round the surface of the earth; a process known as **diffraction**.

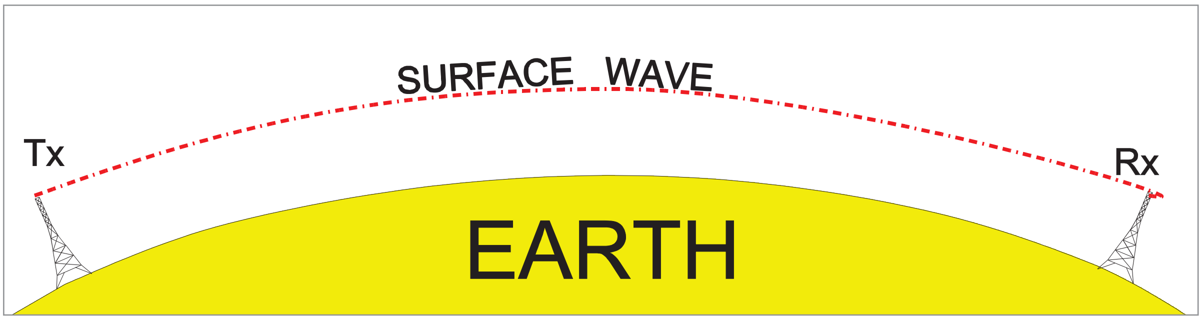


Figure 2.3 Surface Wave

The range achievable is dependent on several factors: the frequency, the surface over which the wave is travelling and the polarization of the wave. As the frequency increases, surface attenuation increases and the surface wave range decreases; it is effectively non-existent above HF.

The losses to attenuation by the surface of the earth are greater over land than over sea, because the sea has good electrical conductivity. Hence greater ranges are attainable over the sea. A horizontally polarized wave will be attenuated very quickly and give very short ranges; therefore, vertical polarization is generally used at these lower frequencies.

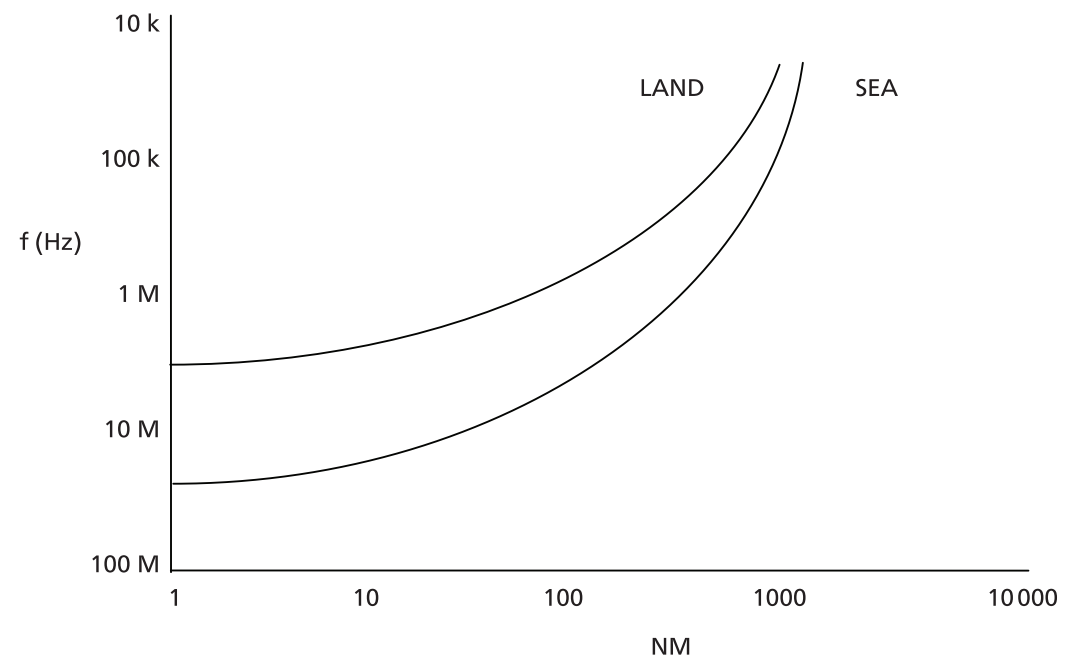


Figure 2.4

This is the primary propagation path used in the LF frequency band and the lower part of the MF frequency band (i.e. frequencies of **30 kHz to 2 MHz**).

An approximation to the useable range achievable over sea and land for an MF transmission at a frequency of 300 kHz is given by:

Sea: $\textbf{range} \approx 3 \times \sqrt{Power}$

Land: $\textbf{range} \approx 2 \times \sqrt{Power}$

So, for example, a 300 kHz transmitter with a power output of 10 kW would give a surface wave range of about 300 NM over the sea and 200 NM over the land.

Space Wave

The space wave is made up of two paths, a direct wave and a reflected wave.

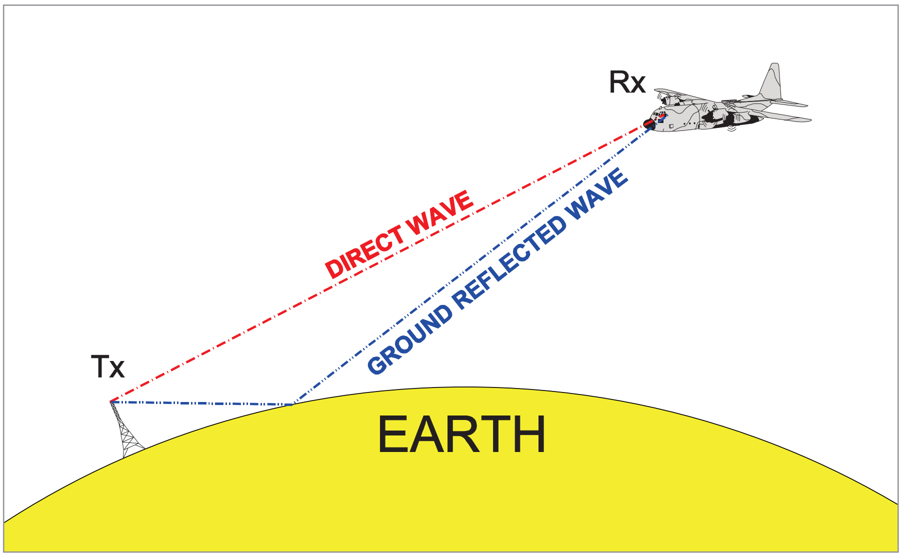


Figure 2.5 Space wave

At frequencies of VHF and above radio waves start to behave more like visible light and as we have a visual horizon with light we have a radio horizon with the radio frequencies. So the only atmospheric propagation at these frequencies is **line of sight**.

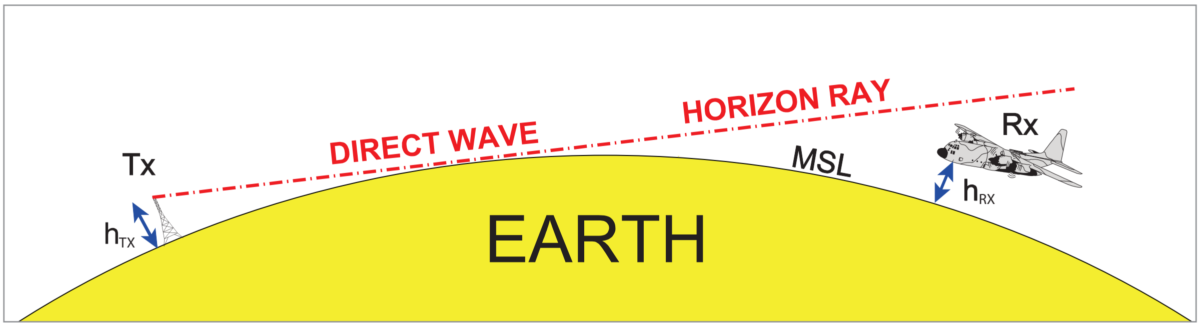


Figure 2.6 Maximum theoretical range

There is some **atmospheric refraction** which causes the radio waves to bend towards the surface of the earth increasing the range slightly beyond the geometric horizon. Since the diameter of the earth is known and the atmospheric refraction can be calculated it is possible to determine the maximum theoretical range at which a transmission can be received. The amount of refraction decreases as frequency increases but for practical purposes for the EASA syllabus the **line of sight** range can be calculated using the formula:

Range (NM) $= 1.23 \times (\sqrt{h_{TX}} + \sqrt{h_{RX}})$

h_{TX} : Transmitter height in feet

h_{RX} : Receiver height in feet

At VHF and above it does not matter how powerful the transmitter is, if the receiver is below the line of sight range, it will receive nothing.

For example:

What is the maximum range a receiver at 1600 ft can receive VHF transmissions from a transmitter at 1024 ft?

Range $= 1.23 \times (\sqrt{1600} + \sqrt{1024}) = 1.23 \times (40 + 32) = 88.6$ **NM**

Note 1: Regardless of the possible propagation paths, if a receiver is in line of sight with a transmitter, then the space wave will be received.

Ionospheric Propagation

Before studying ionospheric propagation it is necessary to know about the processes which produce the ionization in the upper atmosphere and the properties of the ionosphere that produce sky wave.

The Ionosphere

The ionosphere extends upwards from an altitude of about 60 km to limits of the atmosphere (notionally 1500 km). In this part of the atmosphere the pressures are very low (at 60 km the atmospheric pressure is 0.22 hPa) and hence the gaseous atoms are widely dispersed. Within this region incoming solar radiation at ultra-violet and shorter wavelengths interacts with the atoms raising their energy levels and causing electrons to be ejected from the shells of the atoms. Since an atom is electrically neutral, the result is negatively charged electrons and positively charged particles known as ions.

The electrons are continually attempting to reunite with the ions, so the highest levels of ionization will be found shortly after midday (about 1400) local time, when there is a balance between the ionization and the decay of the ionization with the electrons rejoining the ions and the lowest just before sunrise (at the surface). In summer the ionization levels will be higher than in winter, and ionization levels will increase as latitude decreases, again because of the increased intensity of the solar radiation.

Increased radiation from solar flares is unpredictable but can give rise to exceptionally high levels of ionization, which in turn can cause severe disruption of communication and navigation systems, particularly those which are space based. It is not unusual for communication (and other) satellites to be shut down during periods of intense solar flare activity to avoid damage.

As the incoming solar energy is absorbed by the gaseous atoms the amount of energy available to ionize the atoms at lower levels reduces and hence the levels of ionization increase with increase in altitude. However, because the normal atmospheric mixing processes associated with the lower levels of the atmosphere are absent in the higher levels, gravitation and terrestrial magnetism affect the distribution of gases. This means that the increase in ionization is not linear but the ionized particles form into discrete layers.

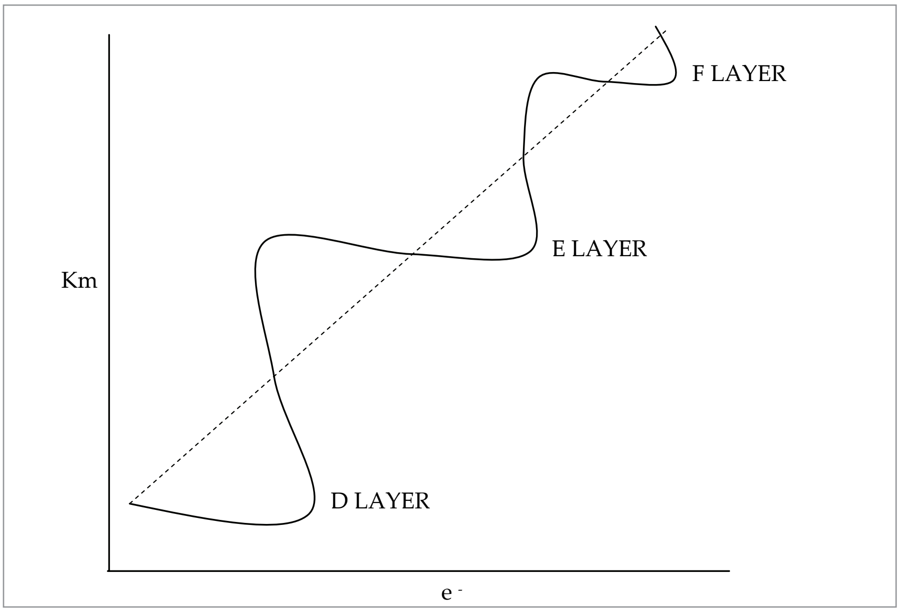


Figure 2.7 Effect of ionisation with height

The ionization is most intense at the centre of the layers decreasing towards the lower and upper edges of the layers. The characteristics of these layers vary with the levels of ionization. The lowest of these layers occurs at an average altitude of 75 km and is known as the **D-region** or **D-layer**. This is a fairly diffuse area which, for practical purposes, forms at sunrise and disappears at sunset. The next layer, at an average altitude of 125 km, is present throughout the 24 hours and is known as the **E-layer**. The E-layer reduces in altitude at sunrise and increases in altitude after sunset. The final layer of significance is the **F-layer** at an average altitude of 225 km. The F-layer splits into two at sunrise and rejoins at sunset, the F_1-layer reducing in altitude at sunrise and increasing in altitude after sunset. The behaviour of the F_2-layer is dependent on time of year, in summer it increases in altitude and may reach altitudes in excess of 400 km and in winter it reduces in altitude.

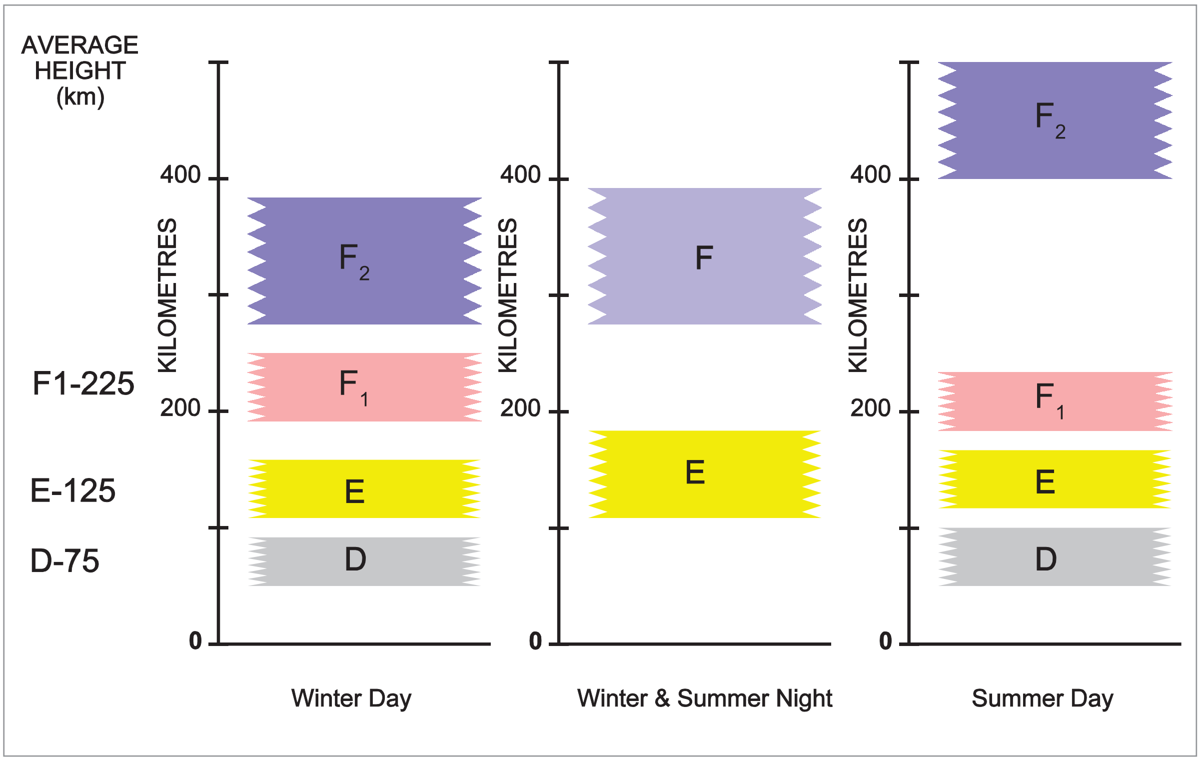


Figure 2.8 Layers of the ionosphere

Although, overall the levels of ionization increase from sunrise to midday local time and then decrease until sunrise the following morning, the levels are continually fluctuating as the intensity of high energy radiation from the sun fluctuates. So it would be possible for the ionization levels to decrease temporarily during the morning, or increase temporarily during the afternoon.

The structure of the ionosphere gives stable conditions by day and by night. Around dawn and dusk, however, the ionosphere is in a transitional state, which leads to what can best be described as electrical turbulence. The result is that around dawn and dusk, radio navigation and communication systems using the ionosphere are subject to excessive interference and disruption.

Sky Wave

The ionization levels in the layers increase towards the centre of the layer. This means that as a radio wave transits a layer it encounters an increasing density of ions as it moves to the centre of the layer and decreasing density as it moves out of the layer. If the radio waves travel across the layer at right angles they will be retarded, but will maintain a straight path. However, if the waves penetrate the layer at an angle they will be refracted away from the normal as they enter, then back towards the normal as they exit the layer.

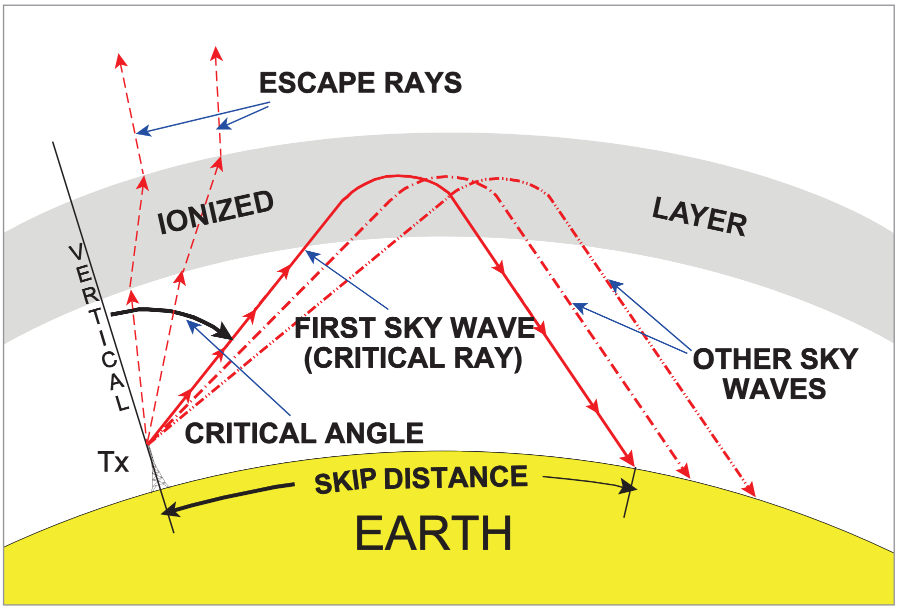


Figure 2.9 Sky wave propagation - critical angle

The amount of refraction experienced by the radio waves is dependent on both the frequency and the levels of ionization. If the radio wave refracts to the (earth) horizontal before it reaches the centre of the layer then it will continue to refract and will return to the surface of the earth as sky wave; this is total internal refraction at the layer.

Starting from the vertical at the transmitter, with a frequency which penetrates the ionosphere, as the angle between the vertical and the radio wave increases, an angle will be reached where total internal refraction occurs and the wave returns to the surface. This is known as the **first returning sky wave** and the angle (measured from the vertical) at which this occurs is known as the **critical angle.** The distance from the transmitter to the point where the first returning sky wave appears at the surface is known as the **skip distance**. As sky waves occur in the LF, MF and HF frequency bands there will also be some surface wave present. From the point where the surface wave is totally attenuated to the point where the first returning sky wave appears there will be no detectable signal, this area is known as **dead space**.

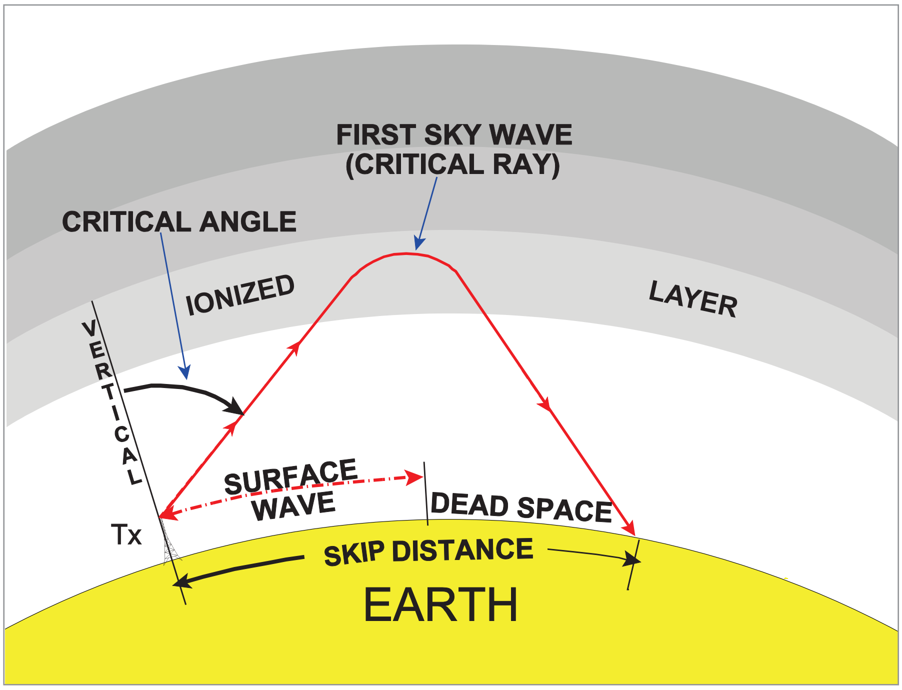


Figure 2.10 Sky wave propagation - dead space

The height at which full internal refraction occurs is dependent on frequency, but, as a generalization frequencies up to 2 MHz will be refracted at the E-layer and from 2 – 50 MHz at the F-layers. Sky wave is only likely to occur above 50 MHz when there are abnormal ionospheric conditions associated with intense sunspot or solar flare activity, therefore, VHF frequencies used for navigation systems do not produce sky waves.

Effect of Change in Ionization Intensity

Since the reason for the refraction is the ionization of the upper atmosphere it follows that if ionization intensity changes, then the amount of refraction of radio waves will also change. At a given frequency, as ionization **increases** the refractive index and hence the amount of refraction affecting the radio waves will also **increase**. This means that refraction will take place at a **smaller critical angle** and the **skip distance and dead space will decrease.** Conversely, a decrease in ionization will result in an increase in critical angle, skip distance and dead space.

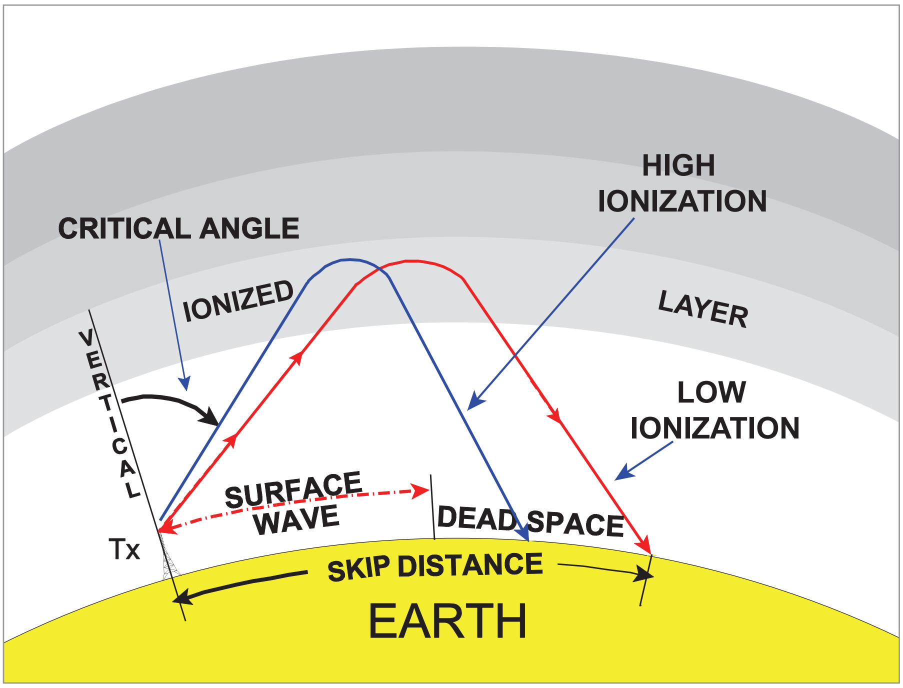


Figure 2.11 Sky wave propagation - effect of increased ionization

Effect of Change of Frequency

For a given ionization intensity, the amount of refraction of radio waves decreases as frequency increases, because as frequency increases the energy contained in the radio wave increases and therefore refraction decreases. So, as frequency increases, the critical angle will increase and the skip distance and dead space will also increase. As frequency increases, the surface wave range will decrease, so there is an increase in dead space caused by both the increase in skip distance and decrease in surface wave range. Conversely, a decrease in frequency will give a decrease in critical angle, skip distance and dead space.

Height of the Layers

The skip distance will also be affected by the altitude of the refracting layers. As the altitude of the layer increases then the skip distance will also increase and greater ranges will be experienced by refraction at the F-layer than the E-layer.

LF and MF Sky Wave Propagation

During the day the D-layer absorbs radio energy at frequencies below about 2 MHz (LF and MF bands). At night the D-layer is effectively non-existent so, at these frequencies, sky waves, refracted at the E-layer are present. This means the sky waves at LF and MF are not reliable for continuous long range use and the presence of sky waves at night at the relatively short ranges associated with these lower frequencies will cause interference with short range navigation (and broadcasting) systems relying on surface wave reception. This affects ADF and will be discussed in more detail in Chapter 7.

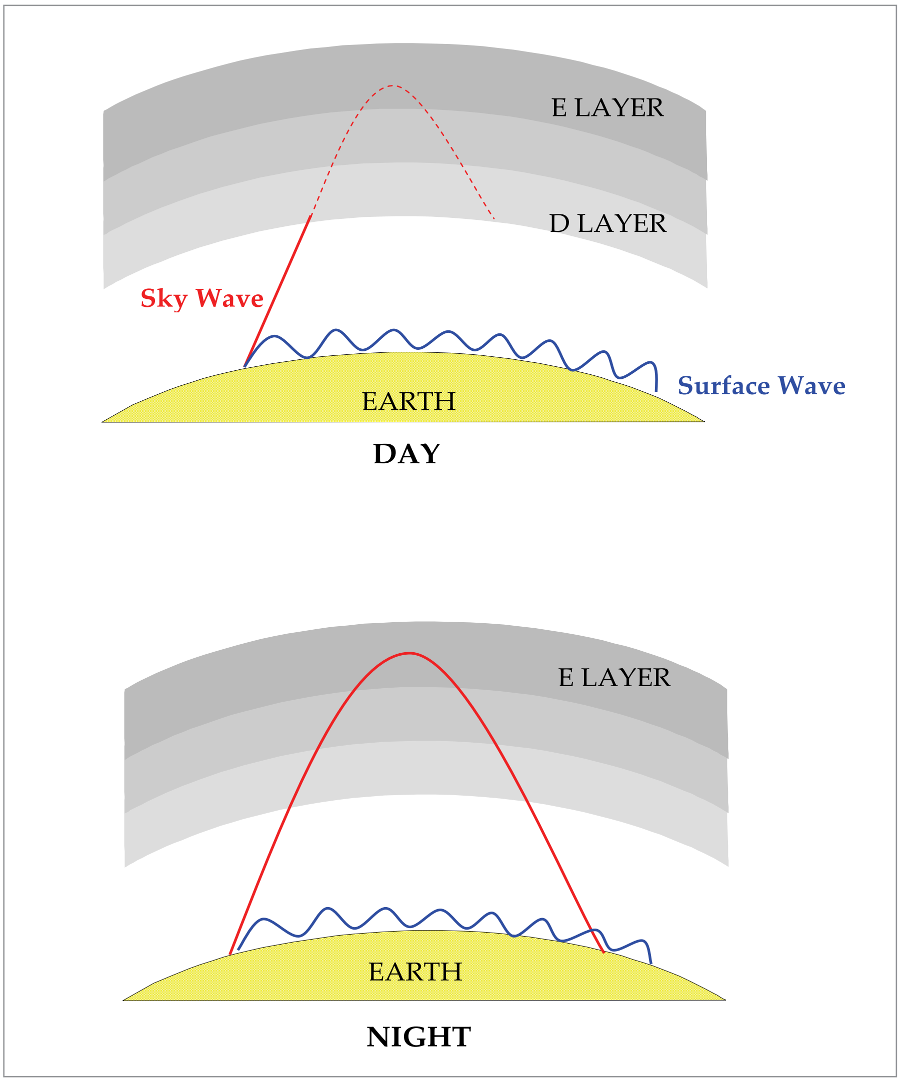


Figure 2.12 LF/MF Sky wave propagation

Achievable Ranges

The maximum range for sky wave will be achieved when the path of the radio wave is tangential at the surface of the earth at both the transmitter and receiver.

A simple calculation shows that the average maximum range for refraction from the E-layer at 125 km is 1350 NM, and the average maximum range from the F-layer at 225 km is 2200 NM. These ranges will obviously change as the height of the ionized layers changes.

Multi-hop sky wave occurs when the wave is refracted at the ionosphere then the sky wave is reflected back from the surface of the earth to the ionosphere etc. Multi-hop sky wave can achieve ranges of half the diameter of the earth.

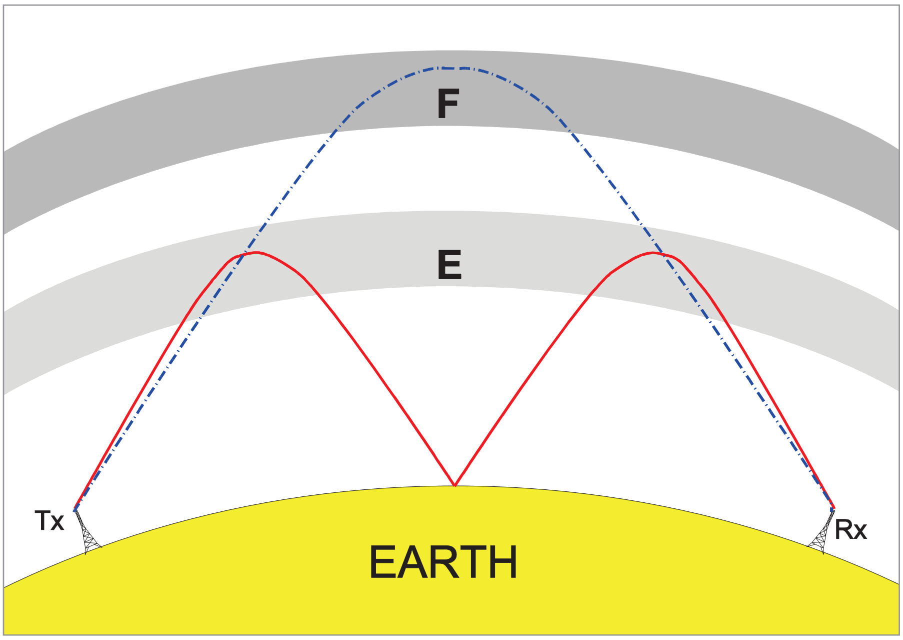


Figure 2.13 Multi-hop Sky wave propagation

HF Communications

Over inhabited land areas VHF communications are ideal for all communications between aircraft and ground. However, over oceans and uninhabited land areas, long range systems are required. Satellite Communications (SatCom) are not yet the norm, so long range communication must be provided by surface wave or sky wave propagation.

To achieve ranges of 2000 - 3000 NM using surface wave propagation would require low frequencies either from the lower end of LF band or the upper end of VLF band. Communication systems utilizing these frequencies would require relatively complex equipment with an associated weight penalty. Lower frequencies are also subject to greater static interference than higher frequencies, making such systems somewhat tedious to use. Furthermore, data rates associated with low frequencies are notoriously low.

Currently, therefore, the only practical solution is HF Communications utilizing sky wave propagation. In the future, no doubt, SatCom will become commonplace.

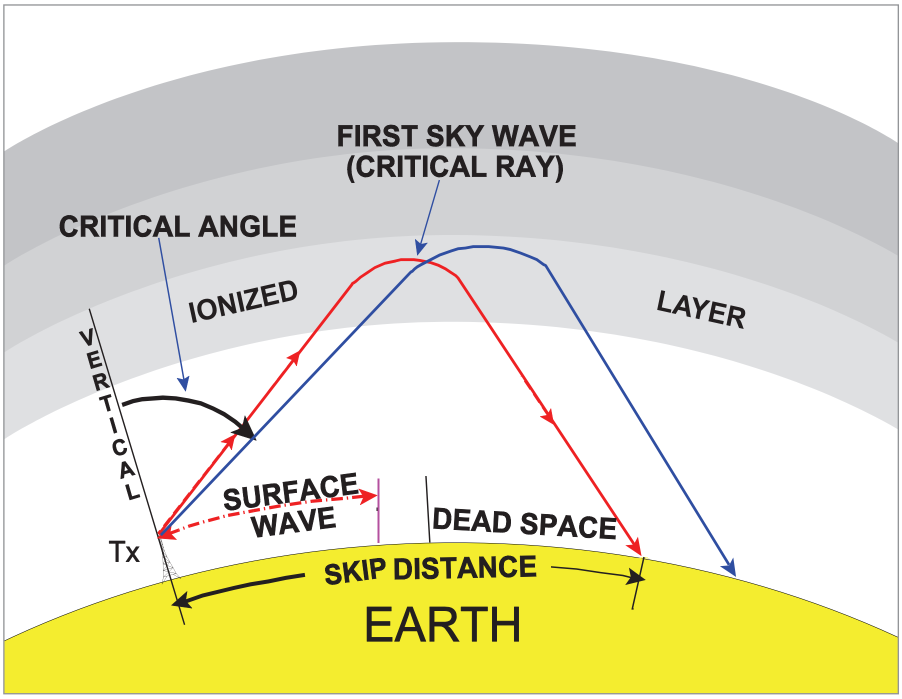


Figure 2.14

The maximum usable frequency (MUF) for a given range will be that of the first returning sky wave and this is the ideal frequency for that range because it will have had the shortest path through the ionosphere, and therefore, will have experienced less attenuation and contain less static interference. However, since the ionization intensity fluctuates, a decrease in ionization would result in an increase in skip distance and hence loss of signal. So a compromise frequency is used, known as the optimum working frequency (OWF), which by decades of experimentation and experience has been determined to be 0.85 times the MUF.

Since ionization levels are lower by night than by day it follows that the frequency required for use at a particular range by night will of necessity be less than the frequency required for use by day. A good rule of thumb is that the frequency required at night is roughly half that required by day.

Because skip distance increases as frequency increases, the range at which communication is required will also influence the selection of the frequency to be used. Short ranges will require lower frequencies and longer ranges will require higher frequency.

A typical example of the sort of problem that may appear is:

An aircraft on a flight from London, UK to New York, USA is in mid-Atlantic at sunrise.

The pilot is in communication with the UK on a frequency of 12 MHz.

What frequency can the pilot expect to use with the USA? (See *Figure 2.16*).

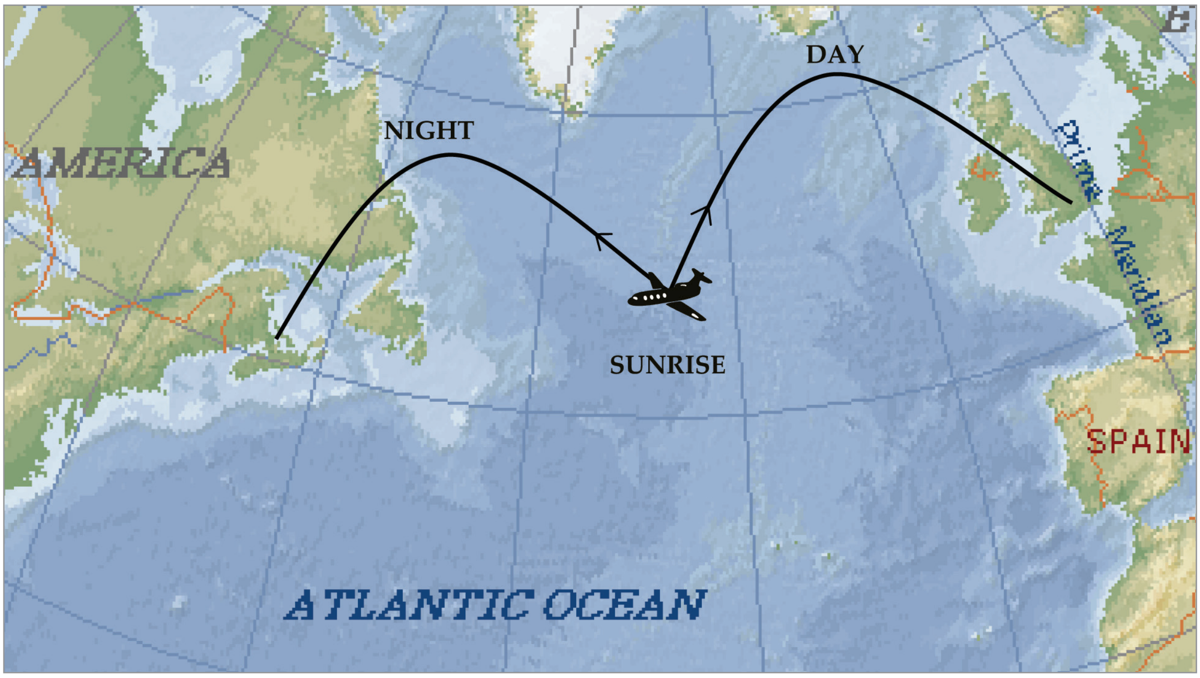


Figure 2.15 HF Communications Mid-Atlantic

Answer: 6 MHz.

The wave will be refracted halfway between the aircraft and the UK, and halfway between the aircraft and the USA. Midway between the aircraft and the UK it is day, so a relatively high frequency will be required. Midway between the aircraft and the USA it is night so a relatively low frequency will be required.

Propagation Summary

The propagation characteristics of each of the frequency bands are summarized below, where propagation paths are in brackets this indicates that the path is present but not normally utilised.

Frequency Band	Propagation Path
LF	Surface Wave (Sky Wave)
MF	Surface Wave (Sky Wave)
HF	Sky Wave (Surface Wave)
VHF	Space Wave
UHF	Space Wave
SHF	Space Wave
EHF	Space Wave

Figure 2.16

Super-refraction

This is a phenomenon which is significant at frequencies above 30 MHz (that is VHF and above). Radio waves experience greater refraction, that is, they are bent downwards towards the earth's surface more than in normal conditions, giving notable increases in line of sight range to as much as 40% above the usual.

The conditions which give rise to super-refraction are:

- Decrease in relative humidity with height
- Temperature falling more slowly with height than standard
- Fine weather and high pressure systems
- Warm air flowing over a cooler surface

In extreme cases when there is a low level temperature inversion with a marked decrease in humidity with increasing height (simply, warm dry air above cool moist air), a low level duct may be formed which traps radio waves at frequencies above 30 MHz giving extremely long ranges. This phenomenon is known as duct propagation and can lead to exceptionally long ranges. When interference is experienced on UK television channels from continental stations, the reason for this is the forming of such a duct.

This phenomenon is most common where warm desert areas are bordering oceanic areas, e.g. the Mediterranean and Caribbean seas. It can also occur in temperate latitudes when high pressure predominates, particularly in the winter months when the dry descending air in the high pressure system is heated by the adiabatic process and is warmer than the underlying cool and moist air.

Sub-refraction

Much rarer than super-refraction, but still of significance in radio propagation, sub-refraction causes a reduction in the normal refraction giving a decrease in line of sight range by up to 20%.

The conditions which give rise to sub-refraction are:

- An increase in relative humidity with increasing height
- Temperature decreasing with increasing height at a greater rate than standard
- Poor weather with low pressure systems
- Cold air flowing over a warm surface

Questions

1. **The process which causes the reduction in signal strength as range from a transmitter increases is known as:**

   a. absorption
   b. diffraction
   c. attenuation
   d. ionisation

2. **Which of the following will give the greatest surface wave range?**

   a. 243 MHz
   b. 500 kHz
   c. 2182 khz
   d. 15 MHz

3. **It is intended to increase the range of a VHF transmitter from 50 NM to 100 NM. This will be achieved by increasing the power output by a factor of:**

   a. 2
   b. 8
   c. 16
   d. 4

4. **The maximum range an aircraft at 2500 ft can communicate with a VHF station at 196 ft is:**

   a. 79 NM
   b. 64 NM
   c. 52 NM
   d. 51 NM

5. **What is the minimum height for an aircraft at a range of 200 NM to be detected by a radar at 1700 ft AMSL?**

   a. 25 500 ft
   b. 15 000 ft
   c. 40 000 ft
   d. 57 500 ft

6. **Determine which of the following statements concerning atmospheric ionization are correct:**

   1. The highest levels of ionization will be experienced in low latitudes
   2. Ionization levels increase linearly with increasing altitude
   3. The lowest levels of ionization occur about midnight
   4. The E-layer is higher by night than by day because the ionization levels are lower at night

   a. statements 1, 2 and 3 are correct
   b. statements 1, 3 and 4 are correct
   c. statements 2 and 4 are correct
   d. statements 1 and 4 are correct

7. The average height of the E-layer is ...... and the maximum range for sky wave will be ......

a. 60 km, 1350 NM
b. 125 km, 2200 km
c. 225 km, 2200 km
d. 125 km, 1350 NM

8. Concerning HF communications, which of the following is correct?

a. The frequency required in low latitudes is less than the frequency required in high latitudes
b. At night a higher frequency is required than by day
c. The frequency required is dependent on time of day but not the season
d. The frequency required for short ranges will be less than the frequency required for long ranges

Answers

1	2	3	4	5	6	7	8
c	b	d	a	b	d	d	d

Chapter

3

Modulation

Introduction

Modulation is the name given to the process of adding information to a radio wave or the formatting of radio waves for other purposes. Of the main forms of modulation, five have application in aviation:

Keyed Modulation

Amplitude Modulation (AM)

Frequency Modulation (FM)

Phase Modulation

Pulse Modulation

The modulation of a radio frequency is generally associated with the transmission of audio information, although the transmission of data, including that in satellite navigation systems, and the determination of bearing in VOR, for example, require modulation for other purposes.

Before an audio signal can be added to a radio wave it must be converted to an electrical signal. This will be achieved by the use of a microphone, which is quite simply a device that converts sound waves to an electrical current.

It will be assumed for AM and FM that this conversion has already been accomplished.

Keyed Modulation

The simplest way to put information onto a carrier wave is to quite simply interrupt the wave to give short and long bursts of energy.

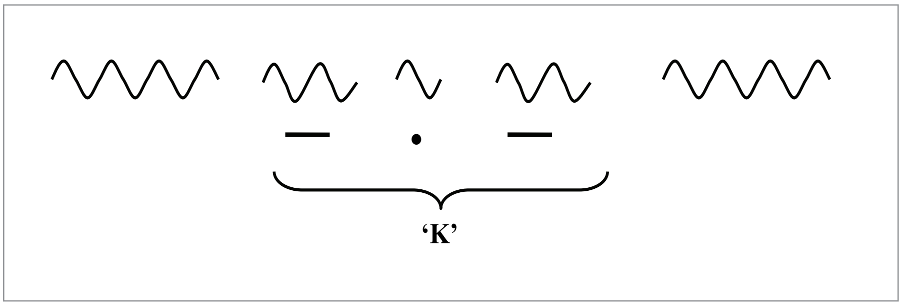


Figure 3.1 Morse 'K' in keyed modulation

By arranging the transmissions into short and long periods of carrier wave transmission we can send information using the Morse code. This is known as telegraphy and until the development of other forms of modulation was the only means of passing information. Keyed modulation is still used by some non-directional beacons (NDBs) for identification and will be discussed further in Chapter 7.

Amplitude Modulation (AM)

In AM the **amplitude** of the audio frequency (AF) modifies the **amplitude** of the radio frequency (RF).

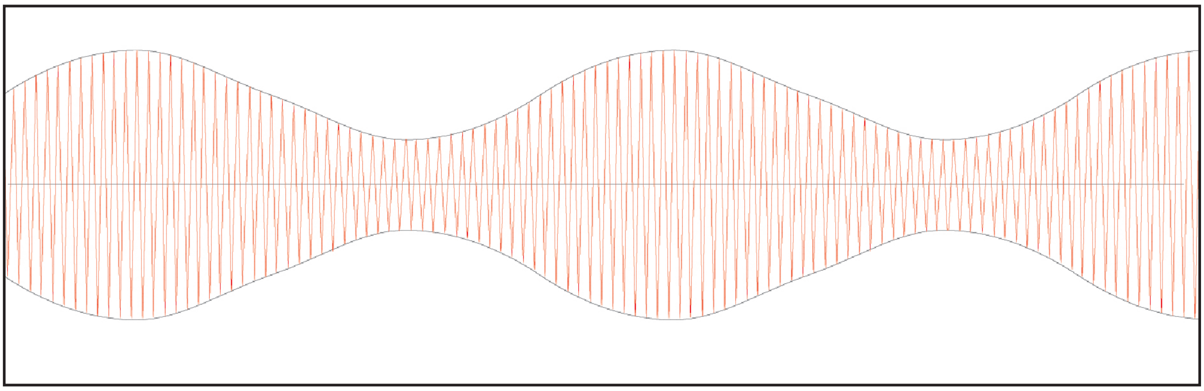


Figure 3.2 Amplitude modulation

As can be seen from the diagram above, positive amplitude in the AF gives an increase in amplitude in the RF and negative amplitude in the AF gives a decrease in amplitude in the RF.

The process of combining a radio frequency with a current at audio frequencies is known as heterodyning. Looking in more detail at the process; the heterodyning process combines the two frequencies, leaving the RF unchanged but producing new frequencies at the sum and difference of the RF and AF. For example an audio frequency of 3 kHz is used to amplitude modulate a radio frequency of 2182 kHz. The RF remains unchanged but the AF is now split into 2 sidebands extending upwards from 2182.001 kHz to 2185 kHz – the **upper sideband (USB**) and a **lower sideband (LSB)** extending downwards from 2181.999 kHz to 2179 kHz. The spread of frequencies is from 2179 kHz to 2185 kHz giving a bandwidth of 6 kHz, i.e. double the audio frequency used.

					2185 kHz	
				(25 W)	⇧	Upper Sideband (USB)
(100 W)	RF	2182 kHz			2182.001 kHz	
			⇨	(100 W)	2182 kHz	
(50 W)	AF	3 kHz			2181.999 kHz	
				(25 W)	⇩	Lower Sideband (LSB)
					2179 kHz	

Figure 3.3 AM sideband production

As can be seen from the table the power that is in the AF is divided equally between the two sidebands, furthermore the information in the AF is contained in both sidebands. It should also be noted that only one third of the signal is carrying the information.

Single Sideband (SSB)

There is redundancy in double sideband transmissions in that the information is contained in both the upper and lower sidebands. Additionally, the original RF carrier wave having served its purpose to get the audio information into radio frequencies is now redundant. So it is possible to remove one of the sidebands and the carrier wave because the remaining sideband contains all the information. This is known as single sideband (SSB) operation.

					2185 kHz	
				~~(25 W)~~ (150 W)	⇧	Upper Sideband (USB)
(100 W)	RF	2182 kHz			2182.001 kHz	
			⇨	~~(100 W)~~	~~2182 kHz~~	
(50 W)	AF	3 kHz			~~2181.999 kHz~~	
				~~(25 W)~~	⇩	~~Lower Sideband~~ ~~(LSB)~~
					~~2179 kHz~~	

Figure 3.4 Single sideband

When using sky wave propagation for communication, the differing refraction occurring at different frequencies leads to an increase in distortion if the bandwidth is too large. The ionosphere comprises electrically charged particles which cause high levels of static interference on radio waves, the use of SSB significantly reduces the effect of this interference. The MF & HF frequencies used for long range communication are in great demand, hence the use of SSB transmissions increases the number of channels available. The use of SSB also reduces the amount of power required.

Thus the main advantages of SSB are:

- Double the number of channels available with double sideband
- Better signal/noise ratio (less interference)
- Less power required hence lighter equipment

Frequency Modulation (FM)

In Frequency Modulation, the **amplitude** of the audio frequency modifies the **frequency** of the carrier wave.

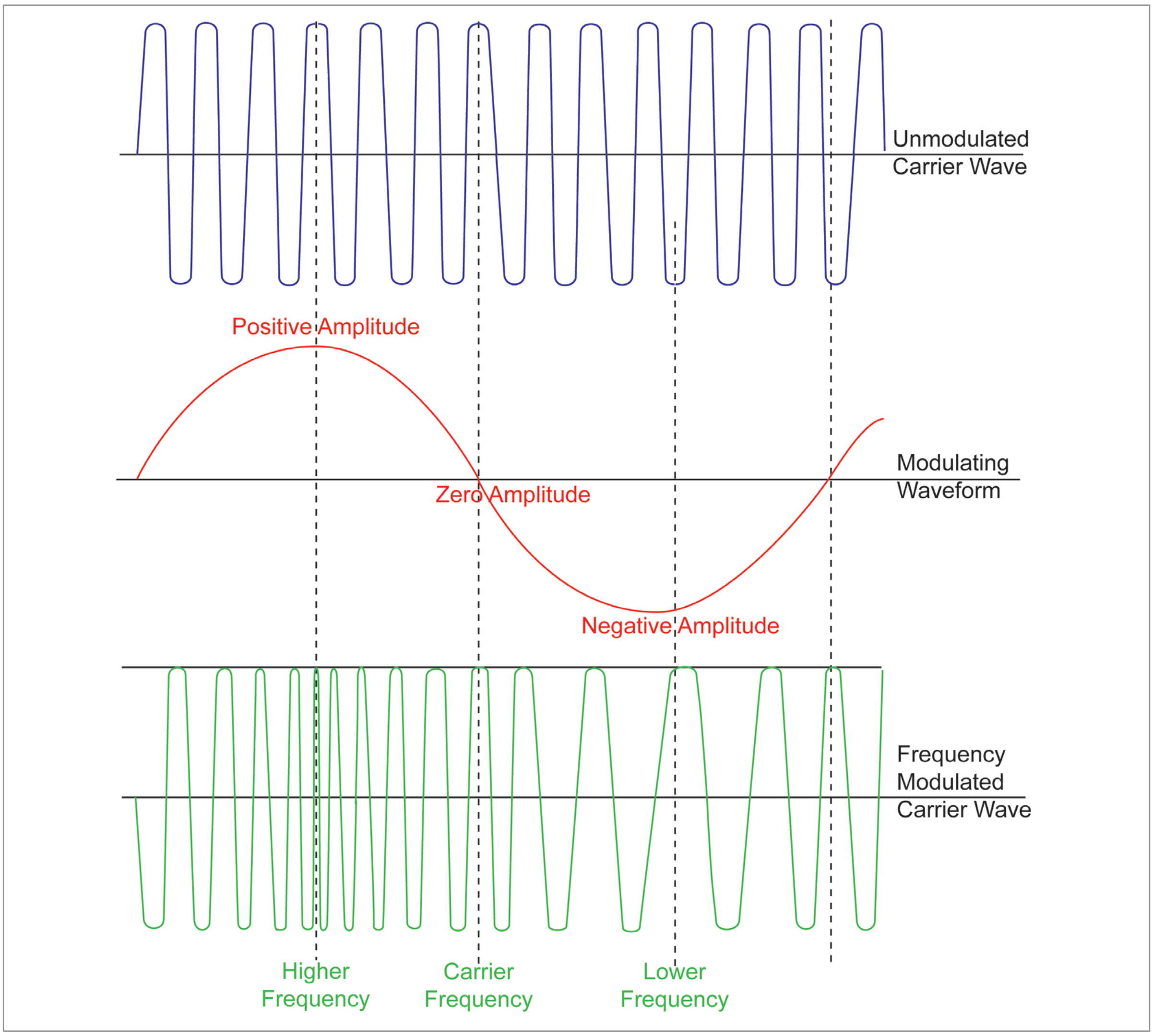


Figure 3.5 Frequency modulation

The change in the carrier wave frequency is dependent on the rise and fall of the amplitude of the modulating wave/audio frequency: the greater the amplitude, the greater the frequency deviation. The **frequency** of the modulating wave determines the **rate of change** of frequency within the modulated carrier wave.

When FM is used for sound broadcasting (for example, music radio stations), the bandwidth permitted by international agreements is 150 kHz, compared to 9 kHz allowed for AM. In general, therefore, FM is unsuitable for use on frequencies below VHF.

For voice communications the bandwidth can be considerably reduced whilst still maintaining the integrity of the information; this is known as Narrow Band FM (NBFM). Typically, NBFM systems have a bandwidth of 8 kHz, which is greater than the 6 kHz permitted for Aeronautical Communications and the 3 kHz used in HF Communications; therefore, NBFM communication systems are not yet used in aviation.

Phase Modulation

In phase modulation the phase of the carrier wave is modified by the input signal. There are two cases: the first is where the input is an analogue signal when the phase of the carrier wave is modified by the amplitude of the signal; secondly, with a digital signal it is known as phase shift keying, the phase change reflects a 0 or 1; e.g. 0° phase shift indicates a zero and 180° phase shift represents a 1. (Note: this is the simplest case as multiple data can be represented by using many degrees of phase shift.)

There are two cases used in navigation systems, MLS and GPS. GPS uses binary phase shift keying, MLS uses differential phase shift keying.

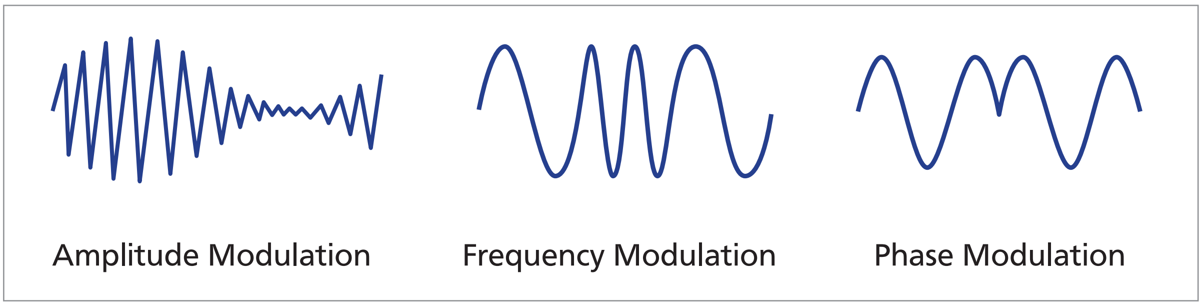


Figure 3.6

Pulse Modulation

Pulse modulation is used extensively in radar systems and for data exchange in communications systems. An intermittent carrier wave is formed by the generation and transmission of a sequence of short period pulses.

Emission Designators

In order to easily identify the characteristics and information provided by electronic signals, a list of designators has been devised. They comprise 3 alphanumerics, where the first letter defines the nature of the modulation, the second digit the nature of the signal used for the modulation and the third letter the type of information carried.

EMISSION CHARACTERISTICS

First Symbol		Second Symbol		Third Symbol	
Type of modulation of the main carrier		**Nature of signals modulating the main carrier**		**Type of information transmitted**	
N	Emissions of an unmodulated carrier	0	No modulating signal	N	No information transmitted
A	Amplitude modulation - Double sideband	1	Single channel containing quantized or digital information without the use of a modulating sub-carrier, excluding time division multiplex	A	Telegraphy for aural reception
H	Amplitude modulation - Single sideband, full carrier	2	Single channel containing quantized or digital information with the use of a modulating sub-carrier, excluding time division multiplex	B	Telegraphy for automatic reception
J	Amplitude modulation - Single sideband – suppressed carrier	3	Single channel containing analogue information	C	Facsimile
				D	Data transmission, telemetry, telecommand
F	Frequency modulation	7	Two or more channels containing quantized or digital information	E	Telephony, including sound broadcasting
G	Phase modulation	8	Two or more channels containing analogue information	F	Television (video)
		9	Composite system with one or more channels containing quantized or digital information, together with one or more channels containing analogue information	W	Combinations of the above
P	Sequence of unmodulated pulses				
K	Sequence of pulses modulated in amplitude	X	Cases not otherwise covered	**X**	Cases not otherwise covered

For example, VHF radio telephony communications have the designation A3E.

Reference to the table gives the following breakdown:

A - Amplitude modulation - Double sideband

3 - Single channel containing analogue information

E - Telephony, including sound broadcasting

This means an RF carrier wave is being amplitude modulated with speech.

HF radio telephony communications have the designation J3E, this gives:

J - Amplitude modulation – single sideband with suppressed carrier

3 - Single channel containing analogue information

E - Telephony, including sound broadcasting

This means an RF carrier wave is being amplitude modulated with speech then the RF carrier wave is being removed along with one of the sidebands.

It is not necessary to know the details of the table.

Other designators relevant to the equipments discussed in phase 2 are:

ADF	N0NA1A or N0NA2A
VHF RTF	A3E
HF RTF	J3E
VOR	A9W
ILS	A8W
Marker Beacons	A2A
DME	P0N
MLS	N0XG1D

With the exception of ADF it is unlikely that knowledge of these designators will be examined.

Questions

1. **The bandwidth produced when a radio frequency (RF) of 4716 kHz is amplitude modulated with an audio frequency (AF) of 6 kHz is:**

    a. 6 kHz
    b. 3 kHz
    c. 12 kHz
    d. 9 kHz

2. **Which of the following statements concerning AM is correct?**

    a. The amplitude of the RF is modified by the frequency of the AF
    b. The amplitude of the RF is modified by the amplitude of the AF
    c. The frequency of the RF is modified by the frequency of the AF
    d. The frequency of the RF is modified by the amplitude of the AF

3. **Which of the following is an advantage of single sideband (SSB) emissions?**

    a. More frequencies available
    b. Reduced power requirement
    c. Better signal/noise ratio
    d. All of the above

4. **Which of the following statements concerning FM is correct?**

    a. The amplitude of the RF is modified by the frequency of the AF
    b. The amplitude of the RF is modified by the amplitude of the AF
    c. The frequency of the RF is modified by the frequency of the AF
    d. The frequency of the RF is modified by the amplitude of the AF

Answers

1	2	3	4
c	b	d	d

Chapter

4

Antennae

Antennae

Introduction

Antennae or aerials are the means by which radio energy is radiated and received. The type of antenna used will be determined by the function the radio system is required to perform. This chapter will look at the principles which are common to all antennae and at the specialities required for particular radio navigation systems.

Basic Principles

There are two basic types of aerial used for receiving and transmitting basic communications, the half-wave dipole and the Marconi or quarter-wave aerial.

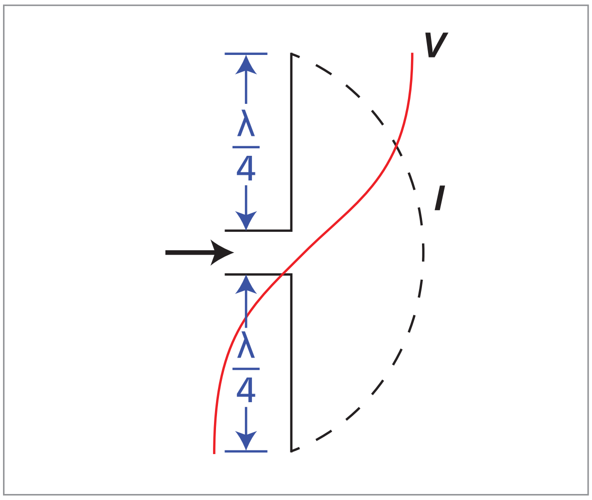


Figure 4.1: Half-wave dipole

With the dipole aerial the power is fed to the centre of the aerial and radiates in all directions perpendicular to the aerial. The Marconi aerial is set on, but insulated from, a metal surface which acts as the second part of a dipole, with the radio energy radiating perpendicular to the aerial. Because of the better aerodynamic qualities, Marconi aerials are used on aircraft.

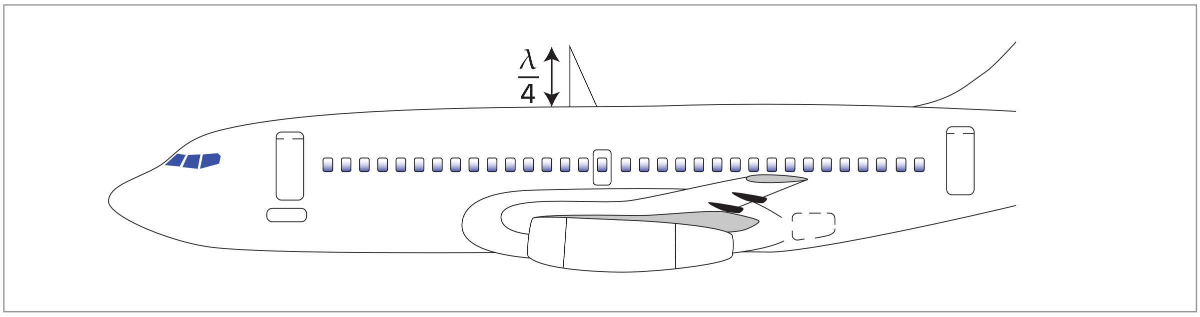


Figure 4.2: Marconi aerial

For an aerial to operate with maximum efficiency it must be the correct length for the wavelength of the frequency in use. As the names imply the ideal length for an aerial is half or quarter of the wavelength of the frequency being transmitted. However, whilst we regard the speed of propagation of electromagnetic energy as being constant, this is only true in a specified medium. If the energy passes from one medium to another the speed will change. In the case of electromagnetic energy, the denser the medium the slower the speed. This needs to be taken into account in the length of aerials.

Example:

What is the optimum length for a Marconi aerial transmitting on a frequency of 125 MHz?

Recall from Chapter 1:

$$\textbf{Wavelength}\ (\lambda) = \frac{300\ m}{f\,(MHz)}$$

$$= \frac{300\ m}{125} = 2.4\ m$$

With a wavelength of 2.4 m, the optimum length will be:

$$\frac{\lambda}{4} = \frac{2.4}{4} = 0.6\text{ m or }60\text{ cm}$$

Aerial Feeders

The means by which energy is carried between the aerial and transmitter or receiver is dependent on the frequency in use and the power levels. At low and medium frequencies a simple wire is adequate to carry the signal over reasonable distances with little energy loss. As frequency increases the power losses increase and into HF and VHF a twin wire feeder is more efficient. At UHF frequencies, the power losses in these simple feeders becomes unacceptably high and a coaxial cable is required.

In the upper part of the UHF band and in the SHF and EHF bands the use of dipole or Marconi aerials is precluded because of the high energy losses and the way the energy is produced. At these frequencies a waveguide is used to carry the energy to or from the aerial. The waveguide is a hollow, rectangular metal tube. The internal dimensions of the tube are determined by the frequency in use, being half the wavelength.

Polar Diagrams

A polar diagram is used to show the radiation or reception pattern of an aerial. It is simply a line joining all points of equal signal strength and is generally a plan view perpendicular to the plane of radiation or reception. From here on we will talk about radiation only, but the same principle applies to reception.

A dipole aerial radiates most energy at right angles to the aerial with signal strength decreasing towards the ends of the aerial, where there is no radiation. A three dimensional representation of radiation from such an aerial would be a torus, centred on the centre point of the aerial:

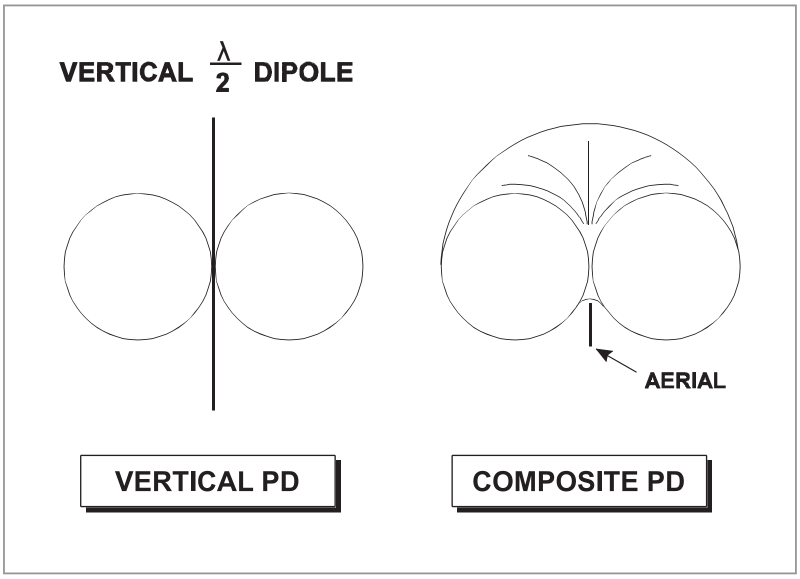


Figure 4.3 3-D Polar Diagram (PD)

Clearly such diagrams would be cumbersome so a plan view of the plane of radiation is used:

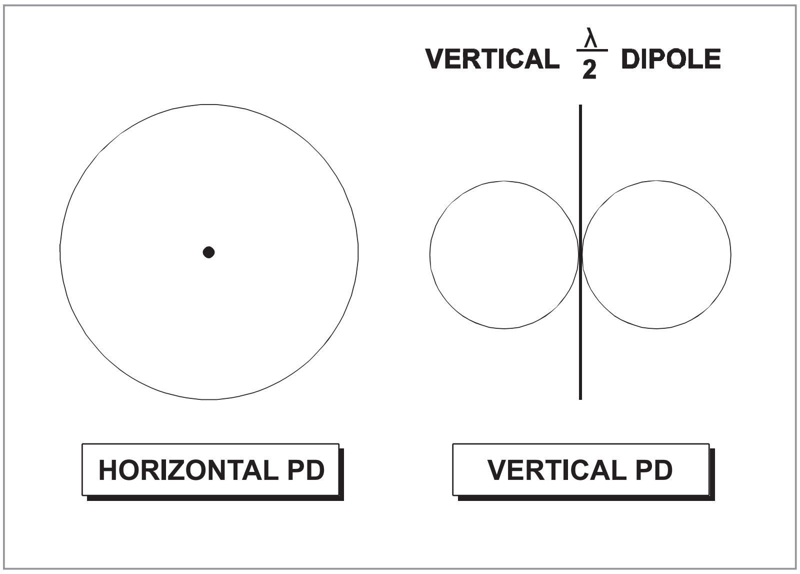


Figure 4.4 Plan view polar diagram

Directivity

Many systems require the directional emission or reception of energy, for example; radar, ILS, MLS and many more. How this directivity is achieved depends on the frequency and application.

The simplest way to achieve directivity is to add parasitic elements to the aerial. If we place a metal rod 5% longer than the aerial at a distance of quarter of a wavelength from the aerial and in the same plane as the aerial, it will act as a reflector.

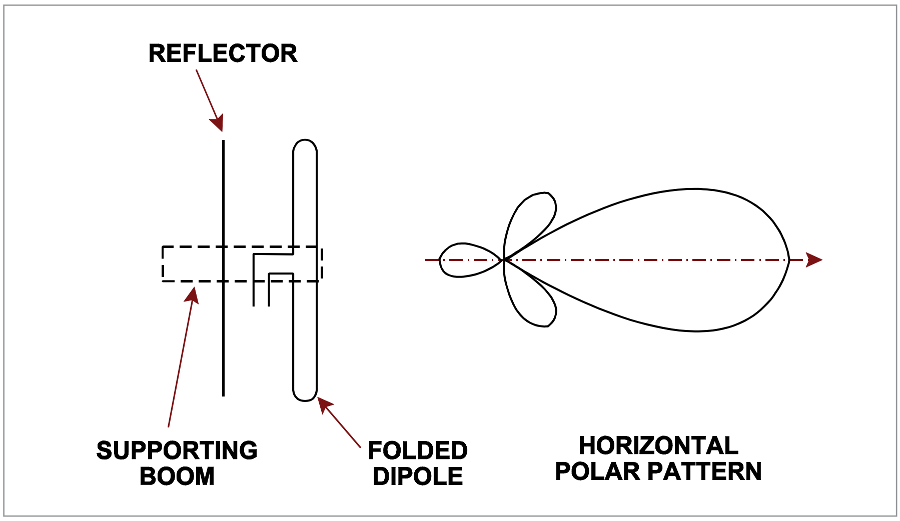


Figure 4.5 Directivity using reflector

This reflector re-radiates the energy 180° out of phase, the resulting polar diagram is shown above, with no signal behind the reflector and increased signal in front of the aerial.

This process can be taken further by adding other elements in front of the aerial. These elements are known as directors and are smaller than the aerial itself.

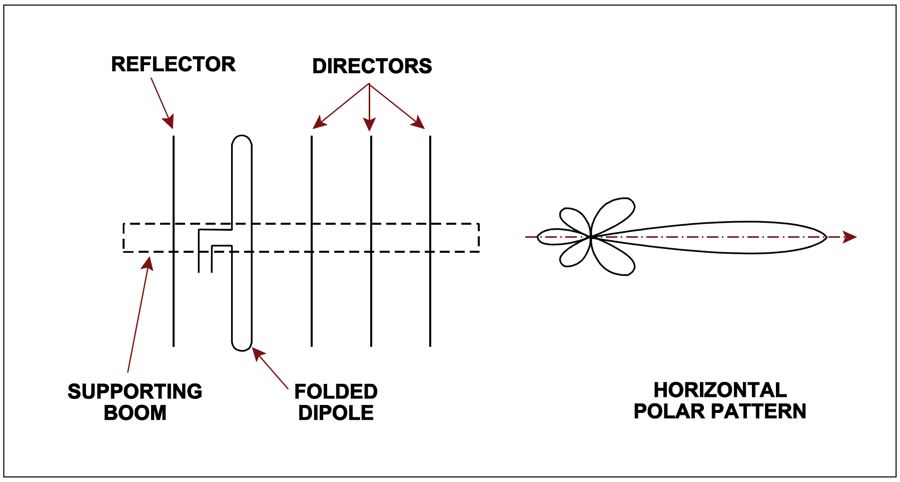


Figure 4.6 Improved directivity using reflector and directors

All will recognize this as being the type of aerial array used for the reception of television signals. The directors have the effect of focussing the signal into (or out of) the aerial, giving a stronger signal than that which would be generated by a simple dipole.

However, directivity comes with its own price. As can be seen from the diagram, we have produced a strong beam along the plane of the aerial, but have also produced many unwanted side lobes which would receive (and transmit) unwanted signals. Signals received in these side lobes produce characteristic ghosting on television pictures, usually caused by reflections from buildings etc. These side lobes give major problems which have to be addressed in SSR and ILS, and also produce problems in primary radars.

The Instrument Landing System (ILS) uses an extension of this idea to produce the narrow beams (or lobes) of energy required to guide aircraft along the runway centre line: the ILS 'localizer' antenna which produces this is an array of 16 or 24 aerials placed in line with half wavelength spacing. There is some modification to the way the signal is fed to the aerials but the end result is that two narrow beams of energy are produced which are symmetrical, close to the centre line of the runway as shown in *Figure 4.7*.

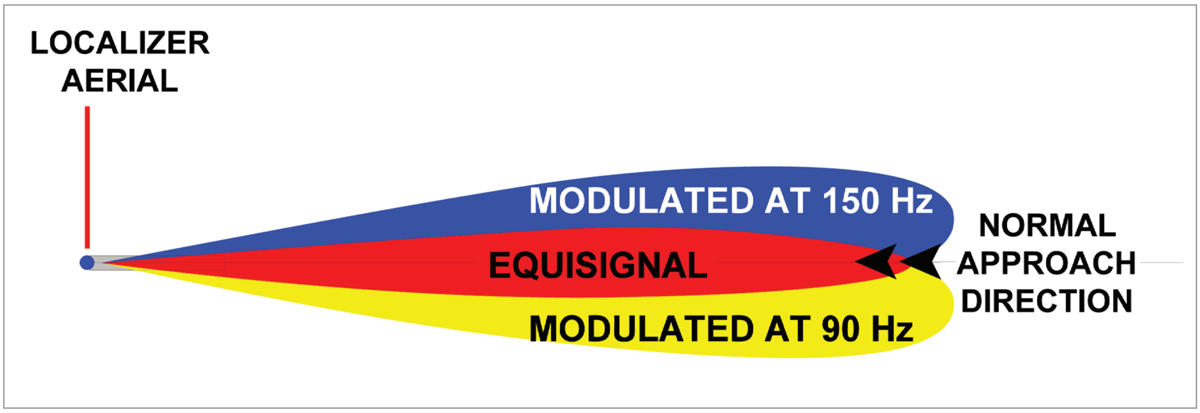


Figure 4.7 ILS localizer lobes.

In the Automatic Direction Finder (ADF) a loop aerial is used to detect the direction of an incoming signal.

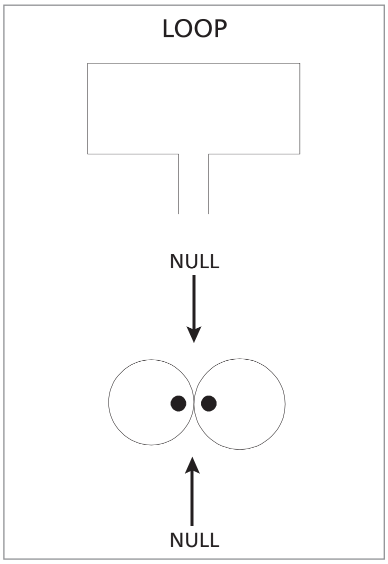


Figure 4.8 Loop aerial 'Figure-of-eight' polar diagram

When the loop is aligned with the incoming signal then there is a phase difference between the signals in each of the vertical elements of the loop and there will be a net flow of current from the loop. If the loop is placed at right angles to the incoming signal then the induced currents will be equal and will cancel each other out giving a zero output.

The resulting polar diagram will have two distinct nulls which can be used to determine the direction from which the radio wave is coming. How this principle is utilized will be discussed in detail in Chapter 7.

Radar Aerials

Radar systems operate in the UHF and SHF bands; the transmission of such frequency energy requires the use of 'waveguides' rather than cables. The parabolic dish is widely used as a 'reflector': the open end of a waveguide (see *Figure 4.9*) is positioned at the focal point of the parabola (the centre of curvature, designated by point F in *Figure 4.10*) and directs the RF energy towards the dish. The energy from the open waveguide is reflected by the dish as parallel rays; the path length FXB, FYA etc. will therefore be equal and the transmitted wavefront will be made up of parallel rays that are all in phase.

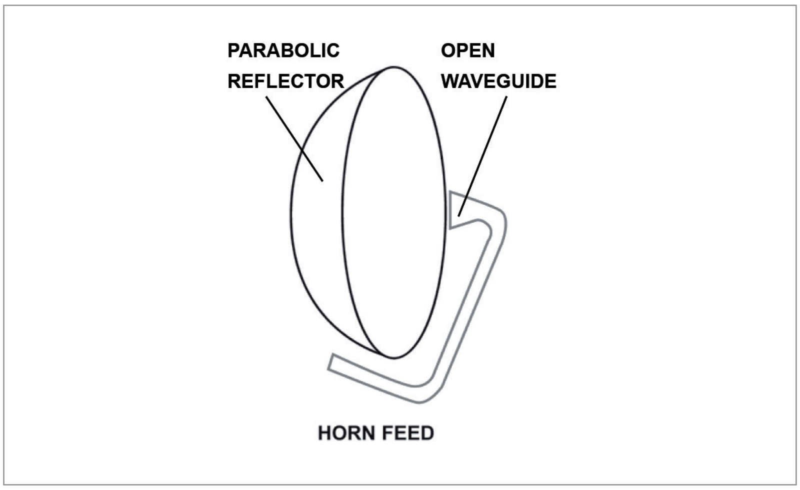


Figure 4.9 Horn feed to Parabolic Reflector

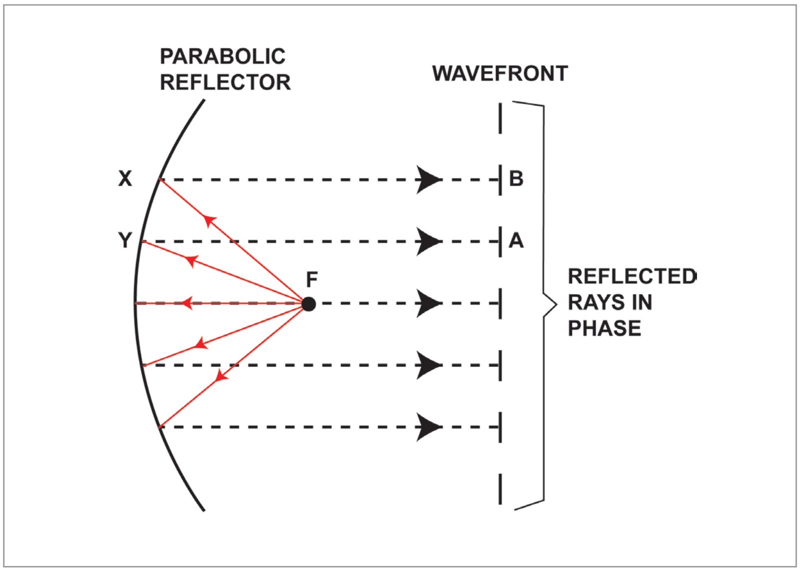


Figure 4.10 Principles of the Parabolic Reflector

In principle a very narrow pencil beam should be produced as shown below, but apart from the region very close to the antenna, the beam, in fact, **diverges.** In effect, the parabolic reflector converts a point source of energy (the open waveguide) at the focal point into a plane wavefront of uniform phase.

In addition, due to uneven reflection, some of the energy ‘spills out’ of the reflector to form side lobes (shown in *Figure 4.11*); these contain sufficient energy to produce valid returns outside the main lobe or beam.

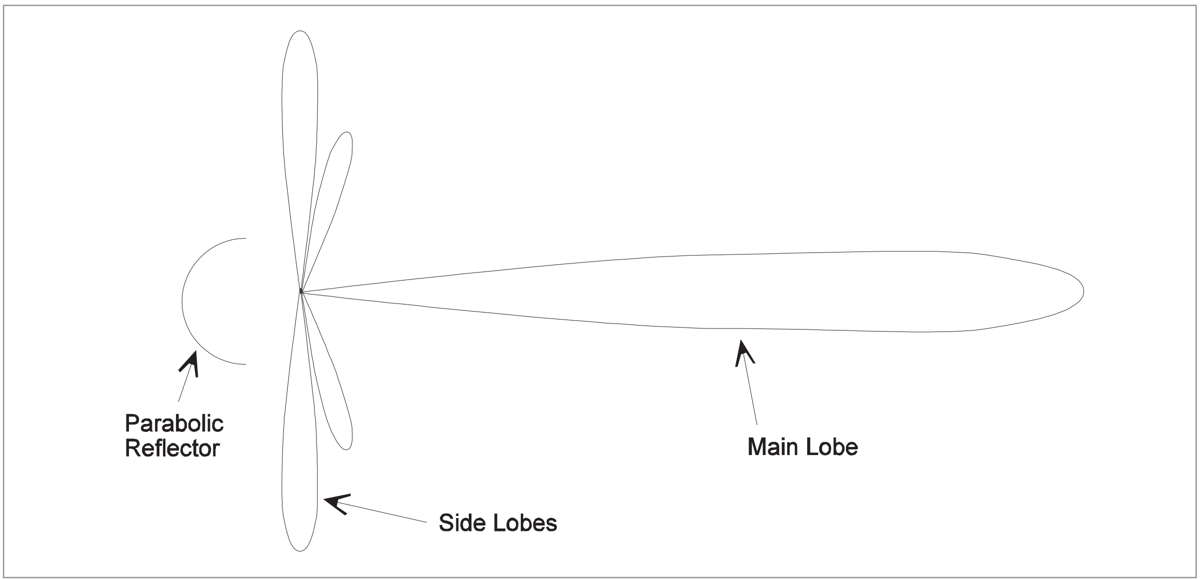


Figure 4.11 Polar diagram of parabolic reflector

Modern Radar Antennae

Modern radar development has introduced a different type of aerial: the Flat Plate Array, Phased Array, or Slotted Antenna (see *Figure 4.12*). The antenna is a ‘flat plate’ with numerous waveguide-size slots cut into it. The individual slots are fed with RF energy from behind the plate; the transmitted radar beam is therefore a result of the interaction of the numerous individual beams.

This type of antenna is more efficient than the parabolic reflector: it ‘wastes’ much less energy in the side lobes and, for a given frequency, the RF energy is concentrated into a narrower beam. Since the flat plate array is a more efficient means of transmission, radars incorporating this technology require less power.

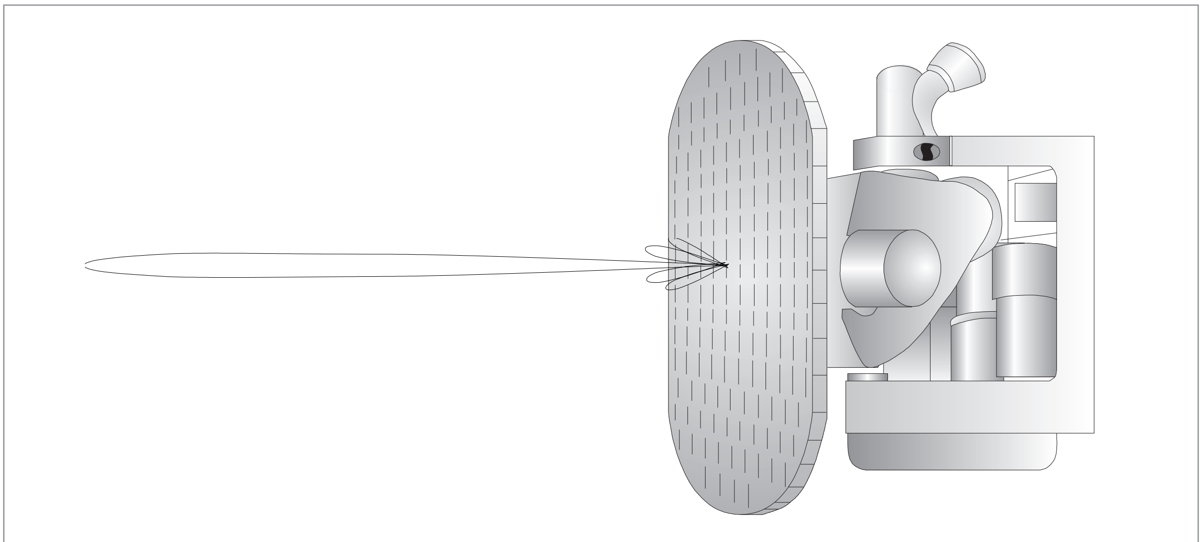


Figure 4.12 Phased array or slotted antenna

The advantages of phased/flat plate array over parabolic reflectors are:

- Narrow beam
- Reduced side lobes
- Less power required for a given range
- Narrower pulse
- Improved resolution

Questions

1. **The ideal length for a Marconi aerial for a frequency of 406 MHz is:**

   a. 36.9 cm
   b. 35.1 cm
   c. 17.5 cm
   d. 18.5 cm

2. **A disadvantage of directivity is:**

   a. reduced range
   b. side lobes
   c. phase distortion
   d. ambiguity

3. **Which of the following is not an advantage of a slotted antenna (phase array)?**

   a. Reduced side lobes
   b. Improved resolution
   c. Reduced power
   d. Directivity

4. **The ideal length of a half-wave dipole for a frequency of 75 MHz is:**

   a. 1.9 m
   b. 95 cm
   c. 3.8 m
   d. 47.5 cm

Answers

1	2	3	4
c	b	d	a

Chapter

5

Doppler Radar Systems

Introduction

The Doppler principle can be used to determine the relative speed between moving objects by measuring the difference between transmitted and received frequencies; for example, police forces all over the world use a form of Doppler radar to check vehicle speeds.

A Doppler navigation system uses the Doppler principle to measure an aircraft's ground speed and drift. The most modern systems combine the inherent accuracy of Doppler measurements with information from other navigation systems (for example: IRS, VOR/DME or GPS) in various configurations to suit customer requirements.

Using these additional navigation inputs helps to eradicate the problems associated with early Doppler Navigation Systems, such as inaccurate heading references, and degradation (or loss) of Doppler inputs when flying over large expanses of water.

The Doppler principle is utilized in many navigation systems, such as Radar, Doppler VOR and VDF.

The Doppler Principle

The Austrian physicist, Christian Doppler, predicted the Doppler Effect in connection with light waves in the 19th Century, but it also holds true for sound and radio waves: a received frequency will only be the same as the transmitted frequency when there is no relative movement between the transmitter and receiver.

A simple analogy would be a visit to the beach. Standing still in the water, the waves rolling in splash you at, for example, four waves per minute. If you walk into the sea, you are progressively reducing the space between each wave and therefore they splash you more frequently than four times per minute. The rate at which the waves are produced has not changed, but you **perceive** that the rate has increased. The faster you walk into the sea, towards the waves, the greater the rate at which they will strike you.

Conversely, if you walk back towards the shore, you are effectively stretching out the distance between each wave and therefore the waves will strike you **less** frequently.

The result is that you (as a receiver) **perceive** an **increase** in the frequency of the waves when there is relative movement **towards** the waves (the sea as transmitter), and a **decrease** in the frequency when the relative movement is **away** from the waves; **there has been no actual change in the frequency of the waves**.

The **difference** between the frequency you **perceive** the waves striking you and the **actual** frequency at which they roll in to shore is the '**Doppler Shift**' or '**Doppler Frequency**'. That difference **varies with the speed** at which you walk into or out of the sea – **the relative motion**.

The same effect occurs at radio frequencies: whenever there is relative motion between a transmitter and a receiver, the receiver will perceive a Doppler frequency shift that is proportional to their relative motion.

Airborne Doppler

A typical airborne Doppler installation employs a slotted waveguide antenna in which the transmitter and receiver elements are screened from each other but share the same aerial. It is arranged that an array of beams is transmitted downwards towards the earth's surface as shown in *Figure 5.1*.

The diagram shows a commonly-adopted configuration: there are four beams, two pointing forward and two pointing aft. This is known as a 4-Beam Janus Array, named after the Roman God of Doorways who was reputed to be able to face both ways simultaneously.

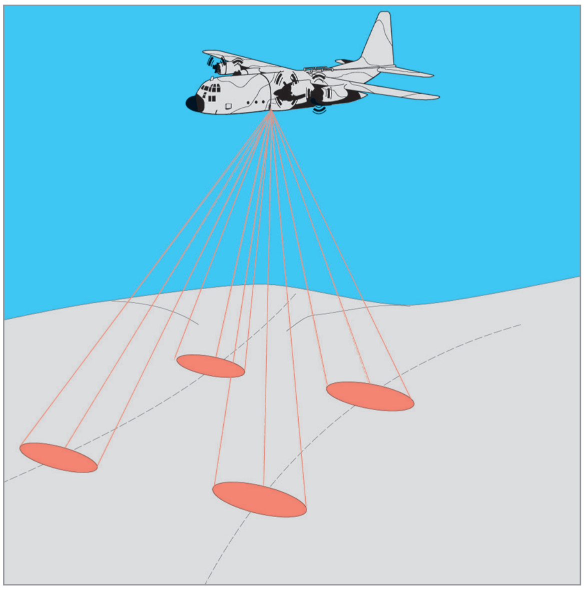


Figure 5.1 Airborne Doppler.

Janus Array System

A Janus array normally comprises 3 or 4 beams. *Figure 5.2*, below, illustrates various ways that the beams can be configured.

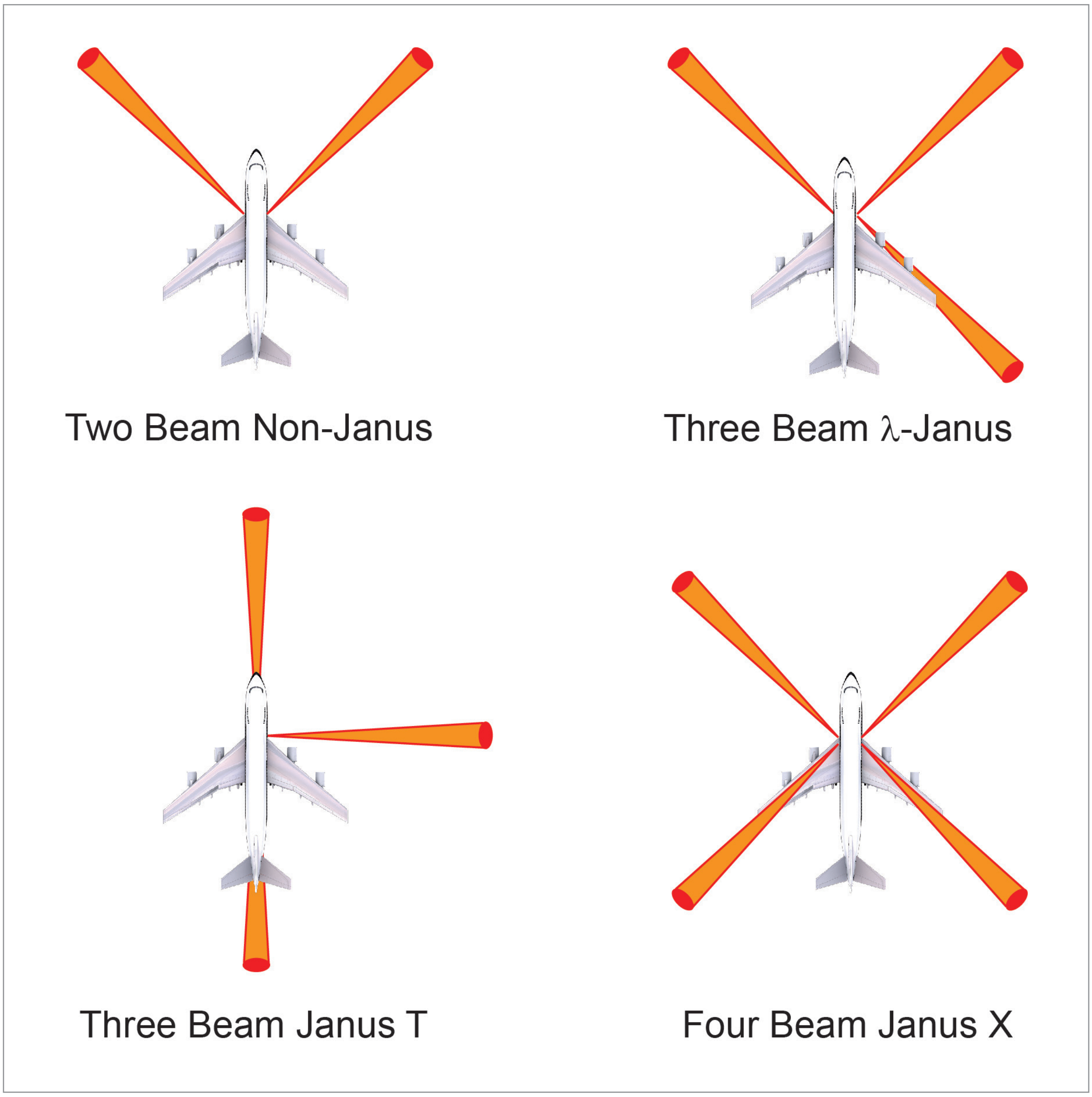


Figure 5.2 Janus Arrays

Doppler Operation

The Doppler functions by continuous measurement of the frequency shift in the reflected signal caused as a result of the aircraft's motion over the ground. The equipment converts the measured values into the aircraft's speed along track (ground speed) and speed across track (used to determine drift).

The frequency shifts detected in a four-beam Janus array of an aircraft travelling forwards with zero drift will be equal (but opposite for fore and aft beams). In other words, the forward beams detect an upward shift in the received frequency and the aft beams detect a downward shift in the received frequency from the beams pointing aft; the magnitude of the shift will be equal but opposite. The shift in both sets of beams is proportional to the aircraft's ground speed.

If the aircraft is drifting left or right, then there will be a difference in the frequencies received from port and starboard beams. In a modern, fixed aerial system the differences in frequencies are electronically processed to provide a continuous indication of drift and ground speed; the information (together with a heading input) can also be provided to a navigation system that can determine the aircraft's position.

In earlier, mechanical systems (using pitch-stabilized, rotating aerials) the difference in frequency shifts was converted to an electrical signal that actuated a motor. The motor then drove the aerial until it was aligned with aircraft track, at which stage the port and starboard frequency shifts would be equalized. A pick-off then measured the difference between the aircraft's fore/aft axis (representing heading) and the alignment of the port and starboard beams (track); the difference being drift.

Doppler Navigation Systems

The Doppler continuously updates the values of aircraft drift and ground speed. In early systems, the aircraft's departure point was loaded into a navigation computer. The values of drift and ground speed, together with an input of aircraft heading, were also fed into the computer, which converted them into aircraft position. The calculated position was then displayed as latitude and longitude or as distances (in nautical miles) along and across track.

Figure 5.3 is the Control and Display Unit (CDU) for the B-52 system mentioned above.

Figure 5.3 Racal RNS 252 Navigation Computer Unit

Questions

1. **Doppler operates on the principle that ...... between a transmitter and receiver will cause the received frequency to ...... if the transmitter and receiver are moving ..... .**

    a. apparent motion, decrease, together
    b. relative motion, decrease, apart
    c. the distance, increase, at the same speed
    d. relative motion, increase, apart

2. **Due to 'Doppler' effect an apparent decrease in the transmitted frequency, which is proportional to the transmitter's velocity, will occur when:**

    a. the transmitter and receiver move towards each other
    b. the transmitter moves away from the receiver
    c. the transmitter moves towards the receiver
    d. both transmitter and receiver move away from each other

3. **The change in frequency measured in an aircraft from a radio transmission reflected from the ground is used to determine:**

    a. the drift and ground speed of the aircraft
    b. the aircraft's track and speed
    c. the across track wind component and heading
    d. track error and ground speed

Answers

1	2	3
b	b	a

Chapter

6

VHF Direction Finder (VDF)

Introduction

The VHF Direction Finder (VDF) is a means of providing a pilot with the direction to fly towards a ground station - a bearing. The bearing can be used to 'home' towards the ground station or, in conjunction with another bearing, or bearings, can be used to establish a fix position. VDF is rarely used because there are so many more sophisticated and more accurate systems available.

Bearings are provided, by voice, on an aircraft's VHF Communications frequency; they are therefore **available on 118.0 - 137 MHz** (Emission Code **A3E**). Auto-triangulation (position **automatically** provided from a number of VDF bearings from different stations) is available, but solely on the VHF International Distress Frequency – 121.5 MHz. At present, UHF DF is limited to military use.

The Aeronautical Stations offering a VDF service are listed in the AD Section of the AIP. Some VDF stations stipulate that the service is not available for en route navigation purposes (except in emergency). VDF bearing information will only be given when conditions are satisfactory and radio bearings fall within the calibrated limits of the station. If the provision of a radio bearing is not possible the pilot will be told of the reason.

Procedures

A pilot may request a VDF bearing using the appropriate phrase or **Q-Code** to specify the service required (see *Figure 6.1*):

'QDM QDM QDM OXFORD APPROACH G-DS REQUEST QDM, G-DS'

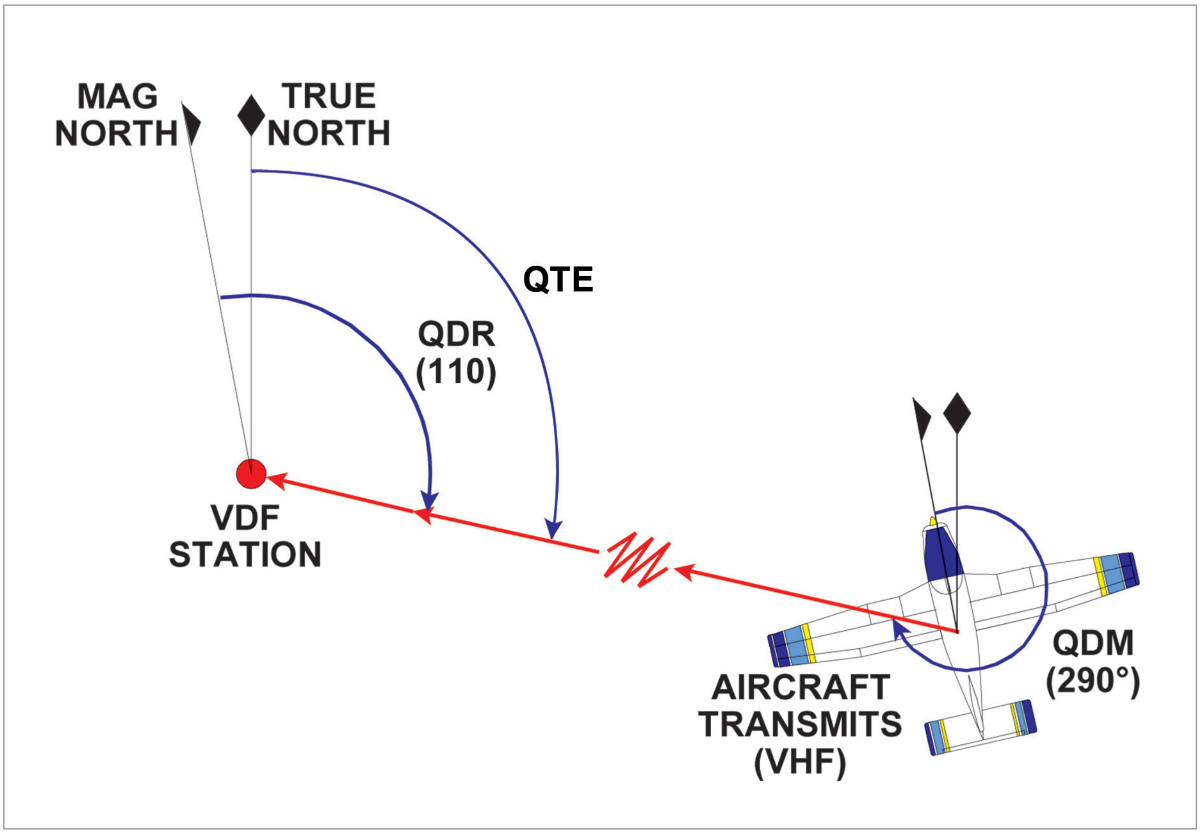


Figure 6.1 QDM/QDR/QTE.

VHF Direction Finder (VDF)

A VDF station will provide the following as requested:

- **QDR** Aircraft's Magnetic Bearing from the station (**Radial**); used for en route navigation
- **QDM** Aircraft's Magnetic Heading to steer (assuming no wind) to reach the VDF station; used mainly for station homing and let-downs using published procedures
- **QTE** Aircraft's True Bearing from the station; used for en route navigation
- **QUJ** Aircraft's True Track to the station; not generally used

Note: QDM is the reciprocal of QDR; QUJ is the reciprocal of QTE. QDR, QDM and QTE are most commonly used.

The direction-finding station will reply in the following manner:

- The appropriate phrase or Q code
- The bearing or heading in degrees in relation to the direction finding station
- The class of bearing
- The time of observation, if required

The accuracy of the observation is classified as follows:

- Class A – Accurate within ± 2°
- Class B – Accurate within ± 5°
- Class C – Accurate within ± 10°
- Class D – Accuracy less than Class C

Note: Normally, bearings no better than Class B will be available. The latest equipment uses Doppler principles to determine a high-resolution bearing that can be displayed as a digital read-out; bearings produced in this manner have an accuracy of ±0.5° (available on UHF and VHF systems).

Principle of Operation

The only equipment required to obtain a VDF bearing is a VHF radio; some specialist equipment is required on the ground: a suitable aerial and a display.

A VHF voice communications radio produces a vertically polarized signal; therefore, the ground antenna is vertically polarized and has an array of vertical elements arranged in a circle. See *Figure 6.2*.

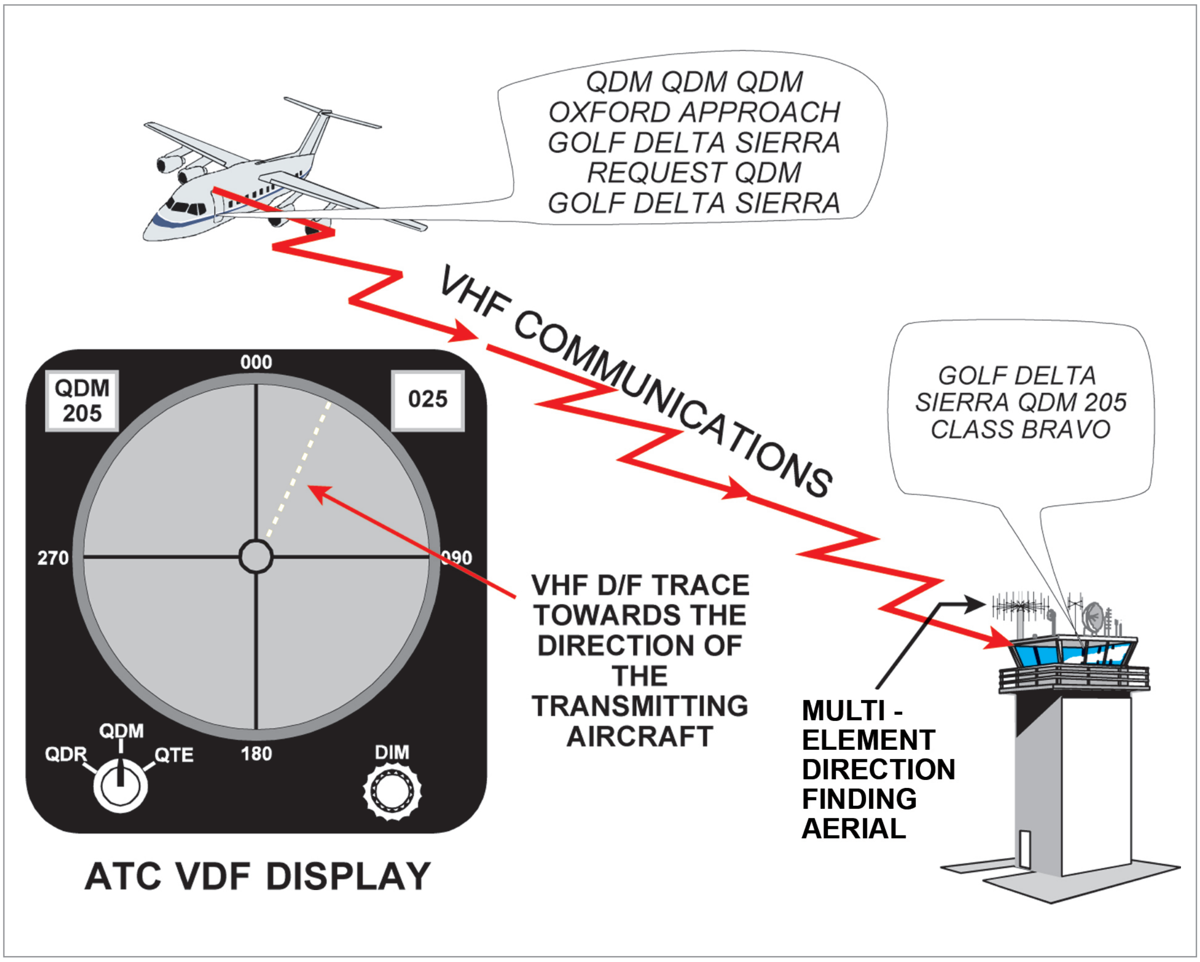


Figure 6.2: Obtaining a VDF Bearing

The equipment resolves the bearing from transmissions received at each element within the array. The bearing is then displayed on the display. The bearing can be displayed relative to either True or Magnetic North (at the station).

Range of VDF

- As VDF utilizes the VHF Band (or UHF as required) the range will obey the line of sight formula: the higher the transmitters the greater the reception range

$$\text{Line of sight Range (MTR)} = 1.23 \times (\sqrt{h_{TX}} + \sqrt{h_{RX}})$$

- Intervening high ground will limit range, especially for low flying aircraft in hilly terrain.
- The power of airborne and ground transmitters will limit ranges.
- Gradients of temperature and humidity can give greater than line of sight range.

Factors Affecting Accuracy

- Propagation error and site error caused by the aircraft's transmissions being reflected from terrain as they travel to the site, or being reflected from buildings at the site.
- Aircraft attitude: the VDF System and VHF Communications are vertically polarized; therefore, best reception and results will be obtained when the aircraft flies straight and level.
- Poor accuracy is likely in the overhead of a VDF receiver, particularly with the latest Doppler systems. The reception of both Direct Wave and Ground Reflected Wave can cause signal fading or loss; the phenomenon is usually short-lived. Together with other multi path signals this gives rise to bearing errors.
- Synchronous transmissions by two or more aircraft will cause momentary errors in bearings.

Determination of Position

If there are sufficient ground stations, linked to an ATCC, the aircraft's position can be fixed using auto-triangulation and the position transmitted to the pilot. This facility may be available to Distress and Diversion Cells, but can not be guaranteed.

VDF Summary

Bearings:	QDM - Mag TO Station QDR - Mag FROM Station QUJ - True TO Station QTE - True FROM Station
Uses:	Track Check Position Line Homing Let-downs
Class:	A = ± 2° B = ± 5° C = ± 10° D = > 10°
Principle:	Ground Equipment – Direction Finding Aerial CRT Display
Range:	Line of Sight Power of Transmitters Intervening High Ground Atmospheric Conditions (Ducting)
Accuracy:	Propagation Error Site Error Aircraft Attitude Overhead Fading Due to Multi-path Signals
Position Service:	Position Fixing by Auto-triangulation

Figure 6.3 VDF Summary

Questions

1. **An aircraft has to communicate with a VHF station at a range of 300 NM, if the ground station is situated 2500 ft AMSL which of the following is the lowest altitude at which contact is likely to be made?**

   a. 190 ft
   b. 1 378 ft
   c. 36 100 ft
   d. 84 100 ft

2. **Class 'B' VHF DF bearings are accurate to within:**

   a. ± 1°
   b. ± 5°
   c. ± 2°
   d. ± 10°

3. **A VDF QDM given without an accuracy classification may be assumed to be accurate to within:**

   a. 2 degrees
   b. 5 degrees
   c. 7.5 degrees
   d. 10 degrees

4. **An aircraft at altitude 9000 ft wishes to communicate with a VHF/DF station that is situated at 400 ft AMSL. What is the maximum range at which contact is likely to be made?**

   a. 115 NM
   b. 400 NM
   c. 143 NM
   d. 63.5 NM

5. **An aircraft is passed a true bearing from a VDF station of 353°. If variation is 8°E and the bearing is classified as 'B' then the:**

   a. QDM is 345° ± 5°
   b. QDR is 345° ± 2°
   c. QTE is 353° ± 5°
   d. QUJ is 353° ± 2°

6. **An aircraft at 19 000 ft wishes to communicate with a VDF station at 1400 ft AMSL. What is the maximum range at which contact is likely ?**

   a. 175 NM
   b. 400.0 NM
   c. 62.5 NM
   d. 219 NM

Answers

1	2	3	4	5	6
c	b	b	c	c	d

Chapter

7

Automatic Direction Finder (ADF)

Introduction

Automatic Direction Finder (ADF) equipment in the aircraft is used in conjunction with a simple low and medium frequency non-directional beacon (NDB) on the ground to provide an aid for navigation and for non-precision approaches to airfields. However, it was due to be phased out in 2005, but still continues in use. Indeed, many UK aerodromes still have NDB instrument approach procedures, and it is the only instrument approach procedure available at some aerodromes.

Non-directional Beacon (NDB)

The Non-directional Beacon (NDB) is a ground based transmitter which transmits vertically polarized radio signals, in all directions (hence the name), in the Low Frequency (LF) and Medium Frequency (MF) bands.

When an aircraft's Automatic Direction Finding (ADF) is tuned to an NDB's frequency and its call sign identified, the direction of the NDB will be indicated.

A 'cone of silence' exists overhead the NDB transmitter during which the aircraft does not receive any signals. The diameter of the cone increases with aircraft height.

Principle of Operation

The ADF measures the bearing of an NDB relative to the fore/aft axis of the aircraft.

If a loop aerial is placed in the plane of the transmitted radio frequency a voltage will be generated in the vertical elements of the loop because of the phase difference of the wave in each of the vertical elements. As the loop is rotated the voltage induced will decrease until it becomes zero when the loop is perpendicular to the radio wave. As the loop continues to rotate a voltage will be induced in the opposite sense etc.

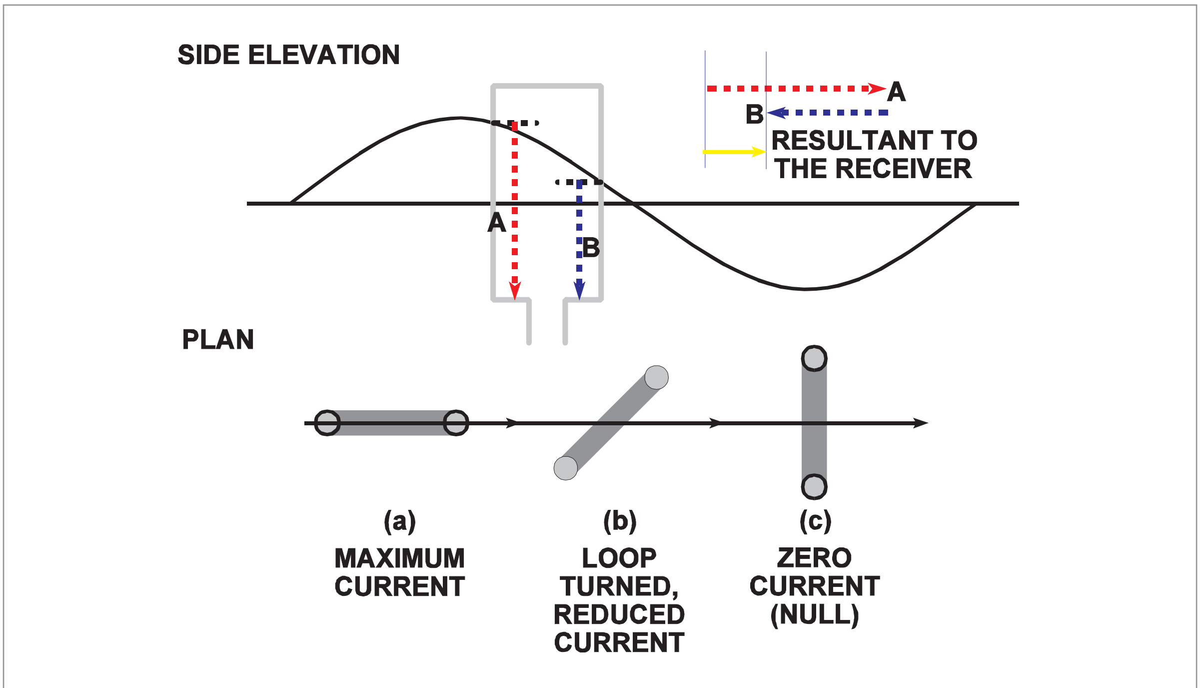


Figure 7.1 A Loop Aerial

The polar diagram formed is a figure of eight as shown below (*Figure 7.2*). It can be seen that there are two null positions and that by rotating the loop until a null is reached the direction of the beacon can be determined. This is fine if the approximate direction of the beacon is known, but if that is not the case then there are two possible choices. Furthermore, if equipment is to automatically determine position, then with only the single loop it would have an insoluble problem.

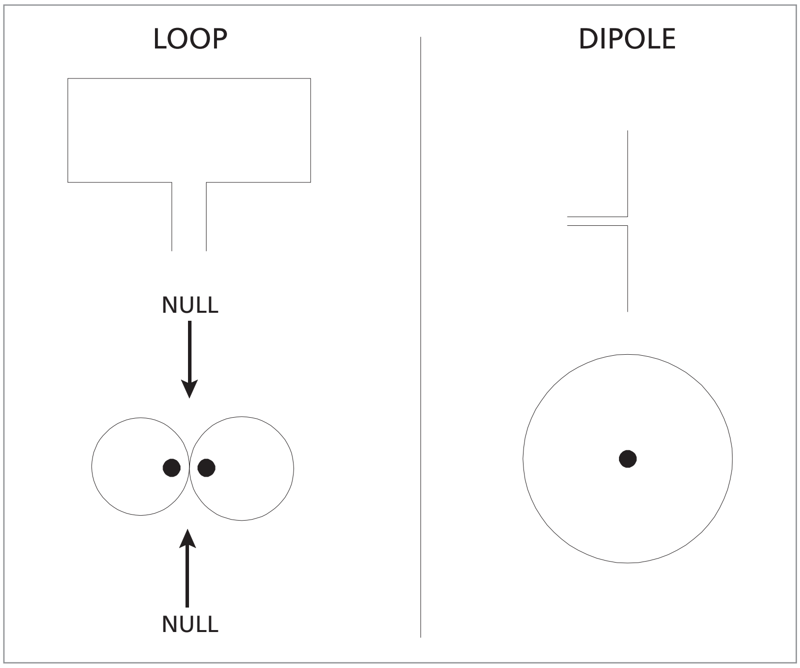


Figure 7.2 Polar diagrams of loop & dipole aerials

To resolve this ambiguity a simple dipole aerial, called a sense aerial, is added. The polar diagram of the sense aerial is circular. The currents generated are combined electronically as if the sense aerial was in the middle of the loop aerial (*Figure 7.3*). The relative signal strengths of the two signals are shown.

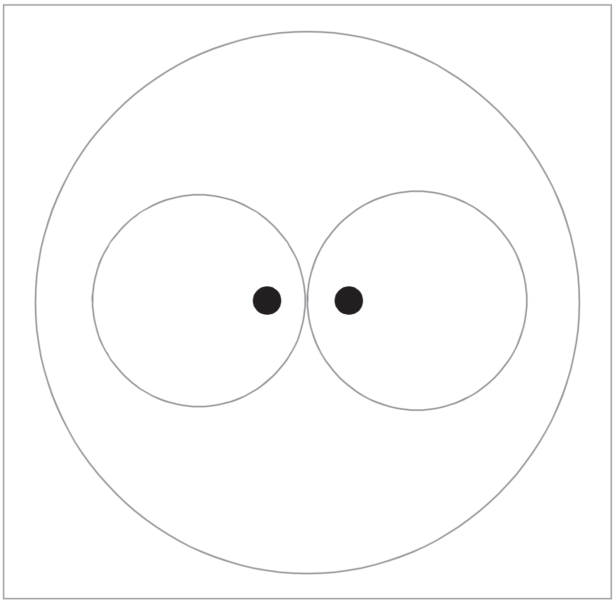


Figure 7.3

It is arranged for the field from the sense aerial to be in phase with one element (the left hand element shown in diagram) of the loop aerial (*Figure 7.4*). The resultant polar diagram is known as a CARDIOID. The cardioid has a single null which as can be seen is ill-defined and would not in itself provide an accurate bearing. However, the correct null in the loop aerial can be defined by introducing a logic circuit which defines the correct null as being that null, in the loop aerial which, when the loop aerial is rotated clockwise, produces an increase in signal strength in the cardioid.

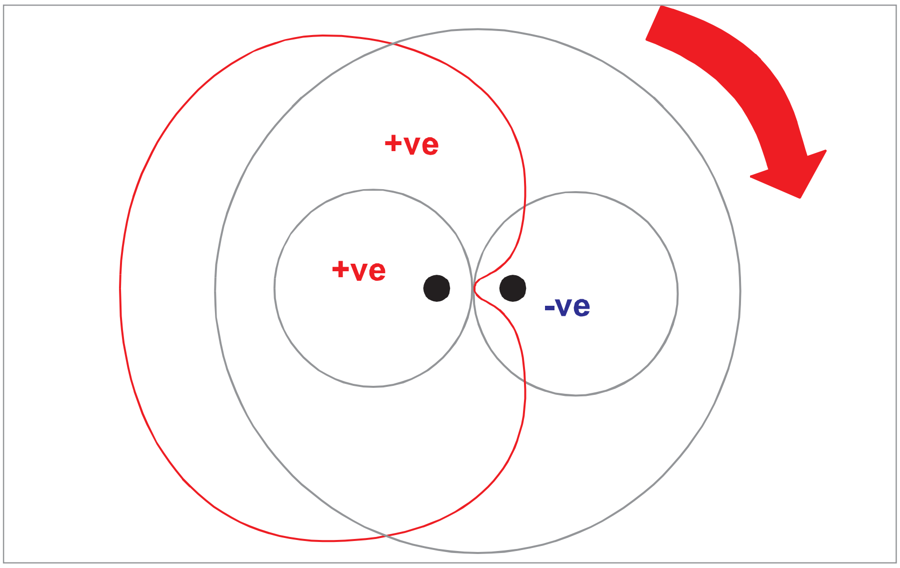


Figure 7.4

The resultant null with a single cardioid is not precise enough to meet the ICAO accuracy requirement of +/-5°. To improve the accuracy to meet the requirements, the polarity of the sense aerial is reversed to produce a right hand cardioid. Then by rapidly switching (about 120 Hz) between the two cardioids, the null is more precisely defined and hence the accuracy is improved.

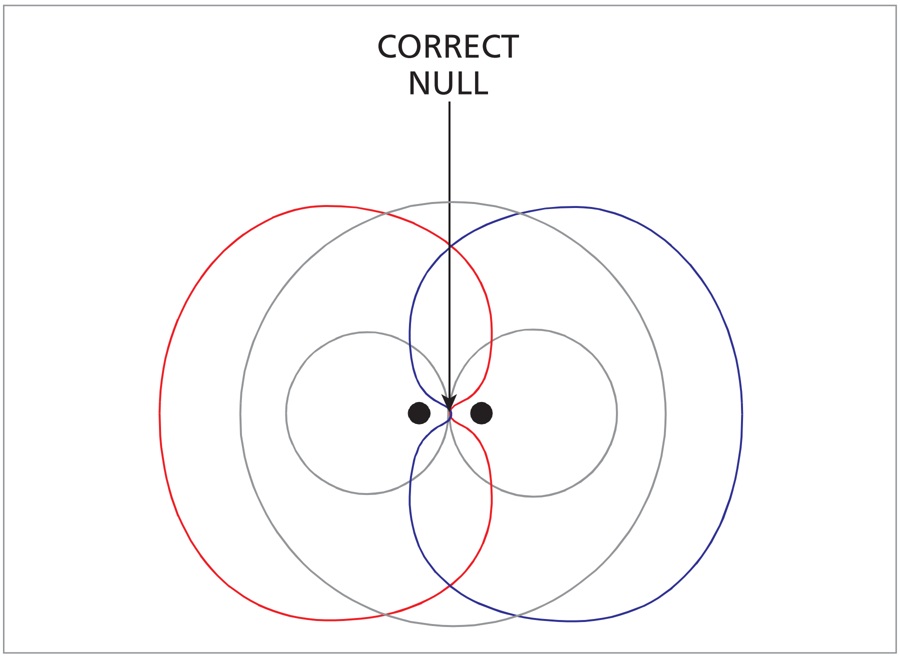


Figure 7.5

In reality it is not feasible to have a rotating loop outside the aircraft, so the loop is fixed and has four elements, two aligned with the fore-aft axis of the aircraft with the other two perpendicular to the fore-aft axis. The electrical fields are transmitted to a similar four elements in a goniometer reproducing the electro magnetic field detected by the aerial. The signal from the sense aerial is also fed to the goniometer where a search coil detects the unambiguous direction. The principle employed within the goniometer is as described above.

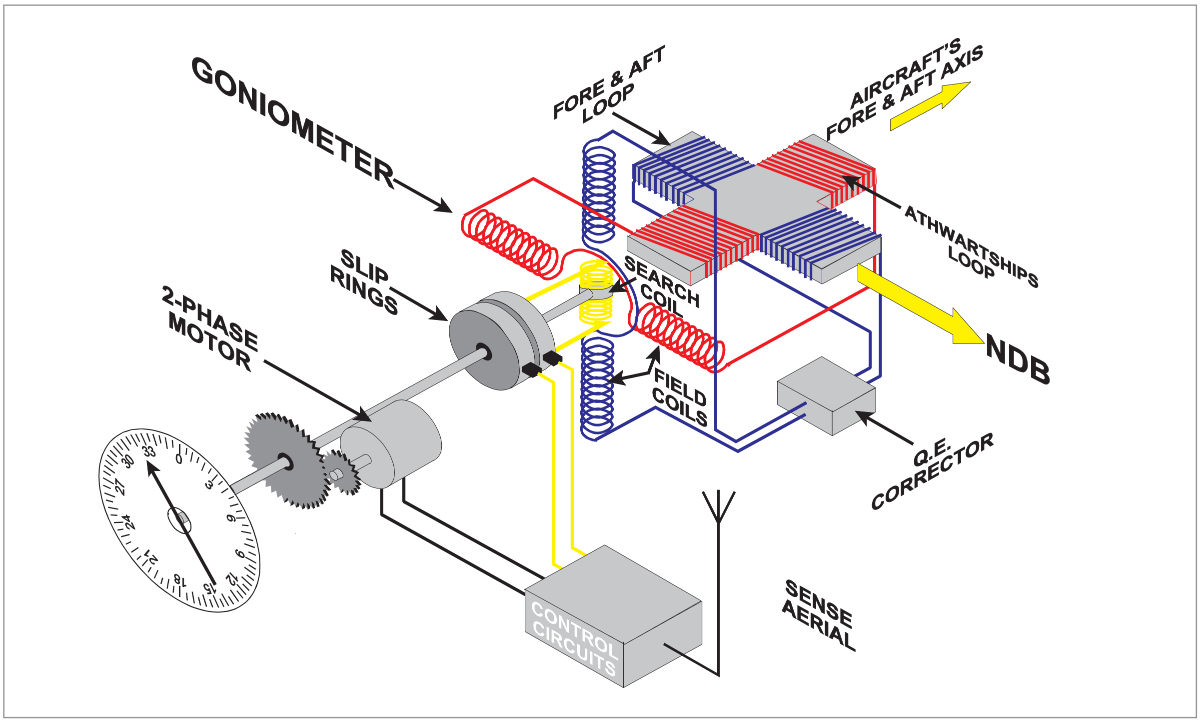


Figure 7.6 Fixed Loop ADF

Frequencies and Types of NDB

The allocated frequencies for NDBs are 190 - 1750 kHz in the LF and MF bands. Since the mode of propagation used is surface wave, most NDBs will be found between about 250 and 450 kHz. There are two types of NDB in current use:

Locator (L). These are low powered NDBs used for airfield or runway approach procedures or are co-located with, and supplement, the outer and middle markers of an ILS system. They normally have ranges of 10 to 25 NM and may only be available during an aerodrome's published hours of operation.

En route NDBs. These have a range of 50 NM or more, and where serving oceanic areas may have ranges of several hundred miles. They are used for homing, holding, en route and airways navigation.

Aircraft Equipment

The aircraft equipment comprises:

- A loop aerial
- A sense aerial
- A control unit
- A receiver
- A display

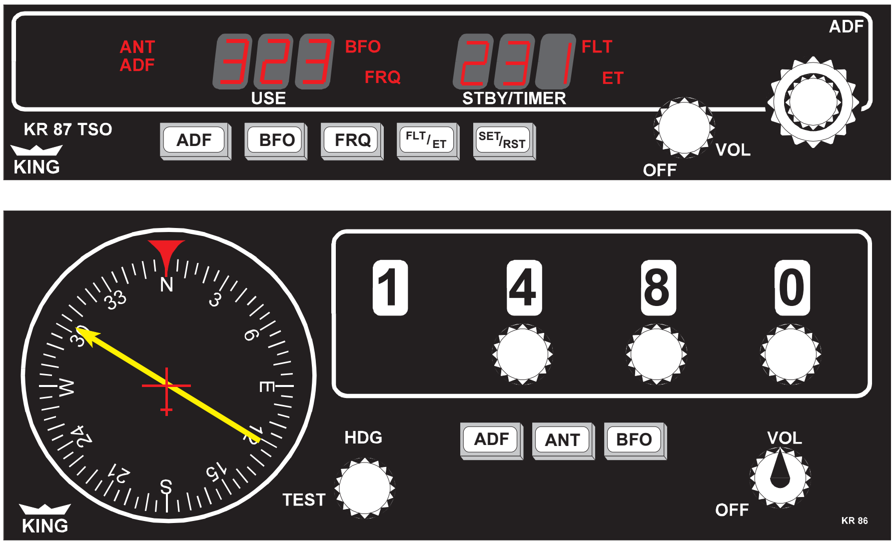


Figure 7.7 Two ADF Receivers

Emission Characteristics and Beat Frequency Oscillator (BFO)

The NDBs have a 2 or 3 letter identification and there are two types of emission:

N0NA1A **N0NA2A**

The N0N part of the emission is the transmission of an unmodulated carrier wave, which would not be detectable on a normal receiver, so a BFO is provided on ADF equipment. When selected, the BFO produces an offset frequency within the receiver which when combined with the received frequency produces a tone of say 400 or 1020 Hz.

The A1A part is the emission of an interrupted unmodulated carrier wave which requires the BFO to be on for aural reception. A2A is the emission of an amplitude modulated signal which can be heard on a normal receiver.

Hence, when using N0NA1A beacons, the BFO should be selected ON for (manual) tuning, identification and monitoring. N0NA2A beacons require the BFO ON for (manual) tuning but OFF for identification and monitoring. (The BFO may be labelled TONE or TONE/VOICE on some equipments).

Presentation of Information

The information may be presented on a relative bearing indicator (RBI) or a radio magnetic indicator (RMI). In either case the information being presented is relative bearing.

Figure 7.8 RBI

Figure 7.9 RMI

The RBI has a standard compass rose where 360° is aligned with the fore-aft axis of the aircraft, although with some RBIs it is possible to manually set heading to directly read the magnetic bearing. In the diagram the aircraft is heading 300°(M), the RBI is showing a relative bearing of 136°, thus the magnetic bearing is 300° + 136° - 360° = 076°. The information from the ADF to the RMI is still relative, but the RMI compass card is fed with magnetic heading, so the bearing shown is the magnetic bearing of the NDB.

The needle always points to the beacon (QDM) and the tail of the needle gives the QDR.

Uses of the Non-directional Beacon

- En route navigational bearings.
- Homing to or flying from the NDB when maintaining airway centre lines.
- Holding overhead at an assigned level in a race-track pattern.
- Runway instrument approach procedures.

Plotting ADF Bearings

The plotting of ADF bearings is dealt with in depth in the Navigation General syllabus. At this stage it is sufficient to remind the reader that the bearing is measured at the aircraft so variation to convert to a true bearing must be applied at the aircraft. Account will also need to be taken of the convergency between the aircraft and beacon meridians.

Track Maintenance Using the RBI

An aircraft is required to maintain track(s):

- When flying airway centre line between NDBs.
- When holding over an NDB or Locator.
- When carrying out a let-down procedure at an airfield based solely upon NDB(s)/Locator(s) or NDB(s)/Locators combined with other navaids.
- When requested by ATC to intercept and maintain a track or airway centre line.
- When carrying out interceptions.

Homing

Figure 7.10 shows an aircraft maintaining 360° relative bearing, in zero wind (zero drift). The aircraft is heading 077° and therefore will track inbound on 077°.

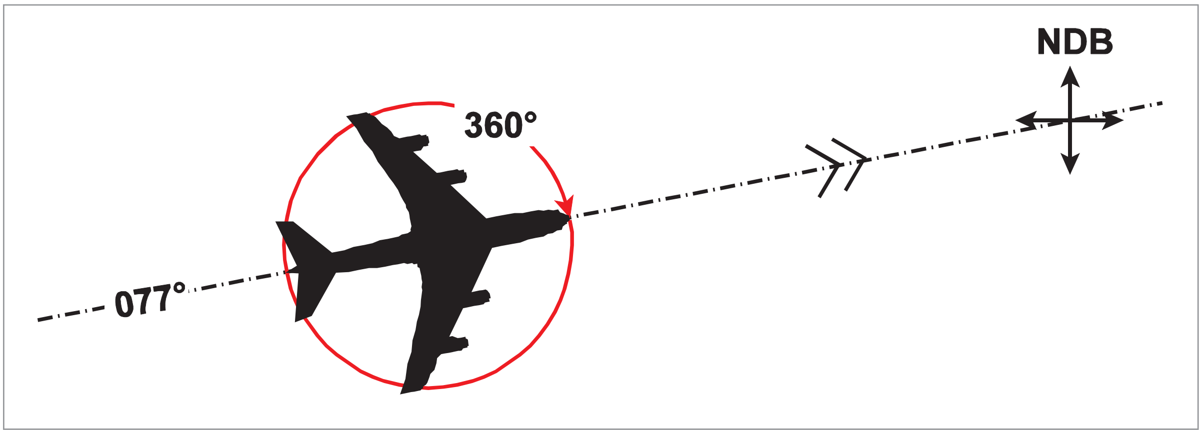


Figure 7.10 Homing in Zero Drift

Figure 7.11 shows an aircraft maintaining a relative bearing of 360°, with a crosswind from the left. As a result a curved track will be followed.

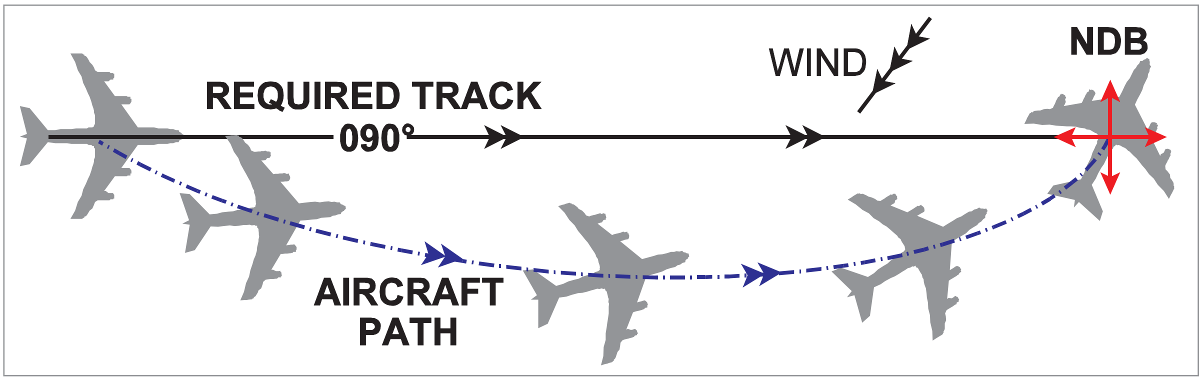


Figure 7.11 Homing Making no Allowance for Drift

Tracking Inbound

To achieve a required track inbound to an NDB, with a crosswind, the correct method is to allow for the anticipated drift therefore maintaining a constant track. In *Figure 7.12*, 20° Starboard drift is anticipated, so 20 is Subtracted from track. The aircraft is heading 060° with a relative bearing of 020°.

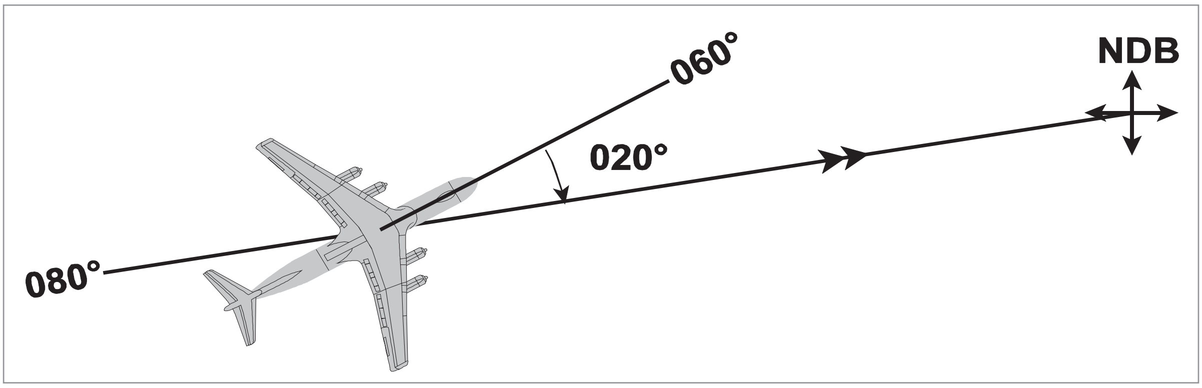


Figure 7.12

In *Figure 7.13*, 28° Port drift is anticipated, so this is added (Plus) to the track value. The aircraft is heading 108° with a relative bearing of 332°.

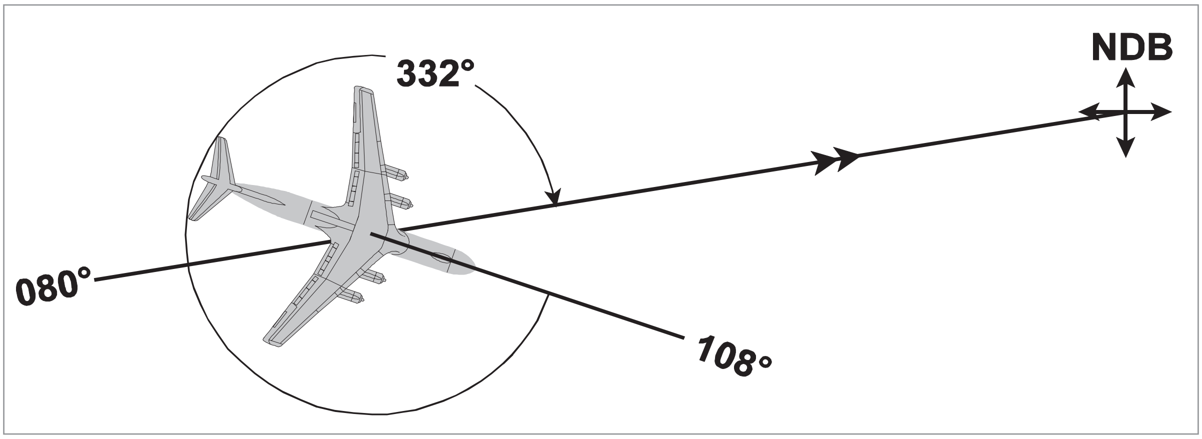


Figure 7.13

Tracking Outbound

Figure 7.14 shows an aircraft maintaining the required track outbound from an NDB in zero wind (zero drift) conditions. The aircraft is heading 260° and has a relative bearing of 180°.

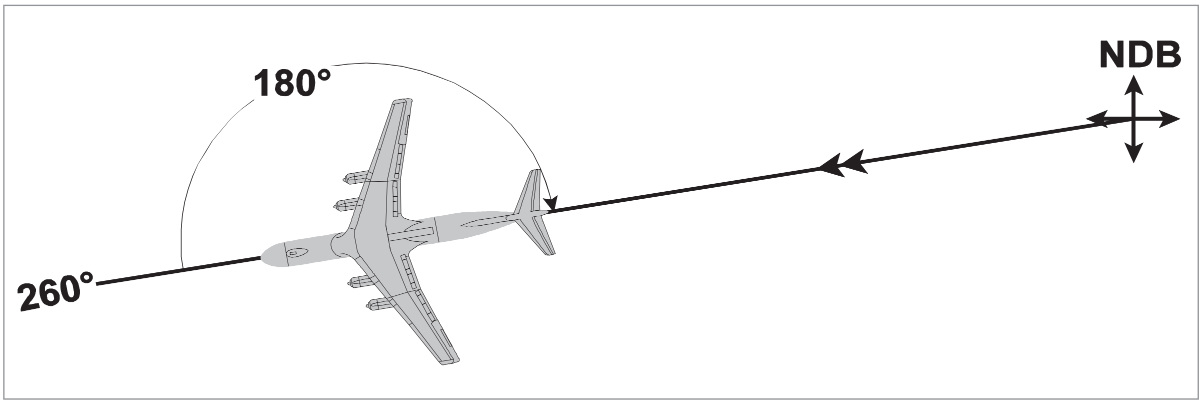


Figure 7.14

Figure 7.15 shows an aircraft maintaining a track of 100° in crosswind conditions where the drift is known. 23° of Starboard drift is anticipated, this is Subtracted from the track, therefore the heading is 077° with a relative bearing of 203° from the NDB.

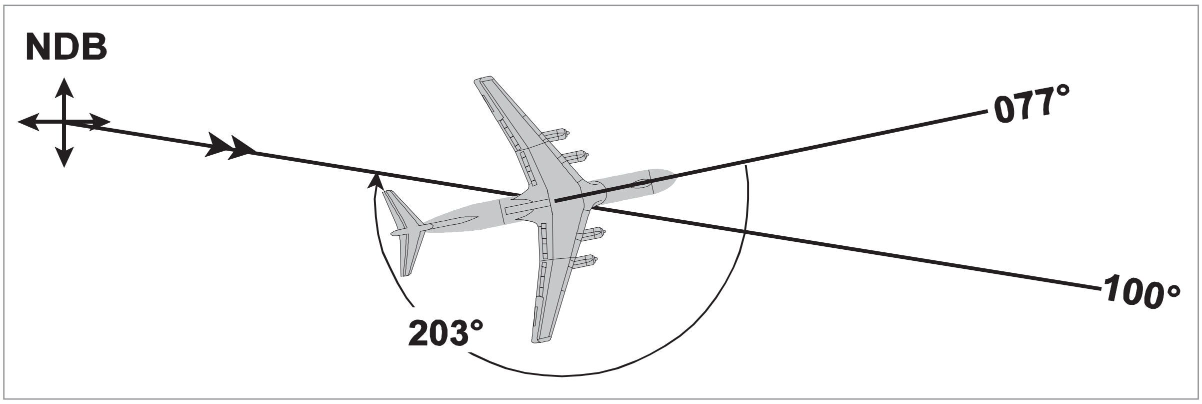


Figure 7.15

In *Figure 7.16* 20° Port drift is anticipated, this is added (Plus) to track giving an aircraft heading of 110° with a relative bearing of 160°.

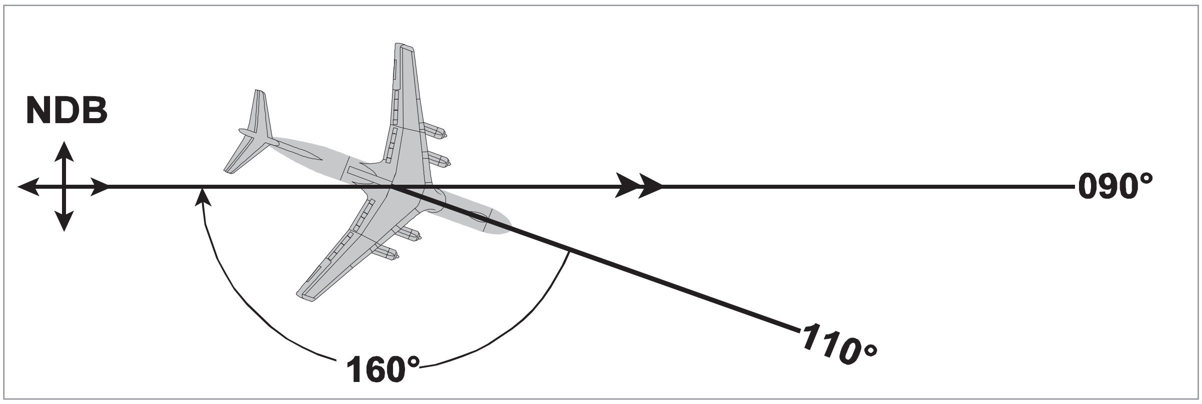


Figure 7.16

Drift Assessment and Regaining Inbound Track

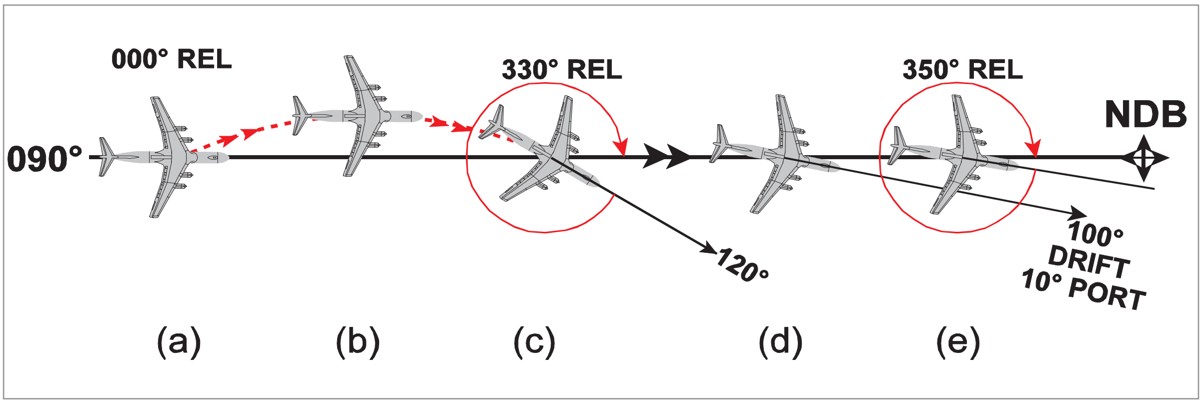


Figure 7.17 Assessing Drift Inbound

Initially, fly the aircraft on the required track with the beacon dead ahead (000° rel.).

Maintain the aircraft heading and watch the relative bearing indicator. If the relative bearing increases the aircraft is experiencing port drift.

Alter heading, say 30° starboard, to regain track. The relative bearing will become 330° when track is regained.

Assume a likely drift (say 10° port) and calculate a new heading to maintain track. When this heading has been taken up, the relative bearing will become 350°.

If the drift has been correctly assessed this relative bearing will be maintained until overhead the NDB. If the relative bearing changes however, further heading alterations and a new assessment of drift will be necessary.

Drift Assessment and Outbound Track Maintenance

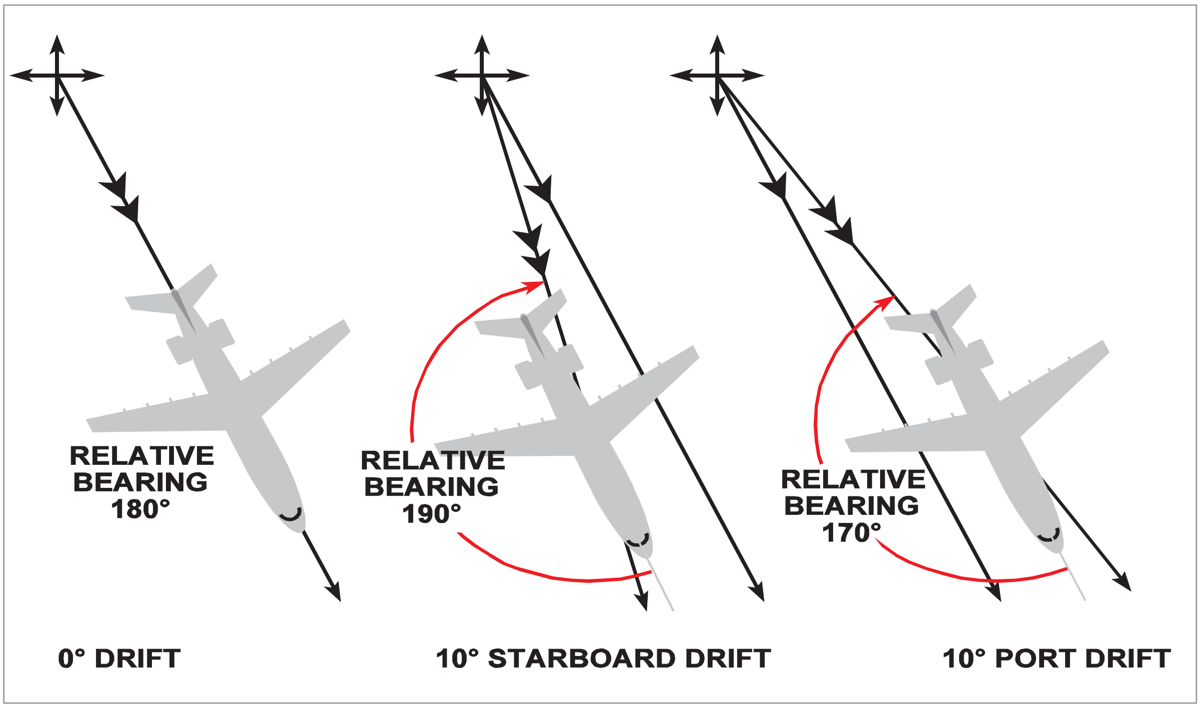


Figure 7.18 Drift Assessing Outbound

In *Figure 7.18* it can be seen that with zero drift the RBI indicates 180° relative. With 10° starboard drift, the relative bearing increases to 190°, and with 10° port drift the relative bearing decreases to 170°. To assess drift by this means the aircraft must maintain a steady heading from directly overhead the beacon.

When the drift has been assessed, alter heading port or starboard, by say 30°, to regain track, until the correct relative bearing of 210° or 150° is obtained. The aircraft is now back on track. The heading must now be altered to take into account the original assessment of drift.

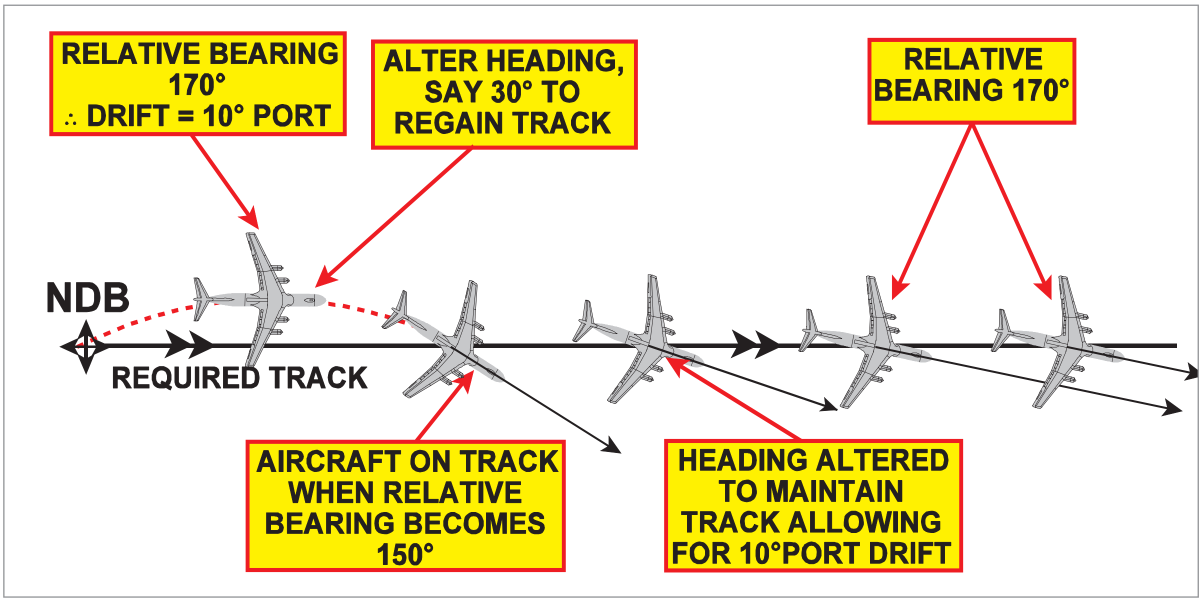


Figure 7.19 ***Determining*** *Drift and Maintaining Track away from an NDB*

Holding

When density of traffic or bad weather delay an aircraft's landing at an airport, the air traffic controller directs it to a **Holding Area**. The area, also known as a 'stack', is organized over a 'radio' beacon where each waiting aircraft flies a special circuit separated vertically from other aircraft by a minimum of 1000 ft. An aircraft drops to the next level as soon as it is free of other traffic, until it finally flies from the stack and comes in to land.

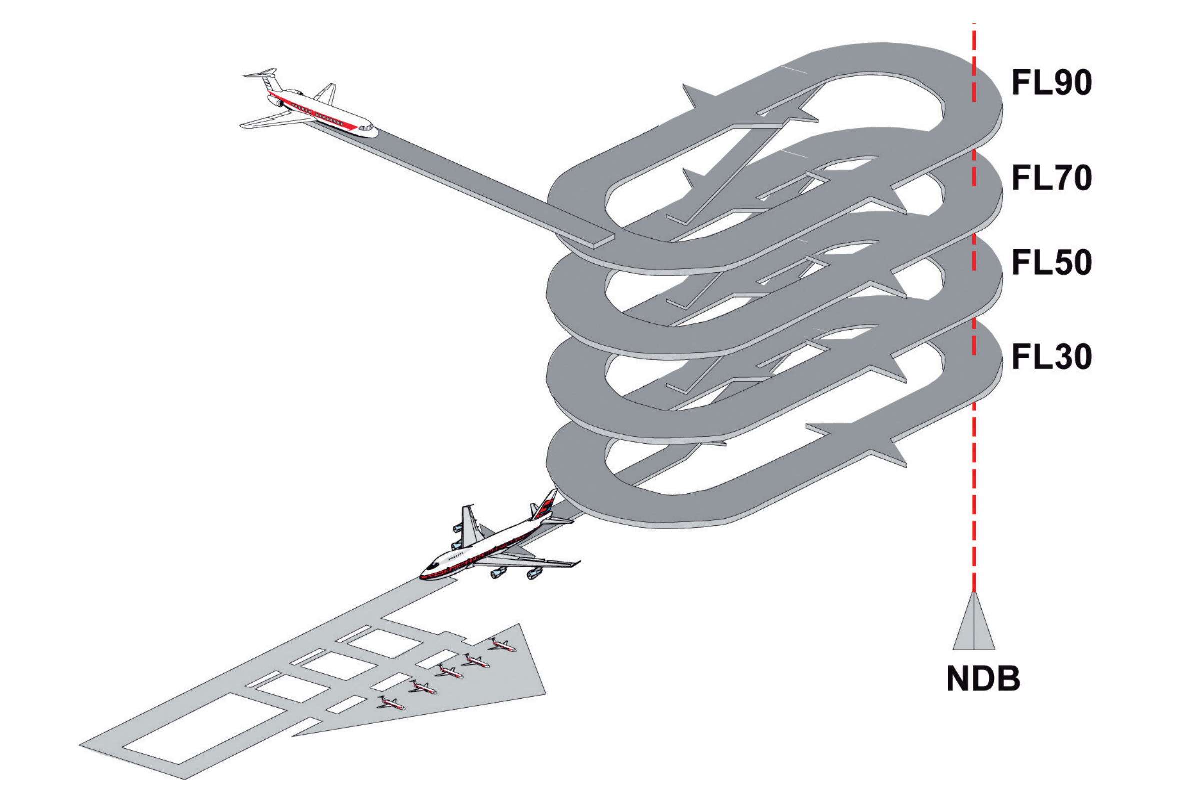


Figure 7.20 The holding system

Runway Instrument Approach Procedures

Most aerodromes have NDB runway instrument approach procedures. The pilot flies the published procedure in order to position the aircraft in poor weather conditions for a visual landing. The NDB may also be used in conjunction with other runway approach aids for the same purpose.

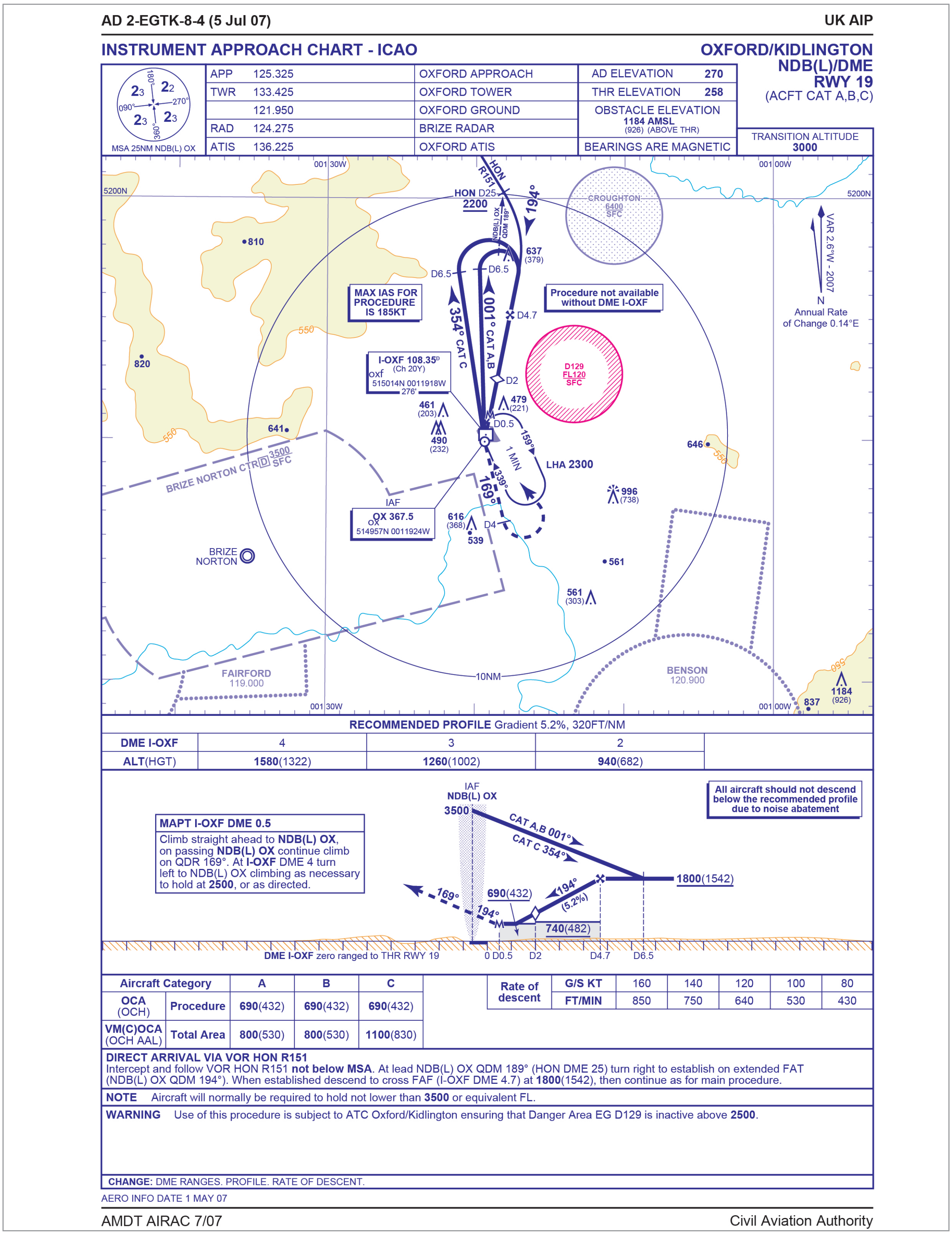


Figure 7.21 Example of an NDB instrument approach

Factors Affecting ADF Accuracy

Designated Operational Coverage (DOC)

The DOC of NDBs is based upon a daytime protection ratio (signal/noise ratio of 3:1) between wanted and unwanted signals that permits the required level of bearing accuracy. At ranges greater than those promulgated, bearing errors will increase. Adverse propagation conditions particularly at night will also increase bearing errors.

Static Interference

There are two types of static interference that can affect the performance of ADF:

Precipitation static is generated by the collision of water droplets and ice crystals with the aircraft. It causes a reduction in the signal/noise ratio which affects the accuracy of the bearings and can, in extreme circumstances completely mask the incoming signal. The indications on the RMI/RBI will be a wandering needle and the audio will have a background hiss, which is also likely to be present on VHF frequencies.

Thunderstorms have very powerful discharges of static electricity across the electromagnetic spectrum including LF and MF. These discharges cause bearing errors in the ADF. A static discharge in a cumulonimbus cloud (Cb) will be heard as a loud crackle on the audio and the needle will move rapidly to point to the Cb. When there are several active cells close together, it is possible for the needle to point to them for prolonged periods. Care must be taken in the use of ADF when Cb activity is forecast. It has been said that during Cb activity the only sensible use of the ADF is to indicate where the active cells are.

Night Effect

By day the D-region absorbs signals in the LF and MF bands. At night the D-region disappears allowing sky wave contamination of the surface wave being used. This arises for two reasons: phase interference of the sky wave with the surface wave because of the different paths and the induction of currents in the horizontal elements of the loop aerial. The effect is reduced by the aerial design having very short vertical elements and by screening the aerial above and below, but the contamination is not eliminated. The effect first becomes significant at 70 - 100 NM from the NDB. The effect is manifest by fading of the audio signal and the needle 'hunting' and is worst around dawn and dusk, when the ionosphere is in transition.

If ADF is to be used at night:

- Positively identify the NDB call sign.
- Continue to check the tuning and the identification.
- Avoid use of the equipment within 1 hour of sunrise or sunset.
- Use NDBs within their promulgated range which is valid during daytime only.
- Treat bearings with caution if the needle wanders and the signal fades.
- Cross-check NDB bearing information against other navigation aids.

Station Interference

Due to congestion of stations in the LF and MF bands, the possibility of interference from stations on or near the same frequency exists. This will cause bearing errors. By day, the use of an NDB within the DOC will normally afford protection from interference. However, at night, one can expect interference even within the DOC because of sky wave contamination from stations out of range by day. Therefore positive identification of the NDB at night should always be carried out.

Mountain Effect

Mountainous areas can cause reflections and diffraction of the transmitted radio waves to produce errors in ADF systems. These errors will increase at low altitude and can be minimized by flying higher.

Coastal Refraction

Radio waves speed up over water due to the reduced absorption of energy (attenuation) compared to that which occurs over land. This speeding up causes the wave front to bend (refract) away from its normal path and pull it towards the coast. Refraction is negligible at 90° to the coast but increases as the angle of incidence increases.

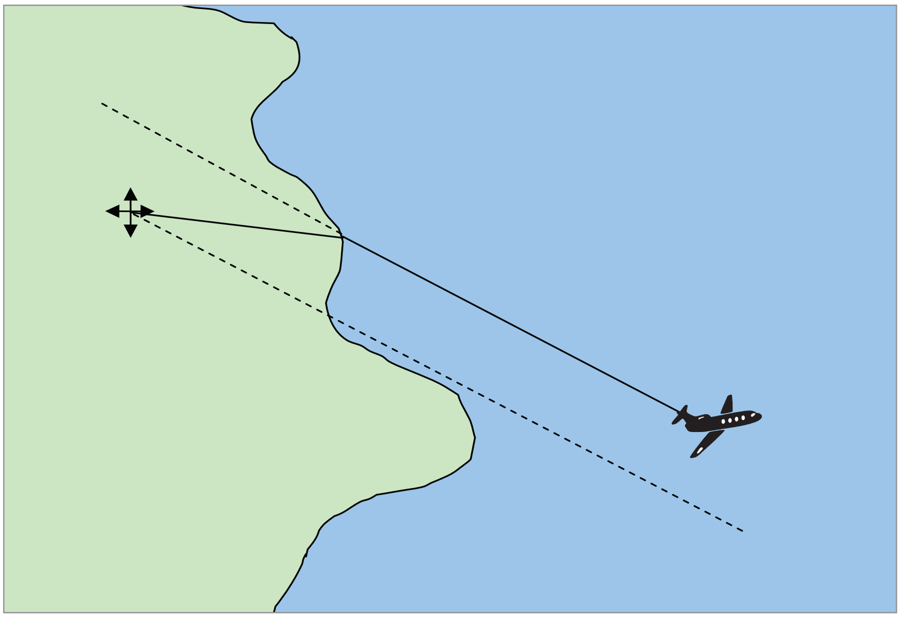


Figure 7.22 Coastal refraction

For an aircraft flying over the sea the error puts the aircraft position closer to the coast than its actual position.

The effect can be minimised by:

- Using NDBs on or near to the coast.
- Flying higher.
- Using signals that cross the coast at or near to 90°

Quadrantal Error

The theoretical reception polar diagram of the loop aerial is distorted by the airframe which produces a strong electrical field aligned fore and aft. Incoming NDB signals are thus refracted towards the fore and aft airframe axis. The maximum refraction occurs in the quadrants (i.e. on relative bearings of 045°, 135°, 225° & 315°.) Older ADF systems are regularly 'swung' to assess the value of quadrantal error. In modern aircraft the error is determined by the manufacturer and corrections are put into the equipment to reduce the effect to a minimum.

Angle of Bank (dip)

A loop aerial is designed to use vertically polarized waves for direction finding. If the incoming wave has any horizontal component of polarization it will induce currents in the top and bottom horizontal members of the loop resulting in a circulating current. This would destroy the nulls of polar diagram (similar to night effect) and reduce the accuracy of the bearings. The angle of bank during a turn causes currents to be induced in the horizontal elements of the loop thereby leading to a bearing error which is referred to as dip error. This error is only present when the aircraft is not in level flight.

Lack of Failure Warning System

False indications due to a failure in the system are not readily detectable because of the absence of failure warning on most ADF instruments. Particular care should therefore be exercised in identifying and monitoring the NDB and independent cross-checks made with other navigational aids where possible. It is essential that when using the ADF as the primary navigation aid, for example for a runway approach procedure, that it is continuously monitored to detect any failure.

Factors Affecting ADF Range

The major factors which affect the range of NDB/ADF equipment are listed below:

NDB transmission power; the range is proportional to the square root of the power output i.e. to double the NDB range, quadruple the power output of the transmitter.

NDB range is greater over water:

$3 \times \sqrt{P}\,(W)$ over water

$2 \times \sqrt{P}\,(W)$ over land

Note: Using ranges calculated by these formulae does not guarantee that the aircraft will be within the DOC.

The lower the frequency, the greater the surface wave (greater diffraction, lower attenuation).

All precipitation, including falling snow, reduces the effective range and accuracy of ADF bearings.

N0NA1A NDBs have greater ranges than N0NA2A. But note that ICAO Annex 10 recommends the use of N0NA2A for long range beacons.

Receiver quality.

Accuracy

The accuracy of ADF is +/-5° within the designated operational coverage, by day only. This refers to the measured bearing and does not include any compass error.

ADF Summary

NDB Types of NDB: Range (NM):	Ground transmitter in LF or MF band (190 - 1750 kHz) Locator (L) - airfield let-down (10 - 25 NM) En Route - Nav-aid (50 NM or more) $3 \times \sqrt{P}\,(W)$ over water $2 \times \sqrt{P}\,(W)$ over land
ADF	Airborne equipment - aerials, receiver, control unit, indicator (RBI / RMI)
Principle of operation	(Relative) Bearing by switched cardioids
Frequencies	190 - 1750 kHz (LF & MF)
Emission characteristics	N0NA1A - BFO ON for tuning, identification and monitoring N0NA2A - BFO ON for tuning, OFF otherwise
Presentation	RBI or RMI
Uses of NDB	Homing, Holding, Approach, En route nav-aid
Errors	Static interference (precipitation and thunderstorms) Station interference Night effect Mountain effect Coastal refraction Quadrantal error Bank angle (dip) Lack of failure warning
Accuracy (Day Only)	+/- 5° within the DOC

Figure 7.23

Questions

1. **The phenomenon of coastal refraction which affects the accuracy of ADF bearings:**

   a. is most marked at night
   b. can be minimized by using beacons situated well inland
   c. can be minimized by taking bearings where the signal crosses the coastline at right angles
   d. is most marked one hour before to one hour after sunrise and sunset

2. **An aircraft is intending to track from NDB 'A' to NDB 'B' on a track of 050°(T), heading 060°(T). If the RBI shows the relative bearing of 'A' to be 180° and the relative bearing of 'B' to be 330° then the aircraft is:**

   a. port of track and nearer 'A'
   b. port of track and nearer 'B'
   c. starboard of track and nearer 'A'
   d. starboard of track and nearer 'B'

3. **ADF quadrantal error is caused by:**

   a. static build up on the airframe and St. Elmo's Fire
   b. the aircraft's major electrical axis, the fuselage, reflecting and re-radiating the incoming NDB transmissions
   c. station interference and/or night effect
   d. NDB signals speeding up and bending as they cross from a land to water propagation path

4. **The overall accuracy of ADF bearings by day within the promulgated range (DOC) is:**

   a. ± 3°
   b. ± 5°
   c. ± 6°
   d. ± 10°

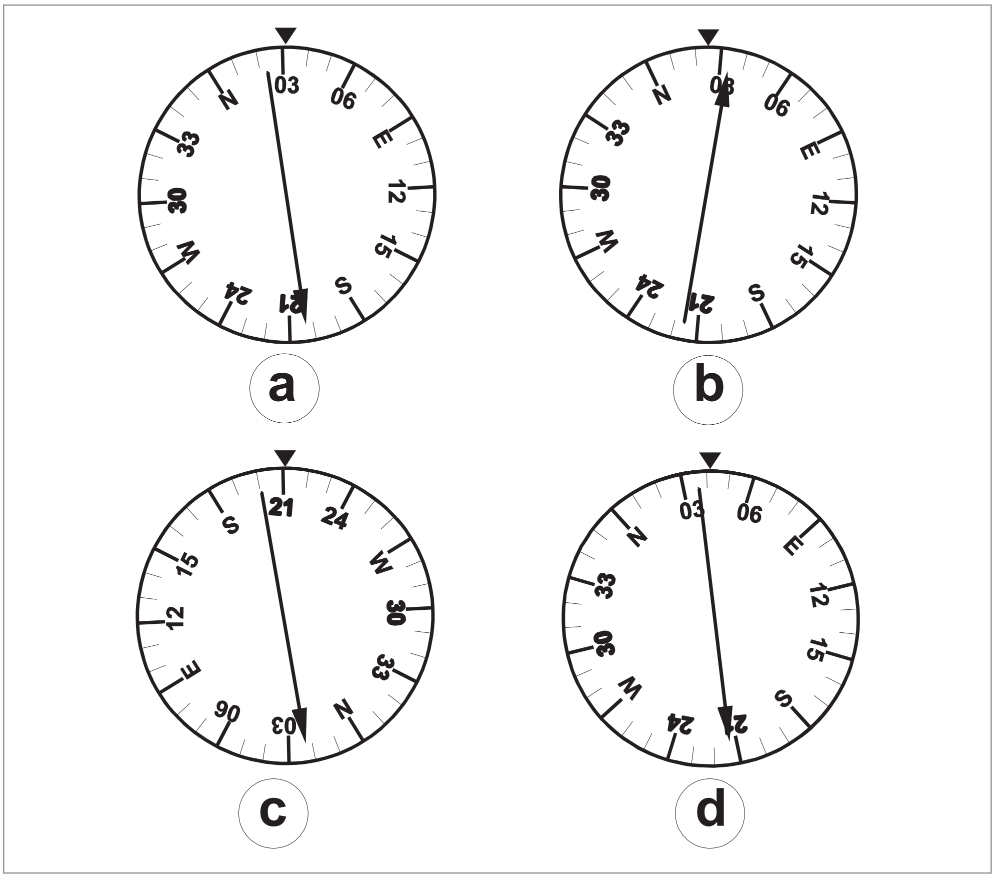
5. **In order to Tune, Identify and Monitor N0NA1A NDB emissions the BFO should be used as follows:**

	Tune	Identify	Monitor
a.	On	On	Off
b.	On	On	On
c.	On	Off	Off
d.	Off	Off	Off

6. **The magnitude of the error in position lines derived from ADF bearings that are affected by coastal refraction may be reduced by:**

   a. selecting beacons situated well inland
   b. only using beacons within the designated operational coverage
   c. choosing N0NA2A beacons
   d. choosing beacons on or near the coast

7. **An aircraft is tracking away from an NDB on a track of 023°(T). If the drift is 8° port and variation 10° west, which of the RMIs illustrated below shows the correct indications?**



8. **The BFO facility on ADF equipment should be used as follows when an NDB having N0NA1A type emission is to be used:**

a. BFO on for tuning and identification but may be turned off for monitoring
b. BFO on for tuning but can be turned off for monitoring and identification purpose
c. BFO off during tuning, identification and monitoring because this type of emission is not modulated
d. BFO should be switched on for tuning, ident and monitoring

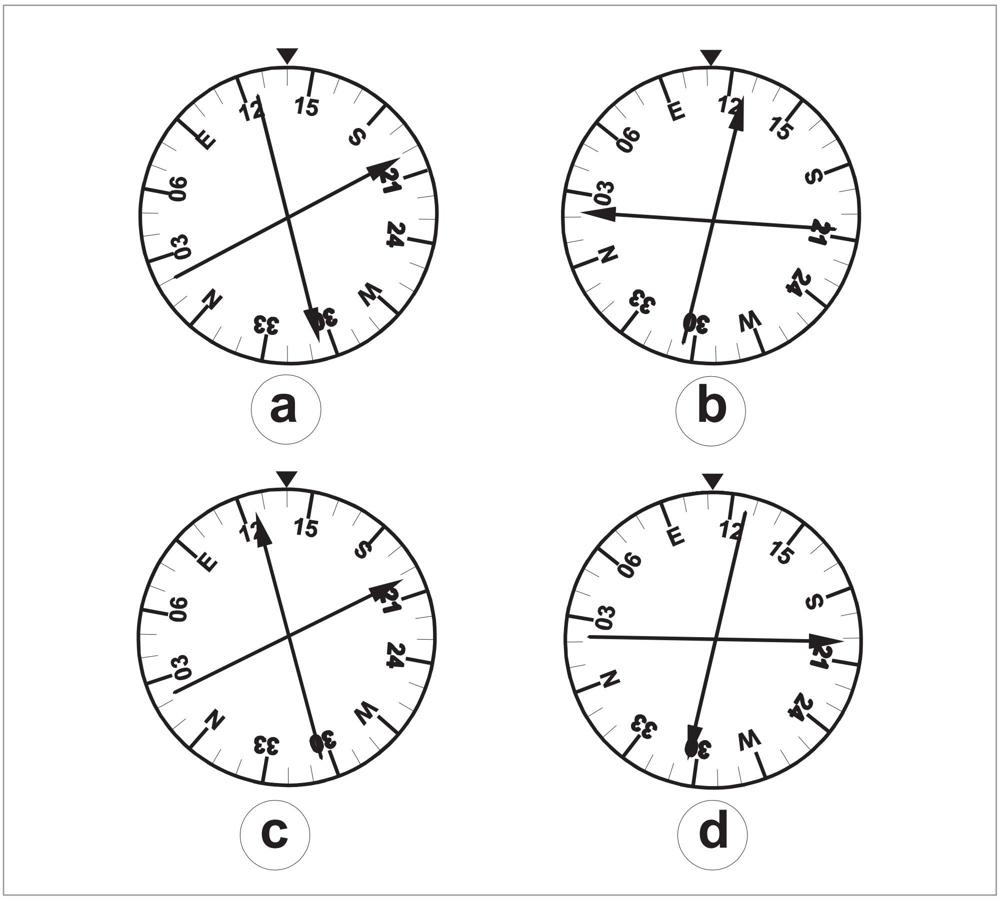
9. **The protection ratio of 3:1 that is provided within the promulgated range/designated operational coverage of an NDB by day cannot be guaranteed at night because of:**

a. long range sky wave interference from other transmitters
b. sky wave signals from the NDB to which you are tuned
c. the increased skip distance that occurs at night
d. the possibility of sporadic E returns occurring at night

10. **An aircraft has an RMI with two needles. Assume that:**

i) The aircraft is outbound from NDB Y on a track of 126°(M) drift is 14° Port
ii) A position report is required when crossing a QDR of 022 from NDB Z

Which of the diagrams below represents the RMI at the time of crossing the reporting point?



11. **Each NDB has a range promulgated in the COMM section of the AIP. Within this range interference from other NDBs should not cause bearing errors in excess of:**

a. day ± 5°
b. night ± 10°
c. day ± 6°
d. night ± 5°

12. **The range promulgated in the AIP and flight guides for all NDBs in the UK is the range:**

a. within which a protection ratio of 3:1 is guaranteed by day and night
b. up to which bearings can be obtained on 95% of occasions
c. within which bearings obtained by day should be accurate to within 5°
d. within which protection from sky wave protection is guaranteed

13. **In order to resolve the 180° directional ambiguity of a directional LOOP aerial its polar diagram is combined with that of a SENSE aerial .... to produce a .... whose single null ensures the ADF needle moves the shortest distance to indicate the correct..............**

a at the aircraft, cardioid, radial
b. at the transmitter, limacon, bearing
c. at the aircraft, limacon, bearing
d. at the aircraft, cardioid, bearing

14. **The protection ratio afforded to NDBs in the UK within the promulgated range (DOC) applies:**

a. by day only
b. by night only
c. both day and night
d. at dawn and dusk

15. **The phenomena of coastal refraction affecting ADF bearings is caused by the signal .... when it reaches the coastline and bending .... the normal to the coast:**

a.	accelerating	towards
b.	decelerating	towards
c.	accelerating	away from
d.	decelerating	away from

16. **In an ADF system, night effect is most pronounced:**

a. during long winter nights
b. when the aircraft is at low altitude
c. when the aircraft is at high altitude
d. at dusk and dawn

17. **When the induced signals from the loop and the sense antenna are combined in an ADF receiver, the resultant polar diagram is:**

a. a limacon
b. a cardioid
c. figure of eight shaped
d. circular

18. **When flying over the sea and using an inland NDB to fix position with a series of position lines, the plotted position in relation to the aircraft's actual position will be:**

a. further from the coast
b. closer to the coast
c. co-incident
d. inaccurate due to the transmitted wave front decelerating

19. An aircraft on a heading of 235°(M) shows an RMI reading of 090° with respect to an NDB. Any quadrantal error which is affecting the accuracy of this bearing is likely to be:

a. a maximum value
b. a very small value
c. zero, since quadrantal error affects only the RBI
d. zero, since quadrantal error affects only the VOR

20. The principal propagation path employed in an NDB/ADF system is:

a. sky wave
b. surface wave
c. direct wave
d. ducted wave

21. The ADF of an aircraft on a heading of 189°(T) will experience the greatest effect due to quadrantal error if the NDB bears:

a. 234°(T)
b. 279°(T)
c. 225°(T)
d. 145°(T)

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	d	b	b	b	d	d	d	a	a	a	c

13	14	15	16	17	18	19	20	21
d	a	c	d	b	b	a	b	a

Chapter

8

VHF Omni-directional Range (VOR)

Introduction

Figure 8.1 A combined VOR/DME

The VHF Omni-directional Range (VOR) was adopted as the standard short range navigation aid in 1960 by ICAO. It produces bearing information usually aligned with magnetic north at the VOR location. It is practically free from static interference and is not affected by sky waves, which enables it to be used day and night. When the VOR frequency is paired with a co-located Distance Measuring Equipment (DME) an instantaneous range and bearing (Rho-Theta) fix is obtained. The equipment operates within the frequency range of 108 - 117.95 MHz.

VOR has the following uses:

- Marking the beginning, the end and centre line of airways or sections of airways.
- As a let-down aid at airfields using published procedures.
- As a holding point for aircraft.
- As a source of en route navigational position lines.

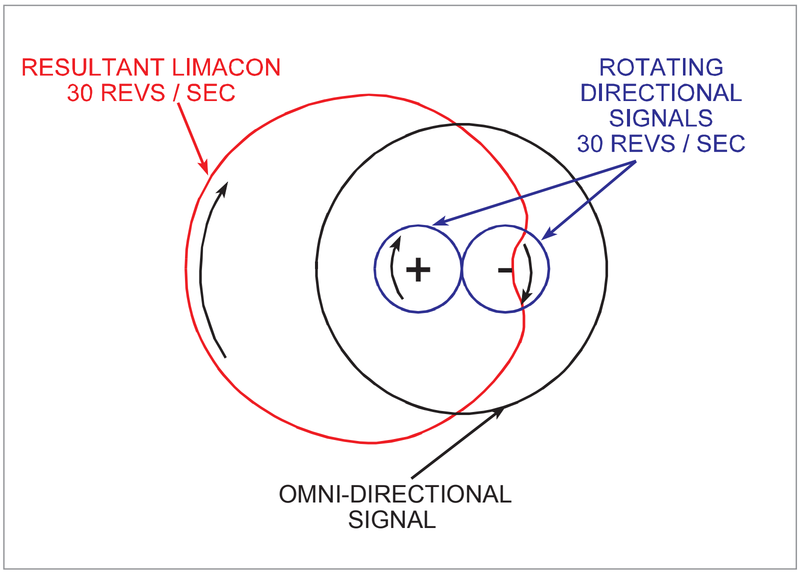


Figure 8.2 A VOR Polar Diagram

The Principle of Operation

VOR bearing is obtained by phase comparison:

- An aircraft's VOR receiver measures the phase difference (angular difference) between two signals from the VOR transmitter:
    - a 30 Hz frequency modulated omni-directional, reference signal which produces constant phase regardless of a receiver's bearing from the VOR, and
    - a 30 Hz amplitude modulated variable phase (directional) signal created by the rotating transmission pattern (limaçon).
- The 30 Hz FM reference signal is synchronized with the 30 revs/sec rotating directional AM signal (limaçon) such that:
    - the two 30 Hz modulations are in phase to an aircraft's VOR receiver when it is due magnetic north of the VOR beacon, and
    - the phase difference measured at any other point will equate to the aircraft's magnetic bearing from the VOR.

The two 30 Hz signals are modulated differently to prevent interaction and merging at the aircraft's receiver. The rotating limaçon polar diagram, which provides the directional information, is created by combining the polar diagrams of the rotating loop and reference signal. In early VORs the loop rotation was mechanical; modern VORs use electronic circuitry.

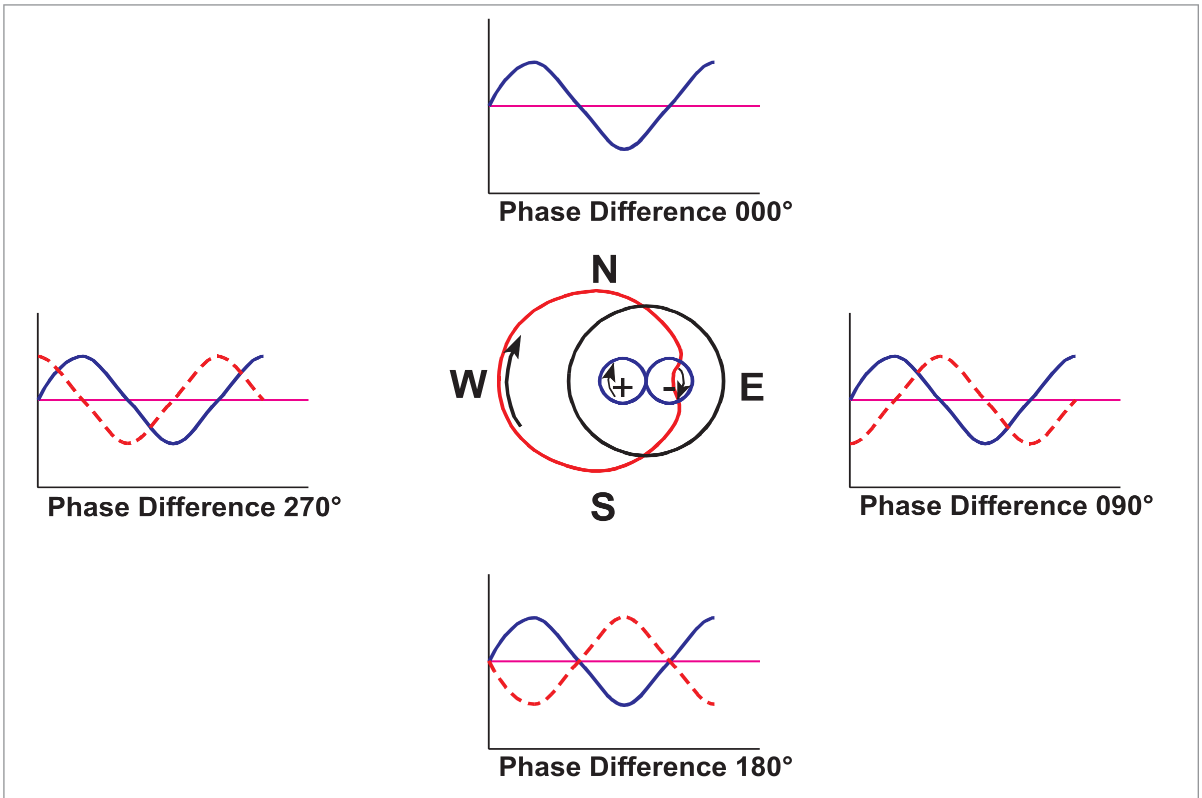


Figure 8.3 Phase differences corresponding to the cardinal points

Figure 8.3. shows one revolution of a limaçon with phase differences corresponding to four cardinal points. The blue sine wave is the reference signal. Hence, for example:

- A phase diff. of 227° measured at the aircraft = 227° Radial.
- A phase diff. of 314° measured at the aircraft = 314° Radial.

Thus a VOR beacon transmits bearing information continuously. This information is supplied even during the identification period.

Terminology

A Radial (QDR) is a magnetic bearing FROM a VOR beacon.

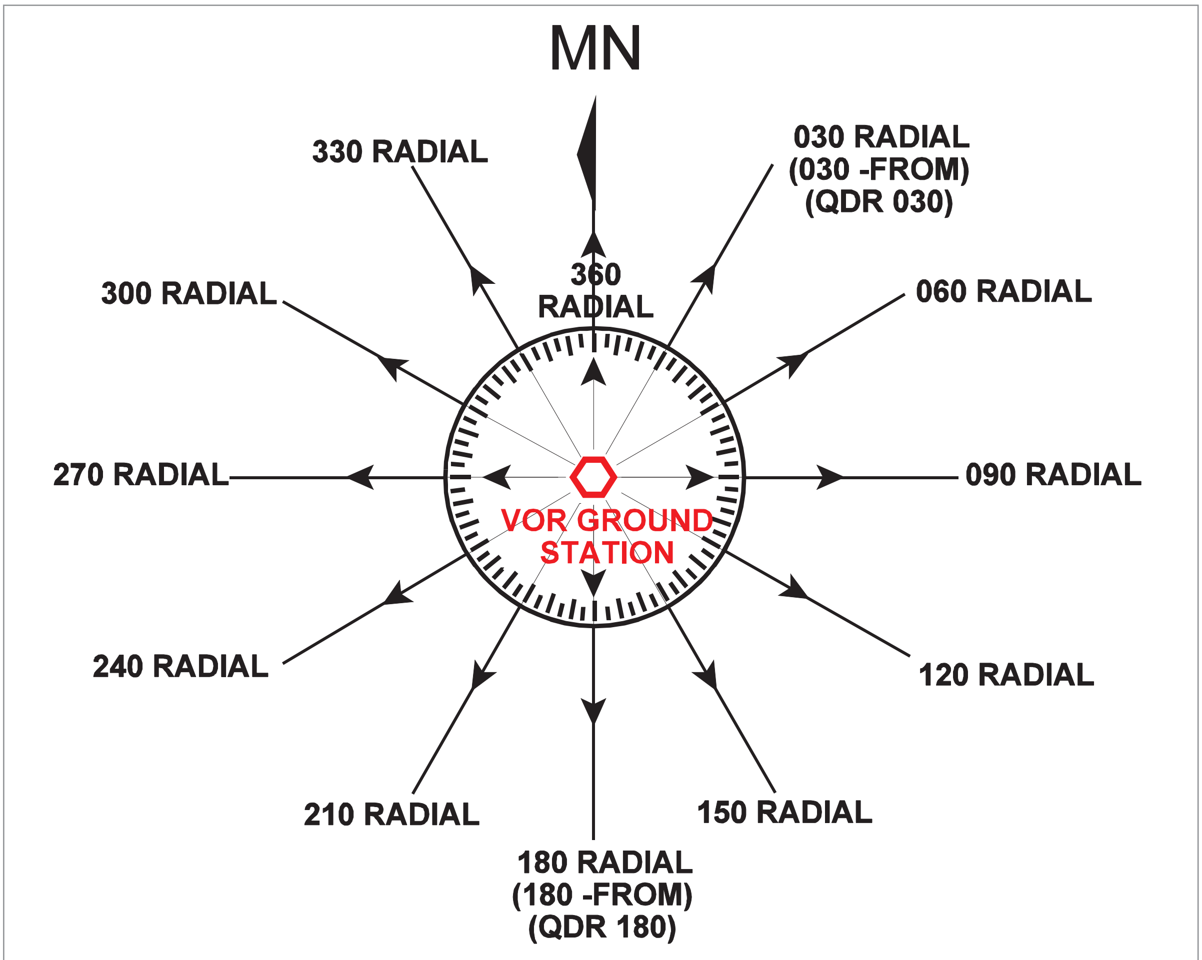


Figure 8.4 A Radial is a Magnetic Bearing from the VOR (i.e. QDR)

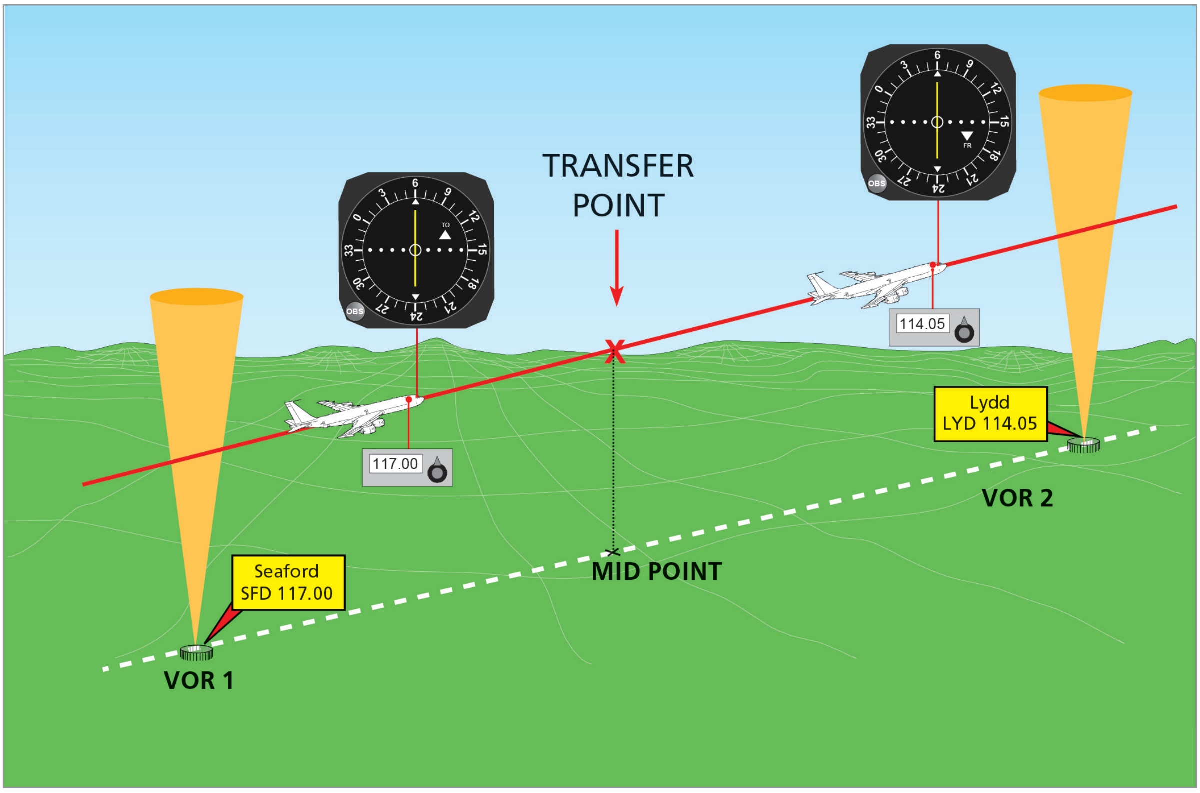


Figure 8.5 Tracking Between Two VORs

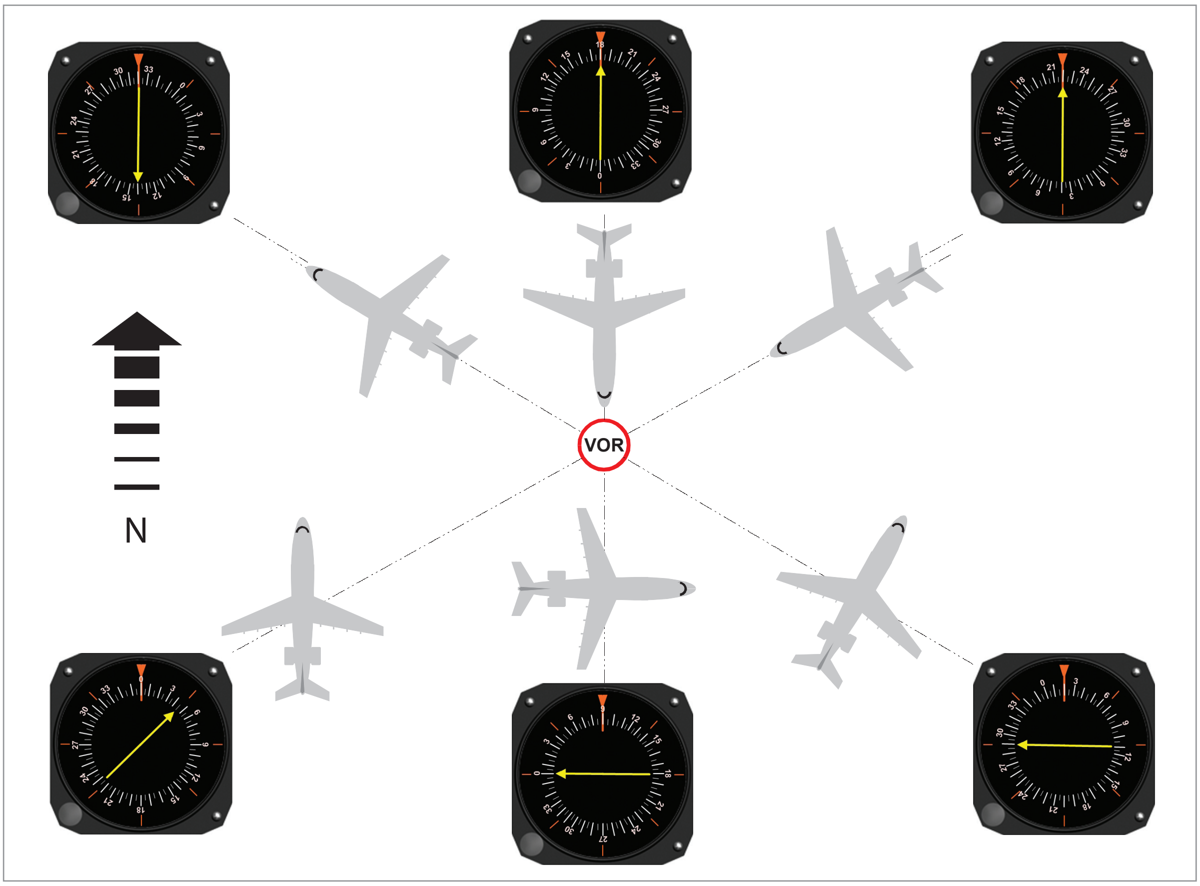


Figure 8.6 RMI Usage

Transmission Details

VOR beacons operate within the VHF band (30-300 MHz) between 108.0 - 117.95 MHz as follows:

- **40 channels, 108-112 MHz:**

  This is primarily an ILS band but ICAO has allowed it to be shared with short range VORs and Terminal VORs (TVOR): 108.0, 108.05, 108.20, 108.25, 108.40, 108.45 ..... 111.85 MHz (even decimals and even decimals plus 0.05 MHz)

- **120 channels, 112 - 117.95 MHz (a channel every 0.05 MHz):**

The emission characteristics are **A9W**:

A = main carrier amplitude modulated double side-band.

9 = composite system.

W = combination of telemetry, (telephony) and telegraphy.

Identification

UK VORs use 3 letter aural Morse sent at approximately 7 groups/minute, at least every 10 seconds. The 'ident' may also be in voice form e.g. "This is Miami Omni etc" immediately followed by the Morse ident. The voice channel is used to pass airfield information via ATIS. This information uses AM (amplitude modulation) and is transmitted at the same time as the bearing information. A continuous tone or a series of dots identifies a TEST VOR (VOT).

Monitoring

All VOR beacons are monitored by an automatic site monitor. The monitor will warn the control point and remove either the identification and the navigational signals or switch off the beacon in the event of the following:

- Bearing information change exceeding 1°.
- A reduction of >15% in signal strength, of both or either of the 30 Hz modulations, or of the RF carrier frequency.
- A failure of the monitor.

When the main transmitter is switched off the standby transmitter is brought on-line and takes time to stabilise. During this period the bearing information can be incorrect and no identification is transmitted until the changeover is completed.

Hence, do not use the facility when no identification is heard. It is vital to monitor a terminal VOR let down into an airfield. If a VOR is transmitting the identification TST it indicates that the VOR is on test and the bearing information should not be used.

Types of VOR

CVOR	Conventional VOR is used to define airways and for en-route navigation.
BVOR	A broadcast VOR which gives weather and airfield information between beacon identification.
DVOR	A Doppler VOR - this overcomes siting errors.
TVOR	Terminal VOR which has only low power; and is used at major airfields.
VOT	This is found at certain airfields and broadcasts a fixed omni-directional signal for a 360° test radial. This is not for navigation use but is used to test an aircraft's equipment accuracy before IFR flight. More than +/-4° indicates that equipment needs servicing.
VORTAC	Co-located VOR and TACAN (DME) beacons.
DBVORTAC	Combination.

The Factors Affecting Operational Range of VOR

The higher the transmitter power, the greater the range. Thus en route VORs with a 200 watt transmitter will have about a 200 NM range, and a TVOR will normally transmit at 50 watts.

The transmitter and receiver height will also have an effect on the operational range of VOR as the transmissions give line of sight ranges, plus a slight increase due to atmospheric refraction. This can be assessed by using the formula:

Maximum theoretical reception range (NM) = $1.23 \times (\sqrt{h_1} + \sqrt{h_2})$

where: h_1 = Receiver height in feet AMSL, and

h_2 = Transmitter height in feet AMSL.

Uneven terrain, intervening high ground, mountains, man-made structures etc., cause VOR bearings to be stopped (screened), reflected, or bent (scalloping), all of which give rise to bearing errors.

Where such bearing errors are known, AIPS will publish details: e.g. "Errors up to 5.5° may be experienced in sector 315° - 345° to 40 NM".

Designated Operational Coverage - (DOC)

To guarantee no co-frequency interference between the 160 frequencies available worldwide, it would be necessary to separate co-frequency beacons by at least twice their anticipated line of sight range, e.g. an aircraft at a height of 25 000 ft and the VOR situated at MSL.

Reception range (NM) = $1.23 \times \sqrt{25\,000}$

= 194.5 NM

Separation = 389 NM

Transmitter power, propagation paths and the degree of co-frequency interference protection required, necessitate co-frequency beacons to be separated for planning purposes by an extra 100 NM to about 500 NM. In practice, a beacon is protected as far as is deemed necessary and this is not always the anticipated line of sight reception range.

In the UK this protection is denoted by a DOC, specified as a range and altitude, e.g a DOC of 50/25 published in AIPs means that an aircraft should not experience co-frequency interference within 50 NM of a VOR beacon, up to a height of 25 000 ft. The DOC may also vary by sectors and it is valid day and night. Use of a VOR outside its DOC can lead to navigation errors. Refer to the latest AIC.

Note: When super-refraction conditions exist interference may be experienced within the DOC.

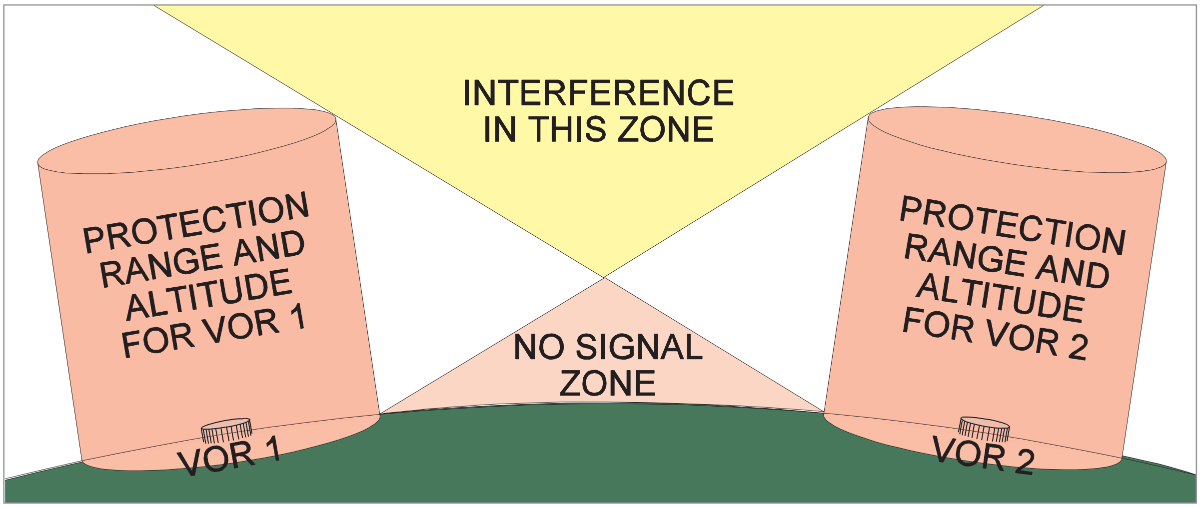


Figure 8.7 Designated Operational Coverage.

VOR 1: DOC 50/25 = No interference within 50 NM range up to 25 000 ft.

VOR 2: DOC 100/50 = No interference within 100 NM range up to 50 000 ft.

Factors Affecting VOR Beacon Accuracy

Site error is caused by uneven terrain such as hills and man-made structures, trees and even long grass, in the vicinity of the transmitter. The error to radiated bearings is termed 'VOR course-displacement error'. Ground VOR beacon site error is monitored to ± 1° accuracy.

Propagation error is caused by the fact that, having left the VOR site with ±1° accuracy, the transmissions are further affected by terrain and distance. At considerable range from the VOR, 'bends' or 'scalloping' can occur. VOR scalloping is defined as an imperfection or deviation in the received VOR signal. It causes the signal to 'bend' as a result of reflections from buildings or terrain; it causes the Course Deviation Indicator to slowly or rapidly shift from side to side.

Airborne equipment errors are caused by aircraft equipment assessing and converting the phase differences to 1° of bearing; maximum aircraft equipment error should be ± 3°.

The above errors are aggregated to give a **total error of ± 5°**. In addition there is pilotage error due to the fact that as an aircraft approaches the VOR the 1° radials get closer together.

The Cone of Ambiguity

As the VOR is approached, the radials converge and the VOR needle becomes more sensitive. Near the VOR overhead the needle oscillates rapidly and the 'OFF' flag may appear momentarily; also the 'TO/FROM' display alternates. This is all caused by the cone where there is no planned radiation. This is known as the cone of ambiguity or confusion. Once the aircraft has flown through this cone the readings at the aircraft will stabilize.

Coverage

The VOR shall provide signals to permit satisfactory operation of a typical aircraft installation at the levels and distances required for operational reasons, and up to a minimum elevation angle of 40°. In practice, modern VOR beacons are capable of providing usable signals within 60° to 80° above the horizon.

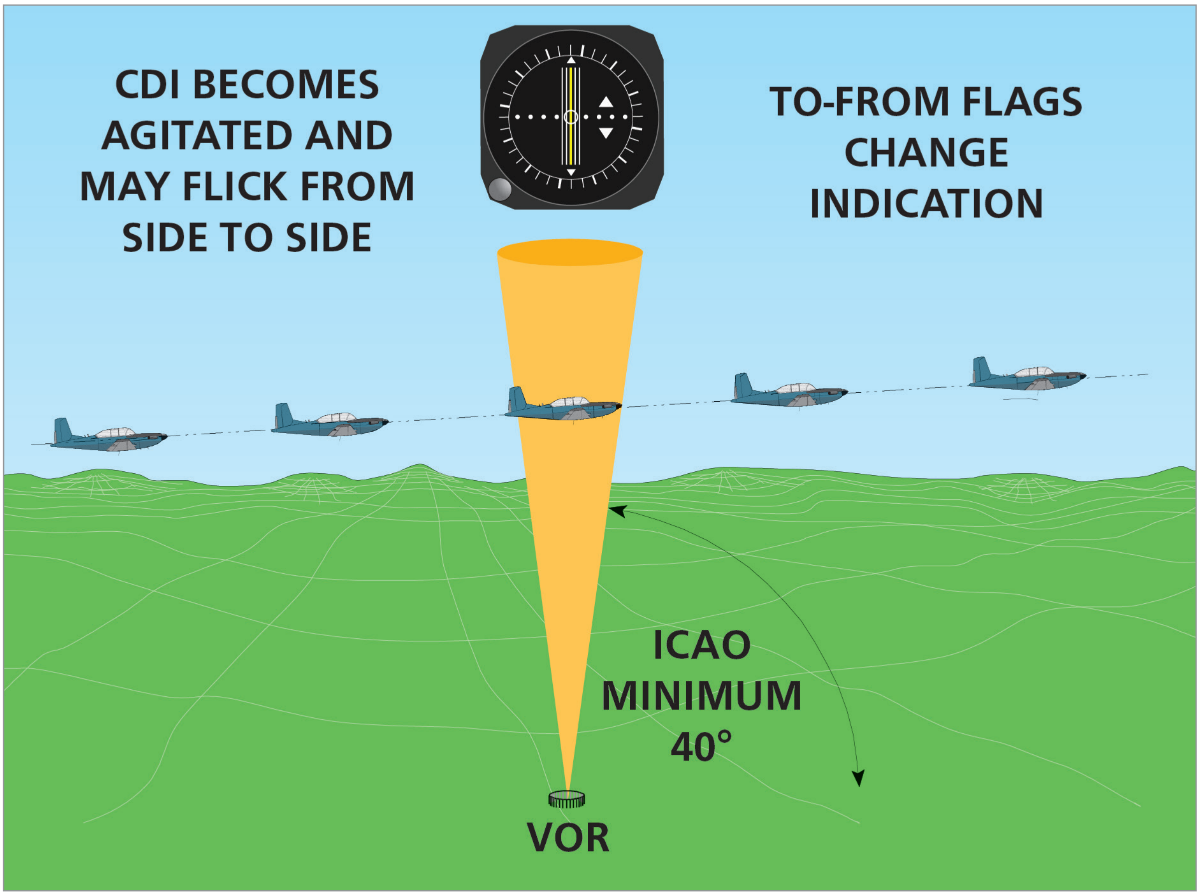


Figure 8.8 The Cone of Confusion

Doppler VOR (DVOR)

Doppler VORs are second generation VORs. Although their transmission frequencies are the same, the transmitted bearing accuracy is improved as the transmissions are less sensitive to site error.

The transmission differences are:

- The reference signal is AM.
- The variable phase directional signal is FM.

- To maintain the phase relationships which exist in conventional VOR transmissions, the (apparent or simulated) rotation of the directional signal is anti-clockwise. As a result the same airborne VOR equipment can be used with either CVOR or DVOR beacons.

VOR Airborne Equipment

There are 3 main components of the VOR equipment in the aircraft, namely:

- **Aerial.** For slower aircraft the aerial is a whip type fitted on the fuselage and for high speed aircraft it is a blade type or is flush mounted on either side of the vertical fin.
- **Receiver.** This is a box fitted in the avionics bay.
- **Indicator.** Information derived from the VOR signal received at the aircraft may be fed to a flight director system or to the more simple displays such as the CDI (course deviation indicator) or the RMI (radio magnetic indicator). These are described below.

VOR Deviation Indicator

This instrument displays VOR information, and is widely used in light aircraft. The instrument indicates the displacement of the aircraft with respect to a bearing (to or from the VOR station) which has been selected on the Course Selector Knob or OBS (Omni-bearing Selector). See *Figure 8.9*.

Figure 8.9 VOR/ILS Deviation Indicator

The indicator drawn in *Figure 8.10* is typical with the azimuth scale having a circle and four dots on each side of the centre. As the circle itself counts as the first dot this is a five dot display with each dot indicating approximately a 2° displacement from the selected VOR bearing. Full scale deflection therefore represents 10°.

This displacement (or deviation) is presented by a deviation bar on the indicator. *Figure 8.10* shows that the displacement of the bar depends on the angular position of the beacon relative to the selected bearing and is independent of the way the aircraft is pointing. In other words, for a given position and bearing selection, the heading of the aircraft does not affect the display on a deviation indicator.

Inspection of *Figure 8.10* shows that aircraft at positions 1 and 3 receive a Fly Right indication. If the aircraft lay exactly on the selected bearing either to or from the station, the deviation bar would be central.

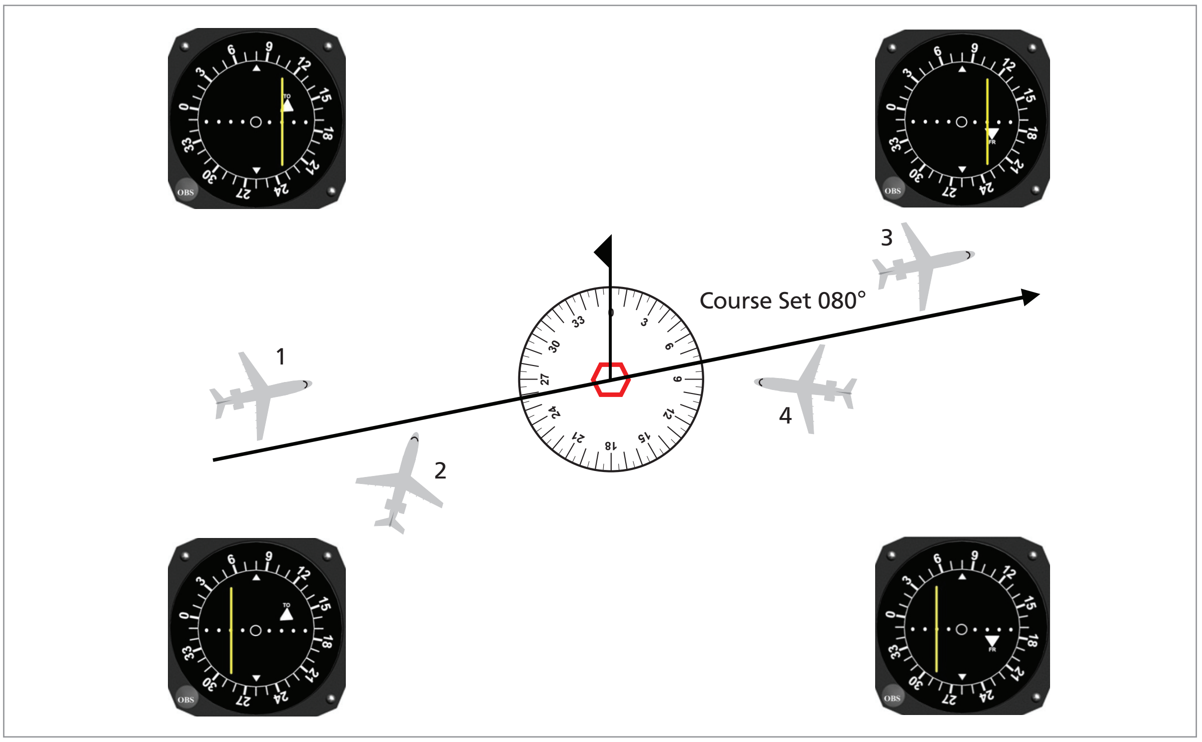


Figure 8.10 Left/Right Indications

Aircraft at positions 2 and 4 both receive a Fly Left indication (deviation bar to the left of centre) but note that the aircraft at position 4 must turn to the right to reduce its displacement from the selected line. The deviation bar 'sense' is wrong for the aircraft at position 4, and this is generally undesirable. To keep the deviation bar sense correct when flying a track to or from a VOR station, the aircraft's heading should be about the same as the track selected on the Omni-bearing Selector (plus or minus any drift allowance).

As the equipment normally includes an automatic To/From flag the rule to be followed to keep the deviation bar sense correct is that:

When inbound to a VOR, select the inbound track on the OBS, so that a 'TO' indication appears. When outbound from a VOR, select the outbound track on the OBS so that a 'FROM' indication is seen.

In addition to the Left/Right display, the deviation indicator shows a 'TO' or a 'FROM' flag depending on whether:

- The aircraft's QDM is within about 80° of the bearing selected, in which case 'TO' appears
- The aircraft's QDR is within about 80° of the bearing selected, in which case 'FROM' appears

This leaves two sectors about 20° wide in which an indeterminate TO/FROM indication is obtained.

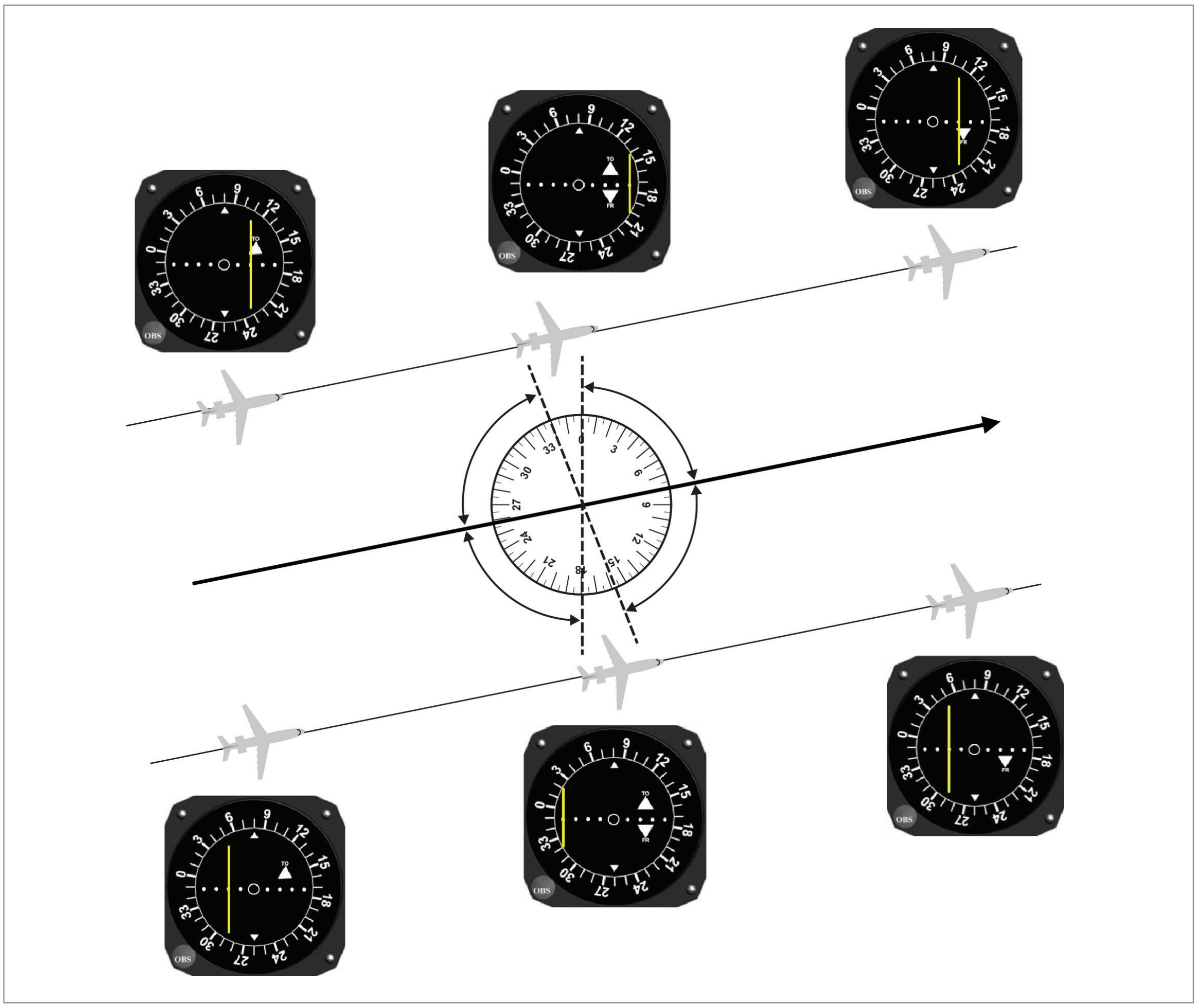


Figure 8.11 To/From Indications

Figure 8.11 depicts the deviation indicator in the various sectors about the VOR beacon. It should be remembered that the six indications in *Figure 8.11* are completely independent of the aircraft's heading. They depend on the aircraft's bearing from the beacon and on the bearing which has been selected on the OBS.

If the VOR transmissions are faulty or the aircraft is out of range or the airborne power supply is inadequate, an 'OFF' flag appears.

There are a few other aspects of deviation indicators which are worth mentioning. Firstly, if the instrument has an ILS glide path needle, this needle will be inoperative, centralized, and flagged 'OFF' when the indicator is being used to display VOR information. Conversely, when ILS information is being displayed, the OBS is inoperative and the TO/FROM indication is meaningless.

Radio Magnetic Indicator (RMI)

The RMI provides an alternative means of presenting VOR bearing information and it has been described at some length in the ADF notes. Briefly, it has a remote-reading compass repeater card which indicates the aircraft's magnetic heading against a fixed heading index at the top of the instrument.

A pointer indicates on the compass card the aircraft's QDM to the beacon. (Two needles are common so that two bearings can be simultaneously displayed). Students for professional licences should note that before display on the RMI, VOR information must be processed differently from ADF information. This is because the aircraft receives a magnetic bearing from the VOR 'dispensed' in the form of a phase difference, whereas the ADF equipment gives a direct indication of relative bearing.

The VOR QDM derived from the measured phase difference between the reference and vari-phase signals is converted to a relative bearing for display on the RMI. (This is achieved by means of a 'differential synchro' which automatically subtracts the aircraft's magnetic heading from the VOR QDM). The resulting relative bearing positions the RMI needle, the point of which, however, indicates the original QDM to the VOR because the magnetic heading which was subtracted is in effect re-applied by the compass repeater card. If the QDM to the VOR shown on the RMI is to be converted to a True bearing for plotting, the variation at the VOR station must be applied.

As an example of the above, and with reference to *Figure 8.12*, suppose the aircraft heading is 040°(M) and the measured phase difference is 270°. The equipment derives from the latter a QDM of 090° and subtracts the heading of 040° to give a relative bearing of 050° which positions the RMI needle 50° clockwise from the heading index. (If there were a difference in variation between the positions of the aircraft and VOR station, this derived relative bearing would have a corresponding error but the QDM indicated by the needle would still be correct). Continuing with the example, the RMI heading index reads 040° and the needle indicates 040° + 050° = 090°, which is the correct QDM to the VOR based on the magnetic meridian at the beacon. Compare this with the case of an ADF bearing displayed by RMI, where the magnetic bearing indicated is based on the magnetic variation at the aircraft.

One useful aspect of RMI presentation deserves mention. The arrowhead of the needle shows the QDM of the beacon, so consequently the 'tail' end of this full-diameter pointer indicates the reciprocal of the QDM, that is, the radial on which the aircraft is positioned. Thus both the bearing TO and the bearing FROM the station are clearly displayed.

It is worthwhile making a comparison between the RMI and the OBS type deviation indicator. The RMI has certain disadvantages in that it is a more complex instrument requiring additional hardware, including a remote-reading magnetic compass and the appropriate power supplies. It is therefore heavier, occupies more space and is more costly.

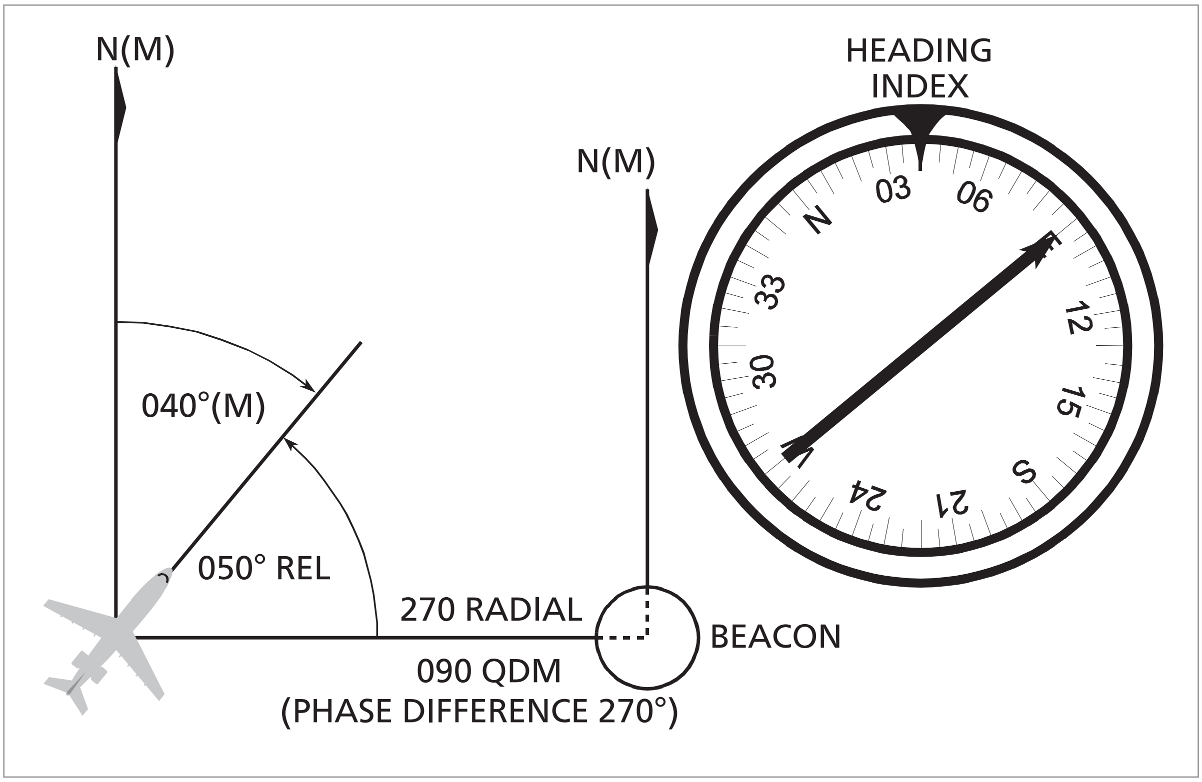


Figure 8.12 VOR QDM on the RMI

In large aircraft these disadvantages are outweighed by the following advantages:

- The RMI provides continuous indication of the QDM to a VOR (and the reciprocal of the QDM, the radial, at the tail of the pointer).
- Magnetic heading is also displayed, on the same instrument; a considerable asset when homing to a VOR or maintaining a track outbound.
- The approximate relative bearing of a beacon is immediately apparent, a 'plan view' of the local navigation situation being presented; this is most useful when flying a holding procedure.
- As the pointer automatically gives a continuous indication of the VOR bearing, the rate of crossing radials during interception of a radial is easily assessed.
- With two-needle RMIs, the bearings of two beacons can be simultaneously displayed which is particularly useful when flying along an airway using one beacon ahead (or astern) for track-keeping, and a second beacon off the airway for reporting abeam.
- ADF bearings can be displayed on an RMI.

VOR - Displays

RMI (Radio Magnetic Indicator)

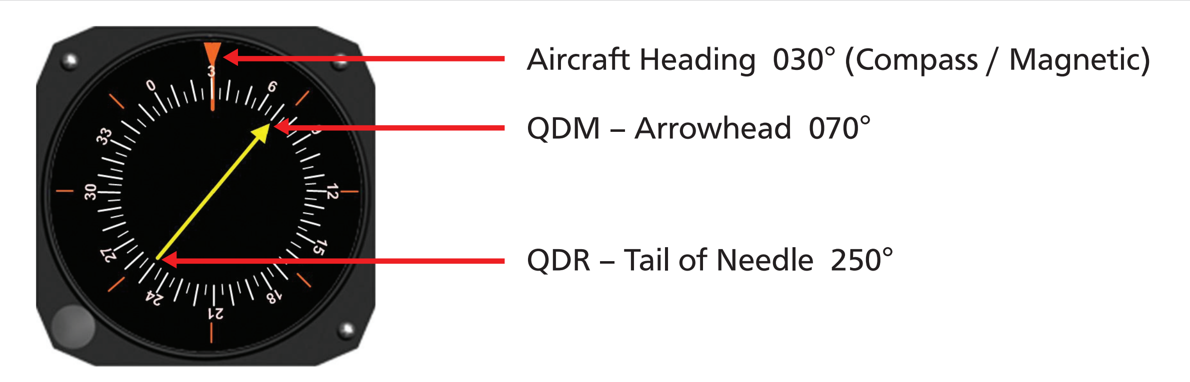


Figure 8.13

Heading displayed will always be Compass Heading, which should be very close (deviation) to Magnetic Heading.

The VOR QDR/QDM displayed will be the Radial that the aircraft is actually on. *(For examination purposes; If the arrowhead and the tail do not agree, due to a bent needle, then the arrowhead will be the correct reading)*

The arrowhead will always point TO the beacon QDM.

The aircraft's heading will not affect the readings.

If heading is correct then both Relative Bearing and Radial will be correct.

If heading is in error then the Radial will be correct but the Relative Bearing will be wrong.

No action is required by the pilot.

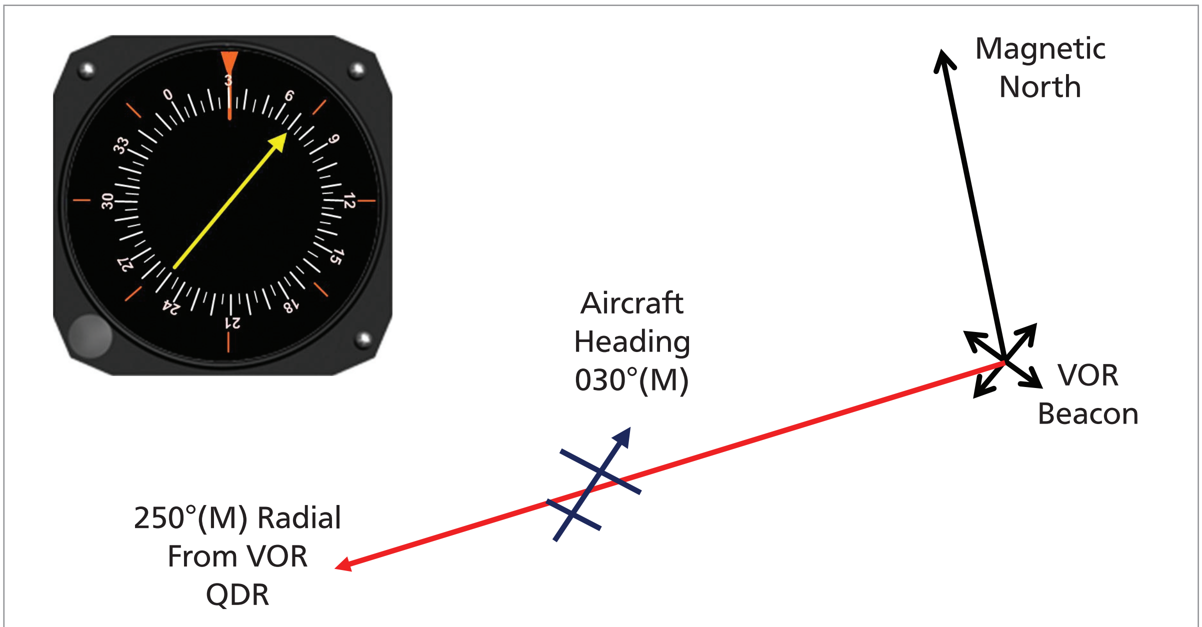


Figure 8.14

CDI (Course Deviation Indicator)

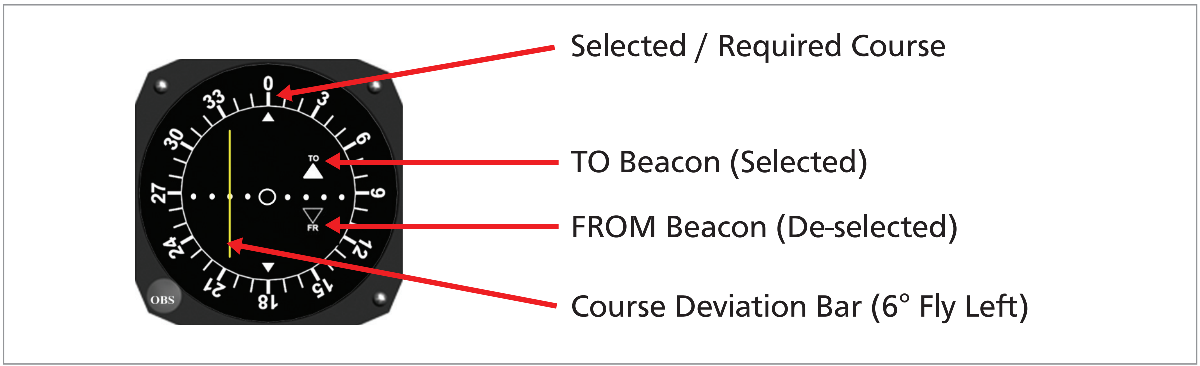


Figure 8.15

Course shown at top/centre of the dial is the Required Course to fly to achieve the desired aim.

The TO/FROM indicator will be decided by the instrument. If the actual radial, which the aircraft is on, is within 90° of the Set Course then FROM will be shown. If the actual radial, which the aircraft is on, is more than 90° from the Set Course then TO will be shown.

The Course Deviation Bar shows the angular difference between the Required Course and the actual VOR Radial the aircraft is on.

1 Dot = 2° **Full Scale Deflection = 10°**

The edge of the inner circle is the first dot = 2°

The aircraft's heading will not affect the readings.

The pilot sets the Required Course, using the OBS knob.

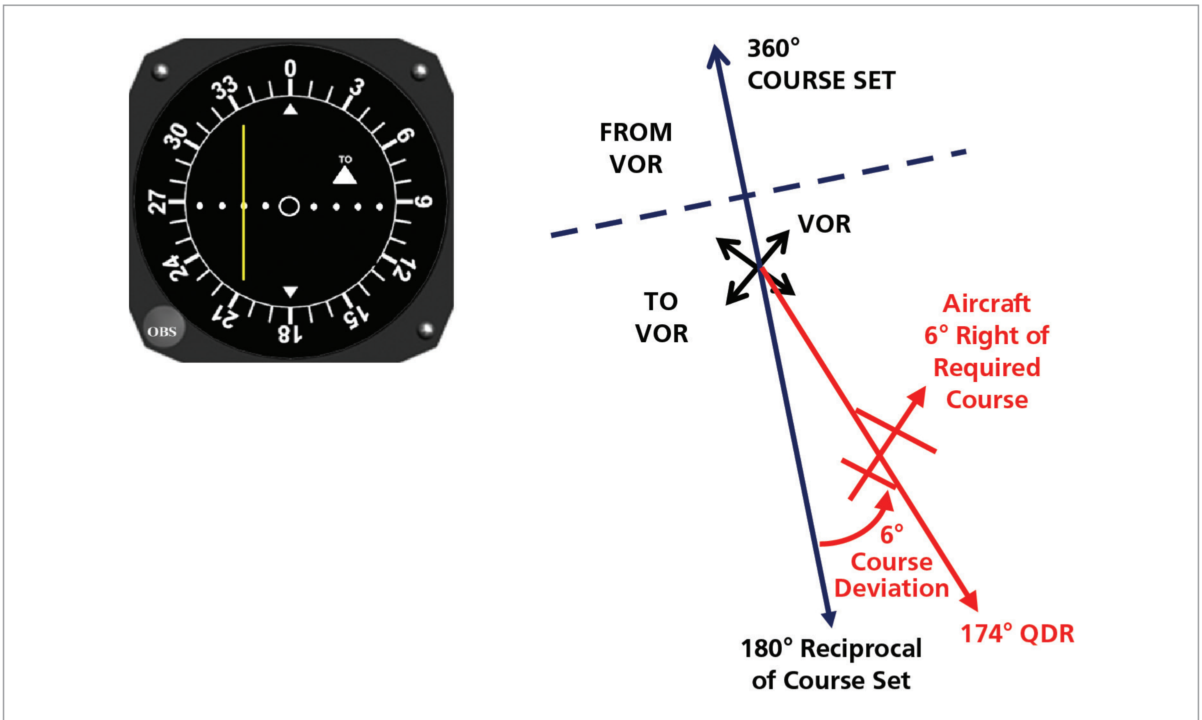


Figure 8.16

HSI (Horizontal Situation Indicator)

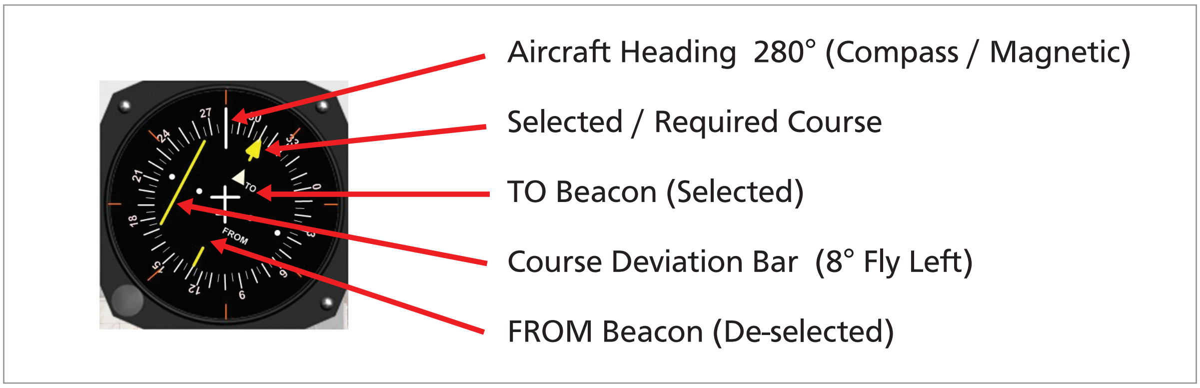


Figure 8.17

Heading displayed will always be Compass Heading, which should be very close (deviation) to Magnetic Heading.

The arrowhead shows the Required Course, set by the pilot.

The TO/FROM indicator will be decided by the instrument. If the actual radial, which the aircraft is on, is within 90° of the Set Course then FROM will be shown. If the actual radial is more than 90° from the Set Course then TO will be shown.

The Course Deviation Bar shows the angular difference between the Required Course and the actual VOR Radial the aircraft is on.

1 Dot = 5° **Full Scale Deflection = 10°**

An HSI may be either a 2 Dot or 5 Dot display
Full Scale Deflection will always be 10°. 2 Dot: display 1 dot = 2°. 5 Dot display: 1 Dot = 5°

Aircraft heading is taken into consideration in displaying a fly left or fly right indication. However, as the instruments includes heading, it is able to determine the best direction to turn to achieve the required radial. So it is possible to be right of the radial but to be given a turn right indication.

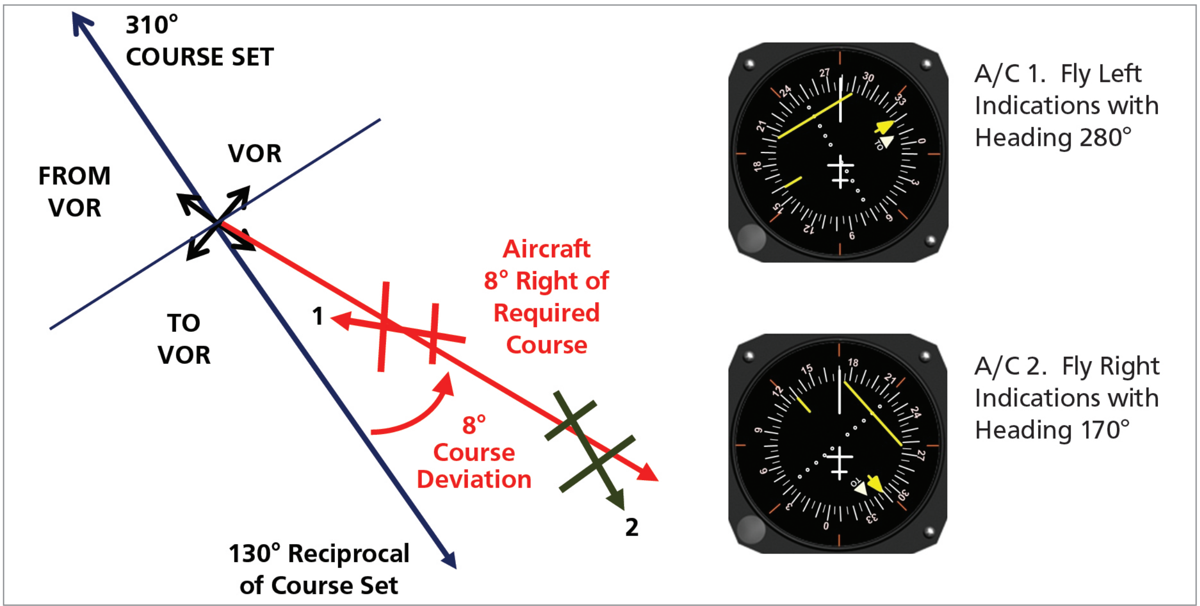


Figure 8.18

Summary

RMI

Aircraft Heading 030° (Compass / Magnetic)

QDM – Arrowhead 070°

QDR – Tail of Needle 250°

Aircraft's Heading is NOT Relevant

CDI

Selected / Required Course

TO Beacon (Selected)

FROM Beacon (De-selected)

Course Deviation Bar (6° Fly Left)

Aircraft's Heading is NOT Relevant

HSI

Aircraft Heading 280° (Compass / Magnetic)

Selected / Required Course

TO Beacon (Selected)

Course Deviation Bar (8° Fly Left)

FROM Beacon (De-selected)

Aircraft's heading will determine Turn Left / Turn Right Indication

Questions

1. Using the CDI shown, what is the aircraft's QDR?

Figure 8.19

2. Using the CDI shown, what is the aircraft's QDM?

Figure 8.20

3. Using the HSI shown, what is the aircraft's QDR?

Figure 8.21

4. Using the HSI shown, what is the aircraft's QDM?

Figure 8.22

In-flight Procedures

Typical uses of VOR by an aircraft equipped with both CDI-type deviation indicator and an RMI are illustrated in *Figure 8.23*.

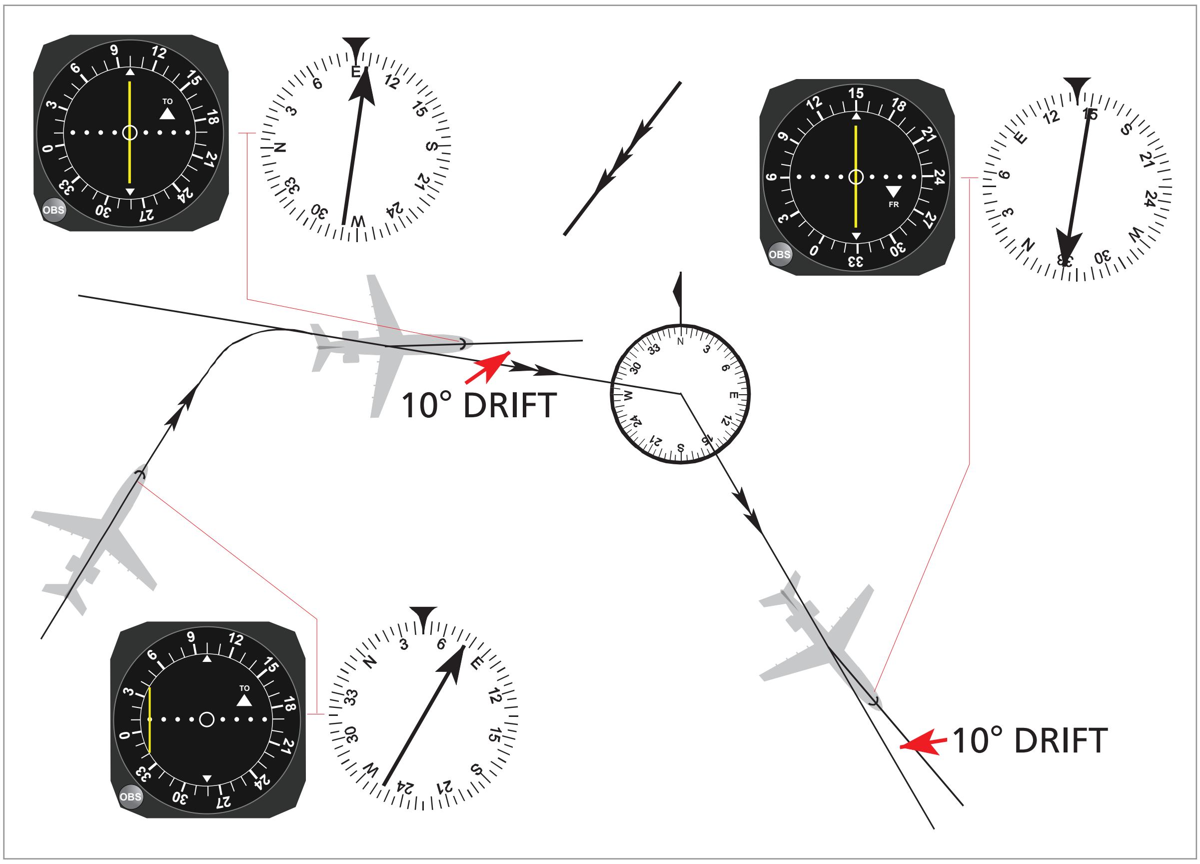


Figure 8.23 In-flight Procedures

Radial Interceptions

In *Figure 8.23* the aircraft is shown intercepting the 280° radial by flying a heading of about 045°(M), commencing the turn shortly before making good the radial so as not to over-shoot it.

A heading of 090°(M) is selected to allow for starboard drift inbound. So the turn is through 45° taking about 15 seconds. Arrival at the 277 radial should be announced by the Left/Right indicator showing about 1.5 dots 'fly left' and the RMI needle pointing a QDM of 097° at which point he would turn onto 090°(M).

Inbound Track-keeping

Having intercepted the inbound radial, the pilot maintains his heading (of 090°(M) in the *Figure 8.23* example) and watches the Left/Right needle. Suppose the needle shows a progressively increasing displacement left; then the aircraft is moving to the right of the desired inbound track. The drift allowance is insufficient and a heading of 085° would perhaps be more suitable. The pilot would probably alter heading 30° port on to 060°(M) until the needle centred, indicating the aircraft to be back on track, before trying the new heading of 085°(M) and again watching the needle.

Further alterations of heading may be necessary before the aircraft is settled down on a good inbound heading with the needle reasonably steady in the central position. It is worth visualizing how the RMI would behave during the homing just described.

After the interception, the heading of 090° would show against the heading index, the RMI needle indicating 100° (the required QDM to the VOR).

Station Passage

Overhead a VOR there is a 'cone (or zone) of confusion' with a vertical angle of about 60° to 80° (ICAO minimum is 40°). This leads to indeterminate indications over the beacon which at high level extend over a considerable area, for instance out to about 4 NM radius at 30 000 ft.

On the VOR/ILS indicator, the needle swings between hard left and hard right, the OFF flag may appear temporarily, and the TO/FROM indicator changes to FROM. The RMI needle fluctuates and then rotates through 180° to indicate the QDM back to the beacon. At low altitude these station passage indications are rapid; at high altitude they are slow.

Outbound Flight

The aircraft is shown outbound on the 150 radial on the right-hand side of *Figure 8.23*. The indications are ideal, the TO/FROM flag showing 'FROM', and the centralized L/R needle showing the aircraft to be on the selected track of 150°. The information on the deviation indicator is confirmed by the RMI needle showing a QDM of 330 back to the beacon.

If these indications were to change, showing a track error developing, the pilot would normally make a firm heading alteration (typically 30°) to regain track before steering a revised outbound heading appropriate to his revised assessment of drift.

Airfield Approach

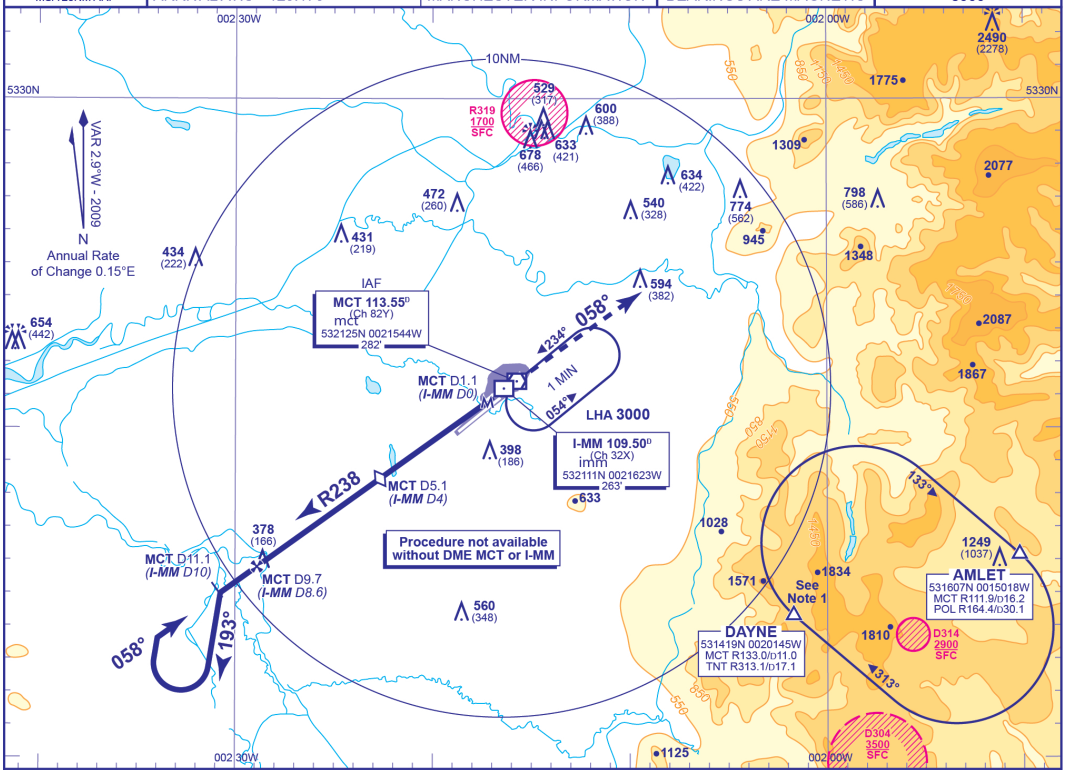
AD 2-EGCC-8-8 (9 Apr 09) UK AIP

INSTRUMENT APPROACH CHART - ICAO

MANCHESTER VOR/DME RWY 05L
(ACFT CAT A,B,C,D)

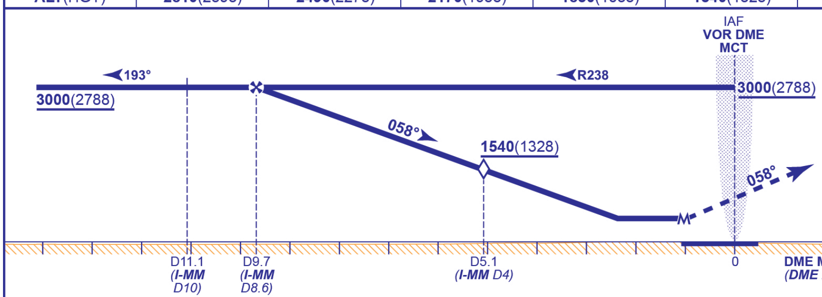
MSA 25NM ARP				
	APP	118.575, 135.000	MANCHESTER RADAR	AD ELEVATION 257
		121.350	MANCHESTER DIRECTOR	THR ELEVATION 212
	TWR	118.625, 119.400	MANCHESTER TOWER	OBSTACLE ELEVATION 2490 AMSL (2278) (ABOVE THR)
		121.850, 125.375	MANCHESTER GROUND	
	ARRIVAL ATIS	128.175	MANCHESTER INFORMATION	BEARINGS ARE MAGNETIC

TRANSITION ALTITUDE 5000



RECOMMENDED PROFILE Gradient 5.2%, 320FT/NM

DME MCT(I-MM)	9.1(8)	8.1(7)	7.1(6)	6.1(5)	5.1(4)	4.1(3)	3.1(2)
ALT(HGT)	2810(2598)	2490(2278)	2170(1958)	1850(1638)	1540(1328)	1220(1008)	900(688)



(Hold if required in VOR MCT hold)

MAPT MCT DME 1.1/ I-MM DME ZERO (THR RWY 05L)

Climb straight ahead to **3500** then as directed.

RCF: From VOR MCT DME 10 at **3500** (if below **3500** continue climb in left turn to reach **3500**), continue climb to intercept and follow VOR POL R164 to AMLET to join the DAYNE hold at **FL60**.

DME MCT reads 1.1NM at THR RWY 05L (*DME I-MM zero ranged to THR RWY 05L*)

Aircraft Category		A	B	C	D
OCA (OCH)	Procedure	640(428)	640(428)	640(428)	640(428)
VM(C)OCA (OCH AAL)	Total Area	750(493)	750(493)	1107(850)	1107(850)

Rate of descent	G/S KT	160	140	120	100	80
	FT/MIN	850	740	640	530	420

NOTE 1 DAYNE HOLD:- Limiting outbound distance MCT DME 16/TNT DME 14. Minimum holding level is FL equivalent of **6000**.
2 DME I-MM may be used if DME MCT is not available.
3 FAT offset 4° from RWY C/L and crosses RWY C/L 0.72NM (nominal) before THR RWY 05L.

CHANGE: MAG VAR. OBSTACLES.

AERO INFO DATE 28 JAN 09

AMDT 4/09 Civil Aviation Authority

Figure 8.24 Example of a VOR DME approach pattern

VOR Summary

Characteristics:	Magnetic bearings, valid day and night
Frequency:	108 to 117.95 MHz; 160 channels
Uses:	Airways; Airfield let-downs; Holding points; En route navigation
Principle of Op:	Phase comparison of two 30 Hz signals
Identification:	3 letter aural Morse or Voice every 10 s, continuous tone for VOT (also ATIS using AM on voice)
Monitoring:	Automatic site monitor +/- 1° Ident suppressed when standby transmitter initially switched on
Types:	CVOR - reference signal is FM; variphase signal is AM - Limacon polar diagram rotating clockwise DVOR - more accurate than CVOR due to less site error - reference signal is AM; variphase signal is FM - simulated anticlockwise rotation of aerial TVOR - low power Tx at airfields VOT - Test VOR giving 180 radial - aircraft should have < +/- 4° error
Operational range:	Transmitter power Line of sight DOC valid day and night
Accuracy affected by:	Site error (less with DVOR) Propagation error Scalloping (bending due to reflections from terrain) Airborne equipment error (+/- 3°)
Cone of confusion:	OFF flag may appear; TO/FROM display and bearings fluctuate
Airborne equip:	Aerial, Receiver, Display (CDI/RMI) CDI: 2° per dot; max 10°; relationship between indication and aircraft position RMI: arrowhead gives QDM; tail gives QDR; Use magnetic variation at station
In-flight procedures:	Radial interceptions; Track-keeping; Station passage

Questions

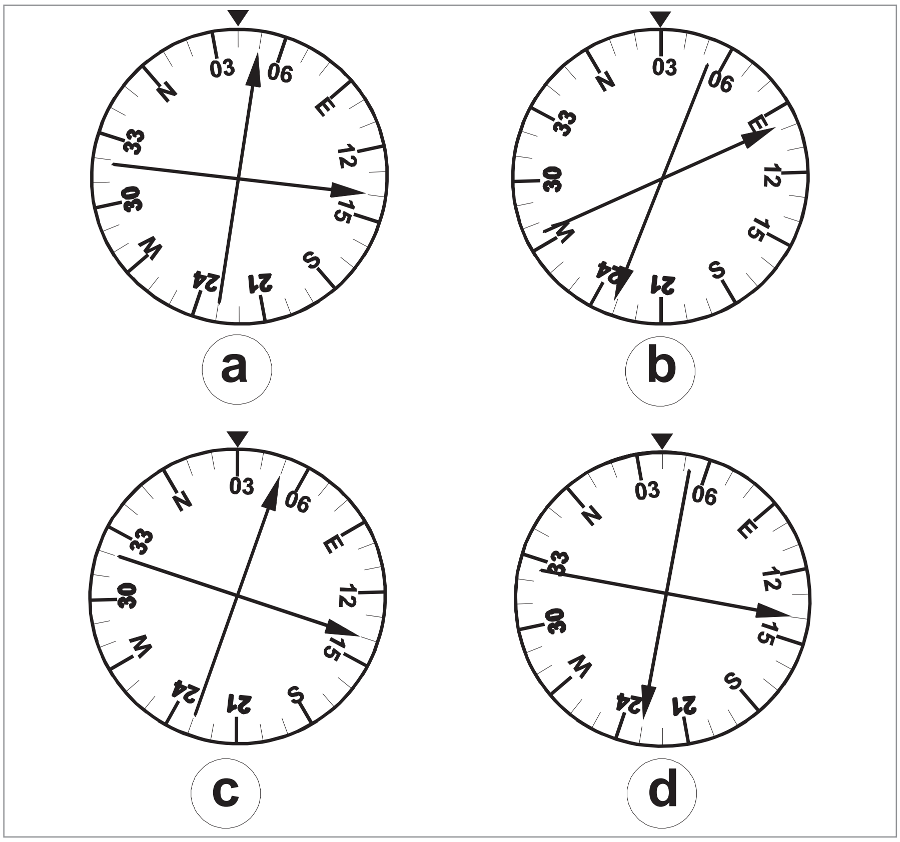
1. Assuming the maximum likely error in VOR to be 5.5°, what is the maximum distance apart that beacons can be situated on the centre line of a UK airway in order that an aircraft can guarantee remaining within the airway boundary?

a. 54.5 NM
b. 109 NM
c. 66 NM
d. 132 NM

2. The Designated Operational Coverage quoted for VOR beacons in the COMM section of the AIP:

a. is only applicable by day
b. guarantees a protection ratio of at least 3 to 1 by day and night
c. defines the airspace within which an aircraft is assured of protection from interference from other VORs on the same channel
d. is determined by the type of surface over which the signal will have to travel

3. An aircraft is tracking away from a VOR on the 050 radial with 10° starboard drift. An NDB lies to the east of the VOR. Which of the RMIs illustrated below shows the aircraft when it is obtaining a relative bearing of 100° from the NDB?



4. What is the theoretical maximum range that an aircraft at flight level 360 will obtain from a VOR beacon situated at 900 ft above mean sea level?

a. 274 NM
b. 255 NM
c. 112 NM
d. 224 NM

5. A conventional VOR:

a. has an FM reference signal and an AM variable signal
b. has a 150 Hz reference signal and a 90 Hz variable signal
c. has an AM reference signal and a 150 Hz variable signal
d. has an AM reference signal and an FM variable signal

6. The OBS on a deviation indicator is set to 330° and gives a 3 dots fly right demand with FROM indicated. What is the QDM of the aircraft to the station?

a. 144
b. 324
c. 336
d. 156

7. An aircraft is homing towards a VOR which marks the centre line of an airway. The beacon is 100 NM distant. If the pilot had the airway QDM set on the OBS what deflection of the deviation indicator would be given if the aircraft was on the boundary of the airway? Assume that one dot equals 2 degrees.

a. 3 dots
b. 2 dots
c. 2.5 dots
d. 1.5 dots

8. What is the theoretical maximum range that an aircraft at flight level 420 will obtain from a VOR beacon situated at 400 ft above mean sea level?

a. 225 NM
b. 256 NM
c. 281 NM
d. 257 NM

9. Concerning conventional and Doppler VORs (DVOR), which of the following is correct?

a. There is no way of knowing from the instrumentation display which type is being used
b. The DVOR will always have a “D” in the ident
c. The DVOR has a higher pitch ident than the standard VOR
d. The conventional VOR has less site error

10. An aircraft is attempting to home to a VOR on the 064 radial. The CDI shows 4 dots fly right with a TO indication. At the same time the co-located DME shows a range of 45 NM. Where is the aircraft in relation to the required track?

a. 6 NM right of track
b. 3 NM right of track
c. 6 NM left of track
d. 3 NM left of track

11. A VOR beacon ceases to transmit its normal identification which is substituted by 'TST'. This means that:

a. the beacon may be used providing that extreme caution is used
b. the beacon is undergoing maintenance or calibration and should not be used
c. this is a temporary short range transmission and will have approximately half its normal range
d. the beacon is under test and pilots using it should report its accuracy to air traffic control

12. What is the approximate maximum range that an aircraft flying at 25 000 ft would expect to obtain from a VOR beacon situated 900 ft above mean sea level?

a. 220 NM
b. 100 NM
c. 235 NM
d. 198 NM

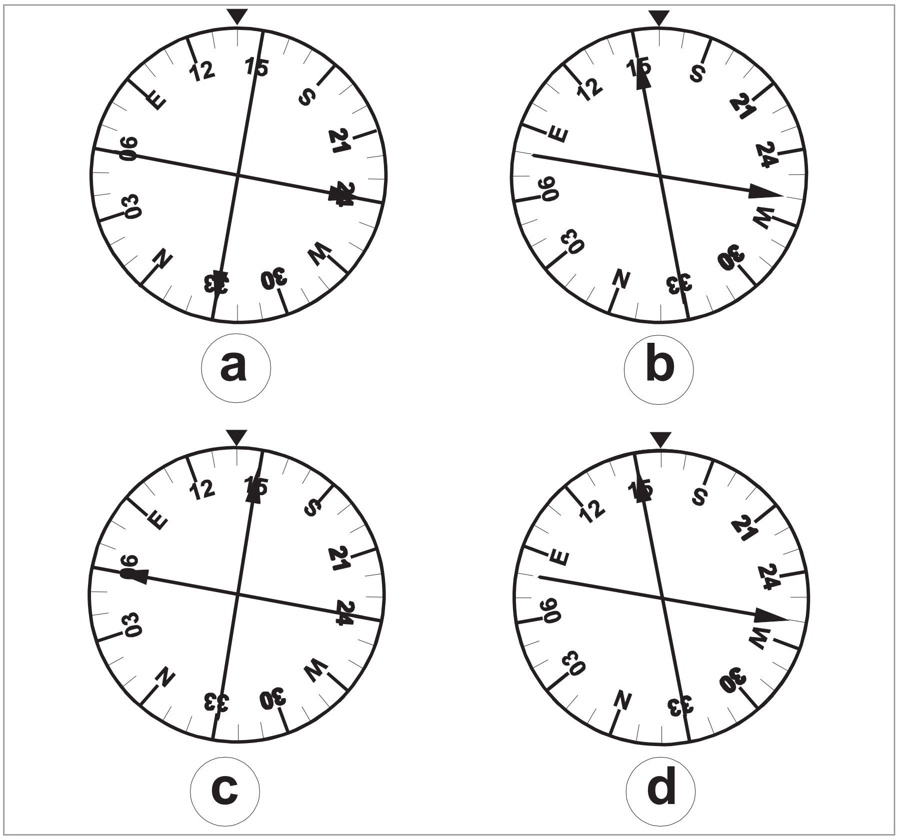
13. An aircraft is on the airway boundary range 100 NM from a VOR marking the airway centre line. Assuming that each dot equates to 2° how many dots deviation will be shown on the deviation indicator?

a. 3.0 dots
b. 2.5 dots
c. 2.0 dots
d. 1.5 dots

14. An aircraft is required to intercept and home to a VOR along the 064 radial. The OBS should be set to:

a. 064 to get correct needle sense and a TO indication
b. 244 to get correct needle sense and a TO indication
c. 064 to get correct needle sense and a FROM indication
d. 244 to get correct needle sense and a FROM indication

15. **An aircraft is tracking away from a VOR on the 150 radial with 10° starboard drift. An NDB lies to the south of the VOR. Which of the RMIs illustrated below shows the aircraft when it is obtaining a relative bearing of 100° from the NDB?**



16. **Assuming the maximum likely error in VOR to be 5°, what is the maximum distance apart that beacons can be situated on the centre line of a UK airway in order that an aircraft can guarantee remaining within the airway boundary?**

a. 60 NM
b. 100 NM
c. 120 NM
d. 150 NM

17. **AN aircraft, heading 150°, is 100 NM north of a VOR, the pilot intends to home to the VOR on the 030 radial. The pilot should set ..... on the OBS and on reaching the 030 radial should turn ..... onto a heading of ....., assuming zero wind.**

a.	210	left	030
b.	030	right	210
c.	210	right	210
d.	150	left	210

18. **The type of emission radiated by a VOR beacon is:**

a. a double channel VHF carrier with one channel being amplitude modulated and the second channel being frequency modulated
b. a single channel VHF carrier wave amplitude modulated at 30 Hz with a sub carrier being frequency modulated at 30 Hz
c. a VHF carrier wave with a 90 Hz frequency modulation and a 150 Hz amplitude modulation
d. a VHF pulse modulated emission with a pulse repetition frequency of 30 pps

19. An aircraft wishes to track towards a VOR along the 274 radial. If variation is 10°W what should be set on the OBS?

a. 274
b. 264
c. 094
d. 084

20. An aircraft is tracking away from a VOR on a heading of 287°(M) with 14° starboard drift. If the variation is 6°W what is the phase difference between the reference and variable phase components of the VOR transmission?

a. 121°
b. 295°
c. 301°
d. 315°

21. What is the theoretical maximum range that a pilot would obtain from a VOR situated 900 ft above mean sea level in an aircraft flying at 18 000 ft?

a. 168 NM
b. 188 NM
c. 205 NM
d. 250 NM

22. An aircraft is attempting to home to a VOR beacon. The pilot has set 329 on the OBS of the deviation indicator. If the aircraft is situated on the 152 radial then the deviation indicator will show:

a. one and a half dots fly right
b. one and a half dots fly left
c. three dots fly right
d. three dots fly left

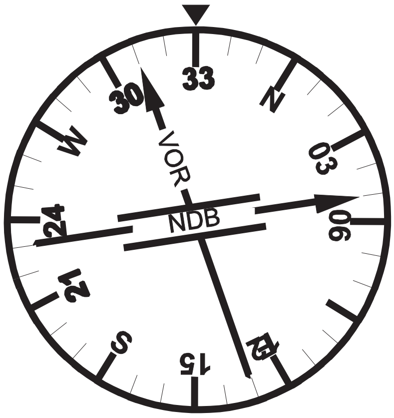
23. A VOR receiver in an aircraft measures the phase difference from a DVOR as 220°. Which radial is the aircraft on?

a. 140
b. 040
c. 320
d. 220

24. The RMI indicates the aircraft magnetic heading. To convert the RMI bearings of NDBs and VORs to true bearings, the correct combination for the application of magnetic variation is:

	NDB	VOR
a.	beacon position	aircraft position
b.	beacon position	beacon position
c.	aircraft position	beacon position
d.	aircraft position	aircraft position

25. **Both the VOR and the ADF in an aircraft are correctly tuned and identified. The indications from both are shown on the RMI illustrated. Use the information to answer the following: The information given on the RMI indicates:**



a. that the aircraft is heading 033°(M), is on the 310° radial from the VOR, and bears 050°(M) from the NDB
b. that the aircraft is heading 330°(M), is on the 310° radial from the VOR, and bears 050° from the NDB
c. that the aircraft is heading 330°(M), is on the 130° radial from the VOR, and bears 050°(M) from the NDB
d. that the aircraft is heading 330°(M), is on the 130° radial from the VOR, and bears 230°(M) from the NDB

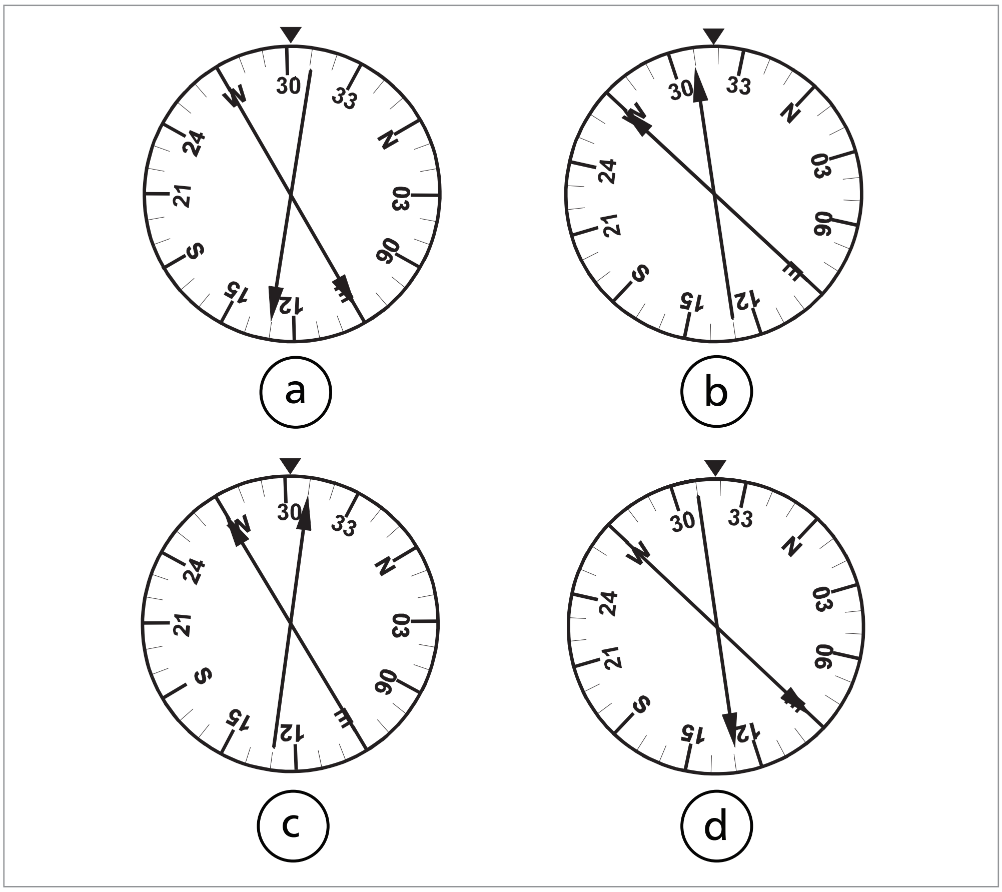
26. **The VOR in an aircraft is correctly tuned and set to define the centre line of an airway within UK airspace which you intend to fly. The indication received on the VOR/ILS deviation indicator is shown to the right. At the same time the DME gave a range of 90 NM from the facility. At the time of the observation, the aircraft's radial and distance from the airway centre line were:**

a.	062 radial	9 NM
b.	074 radial	6 NM
c.	242 radial	6 NM
d.	254 radial	9 NM

27. **The normal maximum error which might be expected with a VOR bearing obtained within the DOC is:**

a. plus or minus 1°
b. plus or minus 2°
c. plus or minus 5°
d. plus or minus 10°

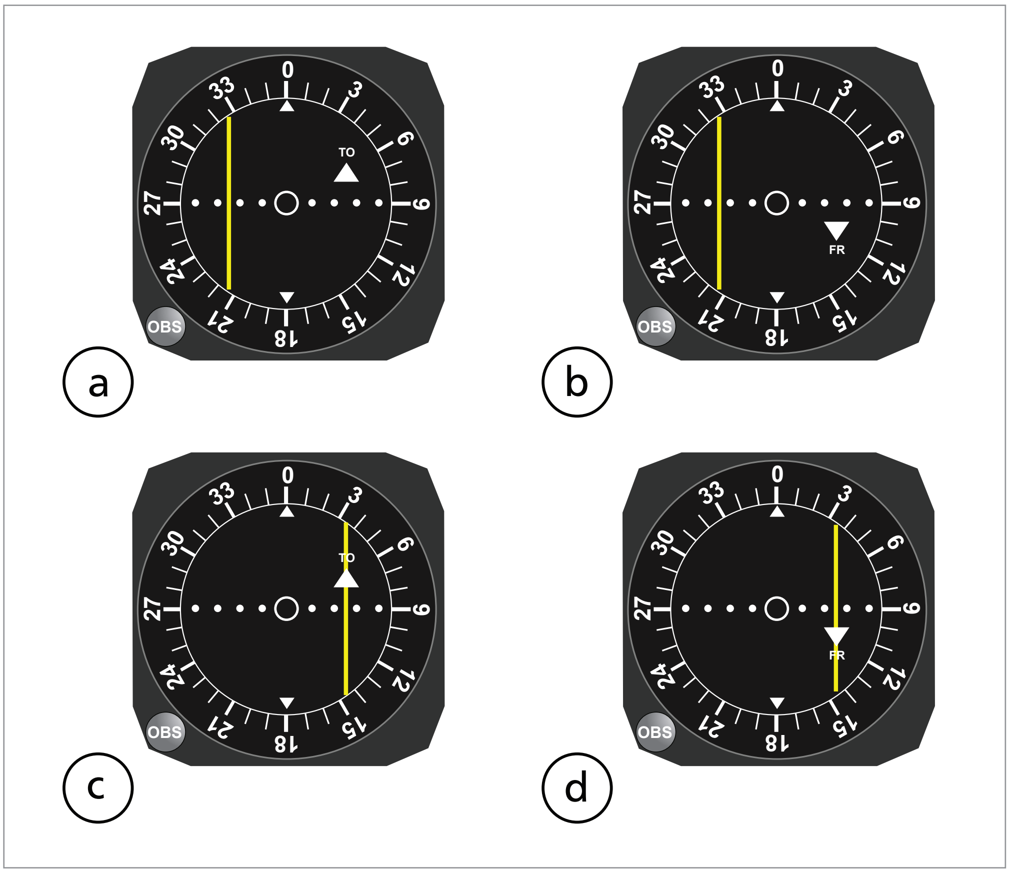
28. **An aircraft is tracking away from VOR "A" on the 310° radial with 8° starboard drift; NDB "X" is north of "A". Which diagram below illustrates the RMI when the aircraft is on its present track with a QDR from "X" of 270°?**



29. **The VOR indications on an RMI whose deviation is not zero:**

a. are magnetic
b. are compass
c. are relative
d. must have deviation applied before being used

30. **An aircraft bears 175°(M) from a VOR. If the aircraft OBS is set to 002 and its heading is 359°(M) which diagram below represents the aircraft VOR/ILS deviation indicator? (assume 1 dot = 2°)**



31. **Using Annex A.**
An aircraft is flying on the 170 radial with a heading of 315°(M).
The course on the HSI is set to 180°.
Which HSI shows the correct indications?

a: A
b: B
c: C
d: D

32. **Using Annex B.**
An aircraft is flying on the 050 radial with a heading of 250°(M).
The course on the HSI is set to 060°.
Which HSI shows the correct indications?

a: A
b: B
c: C
d: D

33. **Using Annex C.**
An aircraft is flying on the 245 radial with a heading of 250°(M).
The course on the HSI is set to 060°.
Which HSI shows the correct indications?

a: A
b: B
c: C
d: D

Annex A

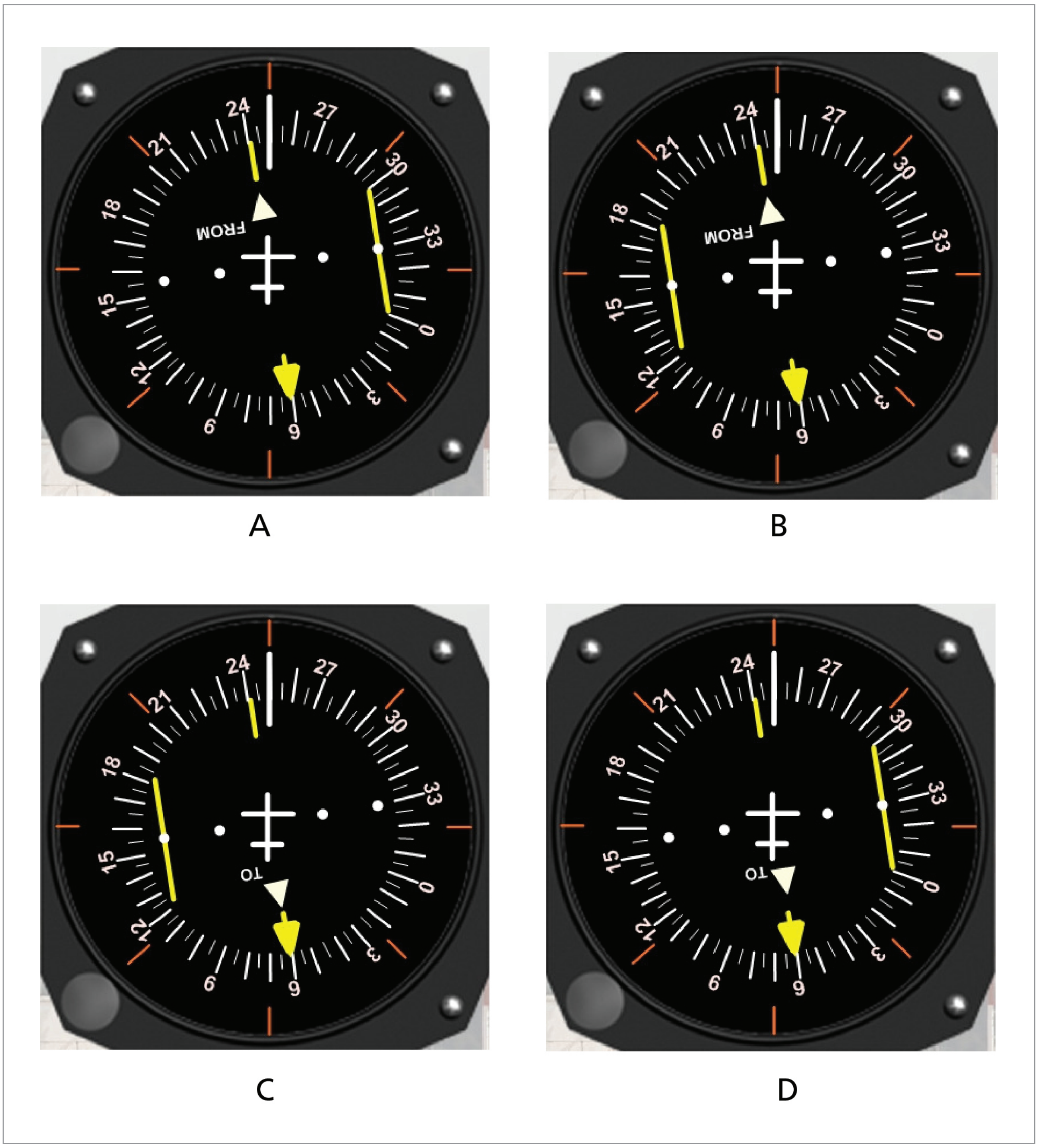
A

B

C

D

Annex B



Annex C


24
27
30
33
0
3
9
6
12
15
18
21
TO

A


24
27
30
33
0
3
9
6
12
15
18
21
TO

B


24
27
30
33
0
3
9
6
12
15
18
21
FROM

C


24
27
30
33
0
3
9
6
12
15
18
21
FROM

D

Answers

1	2	3	4	5	6	7	8	9	10	11	12
b	c	d	a	a	a	d	c	a	c	b	c

13	14	15	16	17	18	19	20	21	22	23	24
d	b	a	c	c	b	c	c	c	a	d	c

25	26	27	28	29	30	31	32	33
d	a	c	a	a	a	c	b	a

Answers to Page 128

1	2	3	4
071°	159°	345°	063°

Chapter

9

Instrument Landing System (ILS)

Introduction

The Instrument Landing System (ILS) has been in existence for over 40 years and is still the most accurate approach and landing aid in current use. The system provides pilots with an accurate means of carrying out an instrument approach to a runway, giving guidance both in the horizontal and the vertical planes. It even enables aircraft to carry out automatic landings. ILS is a precision approach system because it gives guidance in both the horizontal and the vertical plane.

ILS provides the pilot with visual instructions in the cockpit to enable him to fly the aircraft down a predetermined glide path and extended runway centre line (localizer) to his Decision Height (DH). At decision height the pilot decides to land (if he has the required visual references and sufficient room to manoeuvre the aircraft for a safe touchdown) or he goes around (overshoots) and carries out the published missed approach procedure.

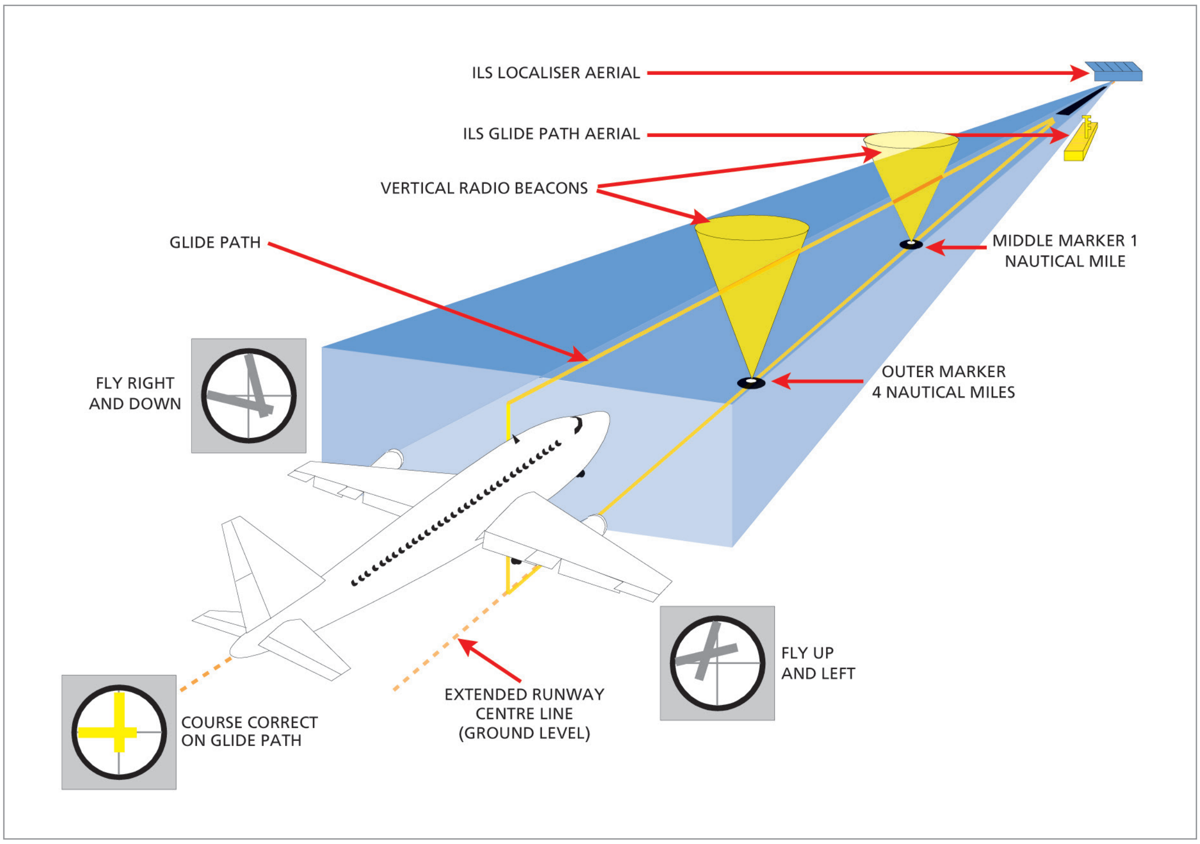


Figure 9.1 The Instrument Landing System (ILS)

ILS Components

The system requires a suitable ground installation and airborne equipment. The ground installation has three distinct components as shown in *Figure 9.1*, namely localizer, glide path and marker beacons; in some installations a back course may also be available.

The localizer (LLZ) transmits in the VHF band and is located about 300 m from the up-wind end of the runway.

The glide path (GP) transmitter operates in the UHF band, and is frequency paired with the localizer. It is located 300 m in from the threshold and about 200 m from the runway edge abeam the touchdown point.

Marker beacons transmit at 75 MHz in the VHF band. These include the outer marker (OM), the middle marker (MM) and possibly an inner marker (IM). They are provided to enable the pilot to cross-check the aircraft's height against ranges and timing to the runway threshold.

Back course approaches are allowed in some countries. This enables aircraft to make a non-precision approach on the back beam of the localizer transmitter.

Some ILS installations also have a co-located low powered NDB, called a locator (L), at the site of the OM beacon.

Distance Measuring Equipment (DME) that is frequency paired with the ILS frequencies are now increasingly provided to supplement or replace the range information provided by marker beacons.

ILS Frequencies

Localizer

The Localizer operates in the VHF band between 108 and 111.975 MHz to provide 40 channels, e.g. 108.1 108.15; 108.3 108.35; 108.5 108.55 -111.95 MHz. This part of the frequency band is shared with VOR: the frequencies allocated are odd decimals and odd decimals + 0.05 MHz.

Glide Path

The glide path operates in the UHF band between 329.15 and 335 MHz to provide 40 complementary channels. e.g. 329.15, 329.3, 329.45, 329.6 - 335 MHz.

Markers

All markers transmit at 75 MHz. There is no interference problem as the radiation pattern is a narrow fan-shaped vertical beam.

Frequency Pairing

The GP frequency is paired with the localizer and selection of the frequency is automatic. The localizer and glide path transmissions are frequency paired in accordance with the list published at ICAO e.g. 108.1 MHz is paired with 334.7 MHz, and 111.95 MHz is paired with 330.95 MHz. The advantages of this are:

- One switch activates both receivers - this reduces the pilot's workload.
- Frequency selection is made easier and quicker as there is only one to consider.
- The potential for a wrong frequency selection is reduced.
- Only one identifier is needed.

DME Paired with ILS Channels

A DME that is frequency paired with an ILS supplements or replaces the range information from markers/locators.

The DME ranges are zero referenced to the ILS runway threshold.

The DME is protected only within the ILS localizer service area up to 25 000 ft. When necessary and notified, the DME is also used for published 'SIDs' and 'STARs'. In such cases the DME coverage is increased. The use of a DME outside the stated limits may give rise to errors.

ILS Identification

Separate identification is unnecessary for ILS localizer and glide path transmissions as the localizer and glide path frequencies are paired. The selection of the localizer VHF frequency automatically energizes the glide path receiver circuits.

The Ident on the localizer transmission is a 2 or 3 letter Morse signal at 7 groups/min. The first letter is usually "I".

The identification is automatically suppressed if the ILS becomes unserviceable or is withdrawn. When an ILS is undergoing maintenance, or is radiating for test purposes only, the identification coding will either be removed completely or replaced by a continuous tone. Under these conditions no attempt should be made to use the ILS as completely erroneous indications may be received.

Additionally, in some instances, because of an unserviceable glide path, the ILS may be radiating for localizer approaches only, in which case the identification coding will be radiating. In this case ATC will warn all users of this fact and no attempt should be made to use the glide path.

Marker Beacons

Two markers are required for each installation and a third may be added if considered necessary at a particular site.

When a marker is used in conjunction with the back course of a localizer, it should have an identification signal that is clearly distinguishable from the front course markers.

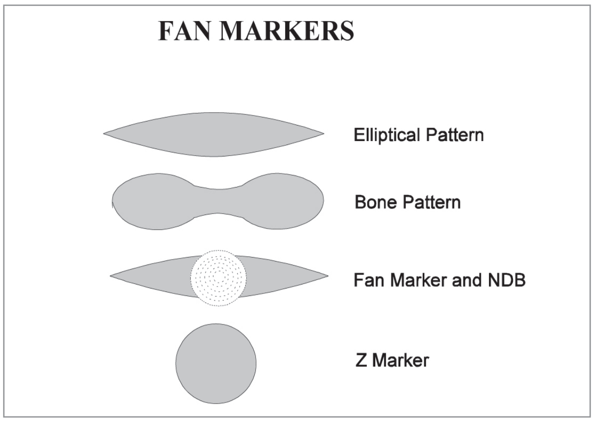


Figure 9.2 Marker beacon radiation patterns

The radiation patterns for ILS marker beacons is vertical and appears lens shaped or bone shaped in plan view. *Figures 9.2* and *9.3* show the horizontal and vertical profiles of ILS marker beacons. The signal is only received if the aircraft is flying within the fan; it is not a directional aid. Reception is indicated by synchronous aural identifiers and lights as shown in the following table.

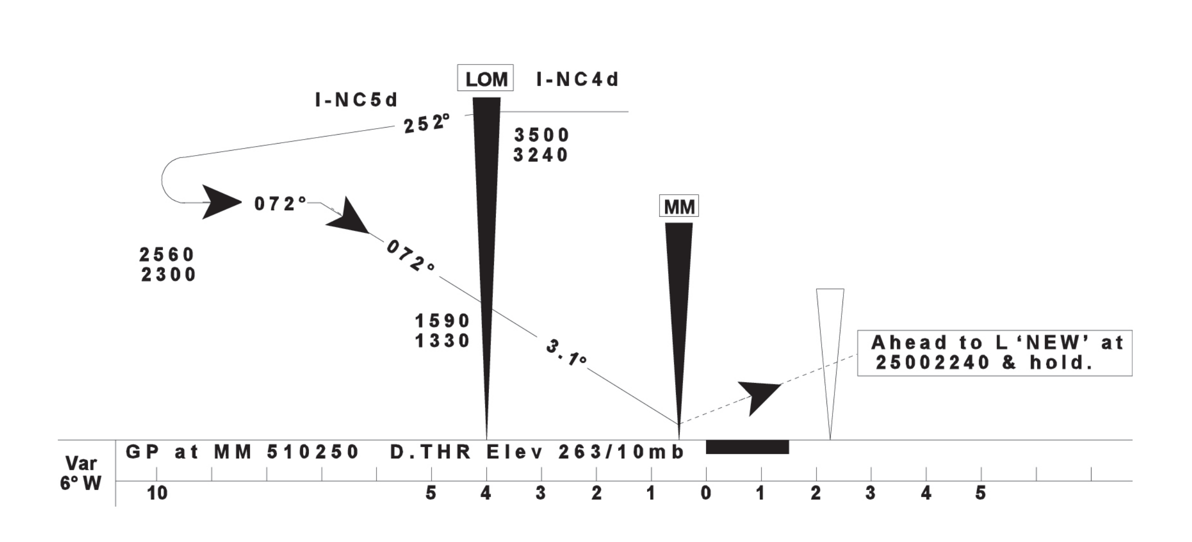


Figure 9.3 The outer marker and the middle marker

	Cockpit Light	Ident	Modulating Frequency	Pitch	Touchdown Range
OM	**BLUE**	2 dashes/sec	400 Hz	**Low**	6.5 – 11.1 km (3.5 – 6 NM)
MM	**AMBER**	Alternate dots and dashes 3/sec	1300 Hz	**Medium**	1050 m ± 150 m (3500' ± 500')
IM	**WHITE**	6 dots/sec	3000 Hz	**High**	75 - 450 m (250' – 1500')

Figure 9.4

Z markers have cylindrical vertical radiation patterns. They are used to mark airway reporting points or co-located with an NDB. Due to the cone of silence directly above an NDB, either Z markers or fan-shaped markers provide an indication when the aircraft is overhead.

Ground Monitoring of ILS Transmissions

Both the localizer and the glide path are automatically monitored by equipment located in an area of guaranteed reception. This equipment will act when:

- the localizer at the reference datum shifts from the runway centre line by more than 35 ft for Cat I, 25 ft for Cat II or 20 ft for Cat III.
- the glide path angle changes more than 0.075 × basic glide path angle.
- there is a power reduction in output of more than 50% from any transmitter.

The monitoring unit will provide warning to a control point and cause any of the following to occur before a standby transmitter is activated:

- Cessation of all radiation.
- Removal of identification and navigational components of the carrier.
- Cat II or III ILS may permit operation to the lower categories I or II.

ILS Coverage

Localizer

The localizer coverage sector extends from the transmitter to distances of:

- 25 NM (46.3 km) within plus or minus 10° from the centre line.
- 17 NM (31.5 km) between 10° and 35° from the centre line.
- 10 NM (18.5 km) outside ± 35° if coverage is provided.

These limits may be reduced to 18 NM within 10° sector and 10 NM within the remainder of the coverage when alternative navigational facilities provide satisfactory coverage within the intermediate approach area.

Glide Path

The glide path coverage extends from the transmitter to a distance of at least:

10 NM (18.5 km) in sectors of 8° in azimuth on each side of the centre line.

The vertical coverage is provided from 0.45θ up to 1.75θ above the horizontal where θ is the promulgated glide path angle. The lower limit may be reduced to 0.3θ if required to safeguard the promulgated glide path intercept procedure.

ILS coverage is illustrated in *Figures 9.5*, *9.6* and *9.7*.

Note: These are the sectors within which the ILS localizer and glide path emissions must provide correct indications. Radiated energy exists outside these vertical and horizontal sectors.

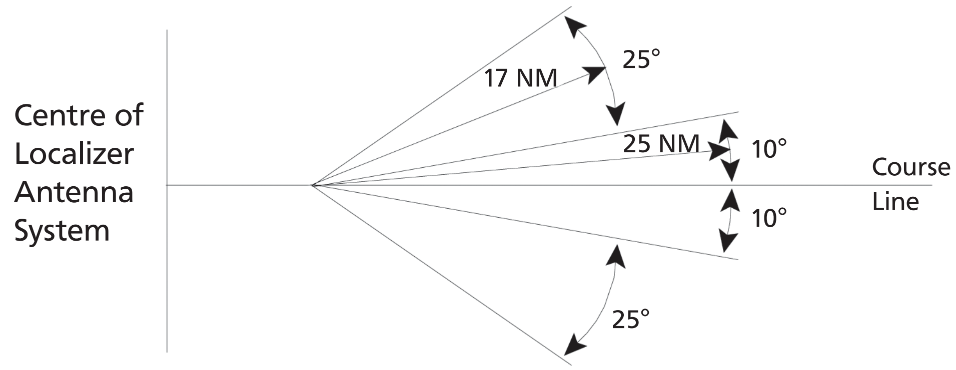


Figure 9.5 Localizer coverage

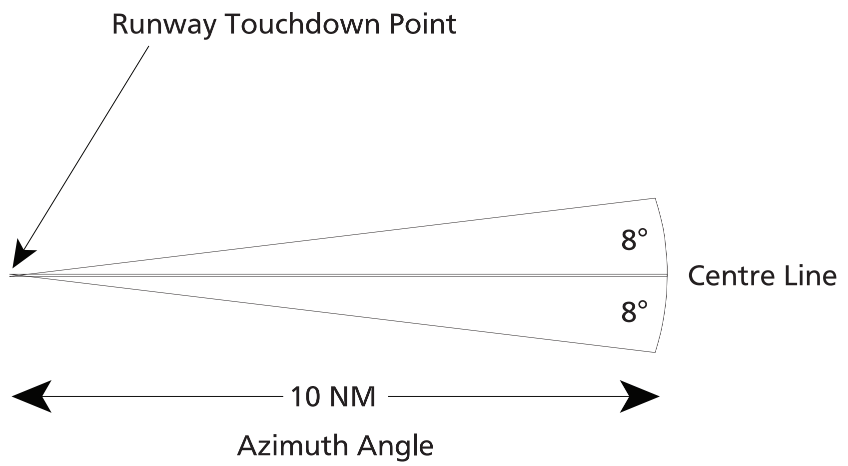
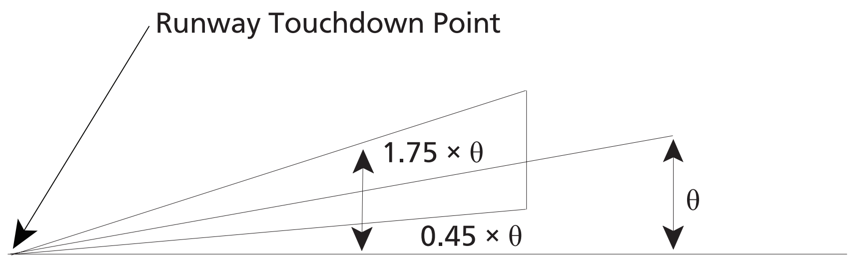


Figure 9.6 Glide path horizontal coverage



(Or to such lower angle, down to 0.3 × θ, as required to safeguard the promulgated glide path procedure)

Figure 9.7 Glide path vertical coverage

ILS Principle of Operation

The Localizer

The localizer antenna produces two overlapping lobes along the runway approach direction (QDM) as shown in *Figure 9.8*. The lobes are transmitted on a single VHF ILS frequency. In order that an aircraft's ILS receiver can distinguish between the lobes:

- the right hand lobe (the blue sector) has a 150 Hz modulation.
- the left hand lobe (the yellow sector) has a 90 Hz modulation.

The depth of modulation (DoM) increases away from the centre line i.e. the amplitude of the modulating signal increases away from the centre line. An aircraft approaching the runway centre line from the right will receive more of the 150 Hz signal than the 90 Hz modulation. This difference in depth of modulation (DDM) relates to the angular displacement of the aircraft from the centre line; it energizes the vertical needle of the ILS indicator, i.e. Go Left.

Similarly an aircraft approaching the runway centre line from the left will receive more of the 90 Hz signal than the 150 Hz modulation; the DDM energises the vertical needle, i.e. Go Right.

A DDM of zero indicates a balance between modulations, a zero needle-deflection and hence the runway centre line.

Back Course ILS

There is a mirror image behind the localizer aerial so ILS indications are received on aircraft equipment. Back Course ILS is used in some countries but is not permitted in the United Kingdom. Ignore any back course indications in the United Kingdom.

The back course ILS has the following disadvantages:

- The glide path indications are incorrect (they would, if used guide the aircraft to the wrong end of the runway).
- The CDI needle (localizer) is sense reversed. (Flying to R/W).
- There are no range-check markers.

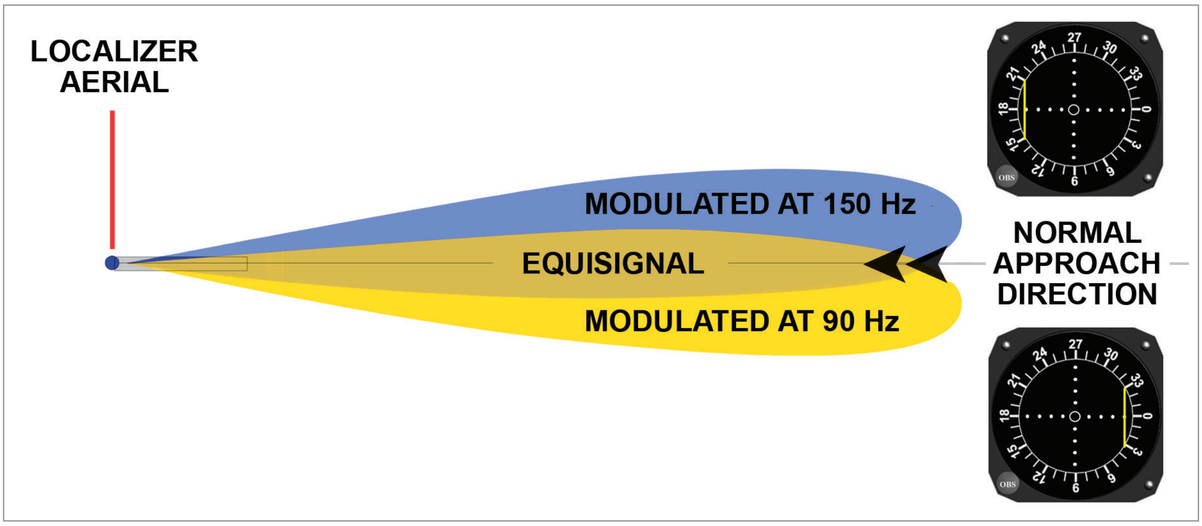


Figure 9.8 *Localizer radiation pattern*

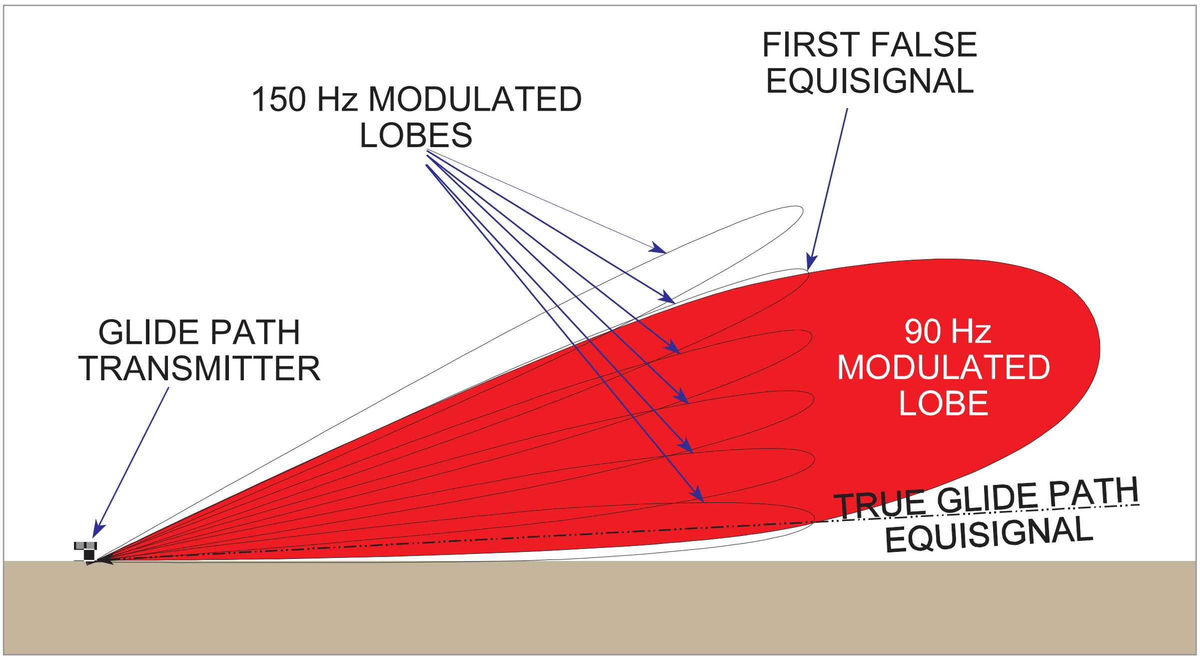


Figure 9.9 Glide path radiation pattern

Glide Slope

The glide slope UHF transmitter is located to one side of the runway approximately 200 m from the runway edge, 300 m upwind of the threshold.

The same principle is used as for the localizer, but a UHF carrier wave is used and the lobes are in the vertical plane. The upper lobe (large lobe) has a 90 Hz modulation, and the bottom lobe (small lobe) has a 150 Hz modulation. The glide path, usually 3° (ICAO require glide path angle between 2° and 4°), is defined where the DDM of the overlapping lobes is zero and the ILS indicator's glide path needle will indicate zero deviation. The radiation pattern is shown in *Figure 9.9*.

False Glide Slope(s)

These are defined as the paths of points, in the vertical plane, containing the runway centre line at which the DDM is zero; other than that path of points forming the ILS glide path. The twin lobes are repeated due to:

- Metallic structures situated at the transmission point, and ground reflections.
- The height and propagation characteristics of the aerial.

The first false glide slope occurs at approximately twice the glide path angle, 6° above ground for a standard 3° glide path. False glide slopes always occur above the true glide slope and should not constitute a danger but pilots should be aware of their presence.

Normal flying practice is to establish on the localizer and intercept the glide slope from below. However at airfields such as London Heathrow a continuous descent approach is used in which the aircraft are positioned by ground radar to capture the glide slope from above. It is advisable to always confirm the aircraft height in relation to distance to go by reference to DME, markers, locators etc.

ILS Reference Datum Point

The ILS reference datum point is a point at a specified height (around 50 feet) located vertically above the intersection of the runway centre line and threshold, through which the downward extended portion of the ILS glide path extends. This value is to be found in the remarks column for the particular airfield in the UK AIP, AD section.

Visual Glide Path Indicators

The approach light systems such as PAPIs give a visual indication of the glide path to the runway that would be the same as that for the ILS so that during the final phase of the approach the pilot should get similar indications of glide path from both systems. However the visual indications are designed for a mean eye height (meht) of the pilot and they would therefore vary slightly since the pilot's position will vary depending upon the size of the aircraft.

ILS Presentation and Interpretation

Indicators

Localizer and glide path information can be displayed:

- on a Course Deviation Indicator (CDI) or
- on the Horizontal Situation Indicator (HSI).

Interpretation of a CDI display is shown in *Figure 9.10*. The HSI display is shown at *Figure 9.11*. The main difference to note is that on the HSI there is a course selector which should be set on the QDM of the runway. The deviation indications then appear in the correct sense.

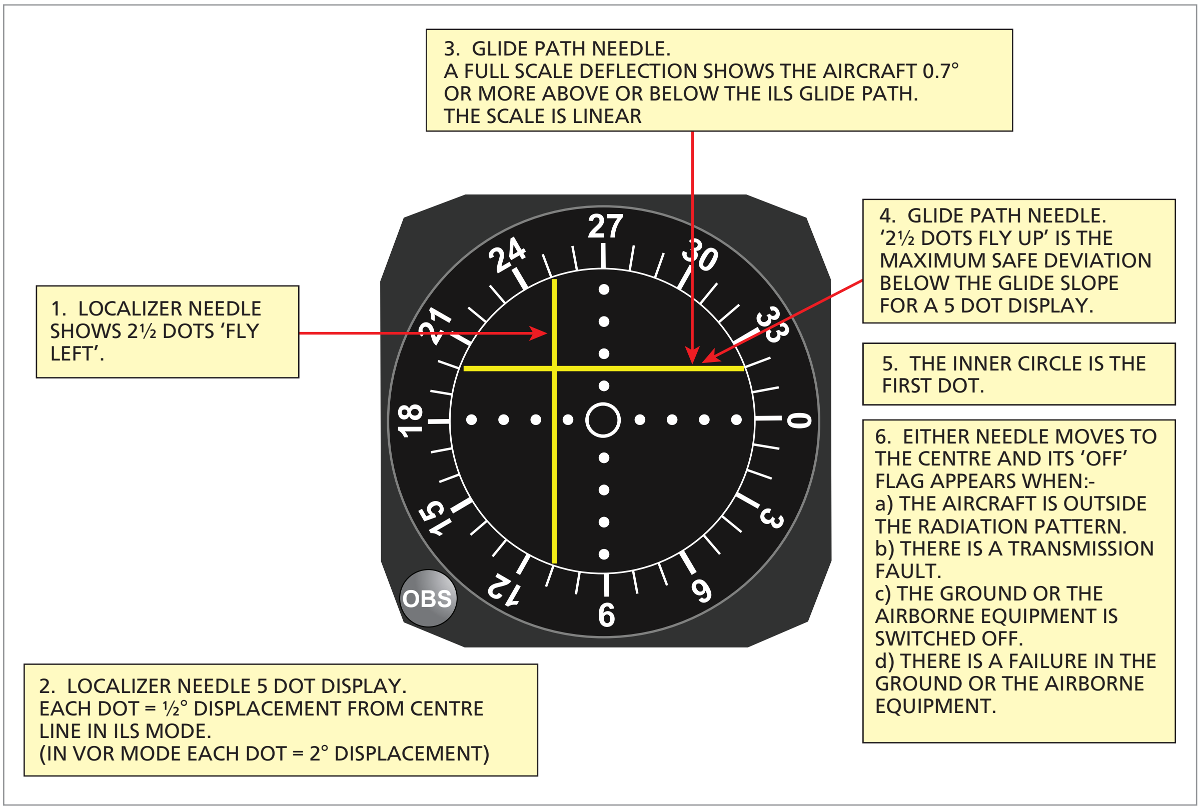


Figure 9.10 ILS course deviation indicator

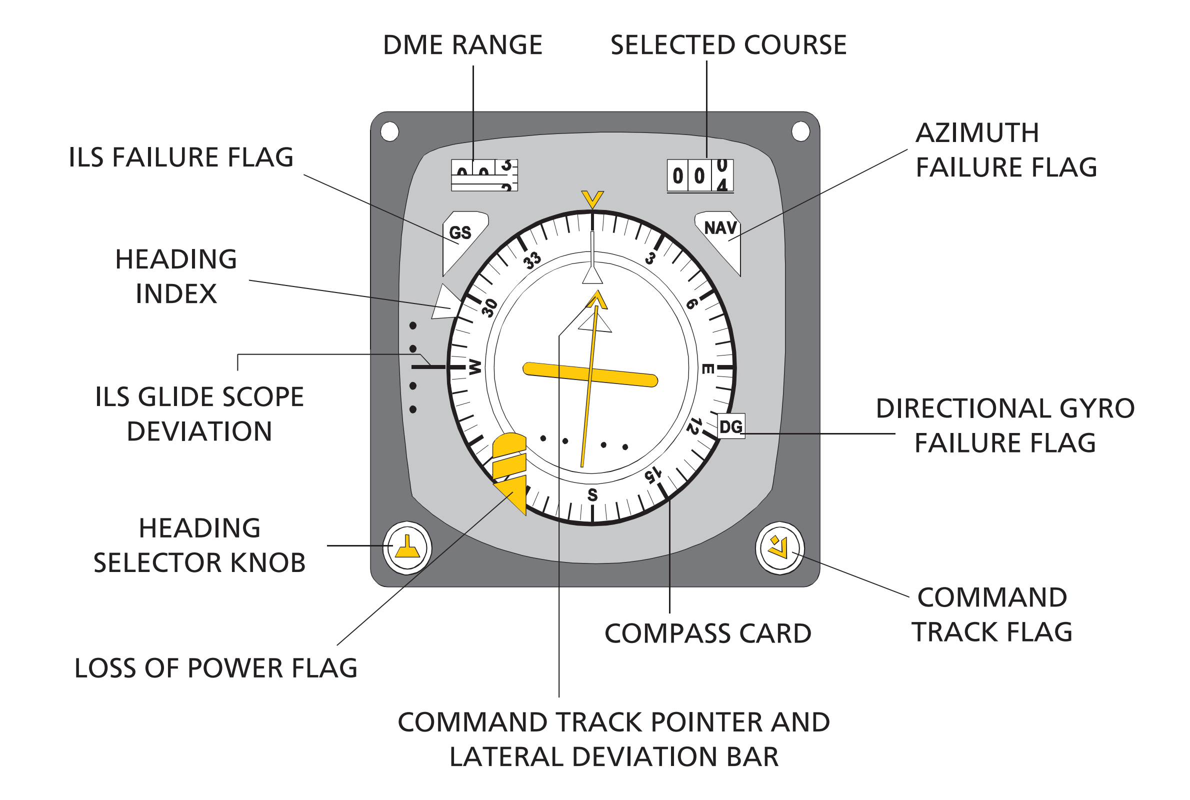


Figure 9.11 A typical HSI

Localizer Indications

Front course approach indications for fly left and right are shown in *Figure 9.12*. Full scale deflection of the needle indicates that the aircraft is 2.5° or more left or right of the centre-line i.e. the sensitivity is 0.5° per dot.

Back Beam Approach

Where a localizer is designed to radiate back course information it can:

- give azimuth guidance on overshoot from main precision approach runway, when the CDI or HSI needle should be obeyed, or
- give back course approach to the reciprocal of the main precision approach runway. In this case the CDI needle will give reverse indications whereas an HSI will give correct indications provided that the front course QDM has been selected.

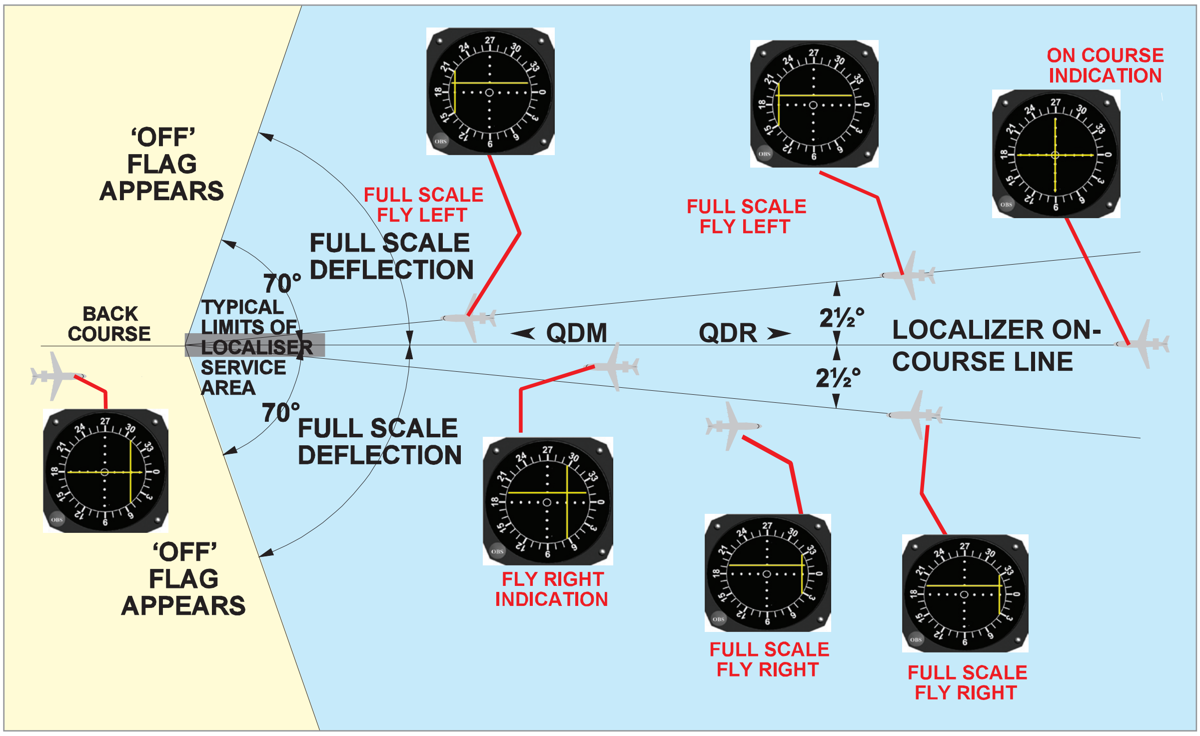


Figure 9.12: Localizer

Glide Path Indications

The glide path indication for fly up or fly down is shown in *Figure 9.13*. Full scale deflection indicates that the aircraft is 0.7° or more above or below the glide path. The sensitivity is 0.14° per dot. Note that the maximum safe deviation below the glideslope is half full-scale deflection i.e. 2.5 dots fly up.

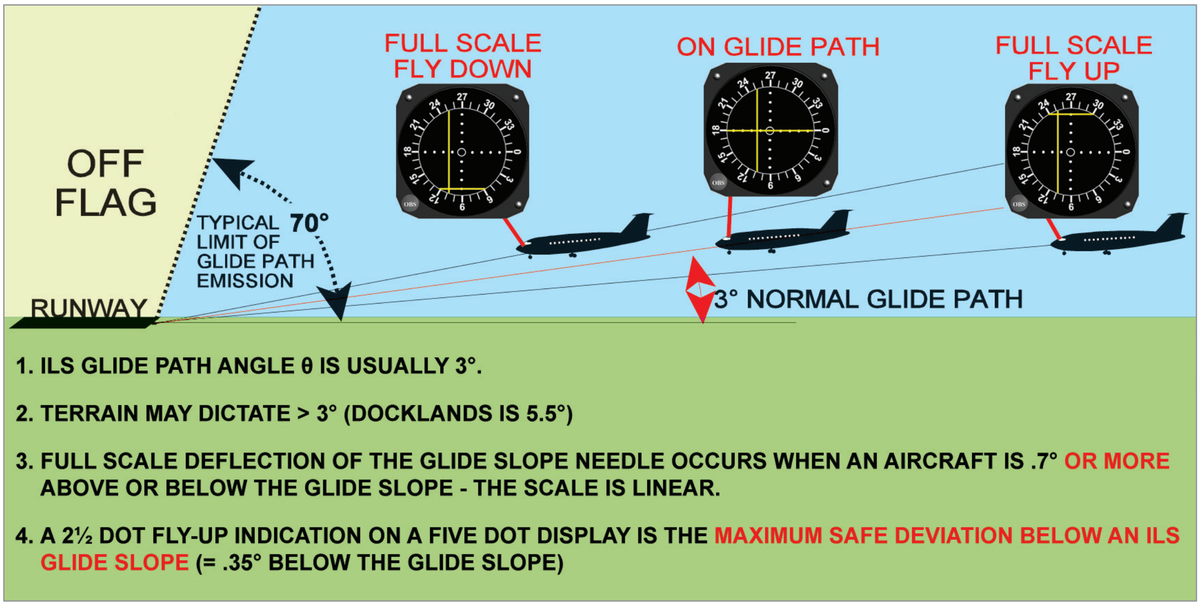


Figure 9.13 Glide path

Note: If, on approach, the left/right deflections or the fly-up indications exceed half full scale then an immediate go-around should be initiated because safe terrain clearance may be compromised.

ILS Categories (ICAO)

ILS Facility Performance Categories (Ground Installation)

Category I
A category I ILS is one which provides guidance information from the coverage limit of the ILS to the point at which the localizer course line intersects the ILS glide path at a height of 200 ft (60 m) or less above the horizontal plane containing the threshold.

Category II
An ILS which provides guidance information from the coverage limit of the ILS to the point at which the localizer course line intersects the ILS glide path at a height of 50 ft (15 m) or less above the horizontal plane containing the threshold.

Category III
An ILS, which with the aid of ancillary equipment where necessary, provides guidance information from coverage limit of the facility to, and along, the runway surface.

Operational Performance Categories
The improvement in the ground installations allows guidance down to the surface of a runway and requires a corresponding improvement in the airborne equipment. An aircraft may be certified to operate to one of the following classifications:

Category I
An instrument approach and landing with :

- a DH not lower than 60 m (200 ft) and
- a Runway Visual Range (RVR) not less than 550 m.

Category II
A precision instrument approach and landing with

- a DH lower than 60 m (200 ft) but not lower than 30 m (100 ft) and
- a RVR not less than 300 m.

Category IIIA
A precision instrument approach and landing with:

- a DH lower than 30 m (100 ft), or no DH; and
- a RVR not less than 200 m.

Category IIIB
A precision instrument approach and landing with:

- a DH lower than 15 m (50 ft), or no DH; and
- a RVR less than 200 m but not less than 75 m.

Category IIIC
No DH and no RVR limitations.

The acceptance of category II or III operations will depend on whether the following criteria are met:

- the aeroplane has suitable flight characteristics.
- the aeroplane will be operated by a qualified crew in conformity with laid down procedures.
- the aerodrome is suitably equipped and maintained.
- it can be shown that the required safety level can be maintained.

Errors and Accuracy

The Instrument Landing System has several limitations in that indications can be affected by:

- beam bends caused by atmospheric conditions
- scalloping caused by reflections which results in rapid fluctuations of the needles on the CDI/HSI which are impossible to follow; and
- beam noise generated by the transmitter or due to interference.

The pilot must be alert to the existence of potential problems and constantly cross-check the information which is being received.

- To minimize interference to the ILS transmissions, the rate of landings has to be kept relatively low, and also vehicle and aircraft movement must be restricted on the ground, especially during low visibility procedures.
- Pilot's serviceability checks of the localizer and glide path may be checked by:
    - ensuring the warning flags are not visible.
    - the pilot monitoring the identification signals. Cessation of the Ident means that the ILS is unserviceable and the procedure must be discontinued immediately.

Factors Affecting Range and Accuracy

ILS Multipath Interference Due to Large Reflecting Objects
Multipath interference to ILS signals is dependent upon antenna characteristics plus any large reflecting objects, vehicles and fixed structures within the radiated signal coverage. Moving objects can degrade the directional signals to an unacceptable extent.

In order to protect the ILS signals from interference, protected areas are defined:

- **ILS Critical Area.** This is an area of defined dimensions about the localizer and glide path antennae where vehicles and aircraft are excluded during all ILS operations. It is protected because the presence of vehicles and/or aircraft inside its boundaries will cause unacceptable disturbance to the ILS signal-in-space.

- **ILS Sensitive Area** This extends beyond the critical area and is where parking or movement of vehicles and aircraft is controlled to prevent the possibility of unacceptable interference to the ILS signal during low visibility ILS operations. The dimensions of this area depend upon the object creating the disturbance.

- **Holding points** Protection of ILS signals during category II and III operations may dictate that pre-take-off holding points are more distant from the runway than holding positions used in good weather. Such holding positions will be appropriately marked and will display signs 'Category II/III Hold'; there may also be a bar of red stop lights.

Weather

Snow and heavy rain attenuates the ILS signals thereby reducing the range and degrading the accuracy.

FM Broadcasts

FM transmitters have wide bandwidths and it is possible for such stations transmitting on frequencies just below 108 MHz to produce frequencies that overspill into the radio navigation band (108 to 117.975 MHz) thereby causing interference with the ILS signals. Since the late 1990s FM suppression circuits have been mandatory in ILS receivers.

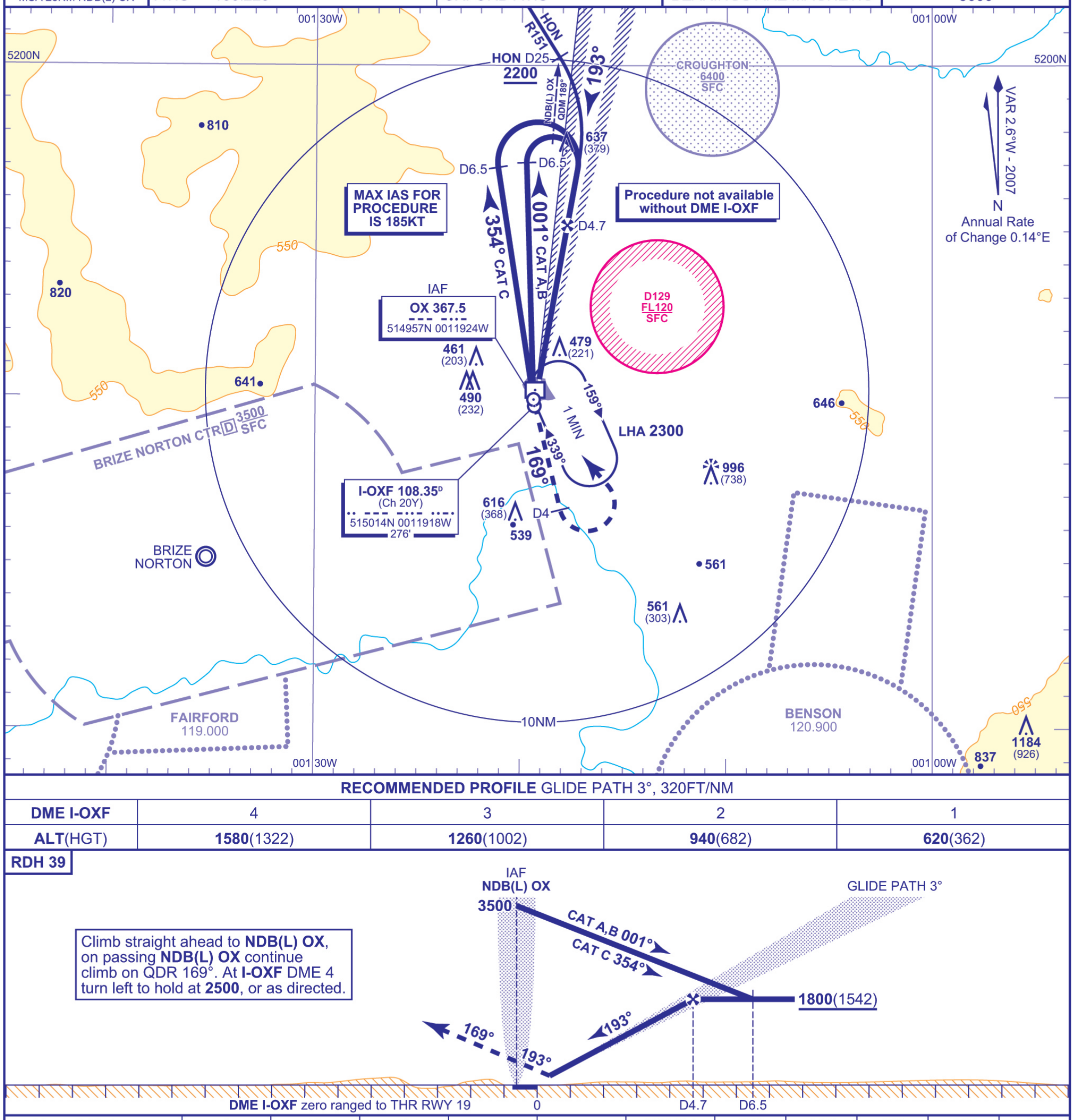
ILS Approach Chart

An Instrument Approach Chart for an ILS approach is shown in *Figure 9.14*. The instrument approach can be divided into the following 3 segments:

- Initial approach - procedure up to the IAF (initial approach fix).
- Intermediate - procedure between IAF and FAF (final approach fix).
- Final approach - procedure after FAF.

An aircraft should be at or above certain altitudes depending upon the sector from which it is approaching. These are known as sector safety altitudes (SSA) and are denoted in some form on the chart (circular in top left on this one).

Landing minima relates to the pilot's decision height (DH) and the RVR. Before commencing the approach the pilot would normally be advised by ATC to check his landing minima.



AD 2-EGTK-8-2 (5 Jul 07) UK AIP

INSTRUMENT APPROACH CHART - ICAO

OXFORD/KIDLINGTON ILS/DME/NDB(L) RWY 19 (ACFT CAT A,B,C)

APP	125.325	OXFORD APPROACH	AD ELEVATION 270
TWR	133.425	OXFORD TOWER	THR ELEVATION 258
	121.950	OXFORD GROUND	OBSTACLE ELEVATION 1184 AMSL (926) (ABOVE THR)
RAD	124.275	BRIZE RADAR	
ATIS	136.225	OXFORD ATIS	BEARINGS ARE MAGNETIC

TRANSITION ALTITUDE 3000

RECOMMENDED PROFILE GLIDE PATH 3°, 320FT/NM

DME I-OXF	4	3	2	1
ALT(HGT)	1580(1322)	1260(1002)	940(682)	620(362)

RDH 39

Climb straight ahead to NDB(L) OX, on passing NDB(L) OX continue climb on QDR 169°. At I-OXF DME 4 turn left to hold at 2500, or as directed.

Aircraft Category		A	B	C
OCA (OCH)	Procedure	441(183)	448(190)	456(198)
VM(C)OCA (OCH AAL)	Total Area	800(530)	800(530)	1100(830)

Rate of descent	G/S KT	160	140	120	100	80
	FT/MIN	850	750	640	530	430

DIRECT ARRIVAL VIA VOR HON R151
Intercept and follow VOR HON R151 **not below MSA**. At lead NDB(L) OX QDM 189° (HON DME 25) turn right to establish on localiser. When established descend to cross FAP (I-OXF DME 4.7) at **1800**(1542), then continue as for main procedure.

NOTE Aircraft will normally be required to hold not lower than **3500** or equivalent FL.

WARNING Use of this procedure is subject to ATC Oxford/Kidlington ensuring that Danger Area EG D129 is inactive above **2500**.

CHANGE: NEW CHART.

AERO INFO DATE 1 MAY 07

AMDT AIRAC 7/07 Civil Aviation Authority

Figure 9.14 ILS approach to runway 19 at Oxford/Kidlington airport

ILS Calculations

When flying an ILS approach it would be sensible to predict the rate of descent required on approaching the glide path, and prudent to have a check on height when established on the glide path. These can be simply achieved by using the 1:60 rule.

Example: An aircraft is at 4 NM from touchdown flying a 3° glide path at a groundspeed of 150 kt. Determine the height the aircraft should be and the rate of descent required.

To determine height by the 1:60 rule:

$$\textit{Height} = \frac{\textit{Glide Path Angle} \times \textit{Range}}{60} \times 6076\ \textit{ft}$$

This can be simplified to:

$$\textit{Height} = \textit{Glide Path Angle} \times \textit{Range} \times 100$$

This gives: $\textbf{\textit{Height}} = \mathbf{3 \times 4 \times 100 = 1200}\ \textbf{\textit{ft}}$

The trigonometric solution, using accurate values gives a height of 1274 ft, so the use of the simple 1:60 formula does underestimate the height. However, we are using this as a check for gross errors.

To determine the rate of descent (ROD) required, using the 1:60 rule:

Find the change of height per NM and then multiply that by the speed in NM/minute:

For a 3° glide path:

$$\textit{ROD} = \frac{\textit{Glide Path Angle} \times 1}{60} \times 6076\ \textit{ft} \times \frac{\textit{Ground Speed}}{60}\ \textit{feet per minute}$$

$$= 3 \times 100 \times \frac{\textit{Ground Speed}}{60}\ \textit{feet per minute}$$

$$= 5 \times \textit{Ground Speed}\ \ \textit{feet per minute}$$

Hence, for the example the ROD required will be 750 feet per minute (fpm).

As with the height this is an approximation and will slightly underestimate the actual ROD, which works out trigonometrically as 796 fpm.

Note: This is only valid for a 3° glide path. For any other glide path angle, calculate for a 3° glide path then divide by 3 and multiply by the glide path angle (or calculate on your Navigation Computer).

ILS Summary

<table>
<tr><td colspan="7">Components and frequencies:</td></tr>
<tr><td>Localizer</td><td colspan="6">VHF - 108 to 111.975 MHz (40 channels). Aerial at upwind end.</td></tr>
<tr><td>Glide path</td><td colspan="6">UHF - frequency paired. Aerial abeam touchdown.</td></tr>
<tr><td>Markers</td><td colspan="6">VHF - 75 MHz. Fan-shaped vertical radiation. OM, MM and IM.</td></tr>
<tr><td>Back beam</td><td colspan="6">From localizer. Non-precision approach.</td></tr>
<tr><td>Locator</td><td colspan="6">Low power NDB at OM.</td></tr>
<tr><td>DME</td><td colspan="6">Freq paired. Possibly in place of markers. Zero-referenced to threshold.</td></tr>
<tr><td>Ident</td><td colspan="6">2 or 3 letters, 7 groups/min. Suppressed when ILS u/s. Continuous tone during maintenance.</td></tr>
<tr><td>Markers</td><td colspan="6">OM: blue, 2 dashes/s, 400 Hz, 6.5 - 11.1 km
MM: orange, 3 characters per second, alternate dots and dashes, 1300 Hz, 1050 m
IM: white, 6 dots/s, 3000 Hz, 75 - 450 m</td></tr>
<tr><td>Ground monitoring</td><td colspan="6">Localizer within 35 ft (Cat I) at ref datum. GP within 0.075 × glide path angle.
Power within 50%.
Otherwise: Cease radiation, remove ident or lower category.</td></tr>
<tr><td>ILS Coverage</td><td colspan="6">LLZ: 25 NM ± 10°, 17 NM ± 35°.
GP: 10 NM ± 8°, 0.45 to 1.75 × glide path angle.</td></tr>
<tr><td colspan="7">Principle of Operation:</td></tr>
<tr><td>Localizer</td><td colspan="6">LH lobe - 90 Hz, RH lobe -150 Hz; DoM increases away from ℄ DDM is zero on ℄.</td></tr>
<tr><td>Back course</td><td colspan="6">If approved use for non-precision approach. Reverse readings on CDI. HSI can operate in correct sense if front course QDM set.</td></tr>
<tr><td>Glide path</td><td colspan="6">Upper lobe - 90 Hz, lower lobe - 150 Hz. DoM increases away from the glide path centre line.
DDM is zero on the glide path centre line.</td></tr>
<tr><td>False GP</td><td colspan="6">at multiples of glide path angle. Be aware.</td></tr>
<tr><td>Ref datum</td><td colspan="6">height of GP over threshold.</td></tr>
<tr><td>Indicators</td><td colspan="6">CDI: 0.5°/dot; max 2.5° . Reverse indication on back course.
HSI: set course selector to front QDM for correct indications.
GP: 0.14°/dot; max 0.7°. max safe dev - 2.5 dots fly up (0.35°).</td></tr>
<tr><td rowspan="5">ILS Guidance Limits (EASA)</td><td rowspan="2">Facility</td><td>Category</td><td>I</td><td>II</td><td>III</td><td colspan="2" rowspan="2"></td></tr>
<tr><td></td><td>≤ 200 ft</td><td>≤ 50 ft</td><td>0 ft</td></tr>
<tr><td rowspan="3">Operational</td><td>Category</td><td>I</td><td>II</td><td>IIIA</td><td>IIIB</td><td>IIIC</td></tr>
<tr><td>DH</td><td>≥ 200 ft</td><td>≥ 100 ft</td><td>< 100 ft or 0 ft</td><td>< 50 ft or 0 ft</td><td>0 ft</td></tr>
<tr><td>RVR</td><td>≥ 550 m</td><td>≥ 300 m</td><td>≥ 200 m</td><td>≥ 75 m</td><td>0 m</td></tr>
<tr><td>Errors:</td><td colspan="6">Beam bends, scalloping, beam noise,
restricted vehicle movements during low vis ops,
check failure flags,
monitor ident.</td></tr>
</table>

Range and Accuracy:	Critical area - aircraft and vehicles excluded for all ILS ops, sensitive area - excluded area during low vis ops, Cat II/III holds, weather, FM broadcasts.
Approach segments:	Initial, intermediate and final, SSAs, landing minima - DH and RVR.

Questions

1. **The coverage of an ILS localizer extends to .... either side of the on-course line out to a range of .... NM.**

   a. 10°, 35
   b. 35°, 10
   c. 35°, 17
   d. 25°, 25

2. **The upper and lower limits of an ILS glide path transmitter having a 3.5° glide slope are:**

   a. 6.125° - 1.575°
   b. 7.700° - 1.225°
   c. 5.250° - 1.350°
   d. 3.850° - 3.150°

3. **The minimum angle at which a false glide path is likely to be encountered on a 3° glide path is:**

   a. 6 degrees
   b. 5.35 degrees
   c. normal glide slope times 1.75
   d. normal glide slope times 0.70

4. **The visual and aural indications obtained when overflying an ILS middle marker are:**

   a. continuous low pitched dashes with synchronized blue light
   b. continuous high pitched dots with synchronized amber light
   c. alternating medium pitch dots and dashes with amber light
   d. one letter in Morse with synchronized white light

5. **An aircraft carrying out an ILS approach is receiving stronger 150 Hz signals than 90 Hz signals. The correct actions to be taken to place the aircraft on the centre line and on the glide path are to fly:**

   a. DOWN and LEFT
   b. UP and LEFT
   c. UP and RIGHT
   d. DOWN and RIGHT

6. **In elevation the upper and lower limits of an ILS glide path transmitter having a 3.0 degree glide slope are:**

   a. 0.35° 0.70°
   b. 3.00° at least 6°
   c. 5.25° 1.35°
   d. 10.0° 35.0°

7. **A category II ILS installation encountered in the UK:**

a. provides accurate guidance down to 50’ above the horizontal plane containing the runway threshold
b. has a steep glide path, normally 7.5°
c. provides accurate guidance down to the runway and along the runway after landing
d. has a false glide path that is exactly twice the true glide path angle

8. **Which of these ILS indicators shows an aircraft on final approach left of the centre line and at maximum safe deviation below the glide path?**

a

b

c

d

9. **An aircraft tracking to intercept the ILS localizer inbound on the approach side but outside the published coverage angle:**

a. will receive false on-course or reverse sense signals
b. will not normally receive signals
c. will receive signals without coding
d. can expect signals to give correct indications

10. **The outer marker of an ILS installation has a visual identification of:**

a. alternating dots and dashes on a blue light
b. continuous dots at a rate of 3 per second, blue light
c. continuous dashes at a rate of 2 per second, amber light
d. continuous dashes at a rate of 2 per second, blue light

11. **The specified maximum safe fly up indication on a 5 dot CDI is:**

a. half full scale needle deflection above the centre line
b. 2.5 dots fly up
c. just before full scale deflection
d. 1.3 dots fly up

12. An aircraft is attempting to use an ILS approach outside the coverage sectors of an ICAO standard system:

a. from the glide slope needle the captain may be receiving false course and reverse sense indications and from the localizer needle intermittent and incorrect indications
b. the aircraft's receiver is not detecting any transmissions and the ILS needle OFF flags are visible
c. from the localizer needle the captain may be receiving false course and intermittent indications and from the glide slope needle reverse sense and incorrect indications
d. from the localizer needle the captain may be receiving false course and reverse sense indications and from the glide slope needle intermittent and incorrect indications

13. The coverage of the ILS glide slope in azimuth is:

a. ± 8° out to 10 NM
b. ± 10° out to 8 NM
c. ± 12° out to 17 NM
d. ± 35° out to 25 NM

14. An aircraft's Instrument Landing System glide slope and localizer receivers are receiving predominant 90 Hz modulated signals. If the aircraft is within the coverage of the ILS, QDM of 264°, it is:

a. north of the localizer and below the glide slope
b. south of the localizer and above the glide slope
c. north of the localizer and above the glide slope
d. south of the localizer and below the glide slope

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	a	a	c	b	c	a	d	a	d	b	d

13	14
a	b

Chapter

10

Microwave Landing System (MLS)

Introduction

The Microwave Landing System (MLS) was designed to replace ILS with an advanced precision approach system that would overcome the disadvantages of ILS and also provide greater flexibility to its users. However, there are few MLS installations in use at present and they are likely to co-exist with ILS for a long time.

MLS is a precision approach and landing system that provides position information and various ground to air data. The position information is provided in a wide coverage sector and is determined by an azimuth angle measurement, an elevation measurement and a range measurement.

ILS Disadvantages

ILS has the following disadvantages:

- There are only 40 channels available worldwide.
- The azimuth and glide slope beams are fixed and narrow. As a result, aircraft have to be sequenced and adequately separated which causes landing delays.
- There are no special procedures available for slower aircraft, helicopters, and Short Take-off and Landing (STOL) aircraft.
- ILS cannot be sited in hilly areas and it requires large expanses of flat, cleared land to minimize interference with the localizer and glide slope beams.
- Vehicles, taxiing aircraft, low-flying aircraft and buildings have to be kept well away from the transmission sites to minimize localizer and glide slope course deviations (bending of the beams).

The MLS System

The Microwave Landing System (MLS) has the following features:

- There are 200 channels available worldwide.
- The azimuth coverage is at least ± 40° of the runway on-course line (QDM) and glide slopes from 0.9° to 20° can be selected. The usable range is 20-30 NM from the MLS site; 20 NM in the UK.
- There is no problem with back course transmissions; a secondary system is provided to give overshoot and departure guidance ± 20° of runway direction up to 15° in elevation to a range of 10 NM and a height of 10 000 ft.
- It operates in the SHF band, 5031 - 5090.7 MHz. This enables it to be sited in hilly areas without having to level the site. Course deviation errors (bending) of the localizer and glide path caused by aircraft, vehicles and buildings are no longer a problem because the MLS scanning beam can be interrupted and therefore avoids the reflections.
- Because of its increased azimuth and elevation coverage aircraft can choose their own approaches. This will increase runway utilization and be beneficial to helicopters and STOL aircraft.

- The MLS has a built-in DME.
- MLS is compatible with conventional localizer and glide path instruments, EFIS, auto-pilot systems and area navigation equipment.
- MLS gives positive automatic landing indications plus definite and continuous on/off flag indications for the localizer and glide slope needles.
- The identification prefix for the MLS is an ‘M’ followed by two letters.
- The aim is for all MLS equipped aircraft to operate to CAT III criteria. *Figures 10.1, 10.2 and 10.3* below show some of these features.

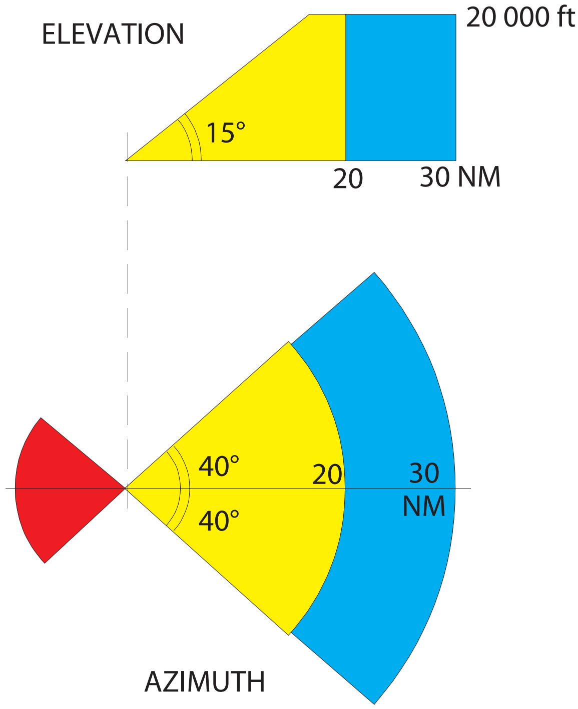


Figure 10.1 LMS Coverage

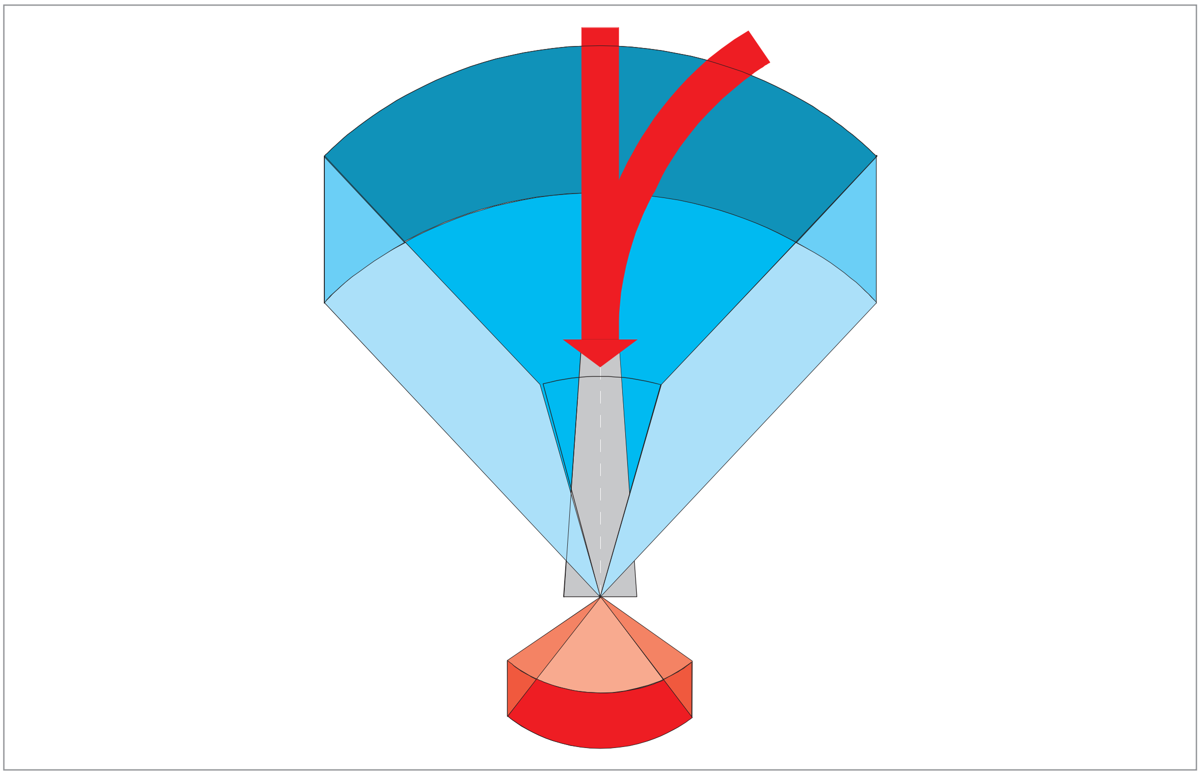


Figure 10.2 Approach Coverage Volume

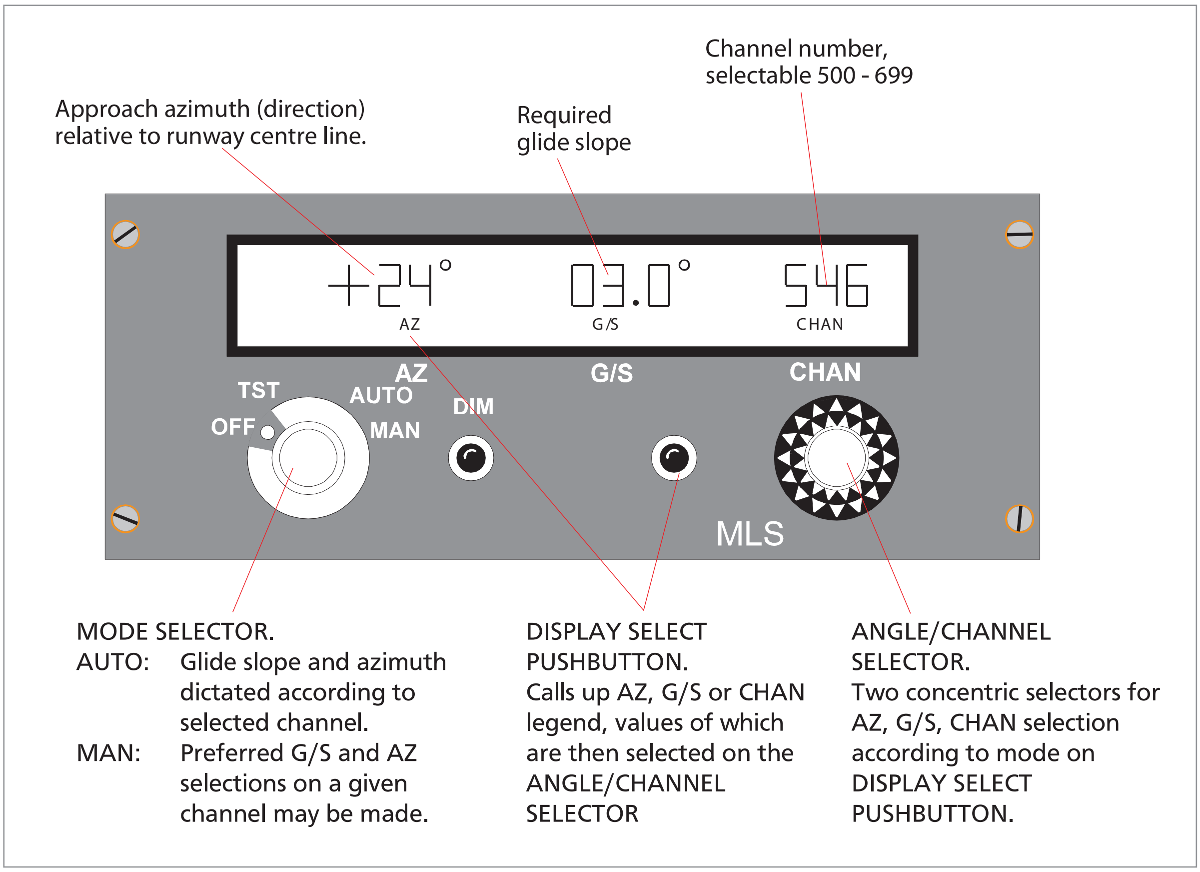


Figure 10.3 Typical MLS Flight Deck Control Panel

Principle of Operation

MLS employs the principle of Time Division Multiplexing (TDM) (see *Figure 10.5*) whereby only one frequency is used on a channel but the transmissions from the various angle and data ground equipments are synchronized to assure interference free operations on the common radio frequency.

- **Azimuth location.** Time referenced scanning beam (TRSB) is utilized in azimuth and elevation as follows: the aircraft computes its azimuth position in relation to the runway centre line by measuring the time interval in microseconds between the reception of the 'to' and 'fro' scanning beams.

  The beam starts the 'to' sweep at one extremity of its total scan and travels at a uniform speed to the other extremity. It then starts its 'fro' scan back to its start position. The time interval between the reception of the 'to' and 'fro' pulses is proportional to the angular position of the aircraft in relation to the runway on-course line.

  The pilot can choose to fly the runway on-course line (QDM) or an approach path which he selects as a pre determined number of degrees ± the runway direction. (See *Figure 10.4*).

- **Glide slope location.** Another beam scans up and down at a uniform speed within its elevation limits. The aircraft's position in relation to its selected glide slope angle is thus calculated in the same manner by measuring the time difference between the reception of the pulses from the up and down sweep. The transmissions from the two beams and the transmissions from the other components of the MLS system are transmitted at different intervals i.e. it uses ' time multiplexing'.

- Other components of the system are:

  - **Flare.** Although the standard has been developed to provide for flare elevation, this function is not intended for future implementation.

  - **Back azimuth.** Gives go-around and departure guidance ± 20° of runway direction up to 15° in elevation.

  - **DME.** Range along the MLS course is provided not by markers but by a DME. For Cat II and III approaches a precision DME (DME/P) that is accurate to within 100 feet must be available.

- Transmission of auxiliary data. This consists of:

  - station identification
  - system condition
  - runway condition
  - weather information

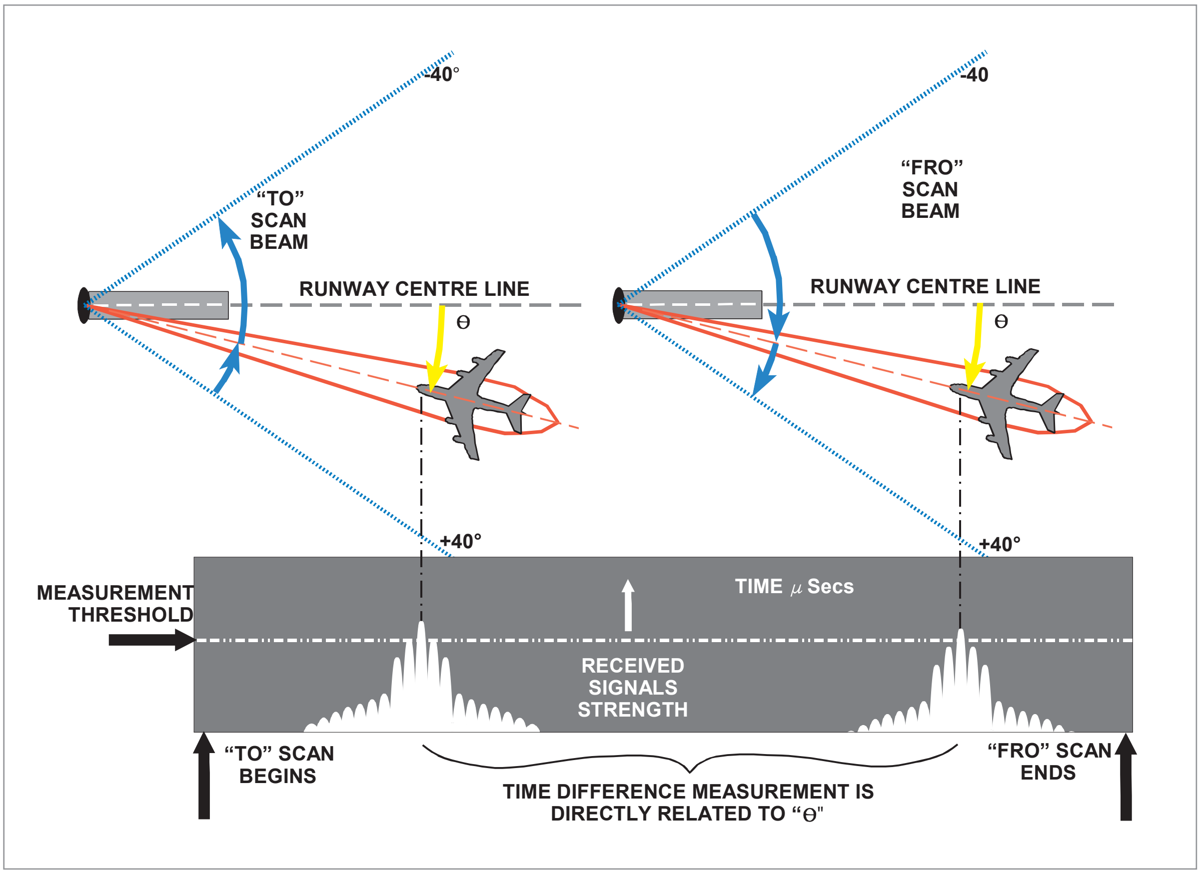

-40°
"TO"
SCAN
BEAM
RUNWAY CENTRE LINE
Θ
-40
"FRO"
SCAN
BEAM
RUNWAY CENTRE LINE
Θ
+40°
+40°
MEASUREMENT
THRESHOLD
TIME μ Secs
RECEIVED
SIGNALS
STRENGTH
"TO" SCAN
BEGINS
"FRO" SCAN
ENDS
TIME DIFFERENCE MEASUREMENT IS
DIRECTLY RELATED TO "Θ"

Figure 10.4

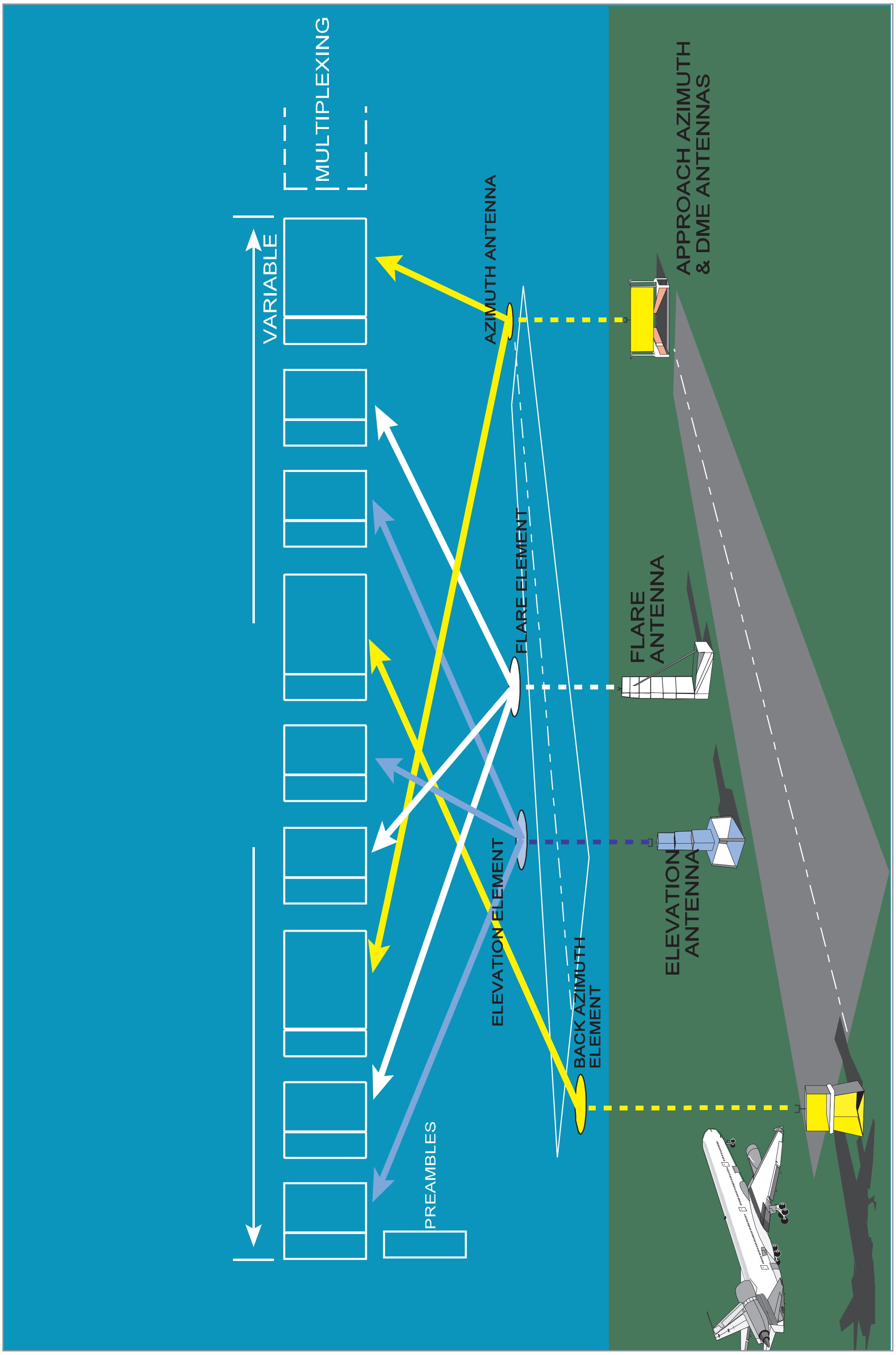


Figure 10.5 MLS component site

Airborne Equipment

The airborne equipment is designed to continuously display the position of the aircraft in relation to the preselected course and glide path along with distance information during approach as well as during departure.

Display

The display consists of two cross bars similar to an ILS display except that the indications are given relative to the selective course. It is possible to program the computer to give segmented approaches and curved approaches for which a DME-P must be installed on the ground.

Control Unit

In order to receive ILS, MLS and GPS transmissions, aircraft are equipped with multi-mode receivers and a combined control unit for ease of use by the flight crew. An example of such a control unit is shown at *Figure 10.6*.

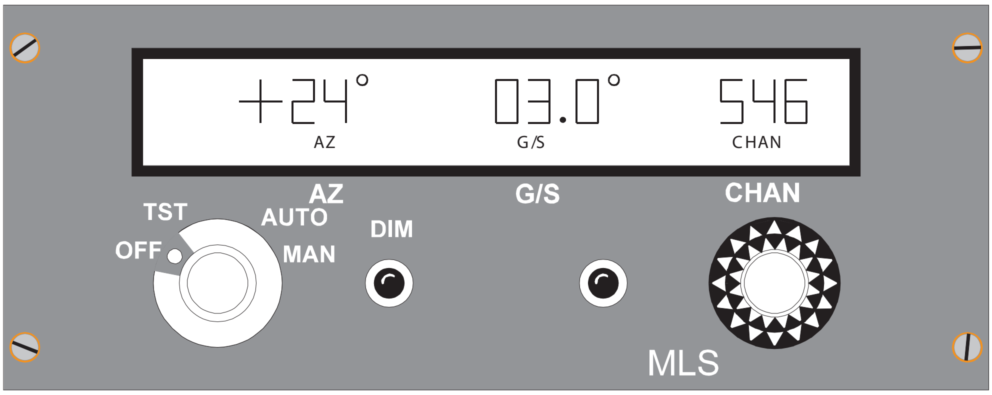


Figure 10.6 MLS control panel

Question

1. **The coverage of the Microwave Landing System in the UK extends to .... up to a height of .... and .... either side of the on course line.**

a.	20 NM	20 000 ft	40 degrees
b.	35 NM	5 000 ft	40 degrees
c.	35 NM	5 000 ft	20 degrees
d.	17 NM	2 000 ft	35 degrees

Answer

1
a

Chapter

11

Radar Principles

Introduction

Radar stands for **RA**dio **D**etection **A**nd **R**anging and was developed prior to World War II. It was used both on the ground as well as in the air by the military. Originally it used pulses for its operation but subsequently **continuous wave (CW)** techniques were also developed for other functions such as the radio altimeter, because CW radars have no minimum range limitation. Today radar is also extremely important in civil aviation. It is used by ground based radars in the control, separation and navigation of aircraft as well as in airborne systems for weather warning and navigation.

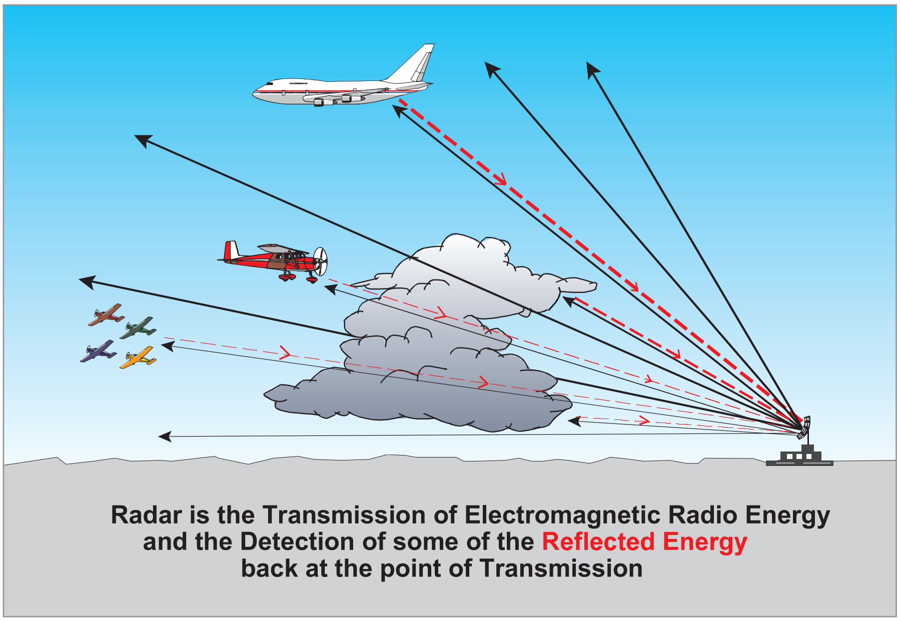


Figure 11.1

Types of Pulsed Radars

A Primary Radar uses **pulses** of radio energy **reflected** from a target i.e. it uses **one frequency** throughout.

A Secondary Radar transmits pulses on one frequency, but **receives on a different frequency** i.e. the object transmits its own energy. It is a system utilizing **an interrogator** and **transponder;** the transponder can be located in the aircraft or on the ground.

This will be covered in detail in Chapter 14.

Radar Applications

Radar has a wide range of applications as follows:

Air Traffic Control uses radar to:

- monitor aircraft in relation to each other whilst they are flying on airways, in control zones or in the airfield vicinity, and to vector the aircraft if necessary.
- provide radar talk-down to a given runway (Surveillance Radar Approach (SRA) or a military Precision Approach Radar (PAR)).
- control and monitor aircraft on ILS let-downs, or during airfield instrument approaches.
- provide information regarding weather e.g. storm clouds.

Air/Ground navigational systems use radar:

- **Secondary Surveillance Radar** provides ATC with information regarding an aircraft's call sign, altitude, speed, track history, destination and type of emergency when appropriate.
- **Distance Measuring Equipment (DME)** provides a pilot with very accurate slant ranges from a ground based receiver/transmitter known as a transponder.

Airborne Weather Radar (AWR) is used to:

- depict the range and bearing of clouds.
- indicate areas of the heaviest precipitation and associated turbulence.
- calculate the height of cloud.
- ground map.

Radar Frequencies

Radar systems are in the VHF and above frequency bands because:

- these frequencies are free from external noise/static and ionospheric scatter.
- the shorter wavelengths produce narrow, efficient beams for target discrimination and bearing measurement.
- the shorter wavelengths can produce shorter pulses.
- efficient reflection from an object depends upon its size in relation to the wavelength; shorter wavelengths are reflected more efficiently.

Pulse Technique

Primary and secondary radar systems use the pulse technique which is the transmission of radio energy in very short bursts. Each burst of energy is in a pulse form of a predetermined shape. The duration of the pulse is equal to the **pulse length or width**. Although a pulse is of short width (time) it can contain many cycles.

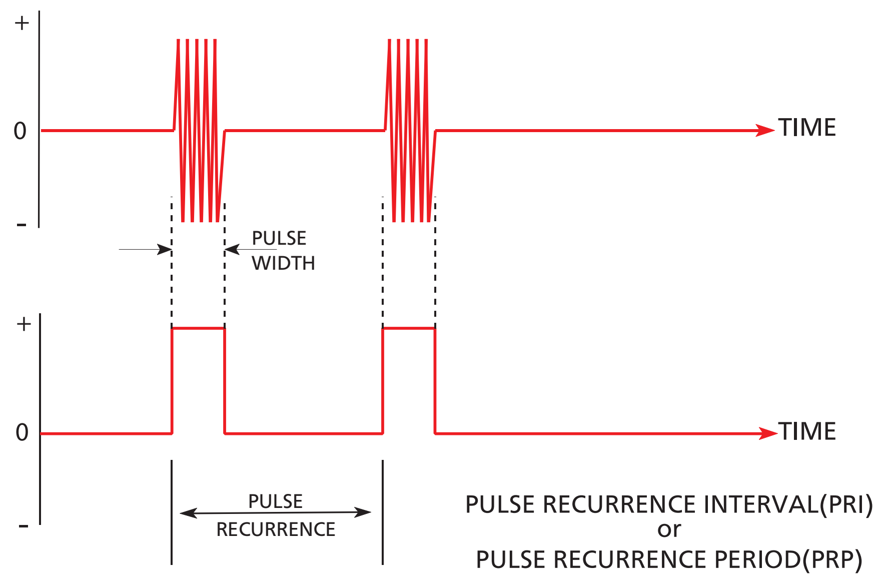


Figure 11.2 Pulse technique

Pulse Recurrence Interval (PRI) is the **time interval** between two pulses.

Pulse Recurrence Frequency (PRF) is the number of pulses transmitted in one second **(pps).**

Example. If the PRF is 250 pps what is the PRI of the transmission?

PRI = 1 / 250 s

PRI = 1 000 000 / 250 μs = 4000 μs

Distance Measurement - Echo Principle

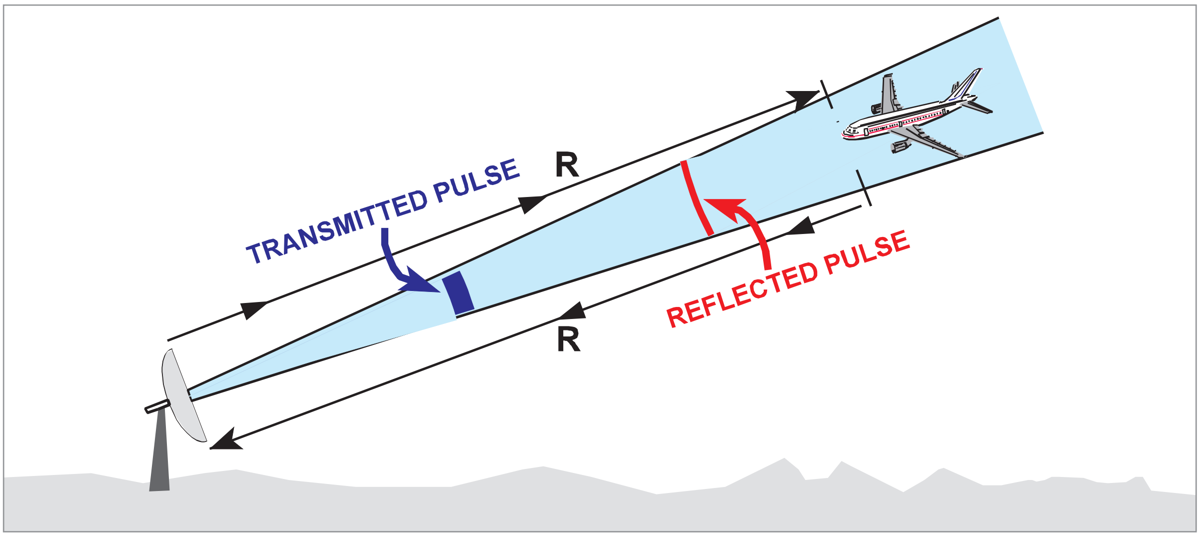


Figure 11.3

The distance to an object is found by timing the interval between the instant of the pulse's transmission and its return as an echo; this is shown in *Figure 11.3*.

For example, if the echo (the time between transmission and reception) is 500 μs then:

$$Distance = 300\,000\,000 \times \frac{500}{1\,000\,000 \times 2}\ m$$

$$= 75\,000\ m = 75\ km$$

or

$$Distance = \frac{162\,000 \times 500}{1\,000\,000 \times 2}$$

$$= 40.5\ NM$$

(c = 300 000 000 m/s or 162 000 NM/s)

Other methods of calculating the range are:

$$Range = \frac{500 \times 300}{2} = 75\ km \qquad Range = \frac{500 \times 300}{2 \times 1852} = 40.5\ NM$$

A radar mile (one NM out and back) = 12.36 μs.

$$Range = \frac{500}{12.36} = 40.5\ NM$$

Theoretical Maximum Range

Relationship to PRF

Maximum theoretical range is determined by the PRF i.e. the number of pulses transmitted in one second (pps) Each pulse must be allowed to travel to the most distant object planned before the next pulse is transmitted; to do otherwise makes it impossible to relate a particular echo to a particular pulse. The maximum range is therefore related to the PRF such that the greater the range required, the lower the PRF used.

Examples

1. We wish a radar to measure a range of up to 187 km. What should the PRF (PRR) be?

2. What is the maximum PRR for a radar required to measure up to 200 NM?

3. Maximum range for a radar is to be 170 km. What is the maximum PRR?

4. An AWR has a 400 pps PRR. Calculate the maximum range in nautical miles for this equipment.

Answers

1. The pulse must travel 374 km (2 × 187) before the next pulse transmission.

   The time for the journey, T = D/S = 374 000/300 000 000 seconds

   = 0.0012466 s = 1246 μs

   i.e. PRI = 1246 μs.

   Thus the second pulse can only leave 1246 μs after the first.

   PRF (pps) = 1/ PRI = 1/ 1246 μs = 1 000 000 / 1246 = 802 pps

   Alternately we can say that PRF = 300 000 000 / 374 000 = 802 pps

2. 405 pps

3. 882 pps

4. 203 NM

Practical Range

The practical range for the radar is less than the maximum theoretical range because the trace on the CRT (cathode ray tube) needs a period of time to return to the point of origin. This period is called the fly-back or **dead time**. During this period returning echoes cannot be displayed thereby reducing the range achievable for a given PRF.

Primary Radars

The pulses are concentrated into the beam dimensions designed for the particular radar. The beam uses the 'echo' **principle to determine range and the 'searchlight' principle to indicate bearing or height.** *Figure 11.4* shows the Plan Position Indicator (PPI) display and *Figure 11.5* shows the ATC radar antennae. The long structures at the top of the primary radar antennae are the secondary radar antennae.

The transmitter and receiver share the same antenna. The receiver is energized to accept 'echoes' from objects in the pulses' path as soon as the transmitter pulse exits the antenna. The reflected pulses are very weak due to the double journey.

The shape and size of the radar antennae determines the size of the main and side lobes as well as the width of the radar beam generated by the system. The larger the aerial, the narrower will be the beam.

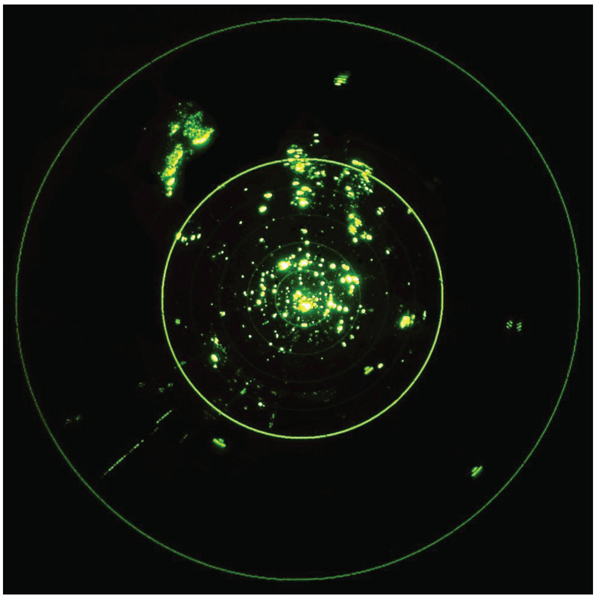


Figure 11.4 A PPI display of primary raw radar

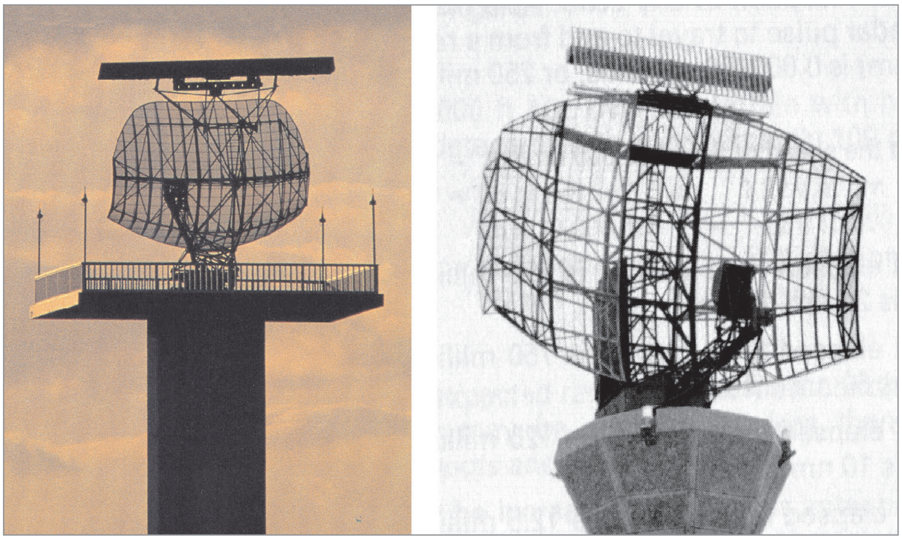


Figure 11.5 Typical radar antennae

The Range of Primary Radar

Maximum Range

The range of a primary radar depends upon the strength of the returning pulses that determines the quality of the target depiction on the PPI. The range is affected by several factors:

- **Transmission power.** A radar signal attenuates with increasing distance from the transmitter. As the signal has to travel out and back the power/range relationship is:

  Power available is proportional to the fourth power of range which means that the power has increased by a factor of 16 to double the range

- **Characteristics of reflecting objects.** Metals are more efficient than wood at reflecting the transmitted signal and the size and shape of the detected object make a considerable difference to the effective range. The aspect of the object also affects the range; for instance, a manoeuvring aircraft presents various aspects which can affect the polarization of reflected waves. The side of the fuselage has a better aspect than the nose of the aircraft.

- **Aircraft height and the height of the radar head.** Radar transmissions, because of their frequency bands, travel in straight lines and give line of sight ranges, plus a little extra due to atmospheric refraction. Thus the curvature of the earth causes much of the surface to be in shadow. Therefore, higher flying aircraft are more likely to be detected because they are above that shadow. Intervening high ground also will screen low flying aircraft from detection. The higher the radar head can be positioned, the greater that radar's range and the less effect intervening high ground will have on stopping signals and reducing its range. The following formula can be used to calculate the maximum theoretical radar range:

  Max. Theoretical range (NM) $= 1.23 \times (\sqrt{H_{TX}} + \sqrt{H_{RX}})$

  H_{TX} = height of radar station in feet AMSL; H_{RX} = height of target in feet AMSL.

- **Wavelength and attenuation by raindrops**

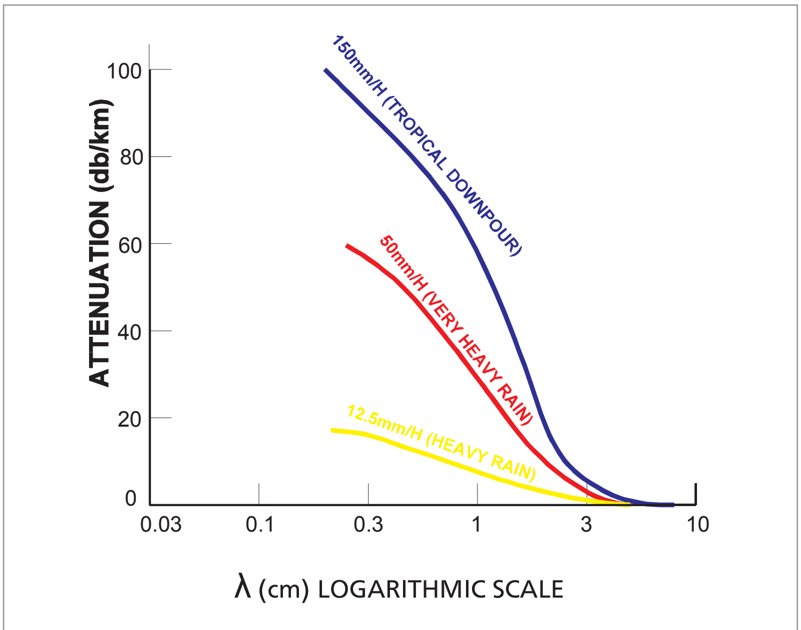


Figure 11.6 Attenuation by raindrops

It can be seen from *Figure 11.6* that energy is absorbed and scattered by raindrops; the total effect depends upon the size of the water droplets and the transmitted wavelengths. At wavelengths longer than 10 cm the attenuation is negligible. If the wavelength is between 10 cm and 4 cm the attenuation is significant only in tropical rain. However, with wavelengths less than 4 cm, attenuation is significant in rain in the temperate latitudes. One conclusion is that wavelengths less than 3 cm should not be used for long range systems. Airfield Surface Movement Indicator **(ASMI)** radars operate at **1.75 to 2 cm** wavelengths. Airborne Weather Radars **(AWR)** and Precision Approach Radars (**PAR**) use **3 cm** wavelengths. **Surveillance radars** (ground) use **10, 23 or 50 cm** wavelengths.

- **Atmospheric conditions.** Certain atmospheric conditions can actually increase the range of radar pulses by refracting the waves which would normally travel in straight lines. This is called super-refraction and it gives radar ranges beyond normal line of sight i.e. it gives over the horizon radar capability by causing the radio waves to refract downwards towards the earth's surface. Such conditions occur when there is a temperature inversion and a decrease in humidity with height. On the other hand, atmospheric conditions can also cause sub-refraction in which the theoretical range of the radar is reduced by causing the waves to refract upwards away from the surface.

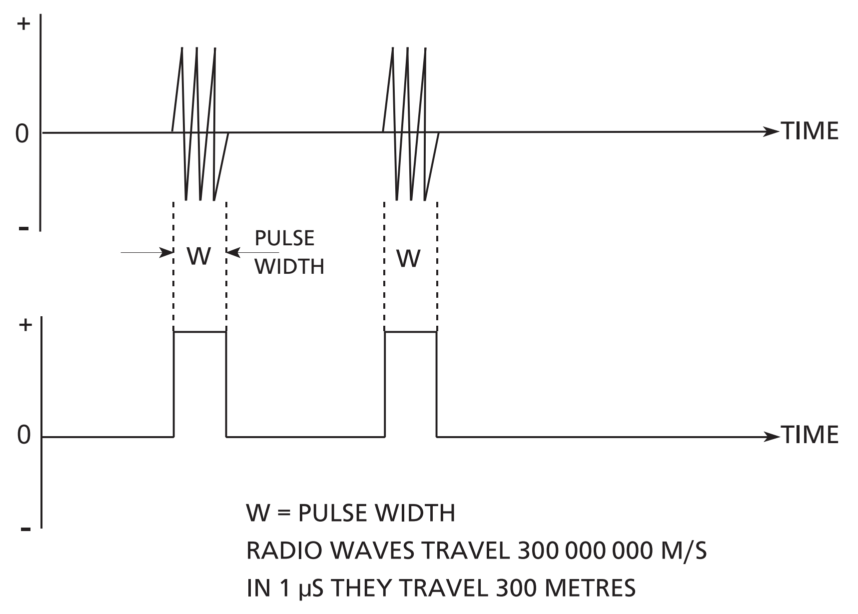


Figure 11.7 Pulse Width Decides Minimum Range

- **Restoration Time** is a design factor that affects the time taken for a receiver to recover to normal after transmission has occurred.

- **Pulse width** determines the minimum range. With reference to *Figure 11.7*, it can be shown that a pulse 1 μs wide would extend 300 metres. Thus an object at 150 metres reflecting this pulse would cause it to arrive back at the receiver as its tail was leaving the transmitter.

  Any object closer than 150 metres would reflect a pulse that could not be received as the transmitter would still be transmitting. Furthermore, two objects in line 150 metres or less apart would appear as a single return. As a result, if short range operation is required for target resolution and accuracy, short pulses are used, e.g. 0.1 μs.

Note: 1 or 2 μs are used for medium range radars and about 5 μs for long range radar.

Question A surface movement radar is required to measure down to 500 m. Calculate the maximum pulse width in microseconds.

Answer 3.3 μs

Radar Measurements

Bearing

Bearing measurement is obtained by using the searchlight principle. Radio pulses are concentrated into **very narrow beams** which are produced by shortening the wavelength or increasing the aerial size and in advanced systems this is done electronically. The beam is rotated at a constant speed. The PPI display is synchronized with the antenna rotation. The direction of an object is the direction of the beam, measured from a fixed datum, at the time when the echo is received.

Range

Calculated from the time interval between the transmission and reception of the radar pulse.

Harmonization

In order that bearing and range information can be determined from the radar system it is necessary to harmonize the rotary speed of the antenna, the pulse duration or width, the pulse repetition frequency, focusing and transmission power.

Radar Resolution

The image painted on a PPI display from a point target will not be a single point but will appear as a rectangle, known as the radar resolution rectangle i.e. the target appears to be stretched both radially and in azimuth. The dimensions of the rectangle depend upon the pulse length, the beamwidth and the spot size.

The **radial resolution** is dependent upon **half the pulse length**. For example, a pulse length of 1 μs would stretch the target by 150 metres (distance that an electromagnetic wave travels in 0.5 μs). If two targets happen to be within half pulse width they will be illuminated simultaneously by the pulse and return only a single echo to the receiver.

The **azimuth resolution** is dependent upon the **full beamwidth**. Therefore a 3° beamwidth at a range of 120 km would stretch the target in azimuth by 6 km (using the 1 in 60 rule).

It follows therefore that in order to resolve adjacent targets the radar should have short pulse lengths and narrow beamwidths. However shortening the pulse length reduces the time the target is illuminated by the pulse and reduces the chance of a good return being received. Beamwidths can only be narrowed by increasing the size of the antenna.

The spot size and the target size also increase the size of the echo displayed on the PPI screen.

Moving Target Indication (MTI)

Surveillance radar equipment incorporates circuitry designed to eliminate returns from stationary objects such as hills or buildings which would give returns that would mask the smaller returns from aircraft. By erasing the permanent echoes the radar is able to display only the moving targets such as aircraft.

It is possible for a radar receiver on MTI to produce false targets as a result of **second trace returns** i.e. a return of the preceding pulse from a target beyond the maximum range selected, appearing during the period of the next pulse as a moving target within the selected range. In order to overcome this problem, MTI radars remove second trace returns by changing the PRI between consecutive pulses, a technique known as 'jittering the PRF'.

Radar Antennae

The **microwave horn**, **parabolic reflector** and **slotted planar array (or flat plate antenna)** shown in *Figure 11.8* and *Figure 11.9* are popular antennae which are used extensively in radar and satellite systems. Microwave horns are very often used as feeds for large parabolic reflectors. Both the parabolic reflector and the flat plate antennae generate main lobes as well as side lobes. Most radars will incorporate circuits for side lobe suppression so that echoes from the side lobes do not interfere with the main pulse returns. *Figure 11.10* shows a radiation pattern with the main and side lobes of a parabolic reflector. The slotted planar array produces a narrower beam with much smaller side lobes hence reducing the power required and improving the resolution.

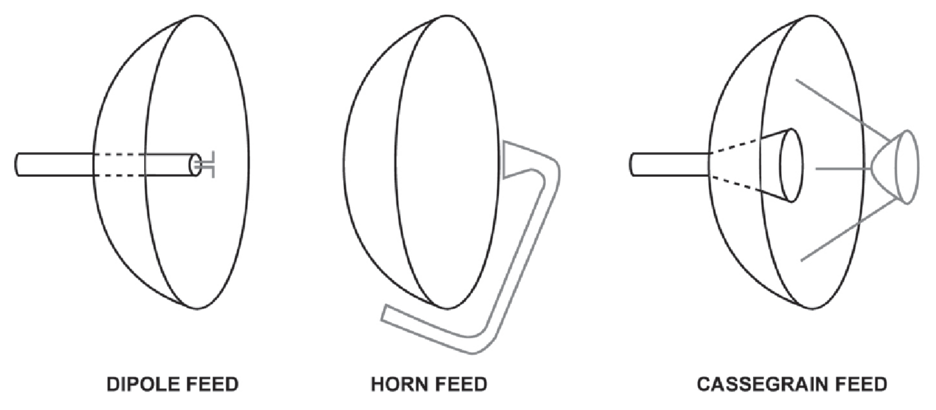


Figure 11.8 Radar antennae

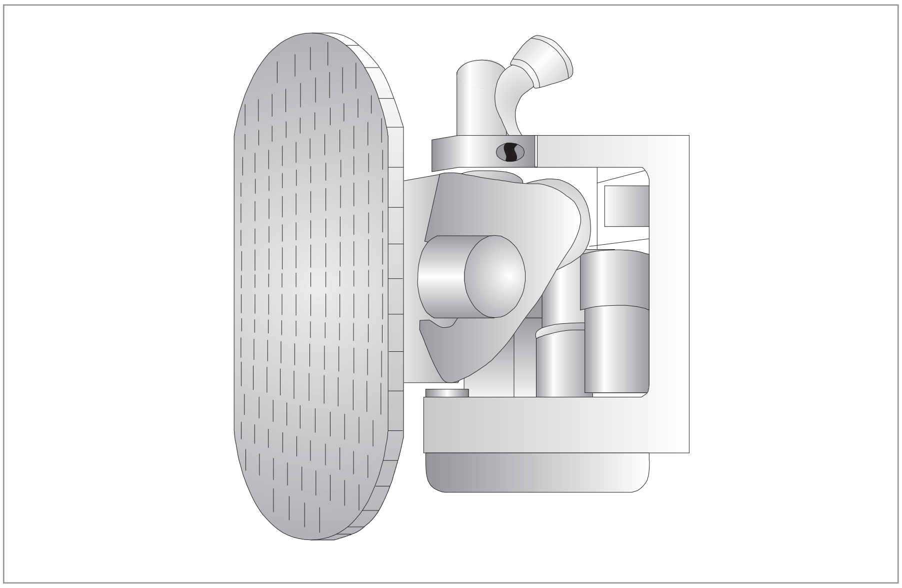


Figure 11.9 Airborne weather radar antenna

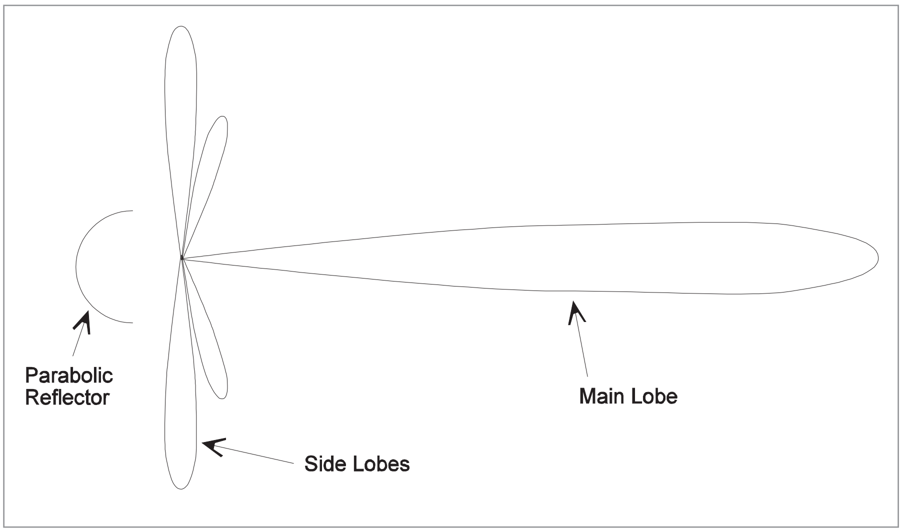


Figure 11.10 Typical radiation pattern

Questions

1. The factor which determines the maximum range of a radar is:

a. pulse repetition rate
b. pulse width
c. power
d. beamwidth

2. The main advantage of continuous wave radars is:

a. no maximum range limitation
b. better range resolution
c. no minimum range limitation
d. better range resolution

3. If the PRF of a primary radar is 500 pulses per second, the maximum range will be:

a. 324 NM
b. 300 NM
c. 162 NM
d. 600 NM

4. To double the range of a primary radar would require the power to be increased by a factor of:

a. 2
b. 4
c. 8
d. 16

5. The time between the transmission of a pulse and the reception of the echo from a target is 1720 microseconds. What is the range of the target?

a. 139 km
b. 258 km
c. 278 km
d. 516 km

6. A radar is required to have a maximum range of 100 NM. What is the maximum PRF that will achieve this?

a. 1620 pulses per second (pps)
b. 1234 pps
c. 617 pps
d. 810 pps

7. If the PRI of a radar is 2100 microseconds, the maximum range of the radar is:

a. 170 NM
b. 315 NM
c. 340 NM
d. 630 NM

8. **To improve the resolution of a radar display requires:**

a. a narrow pulse width and a narrow beamwidth
b. a high frequency and a large reflector
c. a wide beamwidth and a wide pulse width
d. a low frequency and a narrow pulse width

9. **An advantage of a phased array (slotted antenna) is:**

a. better resolution
b. less power required
c. reduced side lobes and clutter
d. all of the above

10. **An echo is received from a target 900 microseconds after the pulse was transmitted. The range to the target is:**

a. 73 NM
b. 270 NM
c. 135 NM
d. 146 NM

11. **The factor which limits the minimum detection range of a radar is:**

a. pulse repetition interval
b. transmitter power
c. pulse width
d. pulse repetition frequency

12. **The use of Doppler techniques to discriminate between aircraft and fixed objects results in second trace returns being generated. These are removed by:**

a. using a different frequency for transmission and reception
b. jittering the PRF
c. making regular changes in pulsewidth
d. limiting the power output of the radar

13. **A radar is designed to have a maximum range of 12 km. The maximum PRF that would permit this is:**

a. 25 000 pps
b. 6700 pps
c. 12 500 pps
d. 13 400 pps

14. **The bearing of a primary radar is measured by:**

a. phase comparison
b. searchlight principle
c. lobe comparison
d. DF techniques

Answers

1	2	3	4	5	6	7	8	9	10	11	12
a	c	c	d	b	d	a	a	d	a	c	b

13	14
c	b

Chapter

12

Ground Radar

Introduction

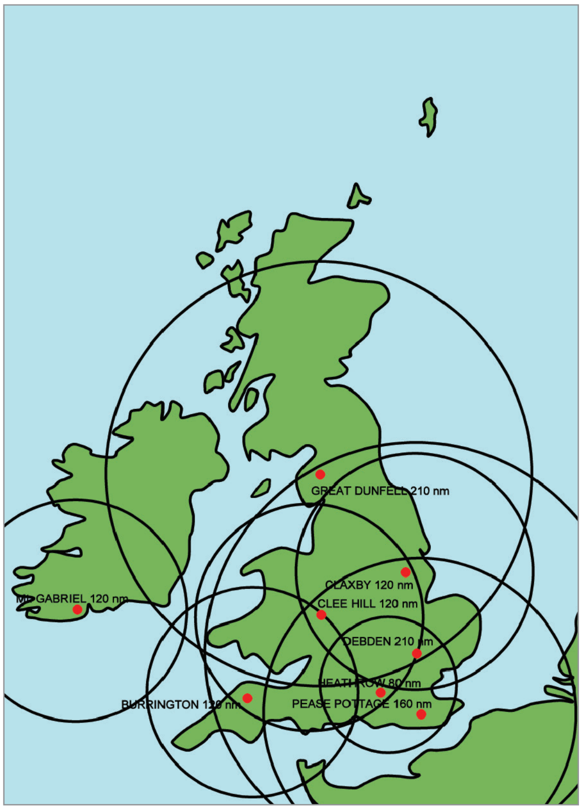
Air Traffic Control services use ground radars extensively to serve a large number of requirements and users. They employ both primary radar and secondary radar techniques. Primary Radar is used to detect aircraft not equipped with a Secondary Radar Transponder. It may incorporate Moving Target Indication (MTI). The services that can be offered by Air Traffic Controllers are Information, Surveillance or Guidance.

Primary radar systems used by ATC include:

- Area Surveillance Radar (ASR)
- Terminal Area Surveillance Radar (TAR)
- Aerodrome Surveillance Radar
- Precision Approach Radar (PAR)
- Airport Surface Movement Radar (ASMR)

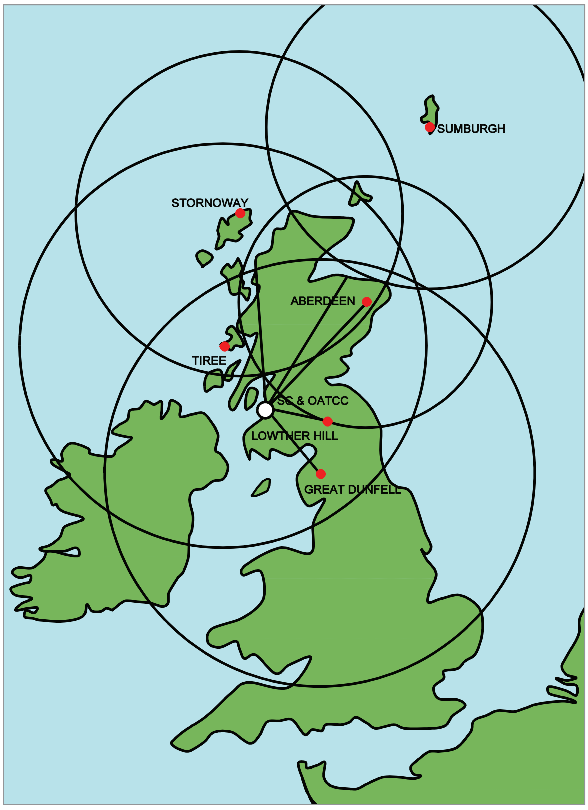
Area Surveillance Radars (ASR)

These are long range radars (200 to 300 NM) used for airway surveillance to provide range and bearing of aircraft. (Additional information is provided by Secondary Surveillance Radar - SSR). *Figures 12.1* and *12.2* show the locations and coverage of the London ACC and Scottish ACC radars and *Figure 12.3* shows the UK Airways structure.



Courtesy of Airbus Industrie

Figure 12.1 Coverage of LACC radars



Courtesy of Airbus Industrie

Figure 12.2 Coverage of SACC radars

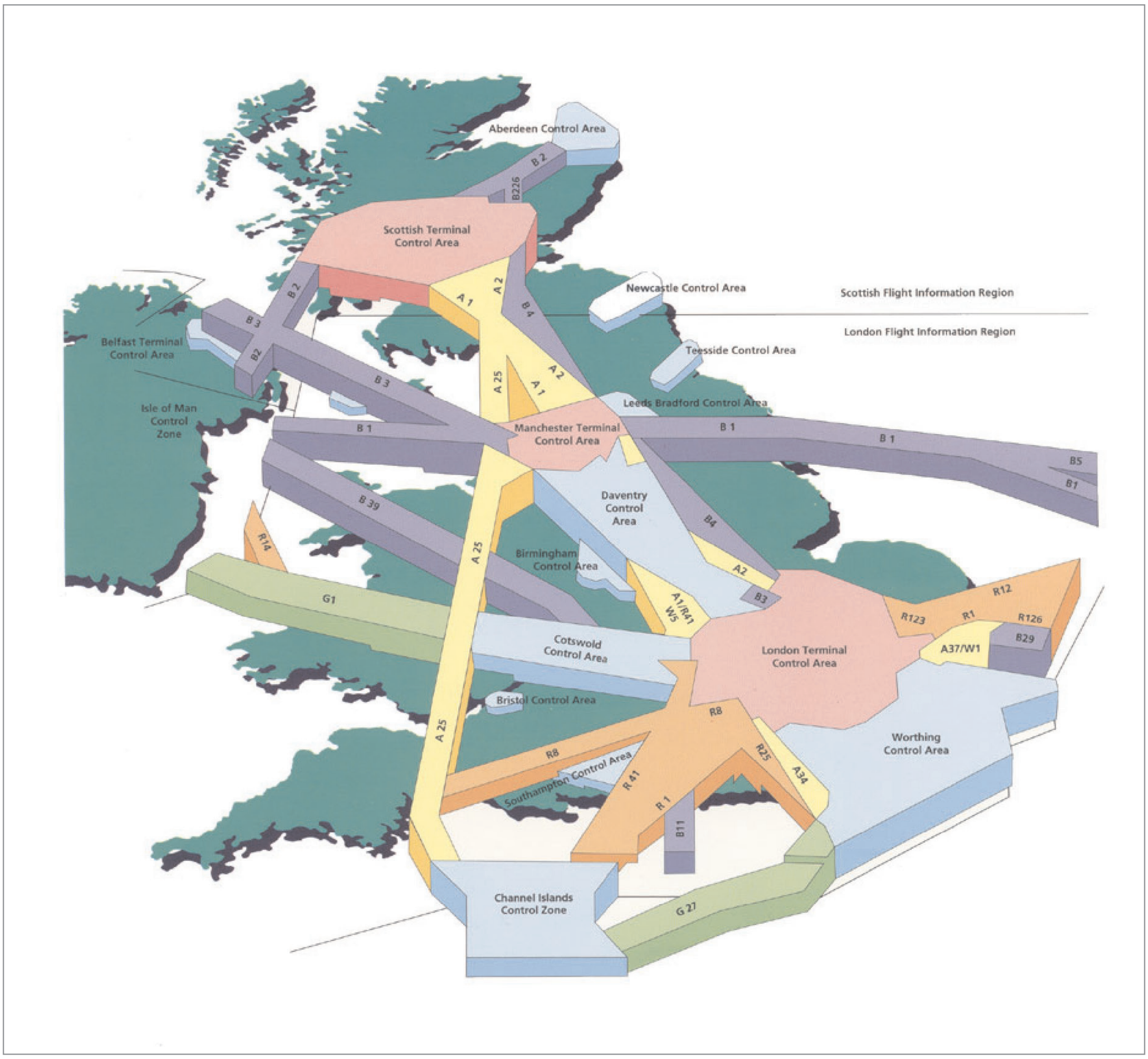


Figure 12.3 Airways in UK Airspace.

For the long range radars the wavelengths and pulse lengths are relatively long (10 to 50 cm and 2 to 4 μs respectively). The longer pulse length ensures that the target is illuminated for sufficient time to give a good return. The PRF and antenna rotation rate (scan rate) are low - 300 to 400 pps and 5 to 6 rpm respectively. This ensures that the next pulse is not transmitted until the first one has had sufficient time to return from the long range target.

Terminal Surveillance Area Radars

These are medium range radars, up to 75 NM, used for controlling traffic in TMAs. (Additional information is provided by Secondary Surveillance Radar - SSR).

Typical wavelengths are 10 cm, 23 cm and 50 cm with pulse widths 1 to 3 μs.

In the UK horizontal radar separation minima may be reduced to 3 NM (5.6 km) within 40 NM (or in certain circumstances 60 NM) of the radar head and below FL245 where the procedure has been officially approved.

Aerodrome Surveillance Approach Radars

These are short range radars providing positional information up to 25 NM. Their wavelengths are 3 cm or 10 cm with pulse widths of 0.5 to 1 μs. They provide:

- Positional information and control of aircraft in the aerodrome vicinity, Approach Radar (RAD)
- Radar Vectoring to the ILS
- Surveillance Radar Approach (SRA)

Airport Surface Movement Radar (ASMR)

This is also known as **AIRFIELD SURFACE MOVEMENT INDICATOR (ASMI)** and is installed at major airfields to provide a very accurate radar display (in all weathers and conditions of visibility) of the aerodrome infrastructure, (taxi-ways, runways, aprons etc.), vehicular traffic and aircraft that are stationary, taxiing, landing or taking off.

ASMI radar is designed to provide a detailed, bright and flicker-free display of all aircraft and vehicles on runways and taxiways so that Air Traffic Control Officers can be certain that runways are clear of traffic before landings or take-offs, and to enable them to ensure the safe and orderly movement of traffic on taxiways. Processing can remove selected fixed features leaving targets on runways and taxiways, etc., clearly visible. This is shown in *Figure 12.4*; the aircraft taking off is a DC9.

The very high definition required by these radars is achieved by designing a radar with:

- a very narrow beam in the order of 0.2° to 1°.
- a scanner rotation rate of 60 rpm.
- a PRF in the order of 4000 to 20 000 pps.
- pulse widths in the order of 0.03 μs.
- frequencies of 15 to 17 GHz (SHF), 2 to 1.76 cm wavelengths.
- ranges of 2.5 to 6 NM in light precipitation.

The frequencies required for ASMI result in the transmissions being increasingly attenuated and absorbed as the intensity of precipitation increases. This has the effect of reducing the radar's range, but this is not a significant problem as the radars are only required to cover the environs of the airfield. The EHF band is not suitable for an ASMI radar as the degree of attenuation in most types of precipitation reduces its effective operational range and capabilities.

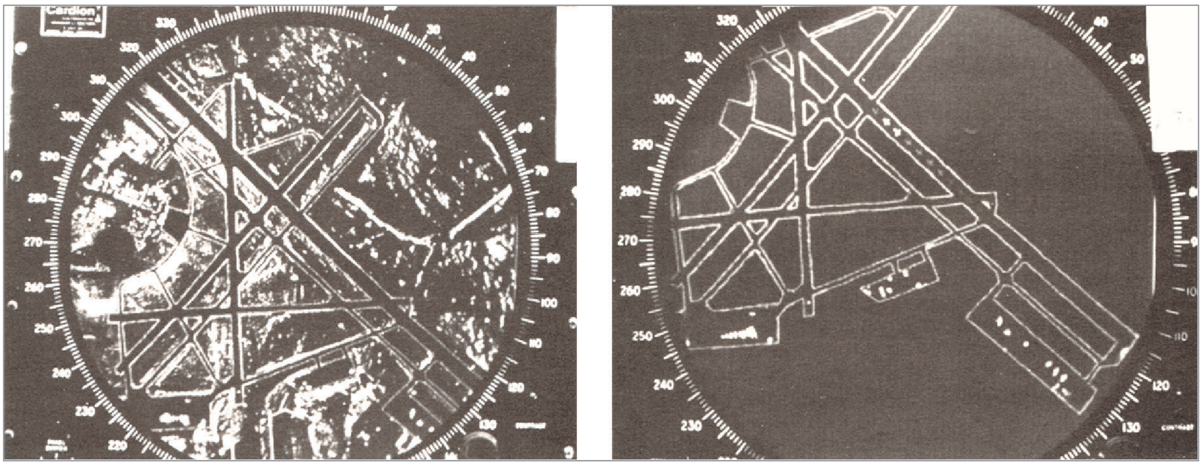


Figure 12.4

ASMI with fixed features | *Processed ASMI*

Questions

1. **A primary radar has a pulse repetition frequency of 275 pps. The time interval between the leading edges of successive pulses is:**

   a. 3.64 milliseconds
   b. 36.4 milliseconds
   c. 3.64 microseconds
   d. 36.4 microseconds

2. **A primary radar system has a pulse repetition frequency of 450 pps. Ignoring pulse width and flyback at the CRT, the maximum range of the radar would be:**

   a. 333 NM
   b. 180 NM
   c. 666 NM
   d. 360 NM

3. **The frequency band and rate of scan of Airfield Surface Movement radars are:**

   a. SHF; 60 rpm
   b. SHF; 200 rpm
   c. EHF; 100 rpm
   d. EHF; 10 rpm

4. **A ground based radar with a scanner rotation of 60 rpm, a beamwidth in the order of 0.5° and a PRF of 10 000 pps would be:**

   a. an Airfield Surface Movement Indicator with a theoretical range of 8 NM
   b. a Precision Approach Radar
   c. an Airfield Surface Movement Indicator with a theoretical range of 16 NM
   d. a high resolution Surveillance Approach Radar

Answers

1	2	3	4
a	b	a	a

Chapter

13

Airborne Weather Radar

Introduction

Airborne weather radar (AWR) is used to provide pilots with information regarding weather ahead as well as navigation. Unlike most other systems, it requires interpretation by the pilot and its use is enhanced by the skill of the user.

The radar information can be displayed on a dedicated unit or shown (on modern aircraft) in combination with the aircraft route on the EFIS navigation display (ND).

Information on cloud formations or terrain features is displayed on the indicator's screen as a range from the aircraft and a bearing relative to its heading. The presentation can be monochrome or, on modern systems, in the colours green, yellow, red and/or magenta. In the weather mode the colours represent the increasing variations in rainfall rate from light to very strong returns; magenta usually indicates the presence of turbulence associated with intense rainfall. For ground mapping green indicates light ground returns, yellow medium ground returns and red heavy ground returns.

Component Parts

The airborne equipment comprises:

- Transmitter/receiver. (*Figure 13.1*)
- Antenna, which is **stabilized in pitch and roll.** (*Figure 13.1*)
- Indicator. (*Figures 13.1, 13.2, 13.3* and *13.4*)
- Control unit. (*Figure 13.1*)

AWR Functions

The main functions of an AWR are to:

- **detect the size of water droplets** and hence deduce where the areas of turbulence are within the cloud.
- **determine the height of cloud tops** by tilting the radar beam up or down.
- **map the terrain** below the aircraft to provide navigational information and high ground avoidance.
- **provide a position fix (range and bearing)** from a prominent feature.

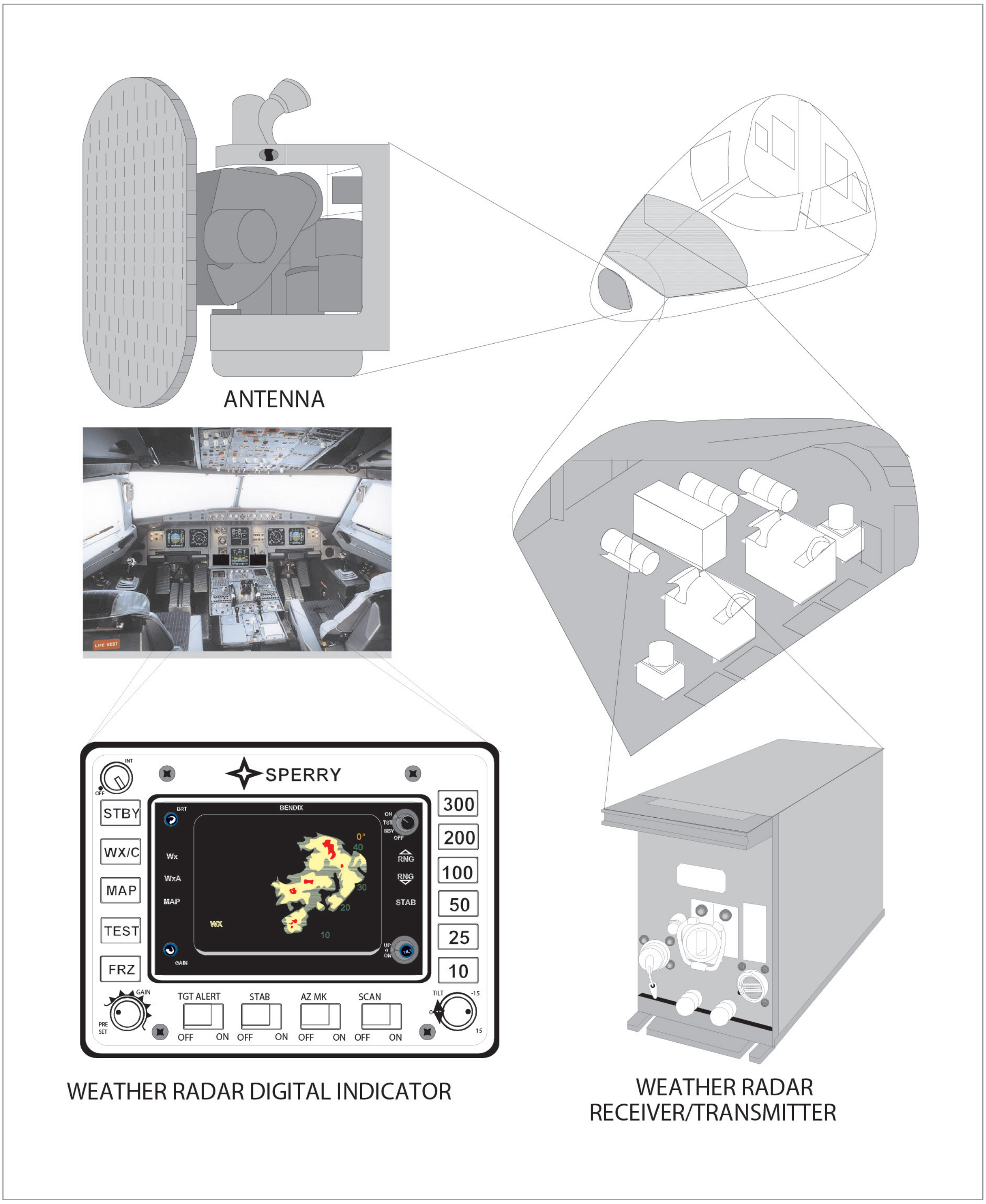


Figure 13.1 AWR Components

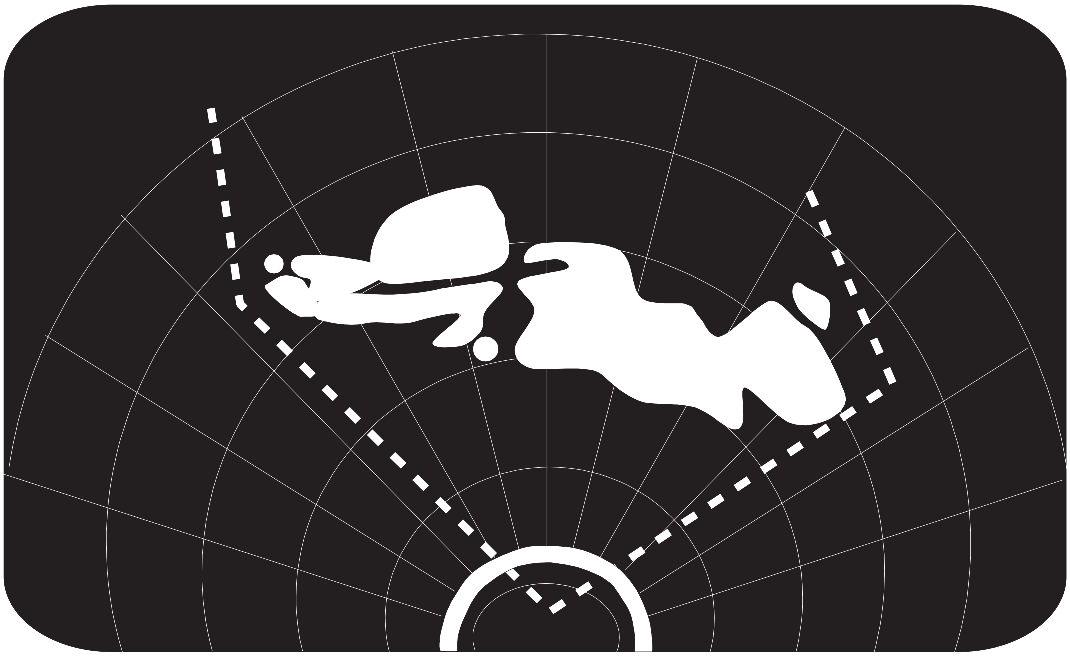


Figure 13.2 Monochrome Cloud Display and Avoidance Courses

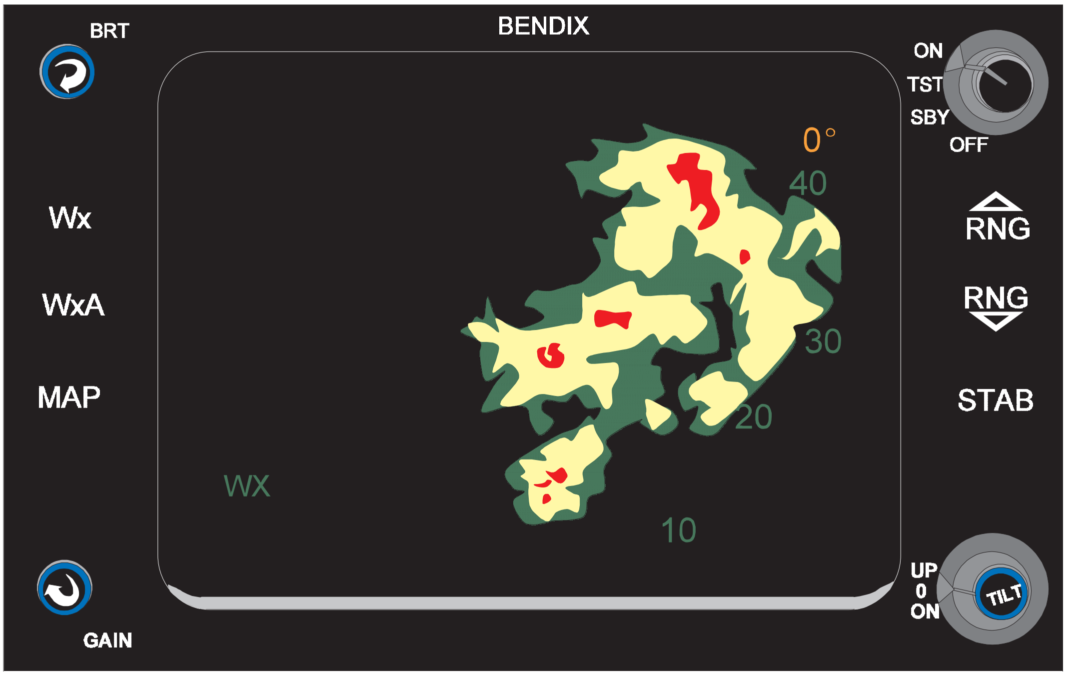


Figure 13.3 Colour Weather Display

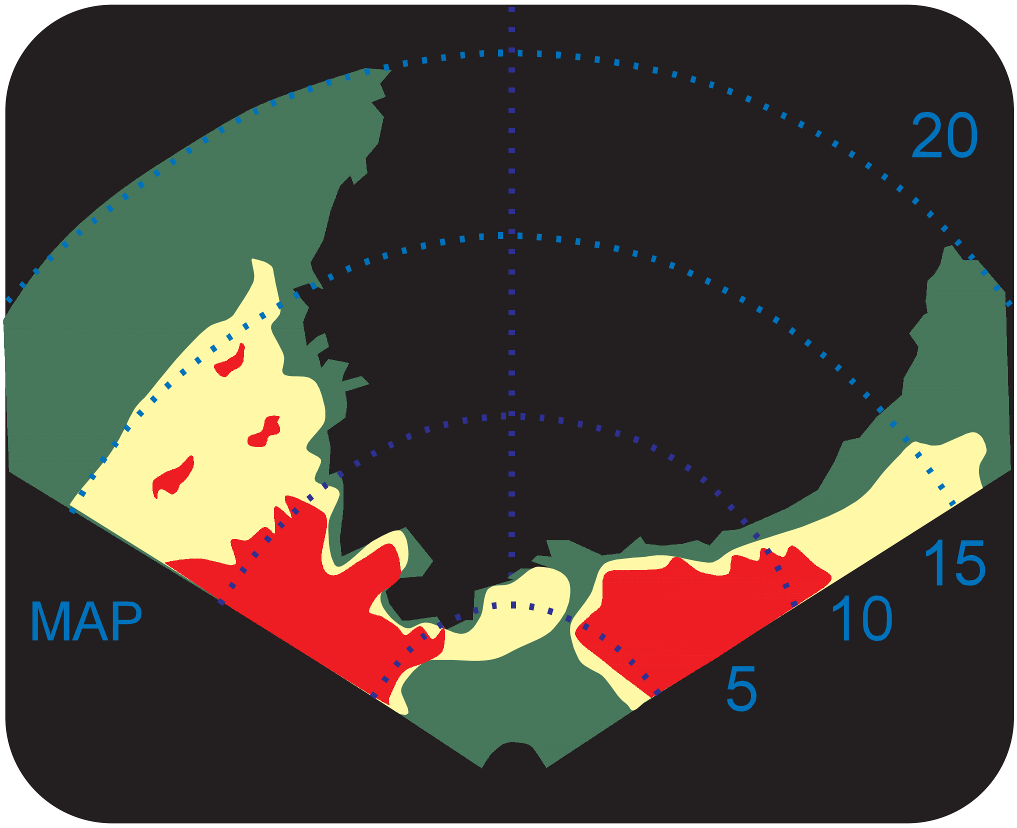


Figure 13.4 Terrain Mapping Display

Principle of Operation

Primary Radar

AWR is a primary radar and both of its functions, weather detection and ground mapping, use the **echo principle** to depict **range** and the **searchlight principle** to depict **relative bearing** of the targets. For this purpose range lines and azimuth marker lines are available (see *Figure 13.2*). It should be noted that the range of ground targets obtained from the display will be the **slant range** and the Pythagoras formula should be used to calculate the ground range.

Antenna

The radar beam is produced by a suitable antenna in the nose of the aircraft. The antenna shape can be **parabolic or a flat plate** which produce both a conical or **pencil-shaped beam** as well as a **fan-shaped** or cosecant squared beam. The type of radiation pattern will depend upon the use; the pencil beam is used for weather and longer range (> 60 NM) mapping while the fan-shaped beam is used for short range mapping. It is usually necessary to **tilt the antenna down** when using the radar in the **mapping mode.** The radar antenna is **attitude-stabilized** in relation to the horizontal plane using the aircraft's attitude reference system otherwise the presentation would become lopsided during manoeuvres.

Radar Beam

The pencil beam used for weather depiction has a width of between 3° and 5°.

The **beamwidth** must be as **narrow as possible** for efficient target resolution. For example, two clouds at say 100 NM might appear as one large return until, at a closer range, they are shown correctly in *Figure 13.5*, as separate entities.

A narrower beam would give better definition but would require a larger antenna which becomes impractical in an aircraft. Therefore, in order to produce the **narrower beams** it is essential to use **shorter wavelengths**.

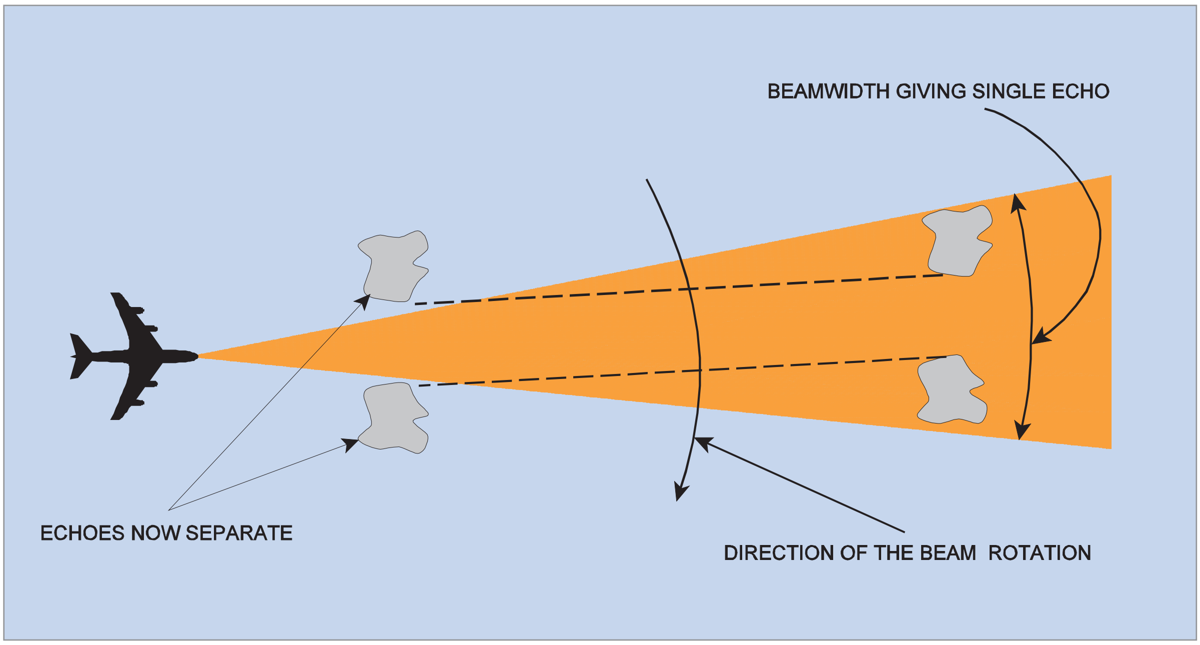


Figure 13.5 Effect of Beamwidth

Radar Frequency

The optimum radar frequency is one that has a wavelength comparable to the size of the objects which we wish to detect, namely the **large water droplets and wet hail** which in turn are associated with severe turbulence; these droplets are about 3 cm across.

The typical frequency adopted by most commercial systems is **9375 MHz**, +/- 30 MHz as it produces the best returns from the large water droplets and wet hail found in convective clouds. With this frequency it is also possible to produce narrow efficient beams. The wavelength, λ is:

$$\lambda = \frac{300}{9375}\ m = 3.2\ cm$$

A frequency higher than 9375 MHz would produce returns from smaller droplets and cause unnecessary clutter whereas a lower frequency would fail to produce sufficient returns to highlight the area of turbulence.

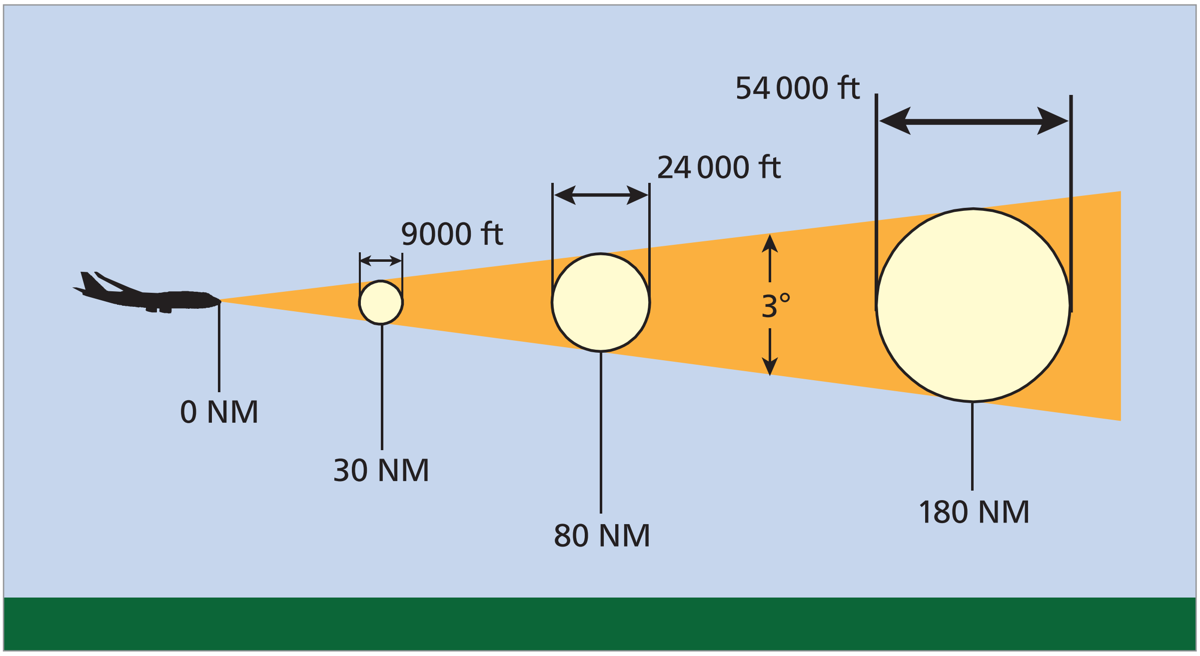


Figure 13.6 *Radar beam coverage at varying ranges*

Water and Ice in the Radome

Some of the energy of the radar waves is absorbed by water and ice as happens in a microwave oven. If there is water in the antenna radome or ice on the outside of it, the energy absorbed will cause the water to evaporate and the ice to melt. This means that less energy is transmitted in the forward direction resulting in weaker returns and a degradation of performance.

Weather Depiction

The equipment is designed to detect those clouds which are likely to produce turbulence, to highlight the areas where the turbulence is most severe and to indicate safe routes to avoid them, where possible.

The size and concentration of water droplets in clouds is an indication of the presence of turbulence (but not of clear air turbulence - CAT). The shorter the distance, in continuous rainfall, between light and strong returns, the **steeper the rainfall gradient and the greater likelihood of turbulence**. *Figure 13.7* depicts the reflective levels of different precipitation types. For a given transmission power a 3 cm wavelength will give the best returns from large water droplets. Wavelengths of **10 cm and above produce few weather returns.**

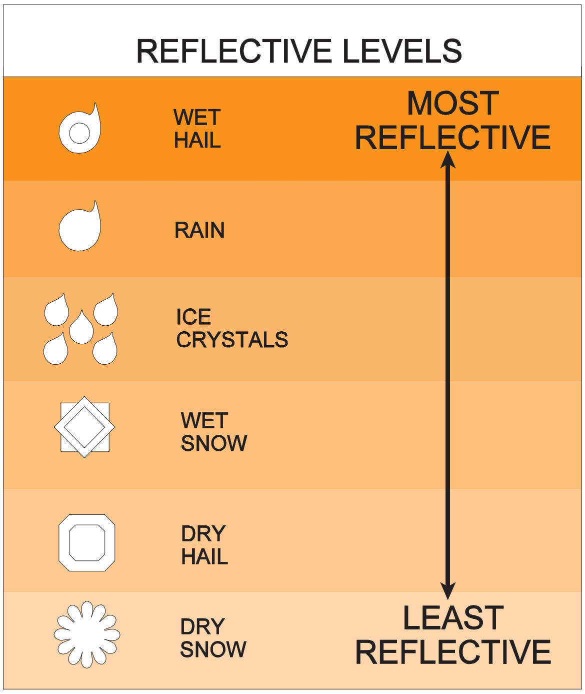


Figure 13.7 Reflective levels

In colour weather radar systems the weather targets are colour-coded according to the intensity of the rainfall as follows:

BLACK	Very light or no returns	Less than 0.7 mm/h.
GREEN	Light returns	0.7 - 4 mm/h.
YELLOW	Medium returns	4 - 12 mm/h.
RED	Strong returns	Greater than 12 mm/h.
MAGENTA	Turbulence	Due to rainfall intensity.

On colour systems without magenta the RED areas may have a CYCLIC function, which causes them to alternate RED/BLACK in order to draw the pilot's attention.

The areas of **greatest potential turbulence** occur where the colour zones are closest together i.e. **the steepest rainfall gradient**. Also turbulence is associated with the following shapes on the display as shown in *Figures 13.8 - 13.11*: **U-shapes, Fingers, Scalloped edges and Hooks**. These are areas to avoid.

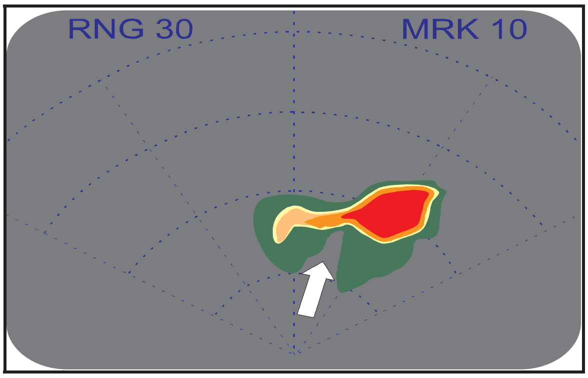


Figure 13.8 U-shape indicating hail activity

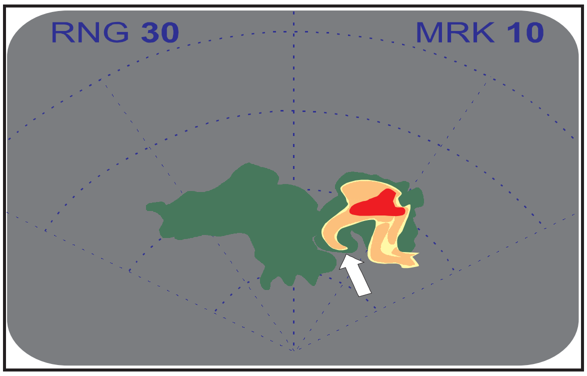


Figure 13.9 Finger indicating hail activity

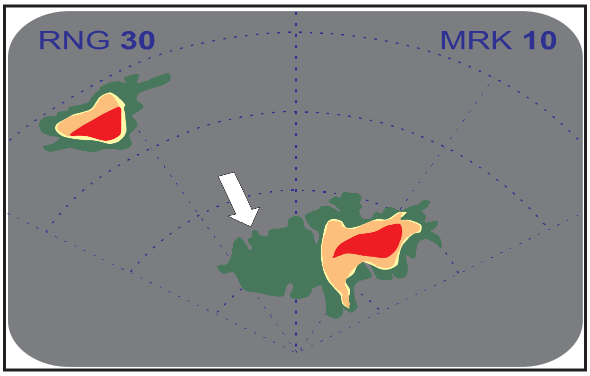


Figure 13.10 Scalloped edge indicating hail activity

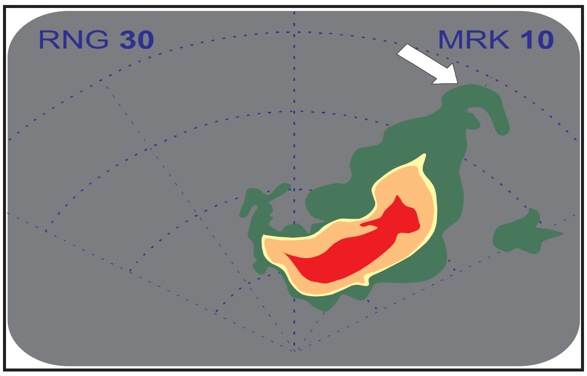


Figure 13.11 Hook indicating hail activity

Control Unit

Figure 13.12 illustrates a basic control unit for a monochrome AWR with range scales 20, 50 and 150 NM; its various functions are described below.

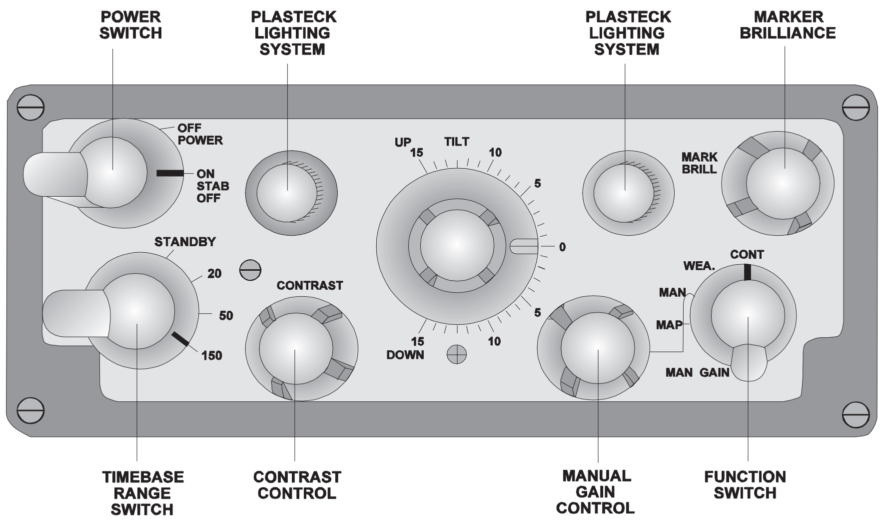


Figure 13.12 Control Unit

Power Switch

In the **ON** position the system is energized and the **aerial** is **automatically stabilized in PITCH and ROLL.** A lopsided or asymmetric display probably indicates that the stabilization has failed. Switching to the **STAB OFF** position **will lock the scanner to the pitch and roll axes of the aircraft.**

Range Switch

The **STANDBY** position is to hold the equipment in readiness during periods **when the AWR is not required.** Selection of a range position energizes the transmitter. Whilst on the ground the STANDBY position must be maintained until it is certain that personnel and any reflecting objects, such as hangars, are not in the radar's transmitting sector. The **radiation can damage health** and the reflections from adjacent structures can damage the equipment. Selection of the MAPPING beam produces the same hazards. In poor weather conditions switch from STANDBY to the 0 - 20 NM scale as soon as the aircraft is clear of personnel and buildings and check the weather conditions in the take-off direction. The maximum practical range for weather and for navigation is in the region of 150 NM.

Tilt Control

This control enables the radar beam to be tilted from **the horizontal** within **15° UP (+)** and **15° DOWN (-)**. In the horizontal plane the antenna sweeps up to 90° either side of the nose though a sector of 60° on each side is generally sufficient for the role of weather depiction and navigation. (See *Figure 13.13*).

For ground mapping the beam has to be tilted down. In order to observe cloud formations it is raised to reduce ground returns. It should be noted that due to the curvature of the earth the **tilt should be higher when the selected range increases or when the aircraft descends to a lower altitude.** Equally, the tilt setting should be lower when the selected range decreases or when the aircraft climbs to a higher altitude. This can be seen in *Figure 13.14*.

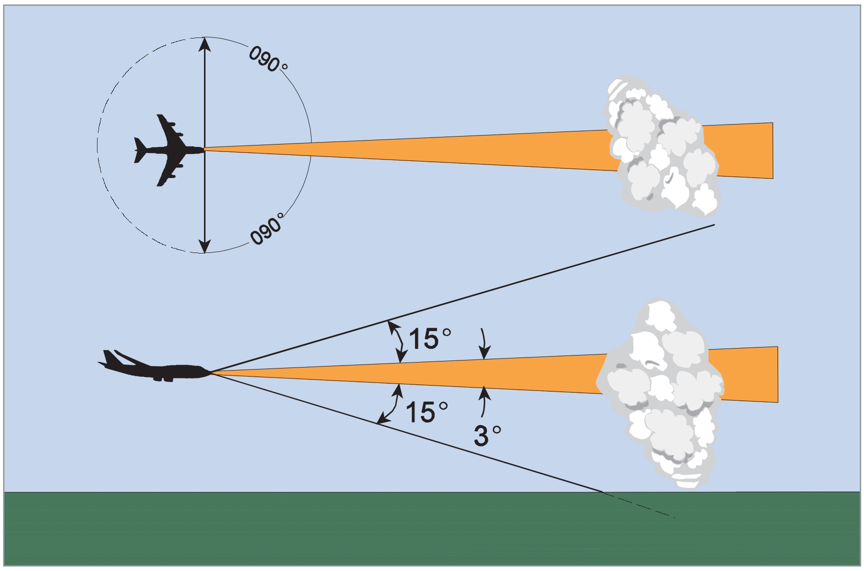


Figure 13.13 *Projected Radar Beam and Tilt Angle*

Function Switch

MAP

In the **MAP** position the radar produces a **mapping beam.** In order to obtain an even presentation of surface features, the transmitted power is progressively reduced as distance decreases so that the power directed to the closest object is minimum. This reduction in power with decreasing range is a function of the cosecant of the depression angle - hence the name **cosecant^2 beam;** another description is **"fan-shaped"** beam. Its dimensions are 85° deep in the vertical plane and 3.5° in azimuth. Signal amplification is adjustable via the adjacent **MANUAL GAIN** knob.

The minimum (15 NM) and **maximum (60 to 70 NM)** mapping ranges depend upon the aircraft's height and type of terrain. To map **beyond 70 NM the conical pencil beam** should be used by selecting the MANUAL position; this enables the gain to be adjusted, for ground mapping. *See Figure 13.15*.

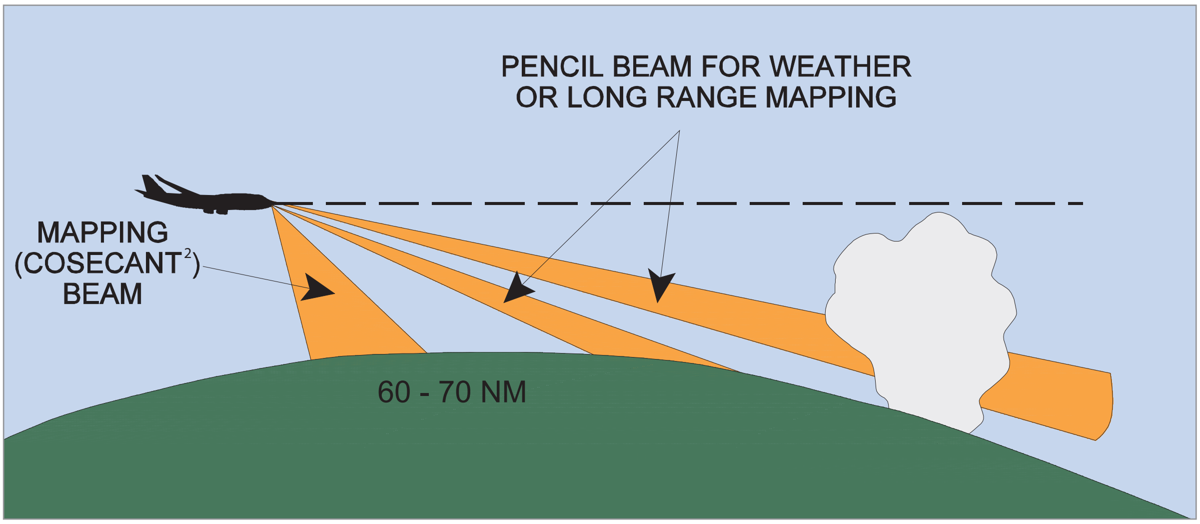


Figure 13.14 *AWR Beam Shapes*

MAN

This is used for cloud detection and mapping between about 70 and 150 NM and selects the conical pencil shaped beam; MANUAL GAIN for signal amplification is operative with this selection.

WEA

This selects the conical pencil beam (*Figure 13.14*) and is the usual position for observing cloud formations; MANUAL GAIN control is now INOPERATIVE. Instead a facility called **Swept Gain, Sensitive Time Control** or **Automatic Gain Control** (AGC) is automatically available. This system of circuits decreases the gain for echoes received from the ever decreasing ranges of clouds. **It operates up to about 25 NM** and ensures that the intensity (brilliance) of display of a particular cloud is independent of range. Thus a small cloud at 5 NM does not give an increasingly stronger return than a larger and more dangerous cloud at 20 NM; all clouds up to about 25 NM are thus compared on equal terms.

CONT

Figure 13.15 is a cloud formation presentation with **CONT** (CONTOUR) selected for a colour display; the **darker colours indicate dangerous areas** of concentrated rainfall and potential turbulence.

The degree of danger depends upon the steepness of the rainfall gradient. Therefore, the narrower the paint surrounding a red area, the greater the danger from turbulence; **hooks, scalloped edges, finger protrusions and U-shapes** are also indicators of potential areas of **severe turbulence**. The Swept Gain facility (or automatic gain control) is also in operation in the CONT position and ensures that a display's intensity does not vary as range decreases.

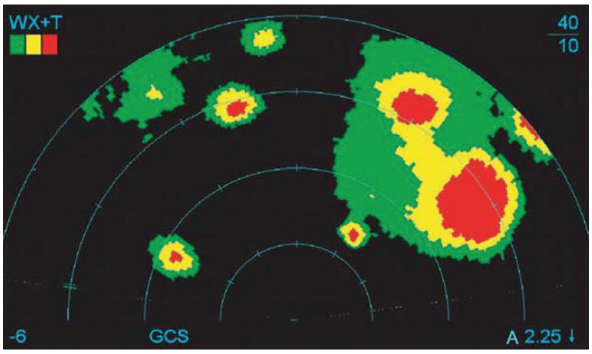


Figure 13.15 Typical cloud display with contour on

Mapping Operation

For the basic monochrome AWR with a maximum range of 150 NM, **the cosecant^2 (fan-shape) beam is used for mapping up to about 70 NM** by selecting MAP. **To map beyond 70 NM, the pencil beam is used** by selecting the MAN position; both have manual gain control in order to improve the radar information obtainable from the presentation.

Adjust the **downward tilt for the best target presentation.** Little energy reflects from a calm sea, fine sand, and flat terrain. Therefore coastlines, built up areas, skyscrapers, bridges and power stations etc. will give very bright returns. Ice has jagged edges which reflect but snow is a poor reflector and masks ground features. Flight over high ground can produce a false image of a series of lakes due to the **radar shadow** caused by the mountains/hills. (*Figure 13.16*).

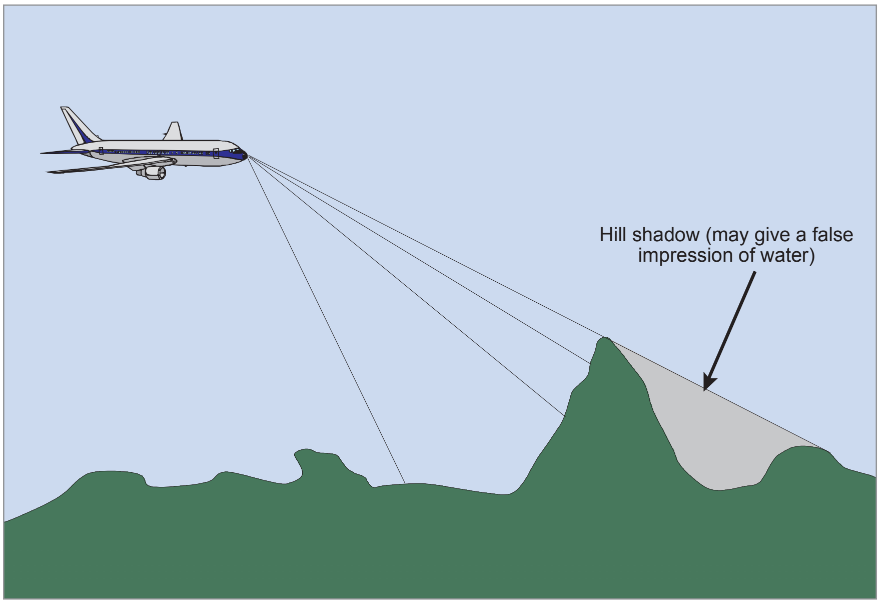


Figure 13.16 Hill Shadow

Pre-flight Checks

Electromagnetic radiation presents a serious hazard to personnel, and electronic equipment, therefore great care must be taken before checking the radar on the ground.

The following precautions should be taken:

- Ensure the aircraft is clear of personnel, other aircraft, vehicles and buildings.
- Select conical beam with maximum uptilt, then switch radar on, check you have a picture, then go back to standby.

Weather Operation

Avoiding Thunderstorms
Select maximum range to detect weather formations in good time and adjust the TILT to remove ground returns. If the storm system is extensive make an early track adjustment, in consultation with ATC, to avoid it. If this is not possible, as the clouds get nearer select the lower ranges and CONT and determine the best track to avoid potential turbulence. Ensure that short term alterations of heading steer the aircraft away from the worst areas and not deeper into them. To achieve this, constant switching between short, medium and longer ranges is necessary in order to maintain a complete picture of the storm system.

Shadow Area
There is also the **danger of not being able to map the area behind heavy rain** where no radar waves will penetrate; this will leave a shadow area which may contain severe weather.

Height of Storm Cloud
The **height of a storm cloud can be ascertained by adjusting the tilt** until the radar returns from it just disappear. The height of the top of the cloud can be calculated by using the 1 in 60 rule.

It is also worth noting that a **thunderstorm may not be detected if the tilt setting is set at too high** an angle.

Height Ring
With the older AWR systems where the conical beam is produced by a dish antenna there is always some vertical overspill of energy which is reflected back to the aircraft and appears as a "height ring", which roughly indicates the aircraft's height. It also indicates that the equipment is serviceable when there is no weather ahead.

Colour AWR Controls

The controls for a colour AWR would be similar to that for the monochrome unit in terms of range, tilt and gain but may have the following additional features such as **Wx, Wx + T, Wx(var)**. These are for Weather, Weather plus Turbulence and Weather with variable gain control. Other sets may have **WxA** control which stands for Weather Alert and would give a flashing display of the areas associated with turbulence. There may also be available a Contour Intensity control to enable adjustment of the display for optimum presentation. The latest AWR controls are activated by push ON/OFF switches located around the colour screen and include:

Test
This displays the colour pattern for pre-flight serviceability check.

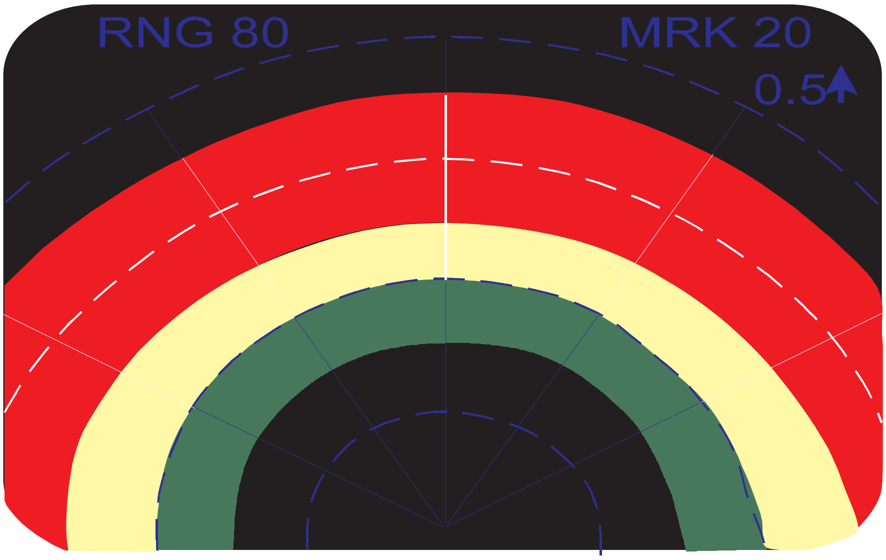


Figure 13.17 Typical Radar System Test Pattern for PPI displays

Hold

This allows the display to be frozen so that storm movements can be assessed. When a storm is located, at say 100 NM, HOLD is selected and a constant heading maintained. HOLD and WX then appear alternately on the screen. After two or three minutes deselect the HOLD facility; this brings back the current display and the storm position is seen to move from its held position to its actual position, thereby indicating its movement relative to the aircraft.

TGT Alert

This operates in conjunction with the WEA facility and alerts a pilot of a storm return of contour strength. When TGT ALERT is selected and no contouring clouds are present the screen shows a yellow T in a red square, (screen top right). If a contouring cloud is detected within 60 to 160 NM and +/- 15° of heading, the yellow symbol TGT, in a red square, flashes on and off once a second instead of the T.

Fault

This is controlled by a fault monitoring circuit and FAULT flashes on the screen if there is a power or transmitter failure.

AWR Summary

Components	Tx / Rx, antenna, indicator, control unit.
Functions	Turbulence, navigation.
Principle of Operation	Echo for range, sweep for relative bearing. Pencil beam for weather and long range (> 60 NM) mapping. Cosecant^2 beam for short range. Antenna attitude stabilized. Beam width dependent on antenna size. Effect of beamwidth on resolution. Frequency of 9375 MHz best for large water droplets/hail.
Weather	Turbulence where rainfall gradient is steepest. Few returns from wavelength of >10 cm. Colours in order: black, green, yellow, red, magenta. Beware U's, fingers, scallops and hooks.
Mono Control Unit	Power/Stab On - antenna attitude stabilised in pitch and roll. Stab Off - antenna locked to aircraft axes. Range - Standby, selections up to about 150 NM. Tilt - ± 15°. Tilt up for increased range or lower altitude. MAP - fan-shaped beam. Use up to 60 NM. MAN - Manual gain with pencil beam to map > 60 NM. WEA - Pencil beam with AGC. CONT - Black holes indicate turbulence.
Mapping	Tilt down for best target presentation. Beware hill shadows.
Weather Operation	Adjust tilt for best weather picture. Too high tilt will miss TS. Beware shadow area.
Colour AWR	Use of controls - Wx, Wx+ T, Wx(Var), WxA, Hold, Tgt Alert.

Questions

1. **A frequency used by airborne weather radar is:**

a. 8800 MHz
b. 9.375 GHz
c. 93.75 GHz
d. 1213 MHz

2. **An airborne weather radar is required to detect targets up to a maximum range of 200 NM. Ignoring pulse length and flyback in the CRT calculate the maximum PRR.**

a. 405 pps
b. 810 pps
c. 1500 pps
d. 750 pps

3. **Using airborne weather radar the weather beam should be used in preference to the fan-shaped beam for mapping in excess of .... NM:**

a. 20 to 25
b. 60 to 70
c. 100 to 150
d. 150 to 200

4. **Airborne Weather Radar is an example .... of radar operating on a frequency of .... in the .... band.**

a.	primary	8800 MHz	SHF
b.	secondary	9.375 MHz	UHF
c.	secondary	9375 MHz	SHF
d.	primary	9375 MHz	SHF

5. **The correct sequence of colours of a colour Airborne Weather Radar as returns get stronger is:**

a.	red	yellow	green
b.	yellow	green	red
c.	green	yellow	red
d.	red	green	yellow

6. **A false indication of water may be given by the AWR display when:**

a. flying over land with the Land/Sea switch in the Sea position
b. flying over mountainous terrain
c. there is cloud and precipitation between the aircraft and a cloud target
d. attempting to use the mapping beam for mapping in excess of 50 NM

7. **Airborne weather radar operates on a frequency of:**

a. 8 800 MHz because gives the best returns from all types of precipitation
b. 13 300 MHz
c. 9 375 MHz because it gives the best returns from rainfall associated with Cb
d. 9.375 GHz because this frequency is best for detecting aircraft in flight

8. The mapping mode of Airborne Weather Radar utilizes:

a. a pencil/weather beam from 70 NM to 150 NM
b. a cosecant^2/fan-shaped beam which is effective to 150 NM
c. a pencil/weather beam with a maximum range of 70 NM
d. a cosecant^2/fan-shaped beam effective 50 NM to 70 NM

9. An Airborne Weather Radar system uses a frequency of 9 GHz because:

a. it has a short wavelength so producing higher frequency returns
b. the short wavelength allows signals to be reflected from cloud water droplets of all sizes
c. the wavelength is such that reflections are obtained only from the larger water droplets
d. the frequency penetrates clouds quite easily enabling good mapping of ground features in the mapping mode

10. The antenna of an Airborne Weather Radar is stabilized:

a. in pitch, roll and yaw
b. in pitch and roll
c. in pitch and roll whether the stabilization is on or off
d. in pitch and roll but only when 0° tilt has been selected

11. The colours used to denote variations in rainfall rate on an Airborne Weather Radar screen are .... for very light or no returns, ... for light returns, ... for medium returns and .... for strong returns.

a. black yellow green magenta
b. black green yellow magenta
c. grey green yellow red
d. black green yellow red

Answers

1	2	3	4	5	6	7	8	9	10	11
b	a	b	d	c	b	c	a	c	b	d

Chapter 14

Secondary Surveillance Radar (SSR)

Introduction

Primary radar relies on the reception of a reflected pulse i.e. the echo of the transmitted pulse. Secondary radar, on the other hand, receives pulses transmitted by the target in response to interrogation pulses. Secondary surveillance radar (SSR) is one type of secondary radar system; DME is another such system that will be discussed in Chapter 15.

Both primary and secondary surveillance radars are used to track the progress of an aircraft. Primary radar provides better bearing and range information of an aircraft than SSR but its biggest disadvantage is the lack of positive, individual aircraft identification; this is required for adequate safe control by ATC, particularly in crowded airspace. Primary radars also require higher transmitter power outputs for the two-way journey of the single pulses.

SSR requires an aircraft to be fitted with a transmitter/receiver, called a **transponder**. The pilot will set a four-figure code allocated by ATC and the transponder will transmit information automatically, in pulse coded form, when it is interrogated by the ground station called the **interrogator.** The transmissions are therefore only one way from transmitter to receiver.

Advantages of SSR

SSR has the following advantages over primary radar:

- requires much less transmitting power to provide coverage up to 200 to 250 NM.
- is not dependent on an aircraft's echoing area or aspect.
- gives clutter free responses as it is does not rely on returning reflected pulses.
- positively identifies an aircraft's primary response by displaying its code and call sign alongside.
- indicates an aircraft's track history, speed, altitude and destination.
- can indicate on a controller's screen that an aircraft has an emergency, has lost radio communications or is being hi-jacked.

Thus when SSR is used in conjunction with primary radar, the advantages of both systems are realized. The two radars are therefore usually co-located as shown in *Figures 14.1* and *14.2*.

SSR Display

The SSR information is displayed in combination with the primary radar information on the same screen as shown in *Figure 14.3*. This includes the call sign or flight number, pressure altitude or flight level, ground speed and destination.

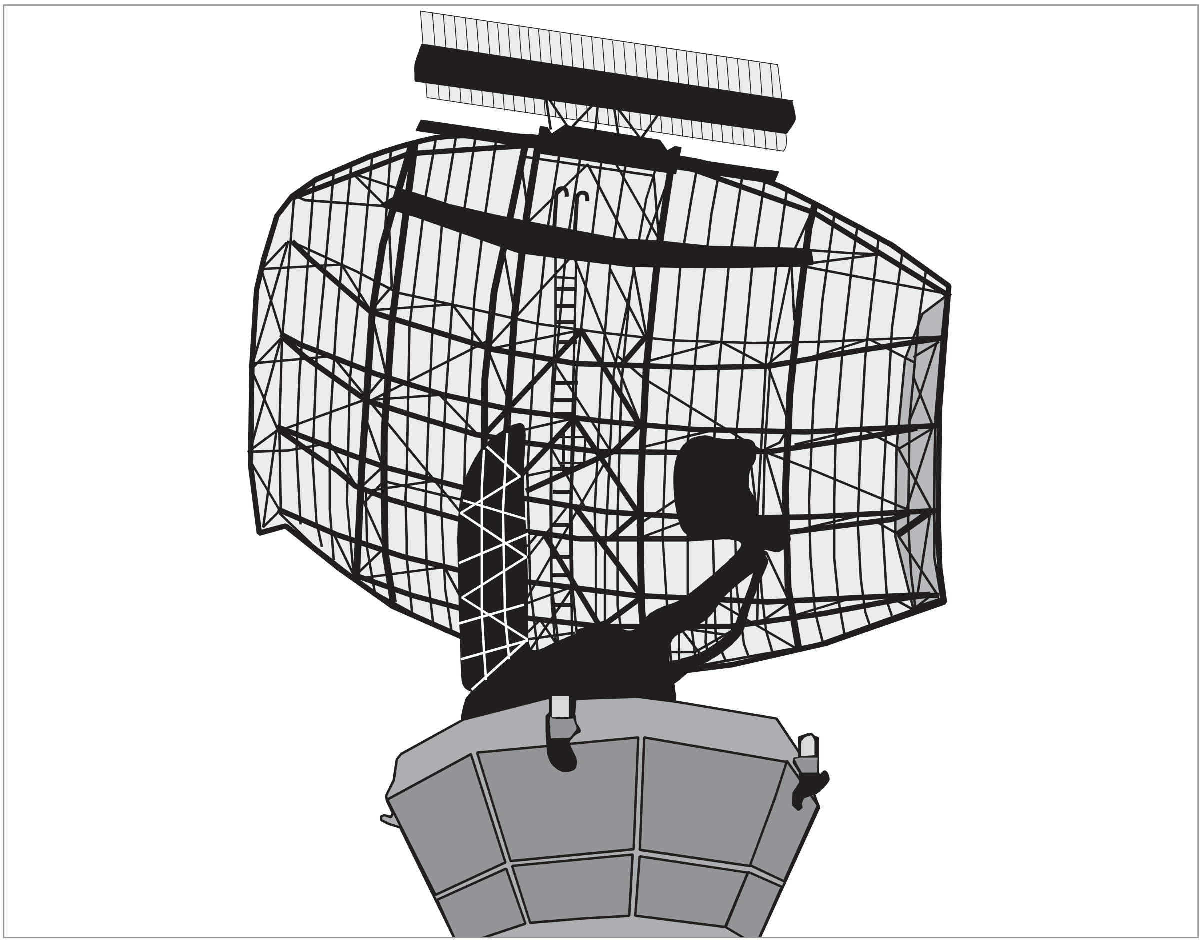


Figure 14.1 SSR aerial mounted on top of a 23 cm primary radar aerial

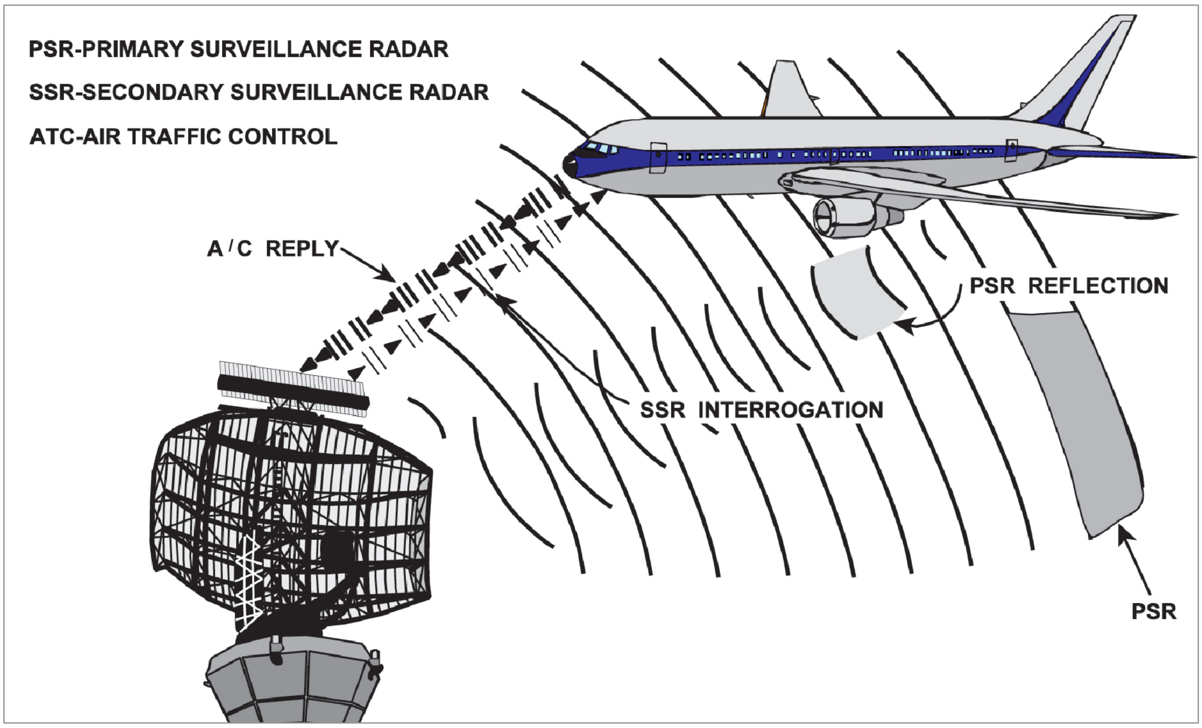
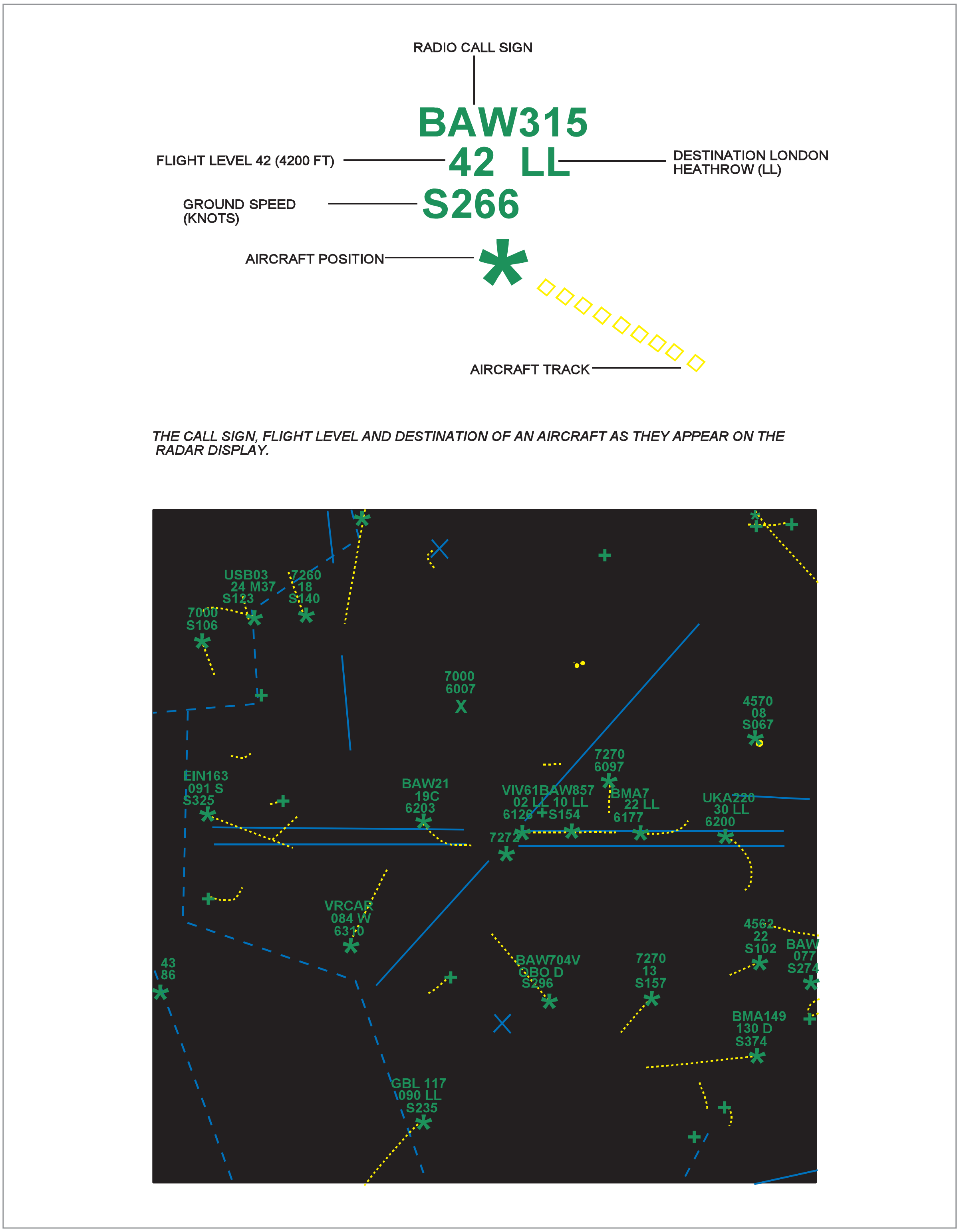


Figure 14.2 Primary and secondary radar used for ATC



THE CALL SIGN, FLIGHT LEVEL AND DESTINATION OF AN AIRCRAFT AS THEY APPEAR ON THE RADAR DISPLAY.

Figure 14.3 A radar display showing positions of aircraft in the London TMA

SSR Frequencies and Transmissions

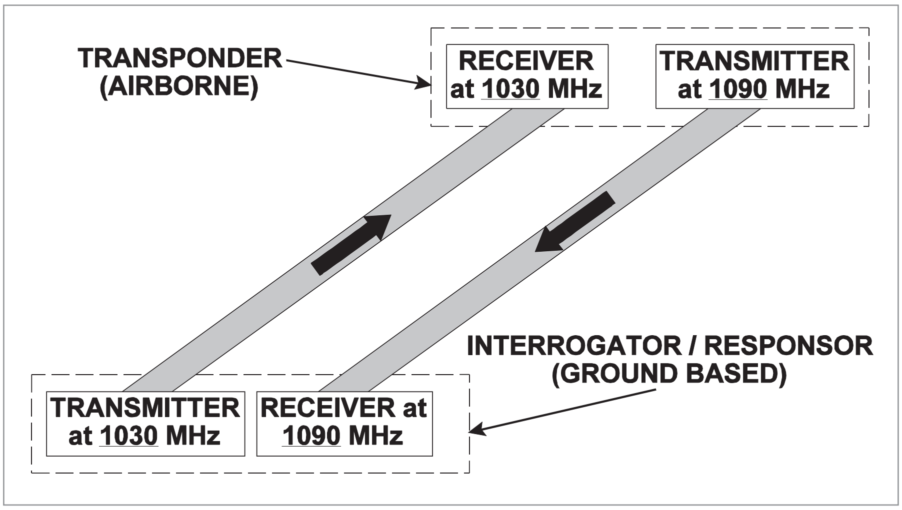


Figure 14.4 SSR operates in the UHF band

The ground station **transmits/interrogates** on **1030 MHz** and **receives** on **1090 MHz**. The aircraft **receives** on **1030 MHz** and **transmits/transponds** on **1090 MHz** after a delay of 50 microseconds. The SSR ground antenna transmits a narrow beam in the horizontal plane while the aircraft transmits omni-directionally i.e. the radiation pattern is circular around the aircraft.

Modes

The aircraft is interrogated from the ground station by a predetermined series of pulses on the carrier frequency of 1030 MHz; its transponder then transmits a coded reply on a carrier frequency of 1090 MHz. The two main modes of operation are:

- Mode A - an interrogation to identify an aircraft
- Mode C - an interrogation to obtain an automatic height read-out of an aircraft.

To differentiate between the interrogations three pulses (P1, P2 and P3) are always transmitted.

The spacing between P1 and P2 is fixed at 2 μs. The spacing between P1 and P3 is 8 μs for a Mode A and 21 μs for a Mode C interrogation.

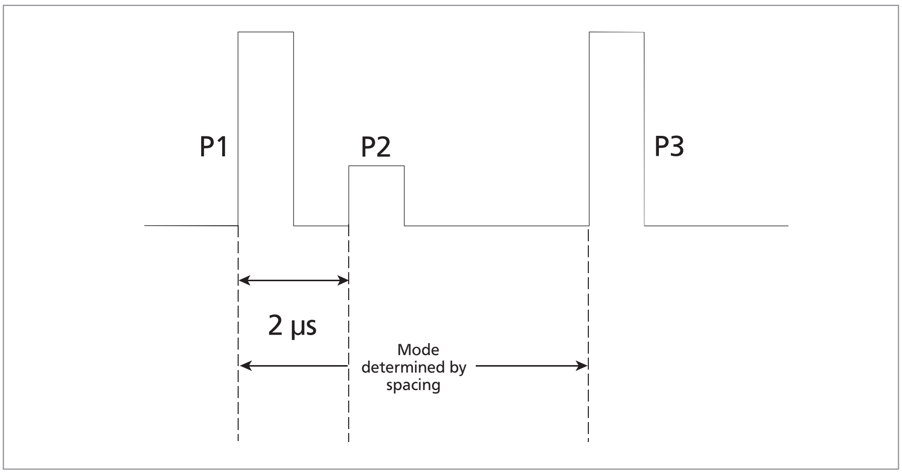


Figure 14.5 Modes

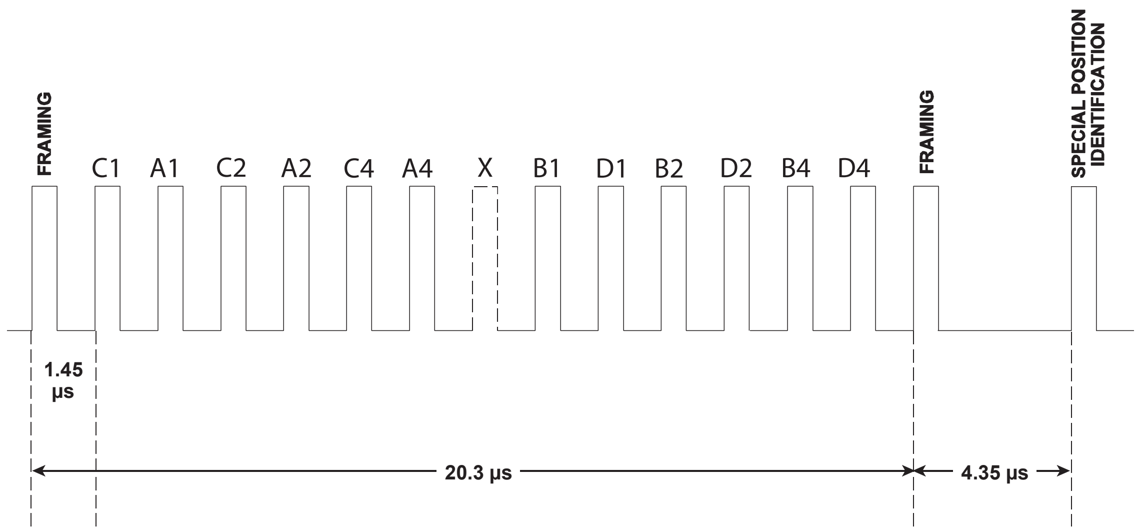


Figure 14.6 SSR reply pulse patterns

The aircraft transponder will reply correctly to a Mode A or C interrogation provided the pilot has correctly selected the mode and code allocated by ATC. On receiving a valid interrogation, the aircraft transponder transmits **two framing pulses**, F1 and F2, 20.3 µs apart. Between the framing pulses there are 12 usable **information pulses** (pulse X is for Mode B which is at present unused). A pulse can be transmitted or not, i.e. there are 2^{12} = 4096 possible combinations of pulses or codes which are numbered **0000 to 7777**; the figures 8 and 9 are not available.

A further pulse called the **Special Position Identification** (SPI) pulse may be transmitted together with the information pulses when the "Ident" button on the pilot's transponder is pressed, usually at ATC's request. This pulse is after the last framing pulse and will be automatically and continuously transmitted for about 20 seconds. It produces a distinctive display so that a controller can pick out a particular aircraft by asking the pilot to "**Squawk Ident**".

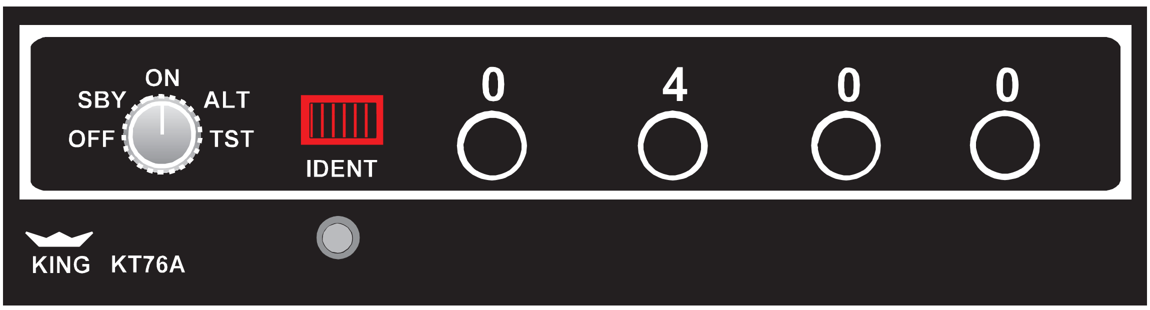


Figure 14.7 Transponder controls & indicators

Mode C

When the aircraft receives a Mode C interrogation the transponder will produce an ICAO determined code that corresponds to its height, **referenced to 1013 hPa**, regardless of the pressure setting on the altimeter and the code selected on the transponder. The Mode C code is determined by an encoder which is mechanically actuated by the altimeter's aneroid capsule and is thus totally independent of the altimeter's pressure setting.

The system provides **Automatic Altitude Telemetering** up to 128 000 ft, with an output change (based upon 50 ft increments or decrements) **every 100 ft** and provides the controller with the aircraft's Flight Level or Altitude e.g. If an aircraft is flying at an allocated level of FL65, then 065 will be displayed on the screen. If the aircraft now drifts downwards, as it passes from 6450 ft to 6445 ft the coded transmission changes and results in 064 being indicated at the controller's consol.

SSR Operating Procedure

Pilots **shall**:

- if proceeding from an area where a specific code has been assigned to the aircraft by an ATS unit, maintain that code setting unless otherwise instructed.
- select or reselect codes, or switch off the equipment when airborne only when instructed by an ATS unit.
- acknowledge code setting instructions by reading back the code to be set.
- select Mode C simultaneously with Mode A unless otherwise instructed by an ATS unit.
- when reporting vertical levels under routine procedures or when requested by ATC, read the current altimeter reading to the nearest 100 ft. This is to assist in the verification of Mode C data transmitted by the aircraft.

Note 1: If, on verification, there is a difference of more than 300 ft between the level read-out and the reported level, the pilot will normally be instructed to switch off Mode C. If independent switching of Mode C is not possible the pilot will be instructed to select Code 0000 to indicate transponder malfunction. (Note: this is the ICAO specification)

Note 2: A standard of ± 200 ft is applied in the UK and other countries.

Special Codes

Special Purpose Codes

Some codes are reserved internationally for special purposes and should be selected as follows:

- 7700 To indicate an emergency condition, this code should be selected as soon as is practicable after declaring an emergency situation, and having due regard for the over-riding importance of controlling the aircraft and containing the emergency. However, if the aircraft is already transmitting a discrete code and receiving an air traffic service, that code may be retained at the discretion of either the pilot or controller.

- 7600 To indicate a radio failure.

- 7500 To indicate unlawful interference with the planned operation of the flight, unless circumstances warrant the operation of code 7700.

Conspicuity Code

When operating under VFR rules at and above FL100, in European airspace, pilots should select code 7000 + Mode C (in North America the code is 1200 + Mode C) except:

- when given a different setting by an ATS unit.

- when circumstances require the use of one of the special purpose codes.

When operating **below FL100** pilots **should** select the Conspicuity Code and Mode C except as above.

MODE C should be operated with all of the above codes.

Disadvantages of SSR

Air Traffic Services in Europe have increased their reliance on SSR (which provides data on an aircraft's position, identification, altitude, speed and track) but the existing civil Mode A (identification) and Mode C (altitude reporting) system is reaching the limits of its operational capability. It has the following disadvantages:

Garbling

This is caused by **overlapping replies** from two or more transponders on nearly the same bearing from the ground station and within a distance of **1.7 NM from each other** measured on a line from the antenna. [The reply pulses from the aircraft are transmitted over a period of 20.3 μs which relates to a distance of just under 1.7 NM in terms of radar miles.]

Fruiting

This is interference at one interrogator caused by replies from a transponder responding to interrogations from another.

Availability of Codes

Only **4096** identification codes are available in Mode A.

Mode S

Mode S is being introduced in order to overcome the limitations of the present modes A and C. 'S' stands for **Selective** addressing. The new system has to be compatible with the existing modes A and C so that it can be used to supplement the present system.

The main features of the new **mode S** are:

Availability of Codes

The aircraft address code will be made up of a 24 bit code. This means that the system will have **over 16 700 000** discrete codes available for allocation to individual aircraft on a permanent basis. The code will be incorporated into the aircraft at manufacture and remain with it throughout its life.

Data Link

The system will be supported by a ground data network and will have the ability to handle uplink/downlink data messages over the horizon. Mode S can provide ground-to-air, air-to-ground and air-to-air **data exchange using communications protocols.**

Reduction of Voice Communications

It is intended that the majority of the present RTF messages will be exchanged via the data link. Messages to and from an aircraft will be exchanged via the aircraft's CDU resulting in a reduction in voice communications.

Height Read-out

This will be in 25 ft increments and more data on an aircraft's present and intended performance will be available to the ground controllers.

Interrogation Modes

Mode S operates in the following modes:

- All Call — to elicit replies for acquisition of mode S transponders.
- Broadcast — to transmit information to all mode S transponders (no replies are elicited).
- Selective — for surveillance of, and communication with, individual mode S transponders. For each interrogation, a reply is elicited only from the transponder uniquely addressed by the interrogation.
- Intermode — mode A/C/S All Call would be used to elicit replies for surveillance of mode A/C transponders and for the acquisition of mode S transponders.

Pulses

Mode S does not transmit the P3 pulse, but has an additional P4 pulse, which can be either long or short in duration.

Intermode A/C/S All Call

Interrogation will consist of P1, P2, P3 and the long P4 pulses.

Intermode A/C only All Call
Interrogation will consist of P1, P2, P3 and the short P4 pulses.

Benefits of Mode S

Unambiguous Aircraft Identification
This will be achieved as each aircraft will be assigned a **unique address** from one of almost 17 million which together with automatic flight identity reporting allows unambiguous aircraft identification. This unique address in each interrogation and reply also permits the inclusion of data link messages to or from a particular aircraft i.e. **selective calling** will be possible in addition to 'All Call' messages.

Improved Integrity of Surveillance Data
The superior resolution ability of Mode S plus selective interrogation will:

- eliminate synchronous garble.
- resolve the effects of over interrogation.
- simplify aircraft identification in the case of radar reflections.

Improved Air Picture Tracking and Situation Awareness
The radar controller will be presented with a better current air picture and improved horizontal and vertical tracking due to unambiguous aircraft identification, enhanced tracking techniques and the increased downlink data from the aircraft.

Alleviation of Modes A/C Code Shortage
The current shortage of SSR codes in the EUR region will be eliminated by the unique aircraft address ability of Mode S.

Reduction of R/T Workload
Due to the progressive introduction of Mode S, R/T between a controller and an aircraft will be reduced; e.g. code verification procedures will not be required.

Improvements to Short Term Conflict Alert (STCA)
The ability of Mode S to eliminate synchronous garbling, to produce a more stable speed vector and to acquire aircraft altitude reporting in 25 ft increments (if supported by compatible barometric avionics) will improve safety. In addition, access to the downlinked aircraft's vertical rate will produce early, accurate knowledge of aircraft manoeuvres.

Note: Whilst the ground system will benefit from altitude reporting in 25 ft intervals there is no intention to change the existing practice of displaying altitude information to the controller in 100 ft increments.

Communication Protocols

Standard Length Communications (Single Transaction)

Comm-A: Transfer of Information from Ground to Air.
Initiated from ground.

Comm-B: Transfer of Information from Air to Ground.
May be either ground or air initiated.

Extended Length Communications (up to Sixteen 80-bit Messages)

Comm-C: Uplink

Comm-D: Downlink

Levels of Mode S Transponders

ICAO Aeronautical Telecommunications, Vol. IV, Annex 10 stipulates that Mode S transponders shall conform to one of four levels of capability:

Level 1 This is the basic transponder and permits surveillance based on Mode A/C as well as on Mode S. With a Mode S aircraft address it comprises the minimum features for compatible operation with Mode S interrogators. **It has no data link capability and will not be used by international air traffic.**

Level 2 This has the same capabilities as Level 1 and permits standard length data link communication from ground to air and air to ground. It includes automatic aircraft identification reporting. **This is the minimum level permitted for international flights.**

Level 3 This has the same capabilities as Level 2 but **permits extended data link communications from the ground to the aircraft.**

Level 4 This has the same capabilities as Level 3 but allows **extended data link communications from the aircraft to the ground.**

Downlink Aircraft Parameters (DAPS)

Basic Functionality

- Automatic reporting of Flight Identity (call sign used in flight).
- Transponder Capability Report.
- Altitude reporting in 25 ft intervals (subject to aircraft availability).
- Flight Status (airborne/on the ground).

Enhanced Functionality

- Magnetic Heading.
- Speed (IAS/TAS/Mach No.).
- Roll Angle (system acquisition of start and stop of turn).
- Track Angle Rate (system acquisition of start and stop of turn).
- Vertical Rate (barometric rate of climb/descent or, preferably baro-inertial).
- True Track Angle/Ground Speed.

Future Expansion of Mode S Surveillance Services

When technical and institutional issues have been resolved the down linking of an aircraft's intentions are recommended for inclusion:

- Selected Flight Level/Altitude.
- Selected Magnetic Heading.
- Selected course.
- Selected IAS/Mach No.

SSR Summary

SSR	Requires Transponder in aircraft and Interrogator at ground station. Advantages over primary radar. Aerial on top of primary radar. Displays call sign, pressure altitude or FL, ground speed, destination.
Frequencies	Ground station transmits narrow beam at 1030 MHz and receives at 1090 MHz. Aircraft receives at 1030 MHz and transmits omni-directionally at 1090 MHz. (in the UHF band).
Modes/Replies	**Mode A** For identity (8 μs interrogation pulse spacing) 12 reply pulses give 4096 combinations (20.3 μs spacing between framing pulses). Extra pulse (SPI) for squawk Ident (for 20 s). **Mode C** For automatic pressure-altitude (21 μs interrogation spacing). Transmitted and displayed every 100 ft (± 50 ft from given level). Switch off if difference > 300 ft (200 ft UK).
Special codes	7700 – emergency 7600 – radio failure 7500 – unlawful interference
Disadvantages of SSR	Garbling - overlapping replies if aircraft < 1.7 NM apart Fruiting - interference caused by replies to other interrogation. Limited codes (4096).
Mode S Features	Selective addressing. Nearly 17 million codes from 24-bit address. Data link air-to-ground, ground-to-air, air-to-air. Height read-out in increments of 25 ft.
Interrogation modes	All Call - mode S. Broadcast (no reply). Selective calling (unique aircraft address). Intermode - A/C/S All call.
Benefits of mode S	Unambiguous aircraft identification. Improved surveillance (eliminates garble, resolves over-interrogation and reflections). Improved situation awareness for radar controller. No code shortage. Reduced R/T. Improved short term conflict alert.

Questions

1. The special SSR codes are as follows: emergency .... , radio failure .... , unlawful interference with the conduct of the flight ....

a.	7700	7600	7500
b.	7700	7600	7500
c.	7600	7500	7700
d.	7500	7600	7700

2. Secondary Surveillance Radar is a form of .... radar with ....type emissions operating in the .... band.

a.	primary	pulse	SHF
b.	primary	pulse	UHF
c.	secondary	FM	SHF
d.	secondary	pulse	UHF

3. If the SSR transponder IDENT button is pressed:

a. it causes a momentary distinctive display to appear on the controller's screen
b. an identification pulse is automatically and continuously transmitted for 20 seconds, 4.35 μs before the last framing pulse
c. an identification pulse is automatically and continuously transmitted for 10 seconds, 4.35 μs after the last framing pulse
d. an identification pulse is automatically and continuously transmitted for 20 seconds, 4.35 μs after the last framing pulse

4. When using SSR the ground controller will ask the pilot to cancel mode C if there is a discrepancy of more than .... between the altitude detected by the radar from the reply pulses and the altitude reported by the pilot read from an altitude with the subscale set to ....

a.	100 ft	Regional QNH
b.	300 ft	1013 HPa
c.	50 ft	1013 HPa
d.	300 ft	Regional QNH

5. Secondary radars require:

a. a target which will respond to the interrogation, and this target will always be an aircraft
b. a target which will respond to the interrogation, and this target will always be ground based
c. a target which will respond to the interrogation, and this target may be either an aircraft or a ground based transponder
d. a quiescent target

Answers

1	2	3	4	5
a	d	d	b	c

Chapter

15

Distance Measuring Equipment (DME)

Introduction

Distance Measuring Equipment (DME) is a secondary radar system that enables an aircraft to establish its range from a ground station. A pilot obtains accurate magnetic bearings from a VHF Omni-range (VOR) beacon and accurate **slant ranges** from a **DME.** The two facilities are normally co-sited to form the standard ICAO approved RHO-THETA short range, "Line of Sight" navigation aid. (Rho = range; Theta = bearing)

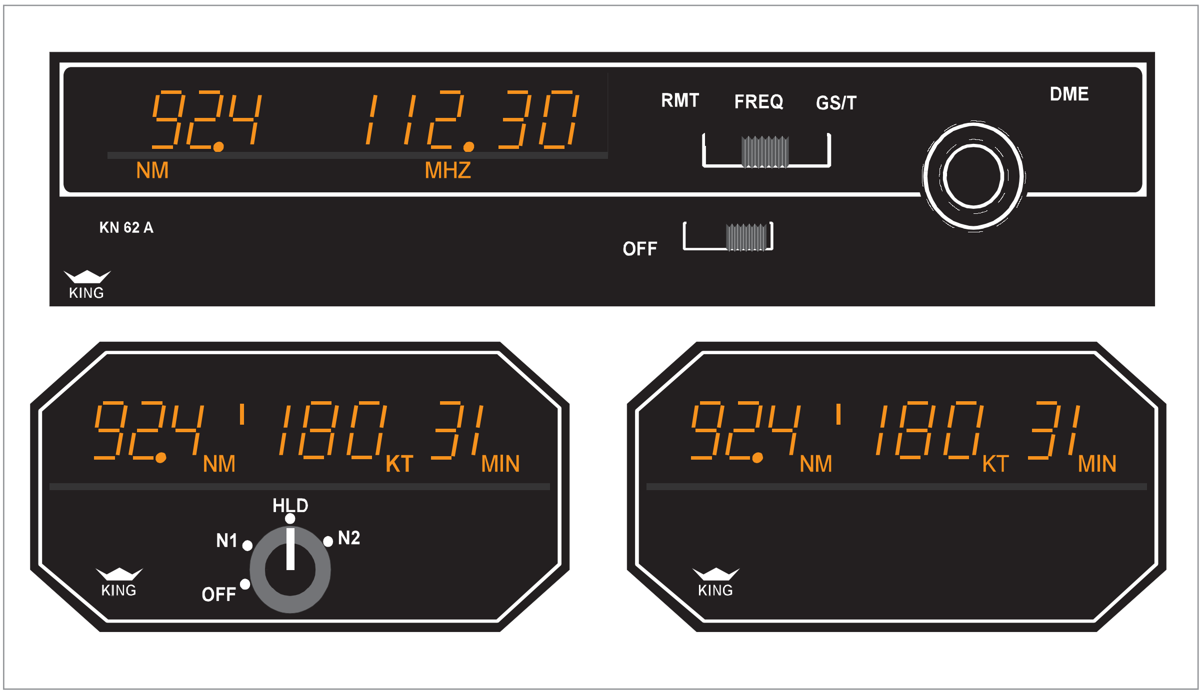


Figure 15.1 Distance Measuring Equipment

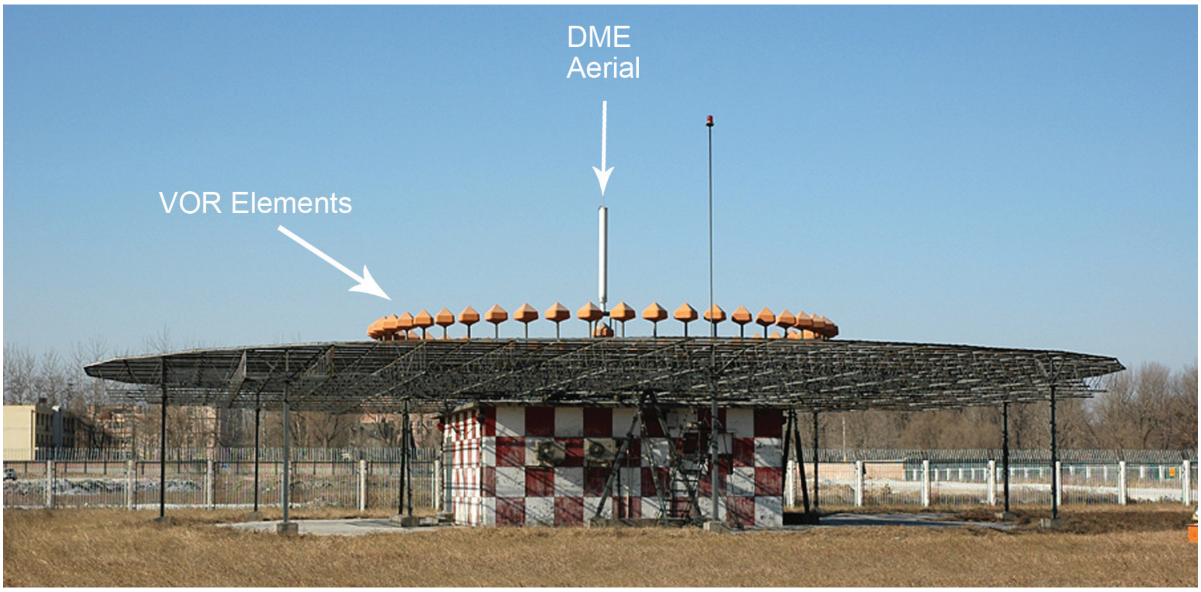


Figure 15.2 Combined Doppler VOR/DME

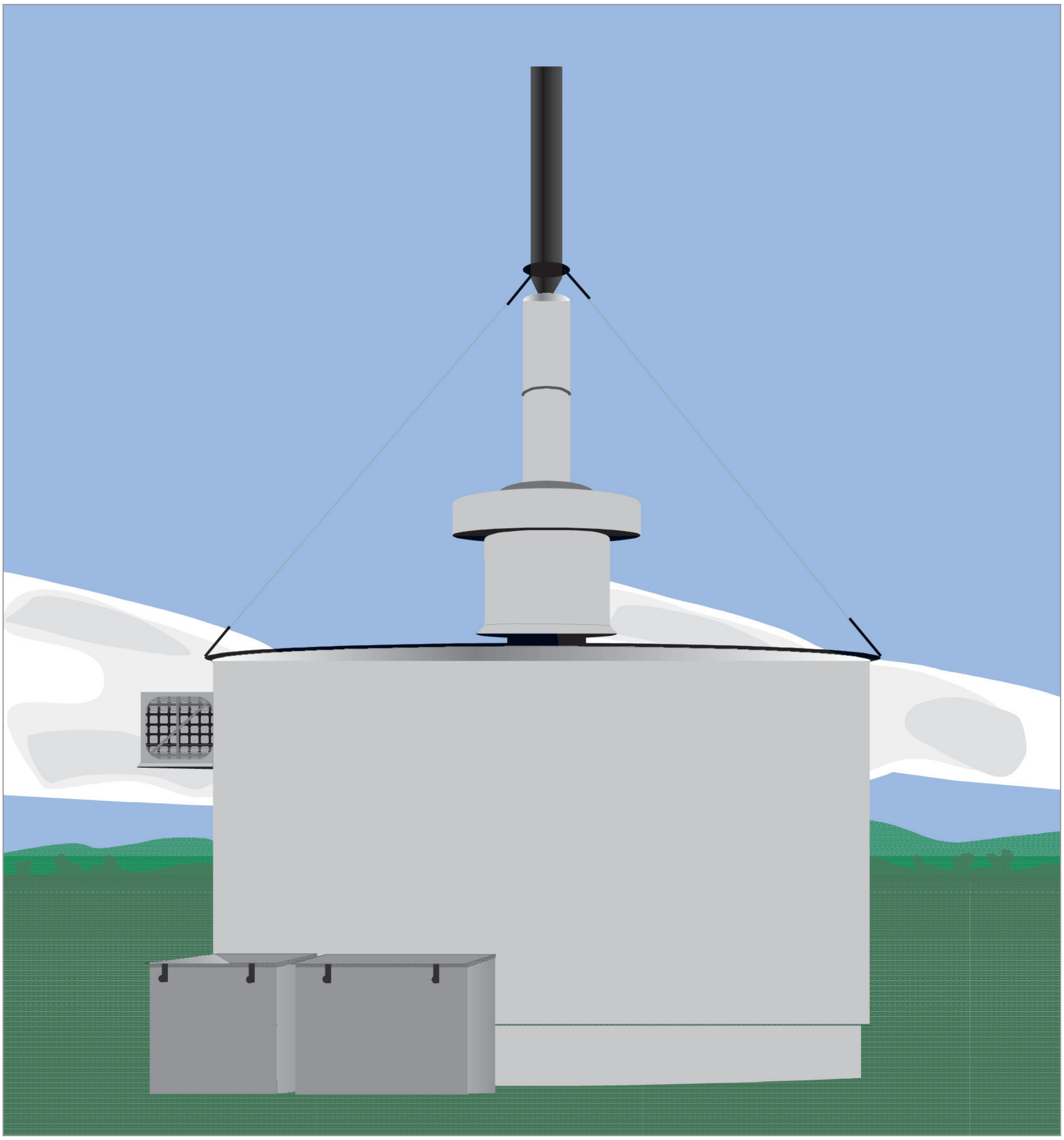


Figure 15.3 A Conventional VOR Installation Surmounted by a DME Antenna

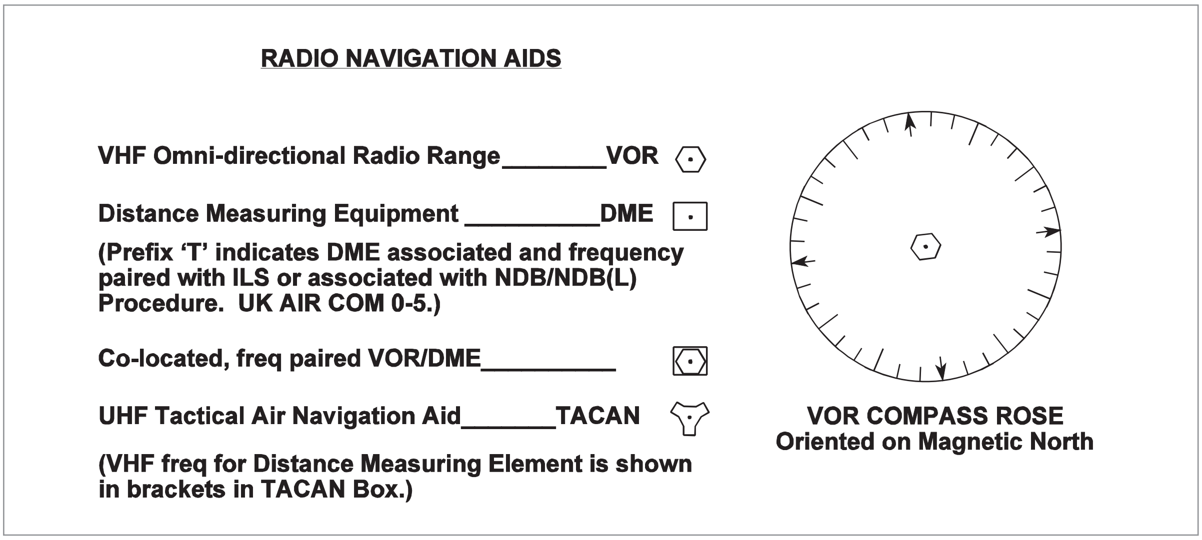


Figure 15.4 DME, VOR and Tacan Presentation - Topographical Chart

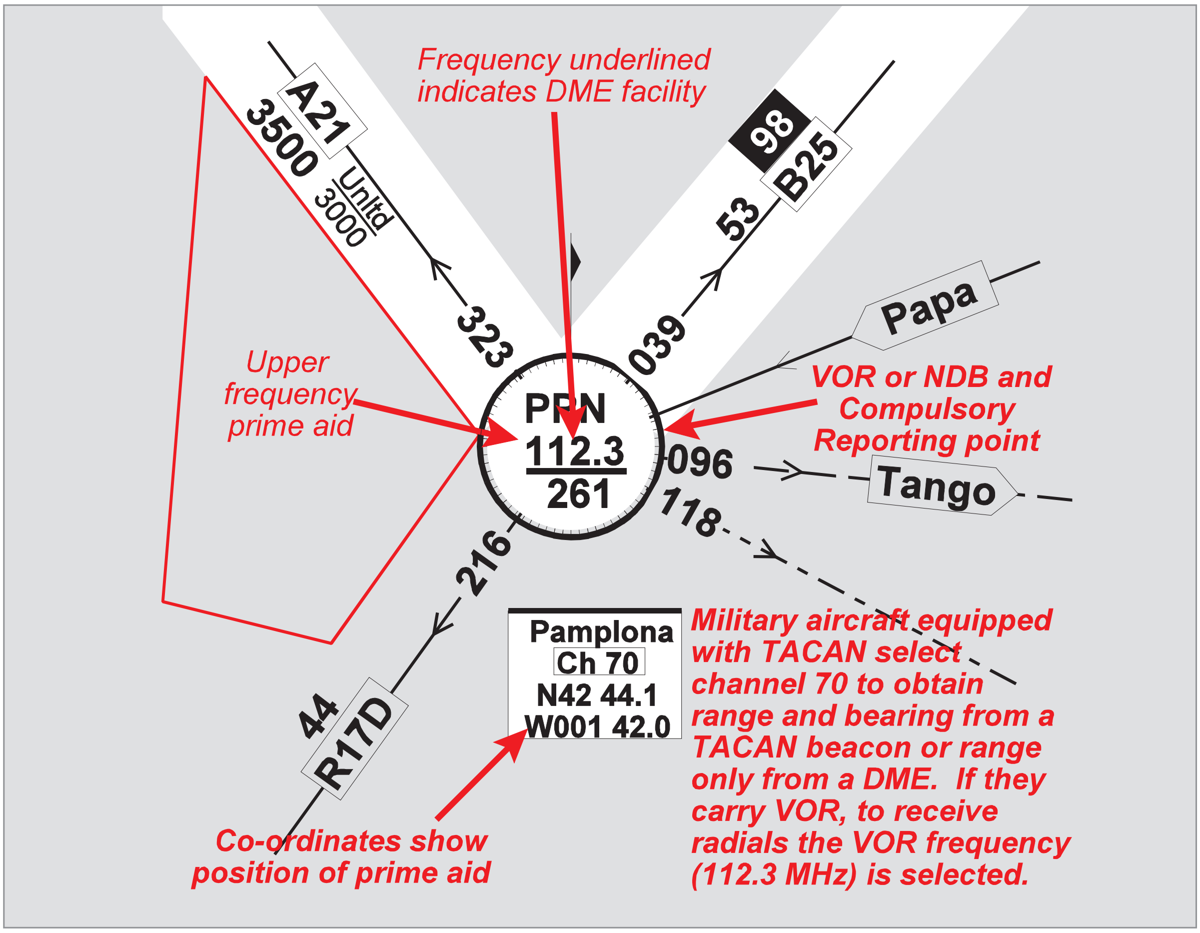


Figure 15.5 DME & VOR presentation - AERAD airways high level chart

Frequencies

Channels

DME (emission code P0N) is a **secondary radar** system operating between **960 and 1215 MHz** in the **UHF** band at 1 MHz spacing; this provides 252 spot frequencies or channels.

There is always **a difference of +/- 63 MHz** between the interrogation and transponding frequencies. The channels are numbered 1 to 126X and 1 to 126Y. A channel number is selected by the pilot of a TACAN (**TAC**tical **A**ir **N**avigation) equipped military aircraft; this equipment provides the pilot with range and bearing. Civil aircraft have the cheaper VOR/DME equipment and select the appropriate paired VHF frequency to obtain **range from** either **a DME** or military **TACAN** facility.

Example Channel Numbers and Paired Frequencies

BEACON	Aircraft Interrogation	Beacon Transponds	Military Aircraft Select	Civil Aircraft Select
MAZ Tacan	1131 MHz	1194 MHz	Channel 107X	116.0 MHz
OX DME	1148 MHz	1211 MHz	Channel 124X	117.7 MHz

DME Paired With ILS Localizer Transmitter

DME is also frequency paired with the **ILS localizer** frequencies. These DME supplement or replace the range information provided by the **Marker Beacons**. The range information is **zero referenced** to the **ILS runway threshold.** DME is obtained by selecting the ILS frequency.

Uses of DME

A DME:

- provides very accurate slant range, a **circular position line** and in conjunction with another DME, or a co-sited VOR, two position line fixes.
- integrates the change of slant range into **groundspeed** and **elapsed times** when the aircraft is fitted with an appropriate computer.
- permits more accurate flying of holding patterns and **DME arcs**.
- provides **range and height checks** when flying non-precision approach procedures, e.g. locator only and VOR let-downs.
- indicates accurate ranges to the runway threshold, and heights for range, when flying an ILS/DME procedure.
- **facilitates radar identification** when the pilot reports his VOR/DME position.
- facilitates the separation and control of aircraft in **non-radar airspace**, based upon a VOR/ DME fix reported by individual aircraft.
- is the basis for a simple **Area Navigation** (RNAV) system when the appropriate computerization is fitted.
- provides accurate range inputs into the more complex and **accurate RNAV systems**; twin, self-selecting DME/DME are used.

Principle of Operation

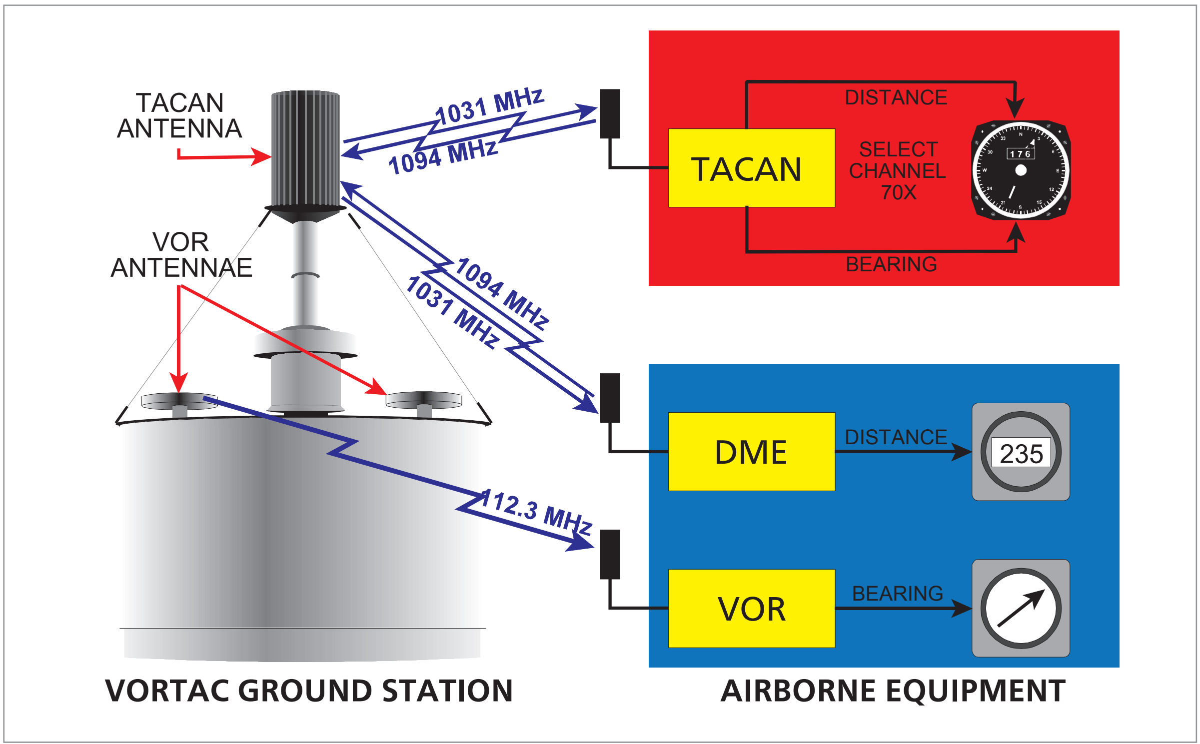


Figure 15.6 VORTAC

Pulse Technique

DME is a secondary radar system providing **slant range** by **pulse technique**.

The aircraft's **interrogator** transmits a stream of omni-directional pulses on the carrier frequency of the ground **transponder**. Simultaneously the interrogator's receiver starts a **Range Search.** At the transponder on the ground the received interrogation pulses are re-transmitted, after a delay of 50 μs, at a frequency that is **+/- 63 MHz removed from the interrogation frequency.**

The airborne system identifies its own unique stream of pulses and measures the time interval, electronically, between the start of the interrogation and the reception of the response from the transponder. The time measurement, and hence range, is very accurate and is based upon the speed of radio waves i.e. 3×10^8 m/s. A modern DME is inherently accurate to **+/- 0.2 NM**

In theory up to 100 aircraft can interrogate a DME transponder. Thus each aircraft is receiving its **own** returning paired pulses **plus** those which result from **other** aircrafts' interrogations, as the pulses have the same carrier frequency.

The width of the interrogation pulses is 3.5 μs (1050 m) and they are transmitted in pairs; (the interval between the individual pulses of a pair is 12 μs for X channel and 36 μs for Y channel).

Aircraft Range Determination

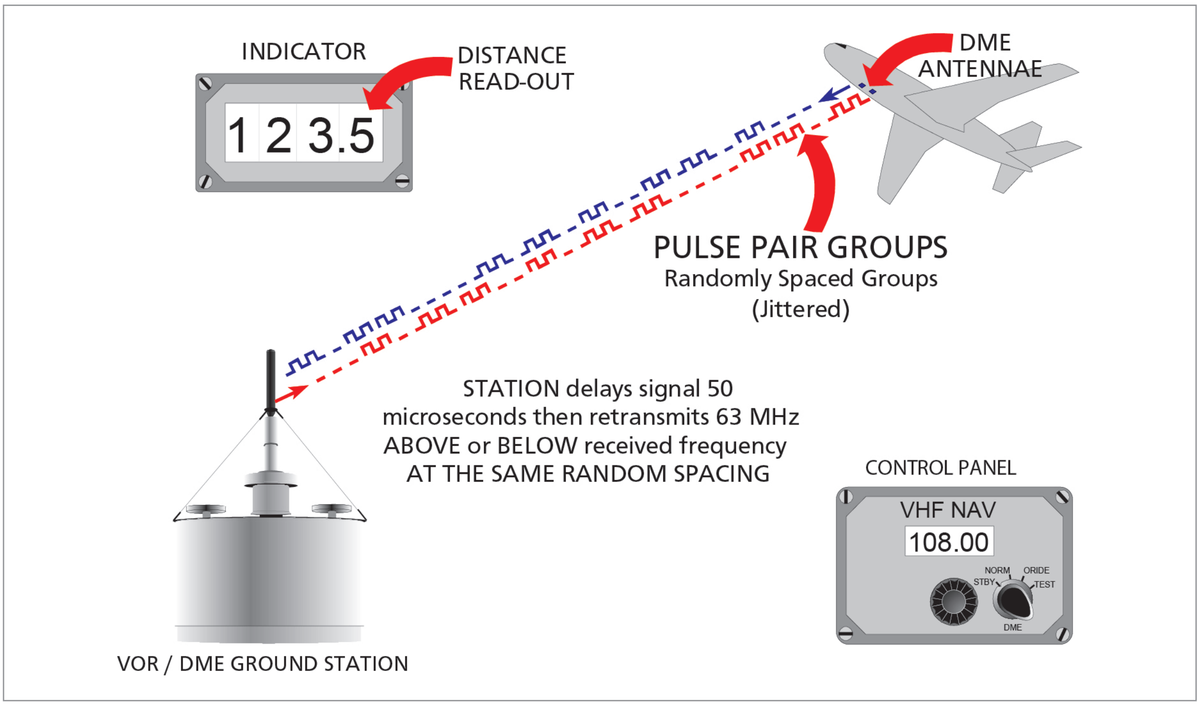


Figure 15.7 The Principle of Range Measurement

For an individual aircraft to achieve an unambiguous slant range measurement and overcome the problem of identification:

- Each aircraft's interrogator is programmed to transmit its **paired pulses at random intervals** i.e. the transmission sequence of pulses is irregular or jittered. This differentiates its pulses from all the others.
- At the instant of transmission, the receiver of an interrogator sets up **gates** to match the random PRF of the transmitted twin pulses.
- The responses on the transponder's carrier frequency include an **individual aircraft's** paired pulses plus those from **other aircraft**.
- The receiving equipment of an aircraft is designed so that only the responses which match its **randomized PRF** are allowed through the gates. The pulses have now achieved **lock-on** i.e. the DME enters the tracking mode.
- As the aircraft's range from the station increases or decreases (unless the aircraft is circling) the gates move to accommodate the corresponding increase or decrease in the time between transmission and reception of the twin pulses. This lock-and-follow technique ensures that the returning twin pulses are continuously tracked.
- The off-set in time between transmission and reception is the measure of the aircraft's slant range from the DME transponder.

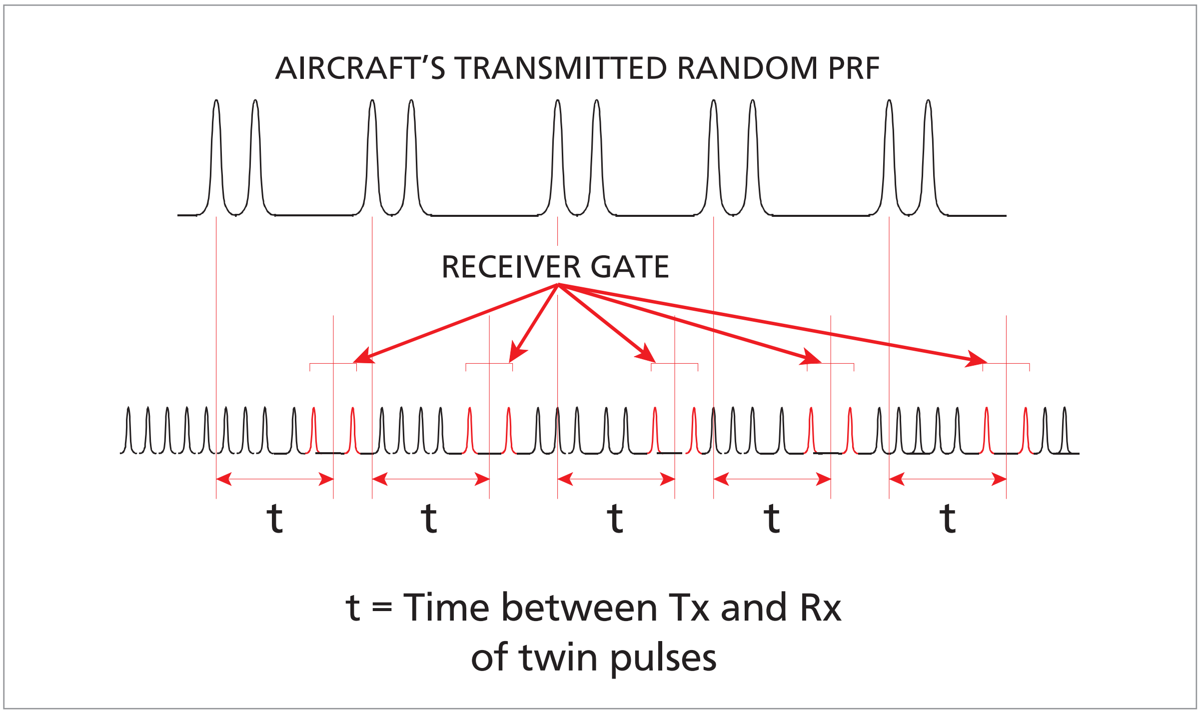


Figure 15.8 Acceptance of Own Pulses

Twin Pulses

The use by the DME system of twin pulses ensures that the receivers never accept matching randomized single pulses which could (possibly) emanate from, for example, other radars, ignition systems or lightning.

Range Search

To achieve a rapid lock-on during the range search, the DME interrogator transmits at **150 pulse pairs per second (ppps) for 15 000 pulse pairs** (100 seconds).

If lock-on is not achieved, it will then reduce the rate to **60 ppps** and maintains this rate until there is a range lock-on. At lock-on the system operates at a random PRF of **27 ppps.**

During the range search the range counters, or pointer, of the indicator rotate rapidly from zero nautical miles through to the maximum range; this takes 4 to 5 seconds in modern equipment and 25 to 30 in older systems. If no response is achieved within this period, the pointer, or counters, return rapidly to zero and the search starts again.

Beacon Saturation

The output of a modern ground beacon is a constant **2700 pulse pairs per second** which, in the absence of any aircraft interrogations, are generated at random intervals. When a ground beacon is receiving 2700 ppps it becomes **saturated** and it then reduces its receiver gain. The effect of this is to exclude the transmissions from aircraft whose interrogation pulses are weaker. This equates to about 100 aircraft using the DME at the same time.

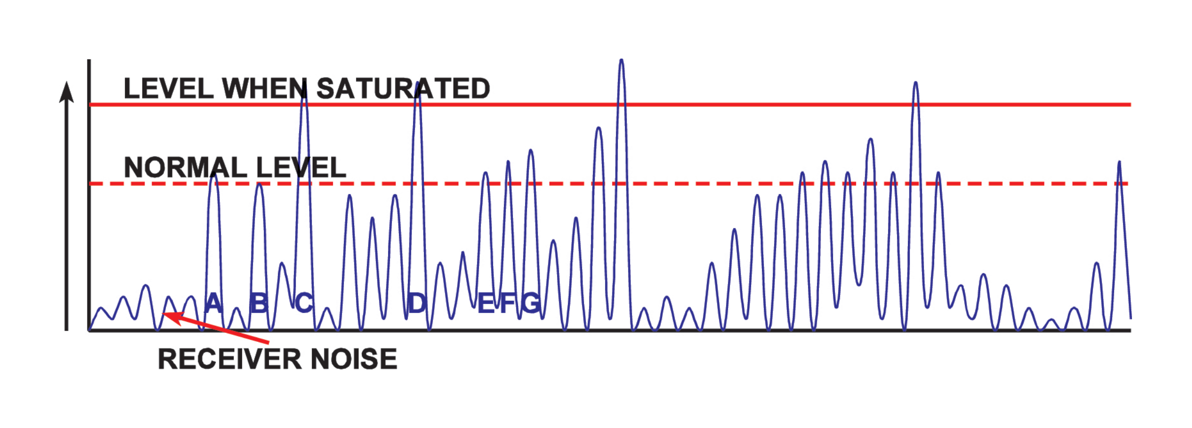


Figure 15.9 Beacon Saturation

In *Figure 15.9* all aircraft A to G are receiving ranges from the transponder with aircraft B just entering the coverage. When the transponder becomes saturated, the receiver gain is reduced and aircraft A, B, E, F and G will be excluded and unlock. The aim is to give preference to the nearest aircraft as the beacon responds to the strongest interrogations.

Station Identification

A 3 letter call sign is transmitted every 30 seconds, usually in conjunction with an associated VOR. During the ident period the random pulses are replaced by regularly spaced pulses keyed with the station identification letters. This means that range information is not available during the ident period. However the aircraft equipment has a 10 second memory circuit to continue displaying the range obtained. The DME identification is distinguished from the VOR identification by having a different tone (usually higher than the VOR).

VOR/DME Frequency Pairing

To facilitate and speed up frequency selection, and to reduce the pilot's cockpit workload, VORs may be frequency paired with a DME or a military TACAN installation. This means that the aircraft's DME circuits are automatically activated when the appropriate VHF VOR frequency is selected. Ideally the VOR and DME or TACAN beacons should be co-sited in order that a range and bearing can be plotted from the same source. This is not always possible. The table explains the siting and frequency pairing and call sign arrangements of VOR/DME or VOR/TACAN facilities.

RELATIVE POSITIONS OF VOR/DME OR TACAN	FREQUENCIES	IDENTIFICATION
Associated: (i) both transmitters co-located, or (ii) the maximum distance between both transmitters is 30 m/100 ft in TMAs, or (iii) the maximum distance between both transmitters is 600 m/2000 ft, for use elsewhere	 Paired Paired Paired	Both transmit the same call sign There are four idents every 30 sec period The VOR transmits 3 of the four The DME transmits the fourth
Not associated but serve the same location	Paired	First two letters are the same; last letter for DME is 'Z'
VOR/DME-TACAN widely separated i.e. > 6 NM	May or may not be paired	Totally different identifications

DME Range Measurement for ILS

When DME is paired with ILS, the transponder is adjusted to give range to the threshold in UK systems, since clearly the ground installation cannot be placed at the threshold. This is achieved by reducing the time delay at the transponder, so that the time taken for the interrogation signal to travel from the runway threshold to the transponder, plus the delay at the transponder, plus the time taken for the reply to travel from the transponder to the runway threshold is 50 microseconds.

For example: if the transponder is 1500 m from the runway threshold, the time for the interrogation and reply pulses to travel between the threshold and transponder will be 5 microseconds each way, so the delay at the transponder must be reduced to 40 microseconds to give a range to the threshold.

Range and Coverage

DME transmissions obey the **'line of sight'** rule. Thus the higher the aircraft, and the ground beacon, the greater the theoretical reception distance.

Intervening high ground will block the line of sight range.

The effect of bank angle is to hide the aircraft antenna from the transponder on the ground and will cause an interruption in the flow of signals. However, the memory circuit ensures that there is no major disruption to range measurement.

In order to overcome range errors which may be caused by mutual interference between two or more facilities sharing the same frequencies, a **Designated Operational Coverage** is published for each DME; this protects a DME from co-channel interference under normal propagation conditions. The DOC is specified as a **range** and **height**. The use of a DME beyond its DOC limitations may result in range errors.

In order to eliminate errors arising from reflections from the earth's surface, buildings or mountainous terrain, the aircraft receiver incorporates an Echo Protection Circuit.

Accuracy

System Accuracy

Based on a 95% probability the system accuracy for DME used for navigation (DME/N) should give a total system error not exceeding **+/-** 0.25 NM +/-1.25% of range. Precision systems (DME/P) are accurate to +/- 100 ft on Final Approach.

The total system limits include errors from causes such as those arising from airborne equipment, ground equipment, propagation and random pulse interference effects.

Slant Range / Ground Range Accuracy

The difference between computed slant range and actual ground distance increases the **higher and closer** an aircraft gets in relation to the DME. As a general rule the difference becomes significant when the aircraft is at a range which is less than 3 × height. When the aircraft is directly over the DME (0 NM ground distance), it will indicate the aircraft's height in nautical miles. There is a small cone of confusion over a DME, plus range indications continue to be computed as the equipment has a 10 second memory circuit.

Aircraft at 36 840 ft:

$$\frac{36\,840}{6080} = 6 \text{ NM}$$

$$10^2 = 6^2 + x^2$$

$$x = \sqrt{100 - 36} = 8 \text{ NM ground range}$$

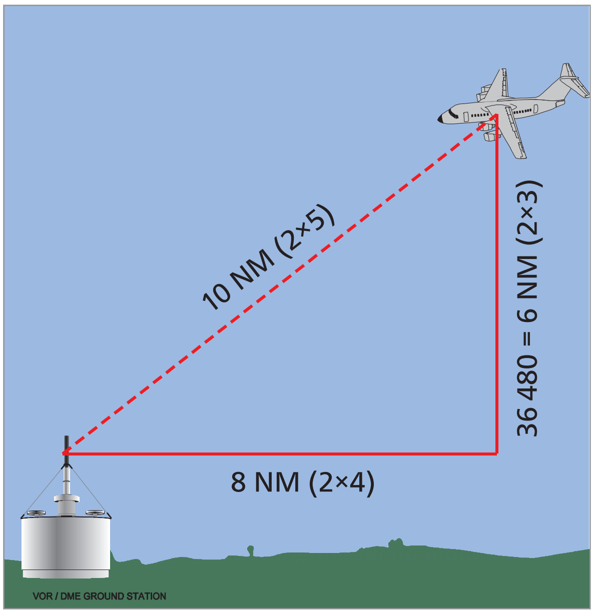


Figure 15.10

Accuracy of Ground Speed Computation

The equipment's indicated ground speed, which is computed from the rate of change of slant range, becomes more inaccurate and under-reads the actual ground speed, the closer and higher an aircraft is in relation to the DME beacon.

An aircraft circling a DME beacon at a constant range will have an indicated computed ground speed of zero knots. A ground speed is only valid when an aircraft is homing to, or flying directly away from, a VOR/ DME - TACAN.

DME Summary

Frequency	UHF band; 962 to 1213 MHz; 1 MHz spacing; 252 channels +/- 63 MHz difference between transmitted and received frequencies. Selection by paired VHF frequency (VOR or ILS). DME paired with ILS gives range zero referenced to ILS runway threshold.
Uses	Circular position line; ground speed and time to/from station. DME arcs. Range and height checks during let-downs. Accurate ranges to threshold. RNAV.
Principle of Op	Aircraft interrogator and receiver: transmits pairs of pulses at random intervals, omni-directionally. Ground station transponder: re-transmits all pulses at +/- 63 MHz after a delay of 50 μs.
Slant Range	Aircraft receiver identifies own pulses and determines range from time interval between transmitted and received pulses (minus 50 μs).
Pulse Characteristics	Twin pulse used to avoid interference. Jittered pulses are used to identify own pulses. Frequency change prevents aircraft locking on to reflections.
Range Search	Pulse rate - initially 150 ppps. - reduced to 60 ppps after 15 000 ppps. - further reduced to about 25 ppps at lock-on.
Beacon Saturation	Occurs at 2700 ppps (approx 100 aircraft interrogating) receiver gain reduced to respond only to strong pulses.
Station Ident	3 letter identifier; range info not available during ident period.
VOR /DME Frequency Pairing:	
Associated	- if co-located or within 100 ft in TMA or 2000 ft outside TMA. - call signs are the same; frequencies paired.
Not associated	- if serving same location then call sign of DME third letter is 'Z'. - frequencies paired.
Separated	- if > 6 NM apart; call signs different.
Coverage:	Line of sight range; reduced by intervening high ground and bank angle DOC gives protected range; echo protection circuit eliminates reflections.
Accuracy:	+/-0.25 NM +/-1.25% of range (+/-0.2 NM for precision systems). Slant range error significant when aircraft range < 3 × height. Ground speed error increases as aircraft goes higher and closer to station.

Questions

1. **Airborne DME equipment is able to discriminate between pulses intended for itself and pulses intended for other aircraft because:**

   a. aircraft transmit and receive on different frequencies
   b. aircraft will only accept unique twin pulses
   c. aircraft reject pulses not synchronized with its own random pulse recurrence rate
   d. each aircraft has its own frequency allocation

2. **A DME beacon having a transmit frequency of 962 MHz would have a receive frequency of:**

   a. 1030 Mhz
   b. 902 Mhz
   c. 1025 Mhz
   d. 962 Mhz

3. **A VOR/DME share the same first two letters of their respective identifiers; the last identifying letter of the DME is a Z. This means that:**

   a. they are co-located
   b. they are more than 600 m apart but serve the same location
   c. they are widely separated and do not serve the same location
   d. they are a maximum distance of 30 m apart

4. **Distance Measuring Equipment is an example of .... radar operating on a frequency of .... in the .... band.**

a.	primary	8800 MHz	SHF
b.	secondary	1030 MHz	UHF
c.	secondary	962 MHz	UHF
d.	primary	9375 MHz	SHF

5. **A DME transponder does not respond to pulses received from radars other than DME because:**

   a. each aircraft transmits pulses at a random rate
   b. DME transmits and receives on different frequencies
   c. it will only accept the unique twin DME pulses
   d. DME only responds to the strongest 100 interrogators

6. **The range indicated by DME is considered to be accurate to within:**

   a. 3% of range
   b. 1.25 % of range
   c. 0.5 NM
   d. +/-0.25 NM +/-1.25% of range

7. **A DME receiver is able to distinguish between replies to its own interrogations and replies to other aircraft because:**

a. DME is secondary radar and each aircraft transmits and receives on a different frequency
b. DME transponders reply to interrogations with twin pulses and the airborne equipment ejects all other pulses
c. each aircraft transmits pulses at a random rate and will only accept synchronized replies
d. when DME is in the search mode it will only accept pulses giving the correct range

8. **When a DME transponder becomes saturated:**

a. it reverts to standby
b. it increases the number of pulse pairs to meet the demand
c. it increases the receiver threshold to remove weaker signals
d. it goes into a selective response mode of operation

9. **An aircraft flying at FL250 wishes to interrogate a DME beacon situated 400 ft AMSL. What is the maximum range likely to be achieved?**

a. 210 NM
b. 198 NM
c. 175 NM
d. 222 NM

10. **For a DME and a VOR to be said to be associated it is necessary for:**

b. the DME to transmit on the same VHF frequency as the VOR
b. the aerial separation not to exceed 100 ft in a TMA or 2000 ft outside a TMA
c. the aerial separation not to exceed 100 m in a TMA or 2000 m outside a TMA
d. both beacons to have the same first two letters for their ident but the last letter of the DME to be a ‘Z’

11. **The transmission frequency of a DME beacon is 63 MHz removed from the aircraft interrogator frequency to prevent:**

a. interference from other radars
b. the airborne receiver locking on to primary returns from its own transmissions
c. static interference
d. receiver accepting replies intended for other interrogators

12. **The accuracy associated with DME is:**

a. + or - 3% of range, or 0.5 NM, whichever is greater
b. + or - 1.25% of range
c. + or - 3% of range
d. +/-0.25 NM +/-1.25% of range

13. For a VOR and a DME beacon to be said to be associated the aerial separation must not exceed .... in a terminal area and .... outside a terminal area.

a.	100 m	2000 m
b.	50 ft	200 ft
c.	30 m	600 m
d.	50 m	200 m

14. DME is a .... radar operating in the .... band and uses .... in order to obtain range information. The correct words to complete the above statement are:

a.	primary	SHF	CW signals
b.	secondary	UHF	twin pulses
c.	secondary	SHF	"jittered pulses"
d.	primary	UHF	pulse pairs

15. The receiver of airborne DME equipment is able to "lock on" to its own "reply pulses" because:

a. each aircraft has its own unique transmitter frequency and the receiver only accepts reply pulses having this frequency
b. the reply pulses from the ground transmitter have the same frequency as the incoming interrogation pulses from the aircraft
c. the aircraft receiver only accepts reply pulses which have the same time interval between successive pulses as the pulses being transmitted by its own transmitter
d. the aircraft receiver only accepts reply pulses which arrive at a constant time interval

16. DME operates in the .... frequency band, it transmits .... which give it the emission designator of ....

a.	SHF	double size pulses	P01
b.	UHF	twin pulses	P0N
c.	EHF	twin pulses	A9F
d.	UHF	double pulses	J3E

17. Referring to DME during the initial stage of the "search" pattern before "lock-on":

a. the airborne receiver checks 150 pulses each second
b. the airborne transmitter transmits 150 pulses each second
c. the ground receiver maintains the ground transmitter pulse transmission rate at no more than 150 per second
d. the aircraft transmits 24 pulses per second and the receiver checks a maximum of 150 pulses per second

18. DME and VOR are "frequency paired" because:

a. the same receiver can be used for both aids
b. the VOR transmitter is easily converted to the required DME frequency
c. cockpit workload is reduced
d. both ground transmitter aerials can be placed on the same site if required

19. A DME receiver is able to distinguish between replies to its own interrogation pulses and those intended for other aircraft using the same transponder because:

a. DME is a secondary radar and each aircraft transmits and receives on a different frequency
b. DME transponders reply to interrogations by means of twin pulses and the airborne equipment rejects all single pulses
c. each aircraft transmits pulses at a random rate("jittering") and will only accept replies that match this randomization
d. when DME is in the range search mode it will accept only pulses separated by + or - 63 MHz from the interrogation frequency

Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	c	b	c	c	d	c	c	d	b	b	d

13	14	15	16	17	18	19
c	b	c	b	b	c	c

Chapter

16

Area Navigation Systems (RNAV)

Introduction

RNAV is defined as a method of navigation which permits aircraft operations **on any desired track** within the coverage of **station-referenced** navigation signal, **or** within the limits of **self-contained** navigation system.

An area navigation (RNAV) system is any system that allows the aircraft to be navigated to the required level of accuracy without the requirement to fly directly over ground based facilities.

The required accuracy is achieved by using some, or all, of the following inputs of information:

- VOR/DME
- ILS/MLS
- GNSS
- INS/IRS
- ADC
- Time

The information is processed within the system to give the most accurate and continuously updated position and the necessary outputs to provide the pilot with course, ETA etc.

Benefits of RNAV

RNAV allows aircraft to take a more direct flight path appropriate to the route they are flying thereby improving the operating efficiency and helping in relieving congestion on the overcrowded airway system. To facilitate this, air traffic control centres have established RNAV routes which are more direct than the traditional airways system allows and do not require aircraft to regularly fly to the overhead of beacons. Hence the benefits are:

- A reduction in distance, flight time and fuel (and hence costs) by giving airlines and pilots greater flexibility and choice of routes.

- An increase in the present route capacity by making full use of the available airspace by providing more direct routes, parallel or dual routes and bypass routes for overflying aircraft in high density terminal areas.

- A reduction in vertical and horizontal separation criteria.

Types and Levels of RNAV

There are two **types of RNAV:**

Basic RNAV (B-RNAV) which is required to give a position accuracy to **within 5 NM** on at least 95% of occasions. It is now mandatory for all aircraft carrying 30 passengers or more to have B-RNAV capability within Euro-control airspace.

Precision RNAV (P-RNAV) must be accurate to **within 1.0 NM** on at least 95% of occasions. P-RNAV routes are now being established in terminal airspace.

There are three **levels of RNAV** capability:

- **2D RNAV** which relates to the capabilities in the **horizontal plane only**.
- **3D RNAV** indicates the addition of a guidance capability in the **vertical plane**.
- **4D RNAV** indicates the addition to 3D RNAV of a **timing function.**

A Simple 2D RNAV System

The flight deck of a simple 2D RNAV system includes the following components:

- Navigation Computer Unit.
- Control and Display Unit (CDU).
- Indicator in the form of a:
    - Course Deviation Indicator (CDI) or
    - Horizontal Situation Indicator (HSI)

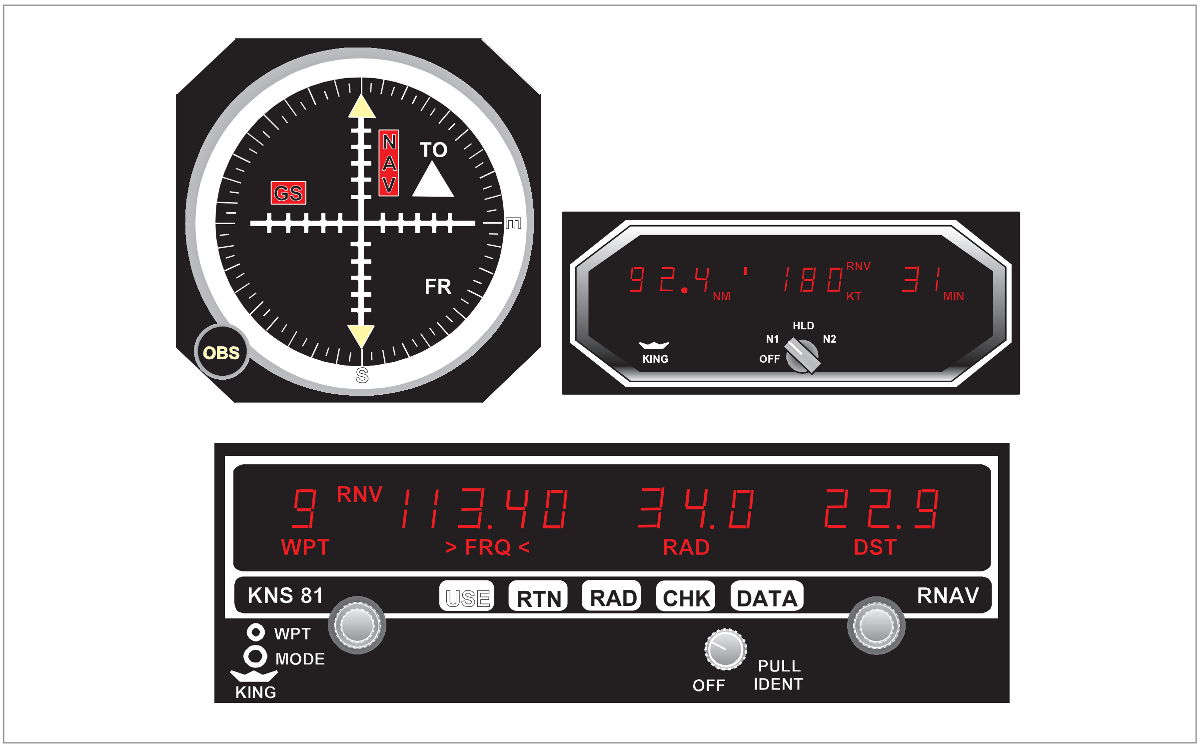


Figure 16.1 VOR/DME RNAV Integrated Nav System

Operation of a Simple 2D RNAV System

A simple RNAV system uses rho/theta (range/bearing) to define position, which is derived from range and bearing information from VOR/DME stations. The pilot defines waypoints along the route to be flown as range and bearing from suitably located VOR/DME. Then the equipment, using the VOR/DME bearing and range, computes the QDM and distance to the waypoint and presents the information to the pilot on a CDI or HSI as if the waypoint itself is a VOR/DME station, hence these waypoints are known as phantom stations.

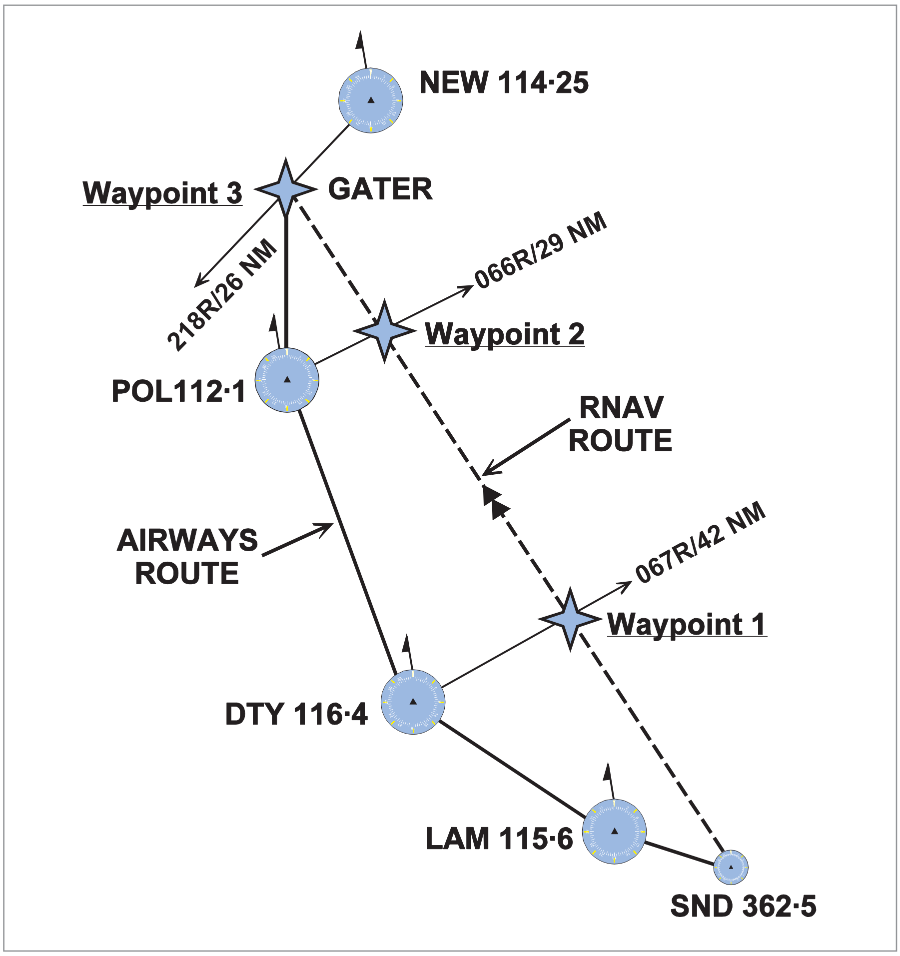


Figure 16.2 An RNAV route & waypoints

In the diagram the pilot has defined waypoints along the planned route from SND to NEW using available and sensibly placed VOR/DME.

Waypoints may be selected and programmed for:

- En route navigation.
- Initial approach fixes.
- Locator Outer Markers.
- ILS frequencies (when selected the instrumentation automatically reverts to ILS mode).

The following table shows the inputs that would be required for the above RNAV route.

WAYPOINT	STATION	FREQUENCY	RADIAL	DISTANCE	APPLICATION
1	DTY	116.4 MHz	067	42	En route Nav.
2	POL	112.1 MHz	066	29	En route Nav.
3	NEW	114.25 MHz	218	26	En route Nav.
4	NEW	114.25 MHz	251	4	Holding LOM
5	I-NC	111.5 MHz	N/A	N/A	ILS

Principle of Operation of a Simple 2D RNAV System

Refer to *Figure 16.3*. The aircraft is flying from waypoint 1 (WP1) defined by DTY VOR/DME to waypoint 2 (WP2) defined by POL VOR/DME. As the aircraft arrives at WP1, POL is selected and the range and bearing measured (145(M)/104 NM). The RNAV knows its position with respect to POL and the pilot has already input waypoint 2 with respect to POL. The computer can now compute the track and distance from WP1 to WP2 (340(M)/102 NM) since it has two sides, the included angle and the orientation of magnetic north. The RNAV now continually computes the aircraft position with respect to POL and compares this position with the computed track to determine the cross-track error and the distance to go. Steering demands are fed to a CDI or HSI for the pilot to keep the aircraft on track and give continuous range read-out to WP2. It should be noted that on such a system the indications of deviation from track are in NM.

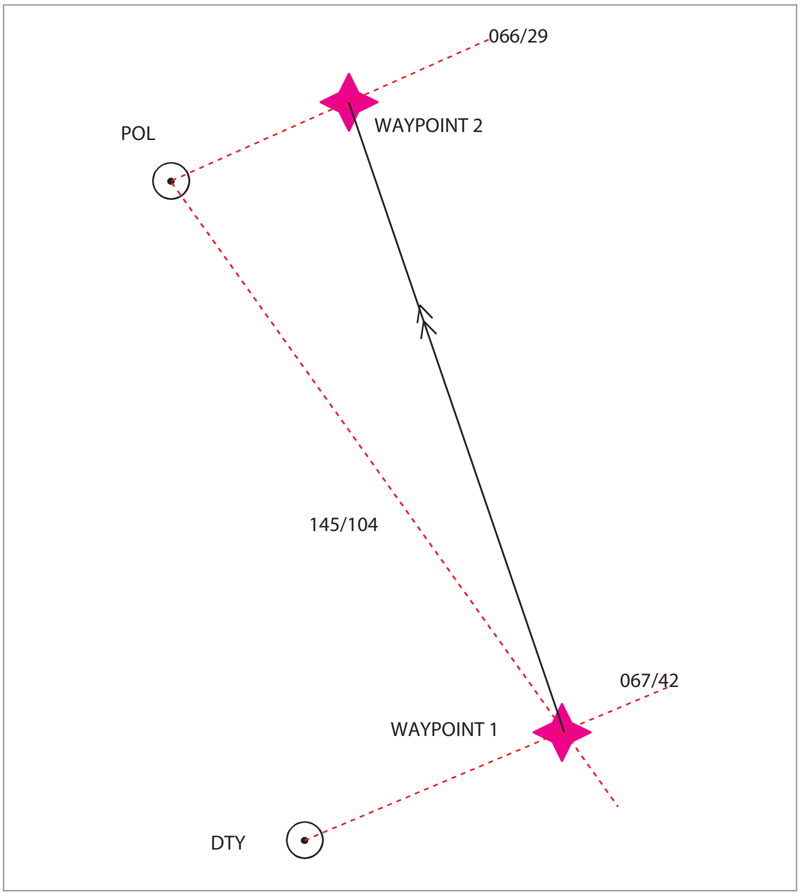


Figure 16.3

Limitations and Accuracy of Simple RNAV Systems

The beacons are selected by the pilot during the pre-flight planning and the pilot must ensure that each waypoint is within DOC of the VOR/DME designating that waypoint and of the VOR/DME designating the next waypoint.

Slant range error in DME must be considered in selecting facilities close to track.

The pilot must ensure that the information is correctly input into the CDU because the computer cannot recognize or rectify mistakes.

To avoid positional errors the aircraft must at all times be within the DOC of the in use facility. The accuracy of the fixing information is dependent on range and whether the VOR or DME element is predominant. If the VOR/DME is close to the planned track to/from the waypoint, the along track element will be most accurate. If the VOR/DME designating the way point is perpendicular to the track, the across track will be most accurate.

Level 4 RNAV Systems

The area navigation function in modern passenger aircraft is carried out by a flight management computer (FMC) which also provides guidance and performance functions. The system outlined below is specific to the BOEING 737-800, but the principle is true for all aircraft.

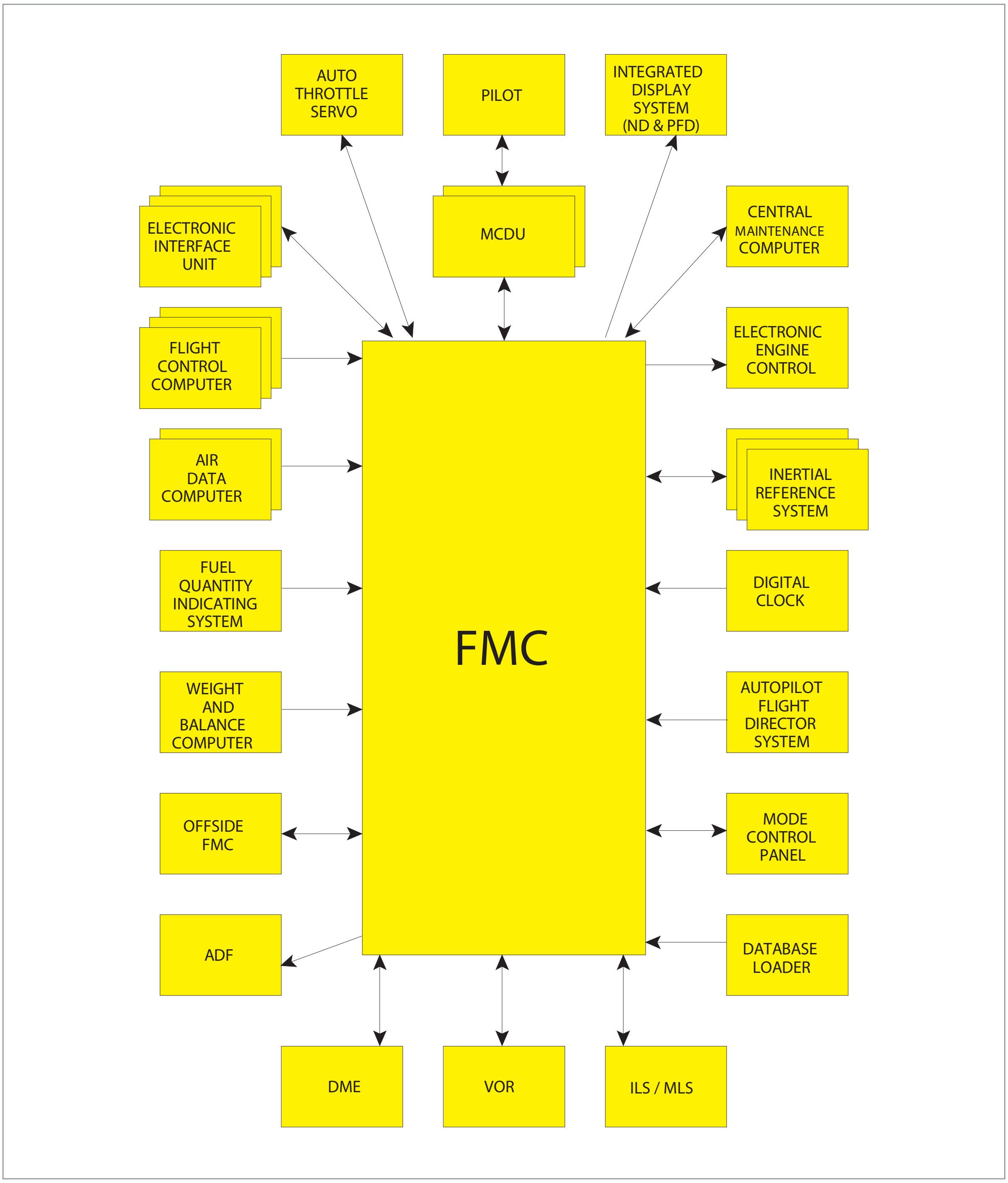


Figure 16.4 FMS schematic

Requirements for a 4D RNAV System

- Display present position in latitude/longitude or as distance/bearing to selected waypoint
- Select or enter the required flight plan through the control and display unit (CDU)
- Review and modify navigation data for any part of a flight plan at any stage of flight and store sufficient data to carry out the active flight plan
- Review, assemble, modify or verify a flight plan in flight, without affecting the guidance output
- Execute a modified flight plan only after positive action by the flight crew
- Where provided, assemble and verify an alternative flight plan without affecting the active flight plan
- Assemble a flight plan, either by identifier or by selection of individual waypoints from the database, or by creation of waypoints from the database, or by creation of waypoints defined by latitude/longitude, bearing/distance parameters or other parameters
- Assemble flight plans by joining routes or route segments
- Allow verification or adjustment of displayed position
- Provide automatic sequencing through waypoints with turn anticipation. Manual sequencing should also be provided to allow flight over, and return to, waypoints
- Display cross-track error on the CDU
- Provide time to waypoints on the CDU
- Execute a direct clearance to any waypoint
- Fly parallel tracks at the selected (offset distance offset mode must be clearly indicated)
- Purge previous radio updates
- Carry out RNAV holding procedures (when defined)
- Make available to the flight crew estimates of positional uncertainty, either as a quality factor or by reference to sensor differences from the computed position
- Conform to WGS-84 geodetic reference system
- Indicate navigation equipment failure

The 737-800 FMS

The 737-800 FMS comprises:

- Flight Management Computer System (FMCS)
- Autopilot/Flight Director System (AFDS)
- Autothrottle (A/T)
- 2 Inertial Reference Systems (IRS)

Each component is an independent system which may be used individually or in various combinations. The term FMS implies the joining of all these systems into one integrated system which provides automatic navigation, guidance and performance management. The FMS provides 4D area navigation (latitude, longitude, altitude and time) and optimizes peformance to achieve the most economical flight possible. It provides centralized cockpit control of the aircraft's flight path and performance parameters.

The Flight Management Computer (FMC) is the heart of the system, performing all the navigational and performance calculations and providing control and guidance commands. A control and display unit (CDU) allows the crew to input the flight details and performance parameters into the FMC. The navigation and performance computations are displayed on the CDU for reference and monitoring. The related FMC commands for lateral (LNAV) and vertical (VNAV) navigation may be coupled to the AFDS and A/T.

In the navigation functions the FMC receives inputs of position and heading from the IRS and fixing information using twin DME. The FMC compares these inputs and by a process known as Kalman filtering produces a system position. In the operation with radio position updating, the FMC is combining the short term accuracy of the IRS with the long term accuracy of the external reference. If the FMS is using just the IRS information to derive position a warning is displayed to the crew indicating that the positional information is downgraded.

The crew may select the level of automation required, from simply using the data displays to fly the aircraft manually, e.g. for heading or TAS/Mach No., to fully automatic flight path guidance and performance control (see *Figure 16.5*).

Even with full FMS operation, the crew have absolute control of the management and operation of the aircraft. Furthermore, certain functions can only be implemented by the crew, e.g. thrust initiation, take-off, altitude selection, ILS tuning, aircraft configuration and landing rollout. The crew should always monitor the FMC navigation throughout the flight to ensure the flight plan is being accurately followed by the automatic systems.

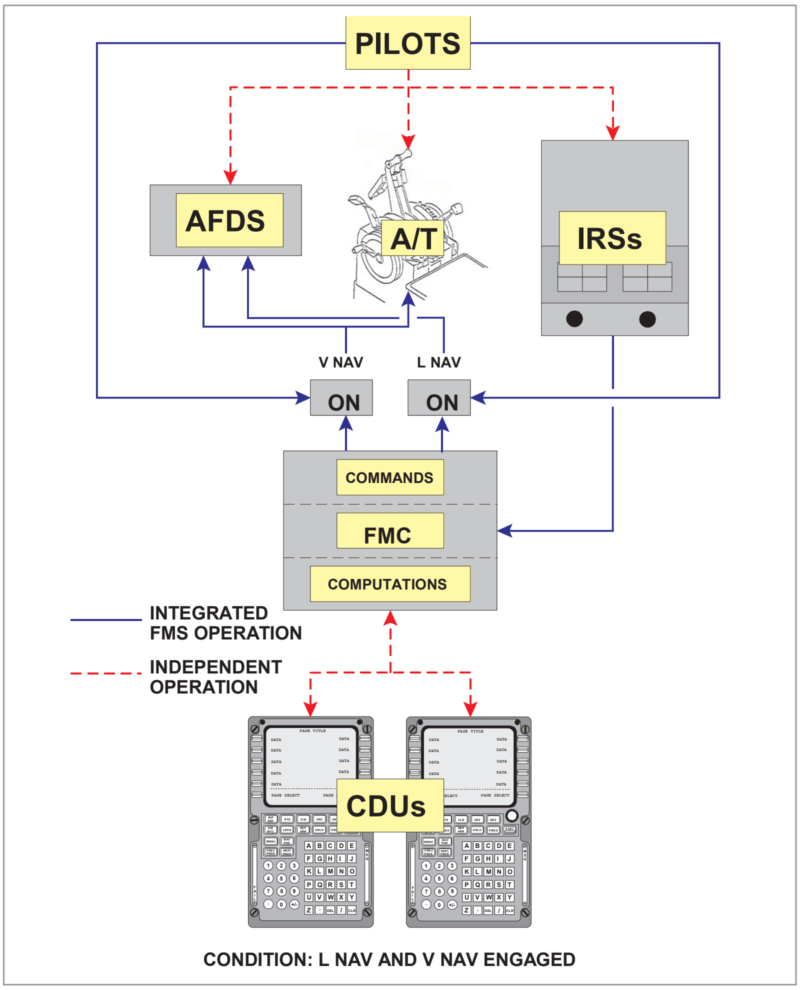


Figure 16.5 B737 - 400 FMS

The FMC contains a performance database and a navigation database. The performance database contains all parameters of the aircraft performance and the company's cost index strategy. The navigation database contains aeronautical information for the planned area of operations of the aircraft, comprising:

- aerodrome details, positions, elevations, runways and lengths etc.
- navigation facilities, including location, altitude, frequency, identification and DOC.
- airways routes, including reporting points.
- SIDs and STARs and runway approaches.
- company routes.

The navigation data is updated every 28 days and the FMC contains the current and next 28 days database (this coincides with the ICAO navigation data cycle). The data may be customized for the specific airline operations.

Control and Display Unit (CDU)

The CDU is the means of communication with the FMC. It is used before flight to initialize the performance and navigation requirements for the flight.

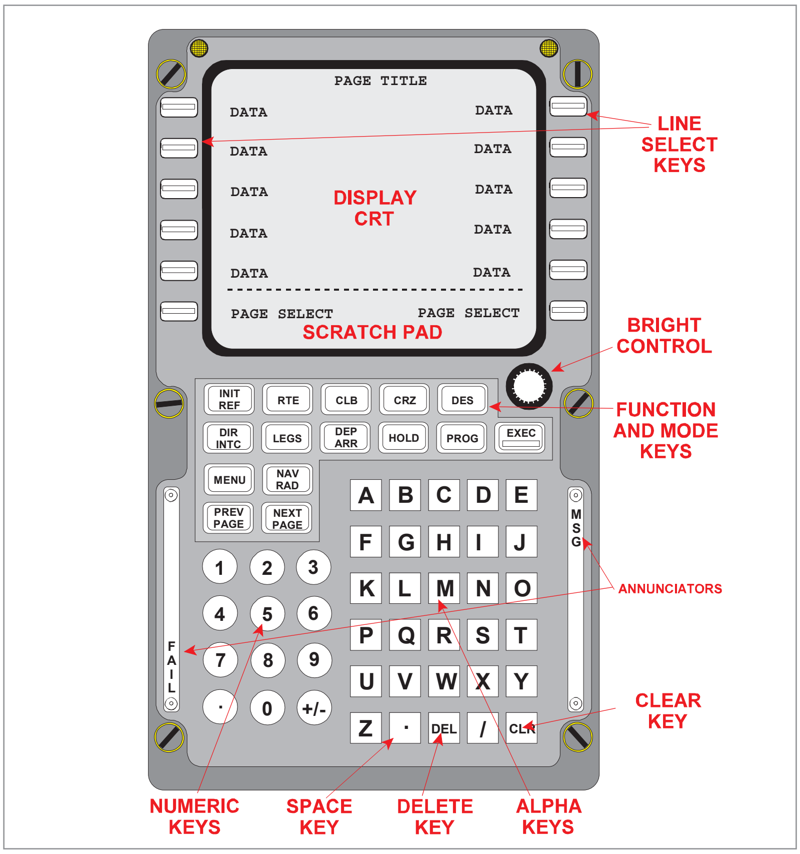


Figure 16.6 Control and display unit

In addition to the alphanumeric keypad and the specific function keys, alongside the display are line select keys (LSK) which are used for inserting or selecting data into the FMC and moving through the various function pages. The format of the display is; in the top field the title of the selected page and, where the selected function has more than one page, the page number (e.g. 1 of 3). In the centre of the display are up to 10 data fields, 5 on the left and right respectively which are accessed using the LSKs. At the bottom of the screen are two or more page select fields and below them the scratchpad. The scratchpad is used to input or modify data for insertion into the appropriate data field.

Pre-flight

The pre-flight initialization of the FMC in the navigation mode requires the pilot to check the validity of the database and input:

- check the correct database installed - IDENT.
- the aircraft position - POS INIT.
- departure and destination aerodromes.
- intended SID and STAR procedures.
- the planned route - POS INIT.

If the aircraft is flying a standard company route then the route designator is inserted, otherwise the pilot will have to input the route manually. Data is initially typed into the scratchpad at the bottom of the screen then inserted in the appropriate position using the line selection keys. Once a valid position has been input it is passed to the IRS.

IDENT Page

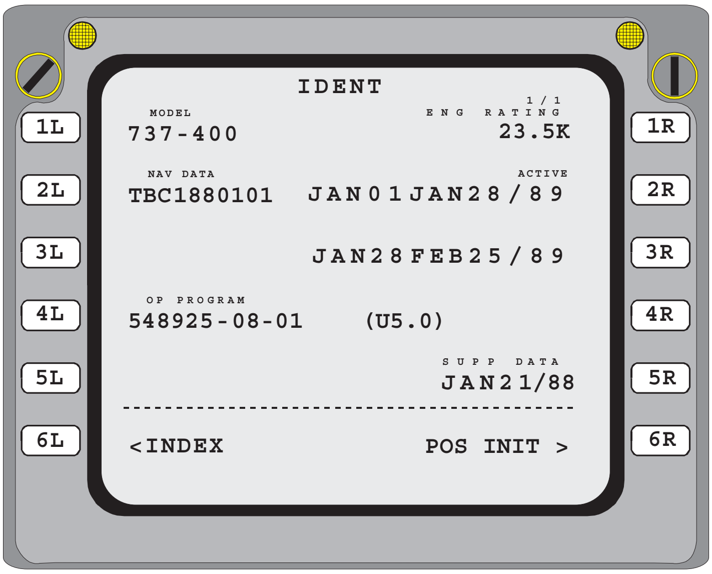


Figure 16.7

When power is applied, the FMS executes an internal test sequence. When the test is successfully completed, it presents the IDENT page on the CDU. This page contains information on the aircraft model and engine thrust from the performance database at 1L and 1R, the identification of the permanent navigation database at 2L with 2R and 3R showing the currency periods of the navigation data in the database. At 4L is the identification of the operating programme and at 5R is the date of the supplementary data. The only information that can be changed on this display is the current nav data at 2R. If this is out of date a prompt will appear in the scratchpad. To change the data, select LSK 3R to downselect the next period of data to the scratchpad, then 2R to insert the data into the active data line. Note that at 6R is the prompt for the next page in the initialization sequence and at 6L is the prompt for the page index. Where any input data is used on other CDU pages the data will automatically 'propagate' to those pages.

POS INIT Page

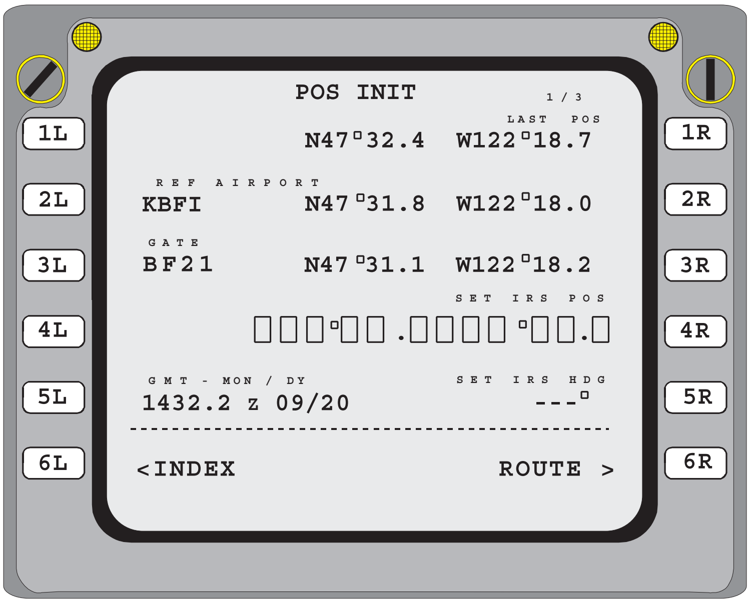


Figure 16.8

The position initialization (POS INIT) page allows initialization of heading and position for the IRS. On all displays the dashed lines, as at 5R, indicate where optional data may be inserted to assist the FMC operation. The boxed areas at 4R indicate where data essential to the operation of the FMC must be inserted. The last position recorded before shutdown is displayed at 1R. The departure airport is inserted at 2L and the gate at 3L. The FMC extracts the airfield reference and gate positions from the database and inserts them at 2R and 3R respectively. At 4R the FMC is asking for the aircraft position to initialize the IRS. The position could be input manually in the scratchpad then inserted by selecting LSK 4R. However, the database has already inserted the position into 3R, so this can be copied by selecting 3R to draw the data down to the scratchpad and then 4R to insert into the field. To speed up alignment, particularly if the aircraft has been moved, the magnetic heading from the standby compass can be input at 5R. Having completed this, the alignment of the IRS will now proceed. The prompt at 6R now directs the pilot to the route (RTE) page.

RTE Page

The route pages are used to insert, check and/or modify a company route, or to insert a route not held in the database.

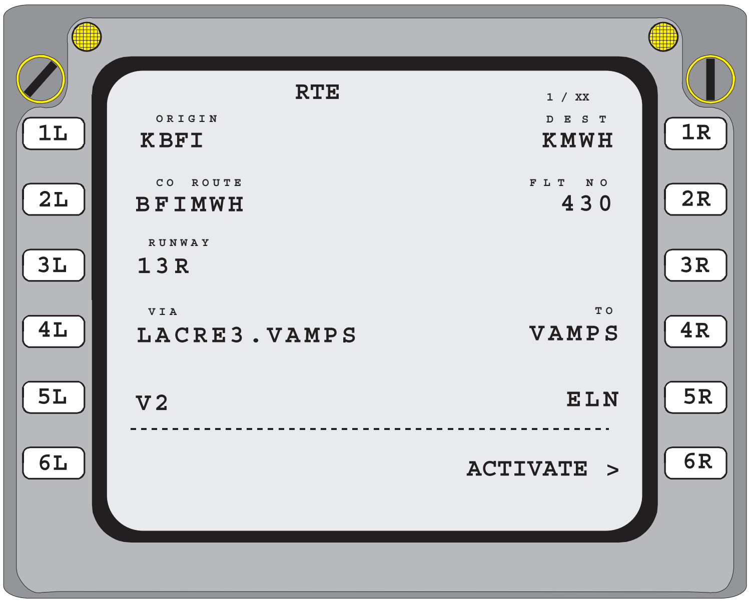


Figure 16.9

The departure and destination aerodromes are input to 1L and 1R respectively. Valid data is any ICAO aerodrome designator held in the database. If the ICAO identifier was input on the POS INIT, then it will appear at 1L. The company route is inserted at 2L and the flight number at 2R. The runway in use and the SID and first route waypoint are inserted at 3L and 4L. Note this will automatically appear if they are defined in the company route. The information at 5L (airway) and 5R (next reporting point on airway V2) is inserted by the computer from the database. To access the subsequent pages of the RTE, select the NEXT PAGE function key on the keyboard to check or modify the route. The 6R prompt directs the pilot to activate the route. Pressing 6R will illuminate the EXEC key on the CDU which should in turn be pressed for the computer to action the route after take-off. After take-off the RUNWAY line is cleared and the VIA/TO moves up to line 3 and the next waypoint appears at 4. As an active waypoint is passed, line three is cleared and replaced with the next active waypoint.

The pre-flight actions for the navigation profile are now complete, but the performance initialization is yet to be actioned. This is dealt with elsewhere in the course. The computer will check the conditions against the performance data and the required cost index profile and inform the pilots of the power, speed and configuration to achieve the required profile. If a manual input of a route is required, this can be achieved through the scratchpad, as can any modifications to the standard company routes.

The valid formats for navigational inputs are:

Latitude and Longitude as either a 7 group alphanumeric (e.g. N05W010) or a 15 group (e.g. N0926.3W00504.7). Note the leading zeros must be entered for the FMC to accept the position.

Up to 5 alphanumerics for ICAO aerodrome designators, reporting points, navigation facilities, airways designators (e.g. EGLL, KODAP, DHD, A23) and runway designators.

Up to 7 alphanumerics for SID and STAR (e.g. TURN05).

Range and bearing from a navigational aid or reporting point (e.g. TRN250.0/76). Note the decimals are optional, the bearing must always be a 3 or 5 digit group, the distance may be 1 to 5 digits. In this case the FMC would give the position the designation TRN01, assuming it was the first or only position specified with reference to TRN. These are known as place bearing/distance (PBD) waypoints.

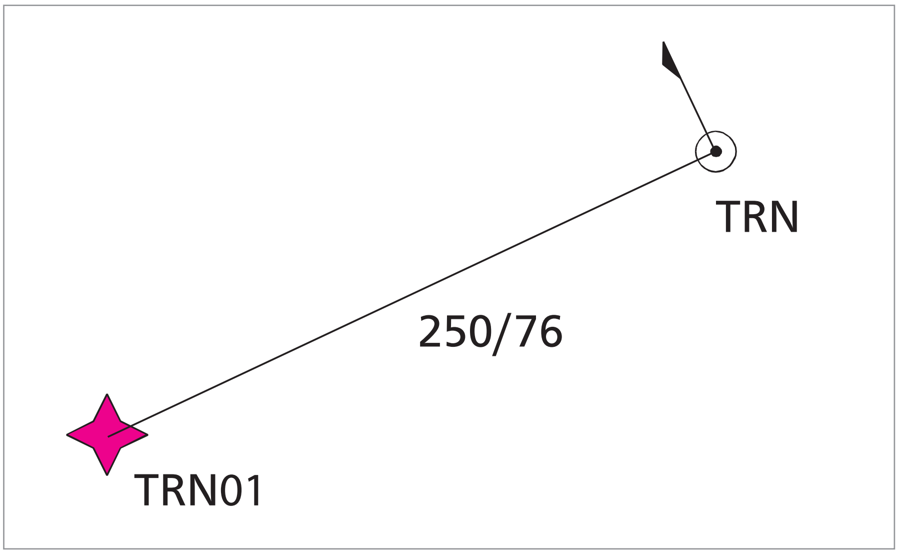


Figure 16.10 Range/bearing waypoint

Course interception waypoints are positions defined where the bearing from any valid database position intersects with a course (e.g. an airway) or the bearing from another database defined position. The format for input is e.g. GOW167.0/TRN090.5, the FMC now produces a PBD waypoint which in this case would be designated GOW01. As above the bearings must be either 3 or 5 digits.

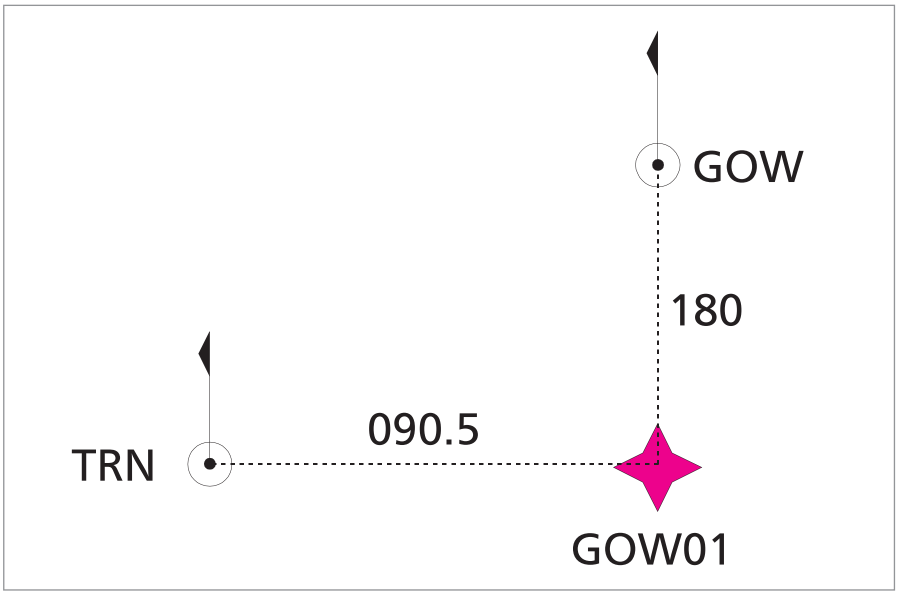


Figure 16.11 Bearing/bearing waypoint

Climb

Normally in the climb the VNAV, LNAV and timing functions will be operative.

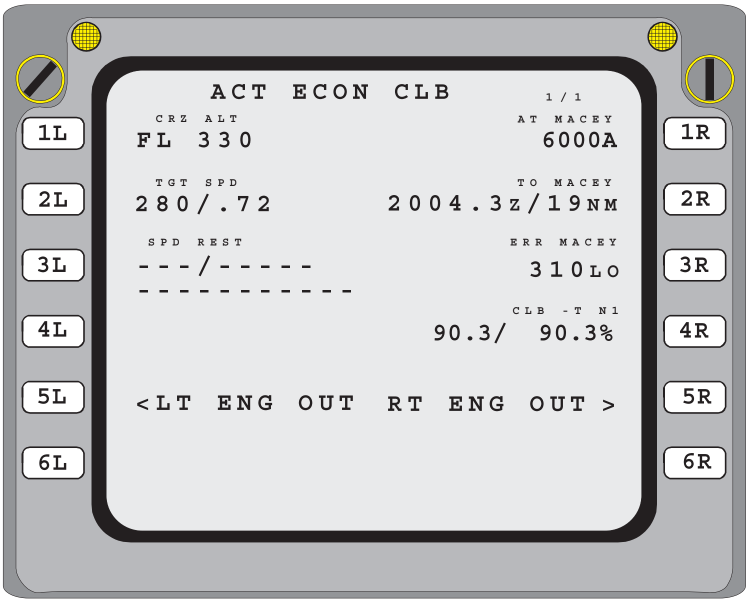


Figure 16.12

On the climb page (CLB) at 1L is the planned initial cruising altitude, if one exists and the climb is active, and at 1R is the current climb restriction. The suffix 'A' indicates altitude. 2L gives the economy speed for the climb and 3L any speed restriction, which defaults to 250 kt and 10 000 ft. Any other speed/altitude restriction imposed by ATC can be input to 3L from the scratchpad. At 2R is the ETA and distance to go to the next position. 3R gives the height error at the next point showing the aircraft will be 310 ft low. The climb engine N1 is displayed at 4R. The prompts at 5 and 6 L and R direct the pilots to the other climb mode pages. (RTA is required time of arrival, to be used if an RTA is specified by ATC).

Cruise

In the cruise all three modes will normally be active.

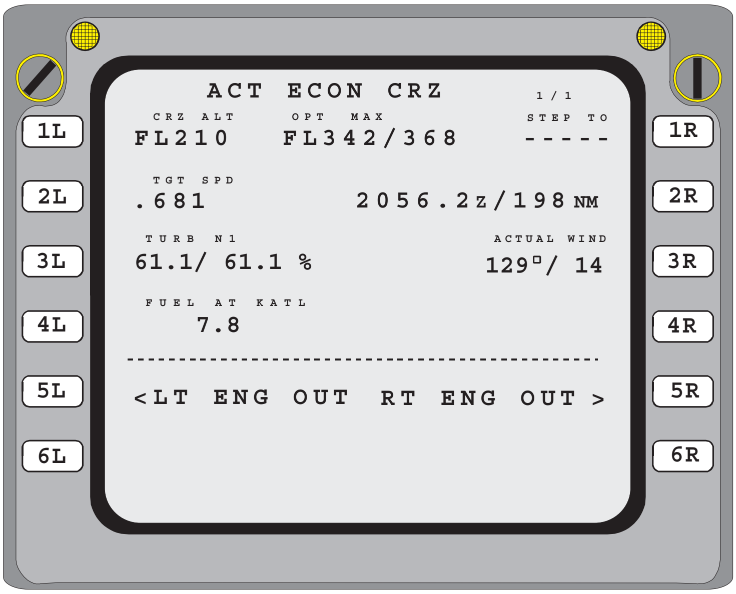


Figure 16.13

The cruise page (CRZ) has the current cruising altitude at 1L with the required cruising speed at 2L; in this case the economy cruise speed. At 3L is the computed EPR/N1 required to maintain the speed at 2L, with the predicted destination fuel shown at 4L. At 1C is the optimum and maximum cruising level for the aircraft weight and the ambient conditions. The next step altitude is displayed at 1R with the time and distance to make the step climb at 2R. 3R shows the estimated wind velocity and 4R shows the predicted savings or penalty in making the step climb indicated at 1R. The other cruise pages are accessed through 5R, 6L and 6R.

Descent

As in the climb the LNAV, VNAV and timing modes are all operative.

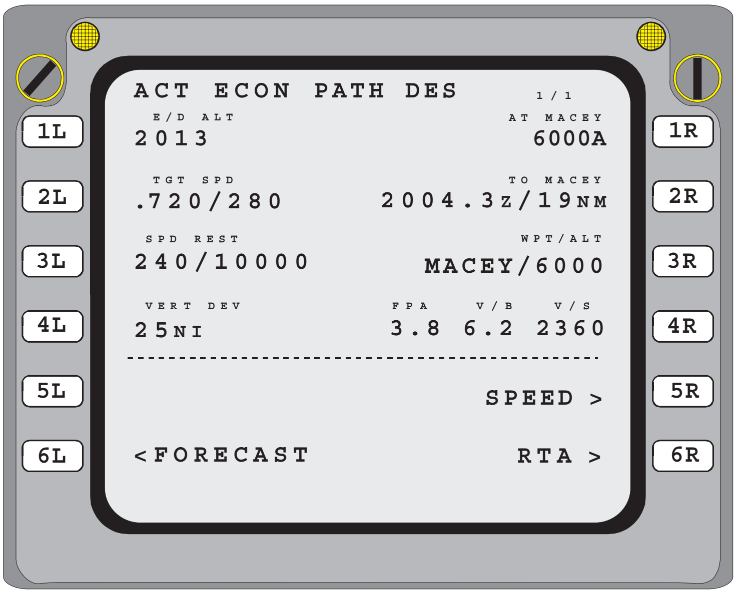


Figure 16.14

With the active economy path descent (ACT ECON PATH DES) page selected, the target Mach number and CAS are at 2L; at 1L is the end of descent altitude. At 1R is the next descent position and altitude; the suffix A indicates at or above. Position 3L contains the speed transition, which is 10 kt less than that stored in the database, and the transition altitude. If none is defined then it defaults to 240/10000. No input is permitted to this field, but the data can be removed. The next waypoint and altitude is shown at 3R, with the expected deviation from this required height displayed at 4L. At 4R FPA is actual flight path angle based on current ground speed and rate of descent. V/B is the vertical bearing i.e. the FPA required to achieve the required height at the next position, and V/S is the actual rate of descent. Access to associated descent pages is gained at 5R, 6L and 6R.

Principle Of Operation - Twin IRS, Twin FMC

In a twin IRS system the left FMC will normally receive information from the left IRS and the right FMC from the right IRS. The systems compare the IRS positions but if there is a discrepancy, they cannot determine in isolation which system is in error. The FMC must have the input of an external reference in order to determine the correct position. Using Kalman filtering, the external reference is compared with the IRS positions to determine the system position. At the start of a flight the IRS position will predominate but as the flight progresses, the IRS positions will degrade and the weighting for the external reference will increase, commensurate with the selection of external reference, and the range from that reference.

There are four possible modes of operation of a twin FMS system. In the dual mode, one FMC acts as the master and the other as the slave. The systems independently determine position and the positional information is co-related, to check for gross errors, before being passed to the EFIS. This means that the position presented on the EFIS may differ from that on each CDU. With independent operation, each FMC works in isolation with no communication.

The information from one of the FMCs will be used to feed the other systems and there will be a difference in position between the two FMCs and between the EFIS and the non-selected FMC. If one FMC is inoperative then the functions can be carried out by the serviceable FMC. If both FMCs are inoperative then IRS information will be used directly in the EFIS but the automatic performance functions will not be available.

Principle Of Operation - Triple IRS, Twin FMC

Positional information and heading from the triple INS/IRS is fed into the FMC where the information is compared to check for any system having gross errors and then averaged. This position may then be compared with an external reference which may be DME/DME, VOR/DME or GNSS. The FMC uses Kalman filtering to produce position and velocity. This filtering may be done purely using the IRS information or using a combination of IRS and external reference.

When operating at latitudes in excess of 84° the FMC will de-couple the IRS with the left FMC using the IRS in the order left, centre, right and the right FMC in the order right, centre, left. Over a short period of time each FMC will change the FMC position to the appropriate IRS position. The reason for the de-coupling is that the calculation of change of longitude from departure is a function of the secant of latitude, which, at values approaching 90°, is increasing rapidly (e.g. sec 86°00 = 14.3356, sec 86°01' = 14.3955). This means that a small error in latitude will result in a large error in the calculation of change of longitude. This would give an apparent large divergence between the IRS positions in terms of the longitude calculated, although in fact the actual difference in position would be small.

Kalman Filtering

Kalman filtering is the process used within a navigation computer to combine the short term accuracy of the IRS with the long term accuracy of the external reference. The model assesses the velocity and position errors from the IRS by comparing the IRS position with the external reference to produce its own prediction of position and velocity. Initially the IRS information will be the most accurate, but as the ramp effect of IRS errors progresses, the external reference information will become the most accurate. The weighting system applied within the model will initially favour the IRS information but as a flight progresses it will become more biased towards the external reference. Consequently the position will be most accurate after the position update on the runway threshold but will gradually decay to the accuracy of the external reference. The position information will again improve when the aircraft is on final approach using a precision system (ILS or MLS). The more complex the model used (i.e. the more factors are included) the better will be the quality of the system position and velocity.

DME - IRS Accuracy

The position accuracy of the IRS continually degrades throughout the flight, although the heading and ground speed maintain a high degree of accuracy. The measurement of position is subject to random errors which are dependent on the range and the cut of the position lines. The second problem is solved by the computer selecting DMEs positioned so that a good cut will be obtained. Slant range error is compensated for in the calculation, but the DME error is constant at +/-0.25 NM +/-1.25% of range, so at 100 NM the error will a maximum of 1.5 NM. At the start of a flight this error will be large compared with the IRS error, but as the flight progresses the IRS is degrading at around 1 NM/h. After several hours, since the DME error is constant, the DME fixing will be significantly more accurate than the IRS.

Questions

1. **The accuracy required of a precision area navigation system is:**

   a. 0.25 NM
   b. 2 NM
   c. 1 NM
   d. 0.5 NM

2. **A basic 2D RNAV system will determine tracking information from:**

   a. twin DME
   b. VOR/DME
   c. twin VOR
   d. any of the above

3. **An aircraft using a basic 2D RNAV system is on a section between WP1 and WP2, a distance of 45 NM. The aircraft is 20 NM from the phantom station, which is 270°/30 NM from the VOR/DME. The aircraft is 15 NM from the VOR/DME. The range read-out will show:**

   a. 15 NM
   b. 20 NM
   c. 25 NM
   d. 30 NM

4. **The sequence of displays accessed on initialization is:**

   a. POS INIT, IDENT, RTE
   b. IDENT, RTE, POS INIT
   c. IDENT, POS INIT, RTE
   d. POS INIT, RTE, IDENT

5. **The IRS position can be updated:**

   a. on the ground only
   b. at designated positions en route and on the ground
   c. on the ground and overhead VOR/DME
   d. at selected waypoints and on the ground

6. **Refer to Appendix A. What are the correct selections to insert the most accurate position into the IRS?**

   a. 3R then 4R
   b. 2R then 4R
   c. 4R then 3R
   d. 3L then 4R

7. **The position used by the FMC in the B737-400 is:**

   a. an average of the two IRS positions
   b. an average of the two IRS positions, smoothed by the Kalman filtering process
   c. taken from the selected IRS, smoothed by Kalman filtering and updated to the external reference
   d. generated from the external reference and updated by the IRS as part of the Kalman filtering process

8. **The FMC position will be at its most inaccurate:**

   a. on take-off
   b. at TOC
   c. at TOD
   d. on final approach

9. **Which positions can be input to the FMC using a maximum of 5 alphanumerics?**

   a. SIDS & STARS, reporting points and airways designators
   b. Navigation facilities, reporting points and airways designators
   c. SIDS & STARS and latitude and longitude
   d. Latitude and longitude, reporting points and airways designators

10. **The FMC navigational database can be accessed by the pilots:**

   a. to update the database
   b. to read information only
   c. to change information between the 28 day updates
   d. to change the information to meet the sector requirements

11. **Above latitudes of 84° a twin FMS/triple IRS system will go to de-coupled operations. The reason for this is:**

   a. to prevent error messages as the IRS longitudes show large differences
   b. to ease the pilot's workload
   c. to improve the system accuracy
   d. because the magnetic variation changes rapidly in high latitudes

12. **The maximum range at which VOR bearing information will be used by the B737-400 FMC for fixing is:**

   a. 10 NM
   b. 25 NM
   c. 50 NM
   d. 60 NM

13. **Concerning FMC operation, which of the following is true:**

   a. the FMC combines the long term accuracy of the IRS with the short term accuracy of the external reference
   b. the FMC combines the long term accuracy of the IRS with the long term accuracy of the external reference
   c. the FMC combines the short term accuracy of the IRS with the short term accuracy of the external reference
   d. the FMC combines the short term accuracy of the IRS with the long term accuracy of the external reference

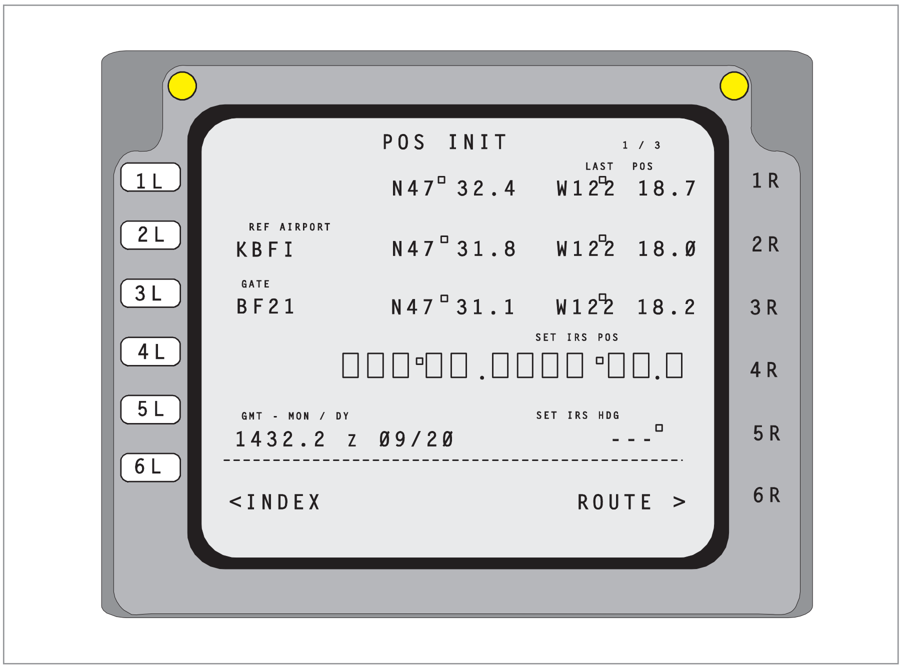
14. The correct format for the input of position 50N 00527E to the CDU is:

a. 5000.0N00527.0E
b. N50E00527
c. N5000.0E00527.0
d. N5000E00527

15. The period of validity of the navigational database is:

a. 28 days
b. 1 month
c. determined by the national authority and may be from 28 days to 91 days
d. 91 days

Appendix A



Answers

1	2	3	4	5	6	7	8	9	10	11	12
c	b	b	c	a	a	c	c	b	b	a	b

13	14	15
d	c	a

Chapter

17

Electronic Flight Information System (EFIS)

Introduction

(EASA CS-25) AMJ 25-11, contains the advisory material for manufacturers to observe when designing electronic horizontal situation indicator (EHSI) displays. It specifies the colour coding to be used, and the requirement on manufacturers to ensure there can be no confusion between colours or symbols. It also defines the probabilities that essential information (e.g. attitude, altitude, heading etc.) will not be lost or inaccurately displayed.

Detailed knowledge of the EASA CS-25 specifications is not required for the examination. Such knowledge as is needed has been reproduced in this chapter.

EHSI Controller

The EHSI displays navigational information, radar information and TCAS information. For the Radio Navigation examination knowledge of, and the ability to interpret, the navigational information is essential.

The inputs to the EHSI are from:

- IRS
- FMC
- VOR, DME, ILS, and ADF
- TCAS
- AWR

The information from all of the inputs is fed to the port and starboard EHSI, through the respective symbol generators, which are the heart of the EFIS. They process the various inputs to generate the correct symbology for the EHSI.

The EHSI controller has a function switch to select the mode of the displays, a range selection switch and 6 switches to control the display of data.

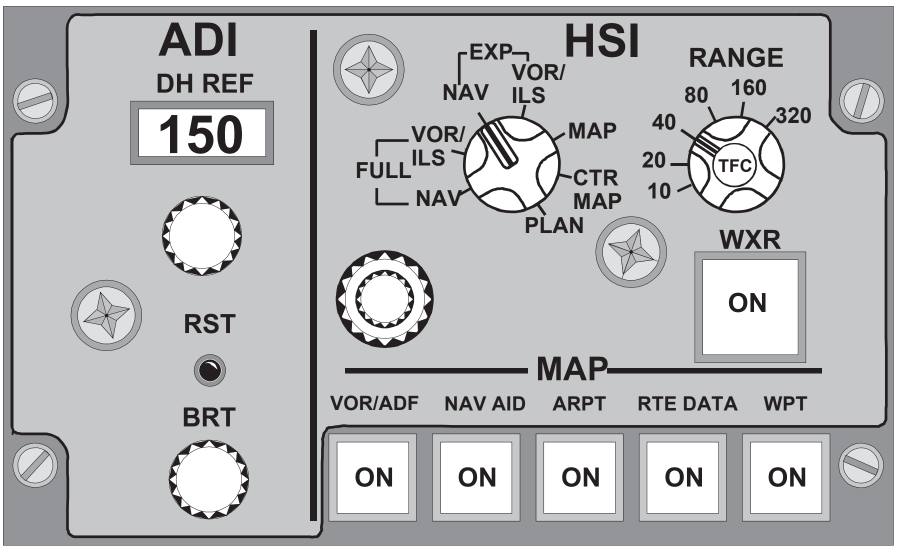


Figure 17.1

The display modes available are:

- Full (or full rose) VOR/ILS.
- Expanded VOR/ILS.
- MAP.
- PLAN.

Weather radar and TCAS information can only be displayed on the expanded VOR/ILS and MAP displays. The selectable map background options are enabled in the Map and Plan modes.

The information available for display is:

- Tuned VOR/ADF radials (VOR/ADF).
- Navigation Aids (NAV AID).
- Airports (ARPT).
- Route Data (RTE DATA).
- Waypoints (WPT).
- Weather (WXR).

The traffic switch in the centre of the range selection knob when pressed will either:

- Display TCAS information, if not already displayed.
- Remove TCAS information from the display.
- When TCAS FAIL is displayed; remove the message.

With the exception of the PLAN mode which is orientated to true north, all the displays are orientated to aircraft heading which may be either magnetic or true. Range arcs (white) are displayed in the expanded VOR and ILS modes when the WXR switch is on, and in the MAP mode at all times.

Display Modes

Expanded VOR Mode

The expanded VOR mode displays VOR information with a VOR selected and either a manual or database generated input of track.

Figure 17.2 Expanded VOR mode

The display shows that VOR2 is in use on a frequency of 116.80 MHz, the aircraft is outbound from the beacon at a range of 13.3 NM (DME) and is 7.5° right of the required track (165°(M)). The heading is 130°(M) and the present track 133°(M). The pilot has selected the heading bug to 104°(M). WXR is selected and the radar is in WX+T mode with 12° uptilt and the display is showing a contouring cloud centred on 105°(M) between 8 and 17 NM. The selected scale is 20 NM and the wind is 126°(M)/20 kt.

Full Rose VOR Mode

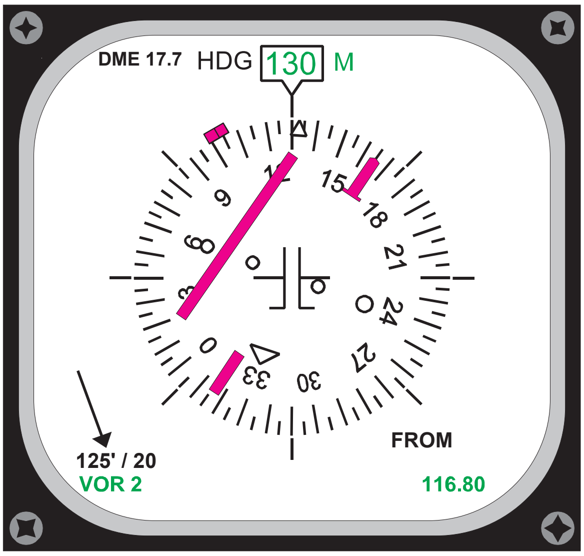


Figure 17.3 Full rose VOR mode

The full rose VOR mode is showing the same information as *Figure 17.4*, with some differences in symbology and the TO/FROM indication is a pointer that will appear either above or below the lateral deviation scale.

Expanded ILS Mode

Figure 17.4 Expanded ILS mode

The expanded ILS mode shows the appropriate ILS information when an ILS localizer frequency is selected. The glide slope indications are suppressed when the aircraft track is more than 90° removed from the ILS localizer course.

Full Rose ILS Mode

Figure 17.5 Full rose ILS mode

The full rose ILS mode shows the same information as the expanded ILS mode and has the same differences from the expanded ILS mode as noted for the VOR modes, except that the localizer deviation scale is doubled.

Map Mode

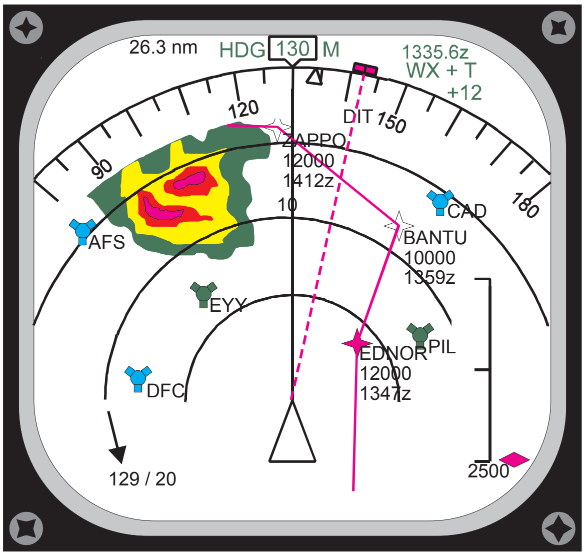


Figure 17.6 Map mode

The map mode shows the navigational information selected on the control panel and is heading orientated.

Plan Mode

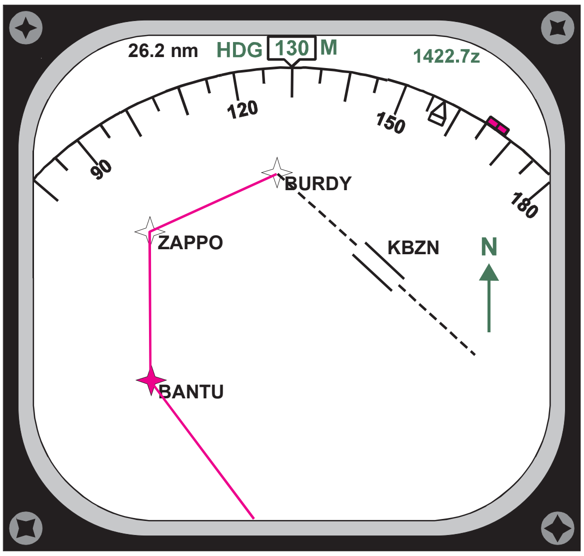


Figure 17.7 Plan mode

The plan mode is orientated to true north and the information displayed at the top of the screen is the same as in the map mode. The plan mode allows the pilot to review the planned route using the FMC/CDU LEGS page. The display will be centred using this page.

EHSI Colour Coding

The colour coding used on the EHSI is to the ICAO standard, which is also the standard adopted by EASA. The EASA CS-25 recommended colour presentation is:

Display features should be colour coded as follows:

Warnings	Red (R)
Flight envelopes and system limits	Red
Cautions, abnormal sources	Amber/Yellow (A)
Earth	Tan/Brown
Engaged modes	Green (G)
Sky	Cyan/Blue (C)
ILS deviation pointer	Magenta (M)
Flight director bar	Magenta/Green

Specified display features should be allocated colours from one of the following colour sets:

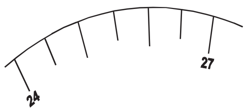
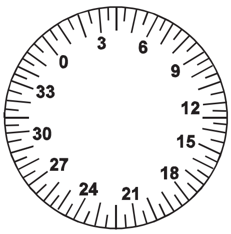
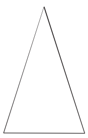
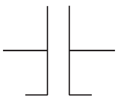
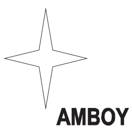
	Colour Set 1
Fixed reference symbols	White (W)
Current data, values	White
Armed modes	White
Selected data, values	Green
Selected heading	Magenta*
Active route/flight plan	Magenta
* Magenta is intended to be associated with those analogue parameters that constitute 'fly to' or 'keep centred' type information	

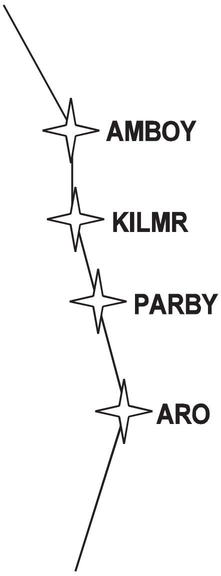
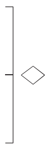
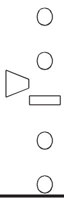
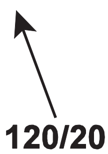
Precipitation and turbulence areas should be coded as follows:

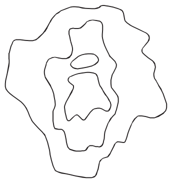
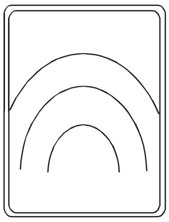
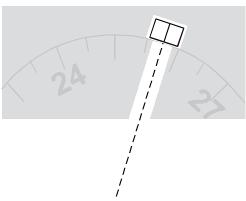
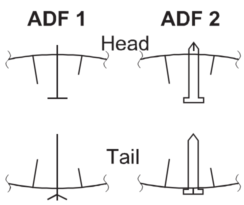
Precipitation	0 - 1	mm/h	Black
	1 - 4	mm/h	Green
	4 - 12	mm/h	Amber/Yellow
	12 - 50	mm/h	Red
	Above 50	mm/h	Magenta
Turbulence			White or Magenta

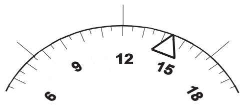
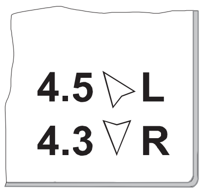
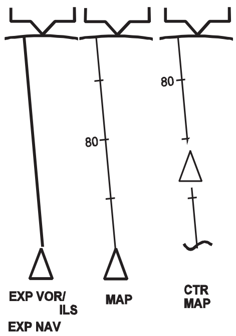
EHSI Symbology

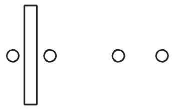
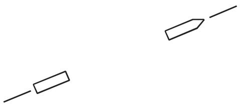
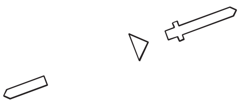
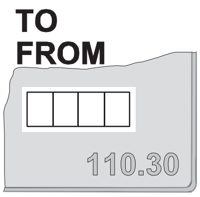
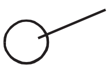
The symbology used in the B737-800 is depicted in the following table, which should be used in conjunction with the displays shown in *Figures* at *17.2* to *17.7.* Detailed knowledge of these symbols is not required for the EASA ATPL examinations.

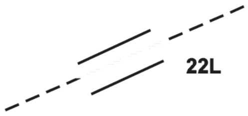
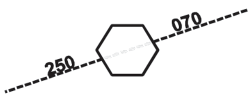
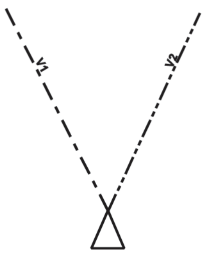
Symbol	Name	Applicable Modes	Remarks
200 NM or DME 124	Distance Display (W)	ALL	Distance is displayed to next FMC Waypoint (NM) or tuned Navaid (DME). Below 100 NM tenths of a NM will be displayed
HDG 263 M	HEADING Orientation (G) Indicator (W) Reference (G)	ALL	Indicates number under pointer is a heading - box indicates actual heading. Referenced to Magnetic (M) or true (TRU) North.
0835.4z	ETA Display (W)	PLAN, MAP	Indicates FMC computed ETA for the active waypoint.
	Expanded Compass Rose (W)	PLAN, MAP VOR, ILS	Compass Data is provided by the selected IRS (360° available but approximately 70° are displayed
	Full Compass Rose (W)	Full VOR, Full ILS	Compass Data is provided by the selected IRS.
	Aeroplane Symbol (W)	EXP VOR/ILS, MAP, PLAN	Represents the aeroplane and indicates its position at the apex of the triangle.
	Aeroplane Symbol (W)	Full VOR/ILS	Represents the aeroplane and indicates its position at the centre of the symbol.
	Waypoint Active (M) Downpath(W)	MAP, PLAN	Active - Represents the waypoint the aircraft is currently navigating to. Downpath - Represents a navigation point making up the selected active route.

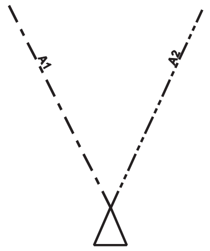
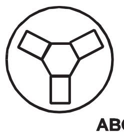
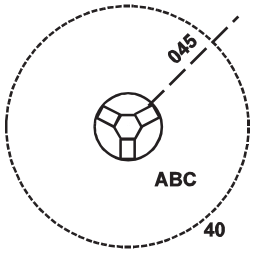
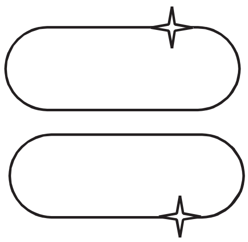
	Trend Vector	MAP	Predicts aeroplane directional trend at the end of 30, 60 and 90 second intervals. Based on bank angle and ground speed. Three segments are displayed when selected range scale is greater than 20 NM, two on the 20 NM and one segment when on the 10 NM scale.
	Active Route (M) Active Route Mods (W) Inactive Route (C)	MAP, PLAN	The active route is displayed with continuous lines (M) between waypoints. Active route modifications are displayed with short dashes (W) between waypoints. When a change is activated in the FMC, the short dashes are replaced by a continuous line. Inactive routes are displayed with long dashes (C) between waypoints.
	Vertical Pointer (M) and Deviation Scale (W)	MAP	Displays vertical deviation from selected vertical profile (pointer) in MAP mode during descent only. Scale indicates +/- 400 ft deviation.
	Glide slope Pointer (M) and Deviation Scale (W)	ILS	Displays glide slope position and deviation in ILS mode.
	Wind Speed and Direction (W)	MAP, VOR, ILS	Indicates wind speed in knots and wind direction with respect to the map display orientation and compass reference.
	North Pointer (G)	PLAN	Indicates map background is orientated and referenced to true north.

○ T / D	Altitude Profile Point and Identifier(G)	MAP	Represents an FMC calculated point and is labelled on the flight plan path as" T/C" (top of climb), "T/D" (top of descent), "E/D" (end of descent) and "S/C" (step climb).
	Weather Radar Returns Mapping Radar Returns (both G,A,R,M)	EXP VOR/ILS, MAP	Multicoloured returns are presented when either "WXR ON" switch is pushed. Most intense regions are displayed in Red, lesser Amber lowest intensity Green. Areas of turbulence are displayed in magenta
	Range Arcs (W)	EXP VOR, EXP ILS, MAP	Range Arcs are displayed in the expanded rose VOR/ILS modes when the Weather Radar Switch is ON. Range arcs are displayed in the MAP mode with or without the WXR Switch ON.
	Selected Heading Bug (M) and Reference Line	ALL	Indicates the heading selected on the MCP. A dashed line extends from the marker to the aeroplane symbol (except for PLAN mode) for ease in tracking the marker when it is out of view.
	ADF Bearing Pointers	ALL	Indicates relative bearing to tuned ADF station as received from the respective ADF radio.

	VOR / ILS Frequency Display (G)	VOR, ILS	Displays frequency of manually tuned navaid. The word 'AUTO' is displayed in place of the frequency if the VHF Nav radio is in the auto tune mode
	Drift Angle Pointer (W)	FULL VOR/ILS	Indicates aeroplane's present track. Replaces track line when a Full Rose mode is selected.
	Altitude Range Arc (G)	MAP	The intersection of the arc with the track line is the predicted point where the MCP altitude will be reached. The prediction is based on present ground speed and aeroplane vertical speed.
	Position Difference Display (W)	MAP	**NUMBERS** - Indicate the Position Difference in NM between the FMC's present position and the L IRS and R IRS present positions respectively. **ARROWS** - Rotate through 360° to indicate the relative bearing to the associated IRS present position. **L or R** - Indicates which IRS present position the displayed Position Difference corresponds to. Displayed when the Position Difference of the L IRS and/or R IRS exceeds the Position Difference limits detected by the FMC or EFIS Symbol generator.
	Present Track Line (W) and Range Scale (W)	EXP VOR, EXP ILS, MAP	Displays present ground track based on aeroplane heading and wind. Range numeric values are one-half the actual selected range. With heading-up orientation, the track line will be rotated left or right at an angle equal to the drift angle.

	Lateral Deviation Indicator Bar (M) and Deviation Scale (W)	VOR, ILS	Displays ILS or VOR course deviation ILS 1 dot ≈ 1° Normal Scale ILS 1 dot ≈ 1/2° Expanded Scale VOR 1 dot ≈ 5°
	Selected Course Pointer (W) and Line (M)	EXP ILS, EXP VOR	Points to selected course as set by the respective MCP course selector (VOR/ILS)
	Selected Course Pointer (W) To / From Pointer (W)	FULL VOR, FULL ILS	Points to selected course as set by the respective MCP course selector (VOR/ILS) TO/FROM symbol is displayed when VOR navigation is being used.
	To/From Annunciation (W)	VOR	Operative in VOR Mode only. Indicates whether or not the selected course, if intercepted directly, and tracked, would take the aircraft TO or FROM the station.
 ABCDE	Off-route Waypoint (C)	MAP, PLAN	When the WPT switch is ON, FMC database waypoints not used in the selected flight plan route are displayed. Displayed only for HSI ranges of 10, 20, or 40 NM.
 KXYZ	Airport (C)	MAP, PLAN	**ARPT switch - OFF** Only origin and destination are displayed. **ARPT switch - ON** All FMC database airports within the MAP area are displayed.
 KABC 22L	Airport Identifier and Runway (W)	MAP, PLAN	Available when the EHSI display range is 80, 160, or 320 NM. Displayed if the airport has been selected as the origin or destination airport with a specific runway selected.

	Airport and Runway (W)	MAP, PLAN	Available when the EHSI display range is 10, 20, or 40 NM. Displayed if the airport has been selected as the origin or destination airport with a specific runway selected. Runway symbol is scaled to represent the length of the selected runway. The dashed centre lines extend outward 14.2 NM from the runway thresholds.
O T/C O S/C O T/D O E/D O	Vertical Profile Points (G) Identifiers (G)	MAP, PLAN	Represents an FMC computed vertical profile point in the active flight plan as T/C (top-of-climb), T/D (top-of-descent), S/C (step-climb), and E/D (end-of-descent). A deceleration segment point has no identifier.
	VOR (C, G) DME/TACAN (C, G) VORTAC (C, G)	MAP, PLAN	**NAV AID switch - OFF** Tuned Navaids (excluding NDBs) are displayed in green. **NAV AID switch - ON** All appropriate navaids in the FMC database and within the MAP area are displayed when the range is 10, 20, or 40 NM. Only high altitude navaids are displayed when selected range is 80, 160, or 320 NM. Nav aids not being used are displayed in Cyan (blue)
	Manually Tuned VOR Radials (G)	MAP, PLAN	When a VOR navaid is manually tuned, the associated MCP selected course and its reciprocal are displayed.
	VOR Radials (G)	MAP	The VOR/ADF switch on the EFIS control panel must be ON and a valid VOR signal must be received.

	ADF Bearings (G)	MAP	The VOR/ADF switch on the EFIS control panel must be ON and a valid ADF signal must be received. Displays relative bearing to the tuned ADF station(s).
	Selected Fix Circle (G) Fix Symbol and Identifier (C or G)	MAP, PLAN	Depicts the selected reference point as entered on the FMC/CDU FIX INFO page. Can appear with other special map symbols (e.g. VOR, VORTAC, airport or waypoint etc.) if stored in the FMC data base.
	Selected Fix Radial (G) Selected Fix Circle (G)	MAP, PLAN	A fix reference radial is displayed for each downtrack bearing entered on the FMC / CDU FIX INFO page. A DME reference circle is displaye for each distance entered on the FMC /d CDU FIX INFO page.
	Holding Pattern Active (M) Modification (W) Inactive (C)	MAP, PLAN	Appears as a fixed size holding pattern if selected range is greater than 80 NM. A scaled representation of the holding pattern is displayed when the selected range is 80 NM or less **and** the aeroplane is within 3 min. of the holding fix.

Questions

1. Refer to appendix A. Which display shows the expanded ILS mode?

a. C
b. B
c. D
d. E

2. Refer to appendix A. Which mode is display C?

a. Plan
b. Map
c. Expanded ILS
d. Expanded VOR

3. Refer to appendix A. Which mode is display F?

a. Full ILS
b. Full VOR
c. Plan
d. Full map

4. On display E, what is the approximate deviation from the required track?

a. 3 NM
b. 8°
c. 3°
d. 1.5°

5. On display E, what is the aircraft's track?

a. 165°
b. 104°
c. 130°
d. 133°

6. The horizontal deviation on the expanded ILS display represented by one dot is approximately:

a. 1°
b. 2°
c. 0.5°
d. 5°

7. On which displays will the range markers be displayed regardless of the weather selection?

a. MAP
b. EXP ILS/VOR, MAP
c. MAP, FULL ILS
d. PLAN, EXP ILS/VOR, MAP

17 Questions

8. The heading inputs to the EHSI are from:

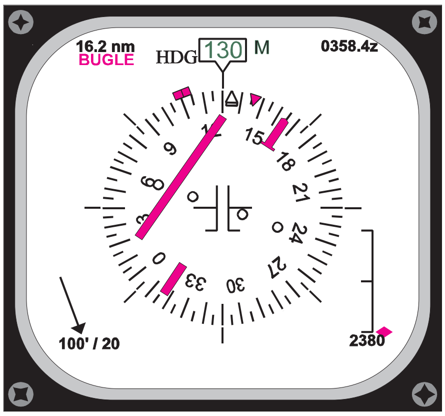
a. the IRS
b. the FMC
c. the IRS through the symbol generator
d. the FMC through the symbol generator

9. Refer to Appendix A. The track direction from BANTU to ZAPPO on display F is:

a. 360°(M)
b. 130°(M)
c. 360°(T)
d. 130°(T)

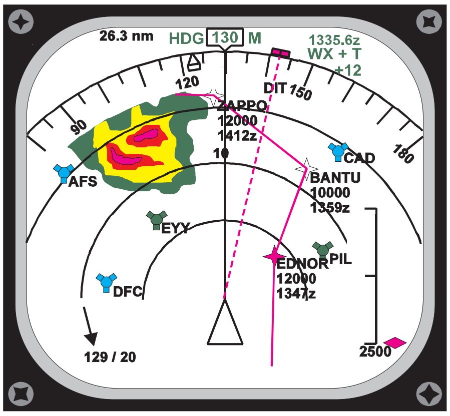
Appendix A

A



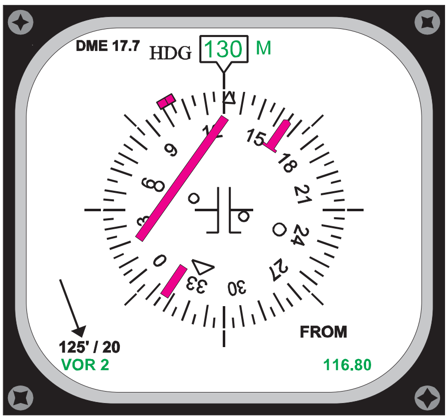
B

C

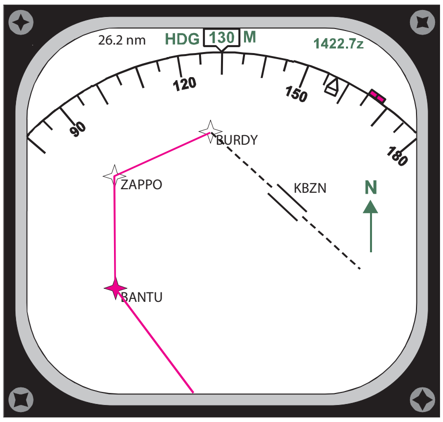


D

E



F



Answers

1	2	3	4	5	6	7	8	9
c	b	c	b	d	c	a	c	c

Chapter

18

Global Navigation Satellite System (GNSS)

Introduction

The development of space based navigation systems commenced in the 1950s with the establishment of the USA Transit system. The current generation began development in the 1970's and the next generation is already under development. It is intended that GNSS will eventually replace all terrestrial radio navigation facilities. However, despite USA assertions that this is imminent, it is unlikely to be achieved in the foreseeable future.

The current systems have brought a new dimension of accuracy to navigation systems with precision measured in metres, and where special differential techniques are used the potential is for accuracies substantially less than one metre.

At present there are two operational global navigation satellite systems (GNSS), enhancements of the existing systems under development and a planned European system. These systems are:

The NAVSTAR Global Positioning System (GPS) operated by the USA.

The Global Orbiting Navigation Satellite System (GLONASS) operated by Russia. After serious problems following the disintegration of the USSR in 1989/1990 the system is now fully operational.

Local area differential GNSS (LADGNSS) to provide improved accuracy and integrity to aircraft making airfield approaches.

Wide area differential GNSS (WADGNSS) of which the European Geostationary Navigation Overlay System (EGNOS) is the European contribution to a global augmentation system providing integrity and improved accuracy.

The European **Galileo**, which is under development and intended to provide a limited service from 2014/2015 and be fully operational by 2020. The principal reason the Europeans are developing their own system is one of internal security, since access to the full GPS or GLONASS facilities is outside European control. China is also developing its own system known as Compass or Beidou 2. The system is expected to be fully operational by 2020.

This chapter will study GPS, LADGNSS and EGNOS in detail, but it should be borne in mind that GLONASS and Galileo operate on similar principles to GPS, although there are differences in implementation.

Satellite Orbits

Johannes Kepler's laws quantified the mathematics of planetry orbits which apply equally to the orbits of satellites:

Using these laws, and given a starting point, the satellites - space vehicles (SVs) calculate their positions at all points in their orbits. The SVs' orbital position is known as **ephemeris.**

Position Reference System

GNSS use an earth referenced three dimensional Cartesian coordinate system with its origin at the centre of the earth.

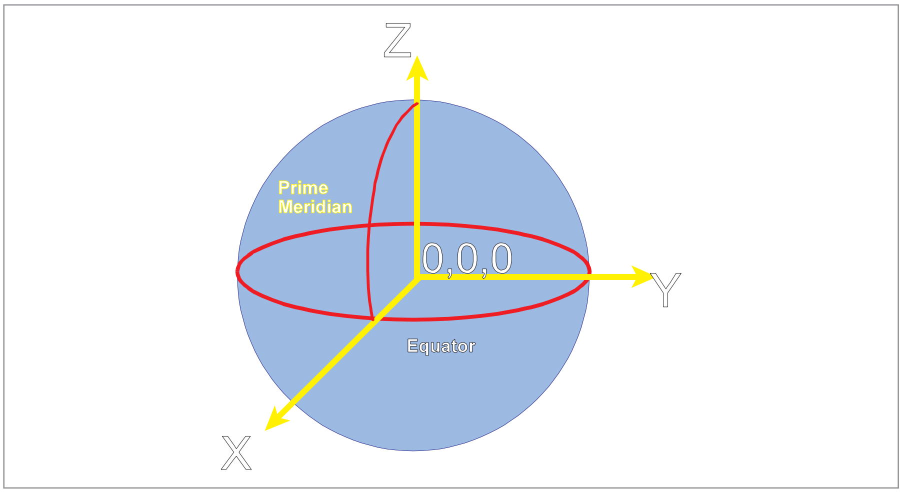


Figure 18.1

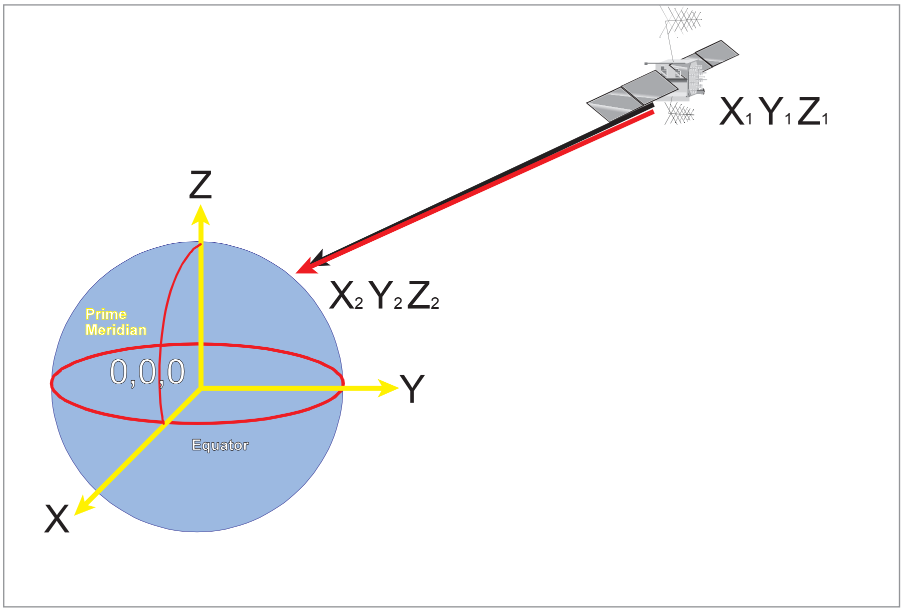


Figure 18.2

Because the systems are global, a common model of the earth was required. The World Geodetic Survey of 1984 (WGS84) was selected as the appropriate model for GPS and all GPS terrestrial positions are defined on this model and referenced to the Cartesian coordinate system. Where other models are required, for instance for the UK's Ordnance Survey maps, a mathematical transformation is available between the models (note this is incorporated as a feature of GPS receivers available in the UK). Galileo uses the European Terrestrial Reference System 1989 (ETRS89) and the Russian model for GLONASS is known as Parameters of the Earth 1990 (PZ90). WGS84 is the ICAO standard for aeronautical positions, however, since all these systems are mathematical models, transposition from ETRS89 to WGS84, for example, is a relatively simple mathematical process. Mathematically all these models are regular shapes, known as ellipsoids.

The ellipsoids cannot be a perfect representation, nor can they represent geographical features, e.g. mountains and land depressions. The distance of mean sea level from the centre of the earth depends on gravitational forces which vary both locally and globally. Hence mean sea level will not necessarily coincide with the surface of the ellipsoid. The maximum variation between mean sea level and the surface of the ellipsoid for WGS84 is approximately 50 m. Hence the vertical information provided by any system referenced to this model cannot be used in isolation for vertical positioning, except when in medium/high level cruise with **all** aircraft using the GNSS reference and in LADGNSS applications - (where the vertical error is removed).

The GPS Segments

GPS comprises three segments:

- The Space Segment
- The Control Segment and
- The User Segment

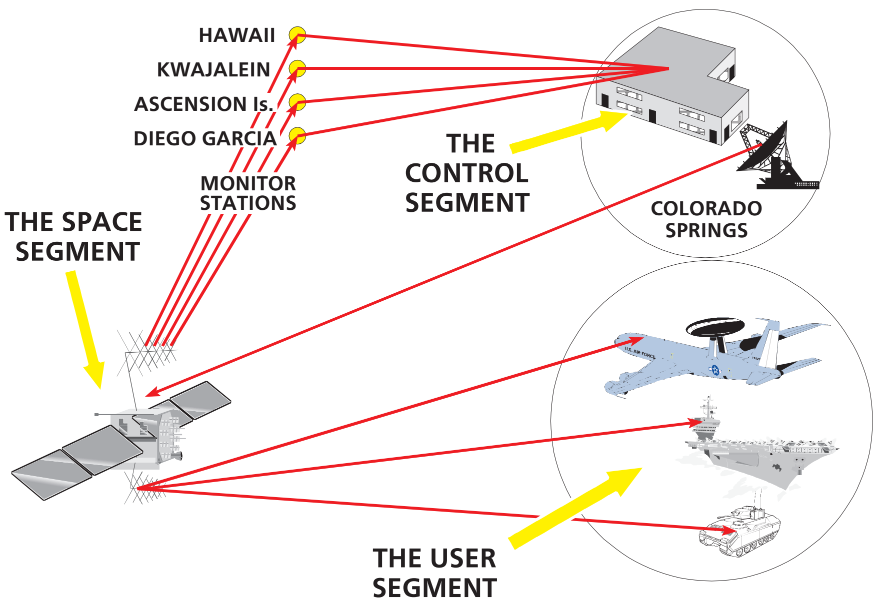


Figure 18.3 The three segments of the GPS operational control

GPS time is measured in weeks and seconds from 00:00:00 on 06 January 1980 UTC. An epoch is 1024 weeks after which the time restarts at zero. GPS time is referenced to UTC but does not run in direct synchronization, so time correlation information is included in the SV broadcast. In July 2000 the difference was about 13 seconds.

The Space Segment

The operational constellation for GPS is specified as comprising 24 SVs. (Currently the USA has 31 SVs providing a navigational service). The orbits have an average height of 10 898 NM (20 180 km) and have an orbital period of 12 hours. The orbital planes have an inclination of 55° and are equally spaced around the equator. The spacing of the SVs in their orbits is such that an observer on or close to the surface of the earth will have between five and eight SVs in view, at least 5° above the horizon. The SVs have 3 or 4 atomic clocks of caesium or rubidium standard with an accuracy of 1 nanosecond.

An SV will be **masked** (that is not selected for navigation use) if its elevation is less than 5° above the horizon.

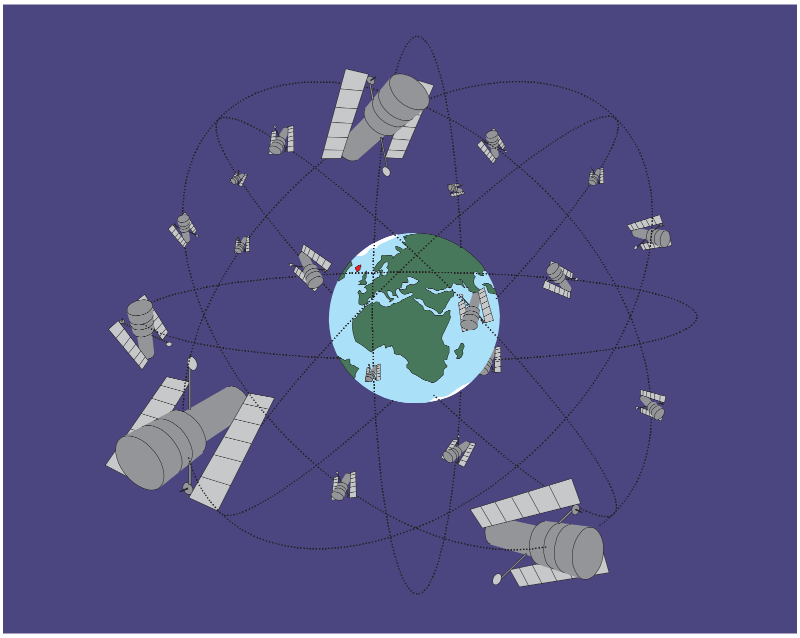


Figure 18.4 The GPS Satellite Constellation

The SVs broadcast **pseudo-random noise (PRN)** codes of one millisecond duration on two frequencies in the UHF band and a NAV and SYSTEM data message. Each SV has its own unique code.

L1 Frequency: 1575.42 MHz transmits the coarse acquisition (C/A) code repeated every millisecond with a modulation of 1.023 MHz, the precision (P) code, modulation 10.23 MHz repeats every seven days and the navigation and system data message at 50 Hz. The navigation and system data message is used by both the P and C/A codes.

L2 Frequency: 1227.6 MHz transmitting the P code. The second frequency is used to determine ionospheric delays.

L3 Frequency: 1381.05 MHz has been allocated as a second frequency for non-authorized users and its use is the same as the L2 frequency.

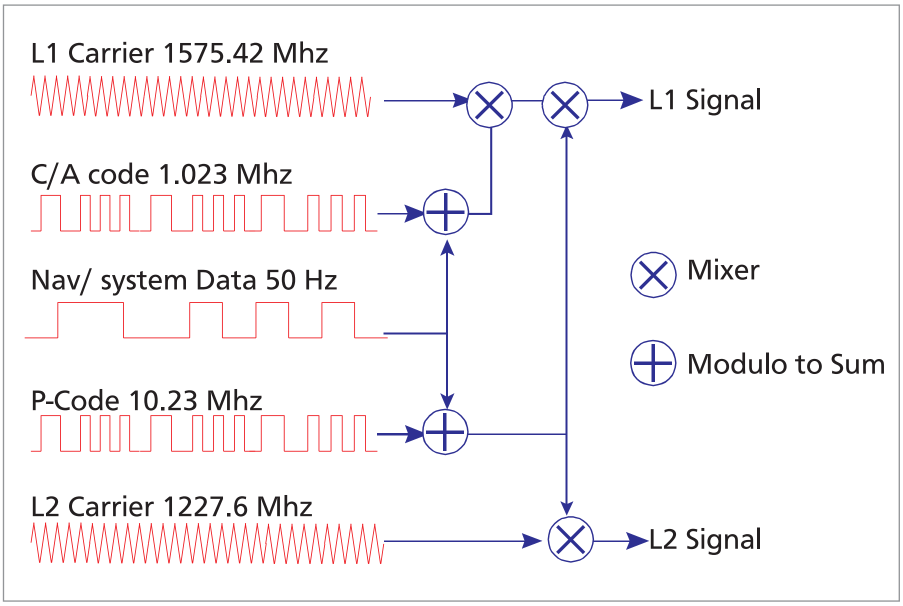


Figure 18.5

Only the C/A code is available to civilian users. The reason the use of two frequencies is important will be discussed in GNSS errors. The P code is provided for the US military and approved civilian users and foreign military users at the discretion of the US DOD. The P code is designated as the Y code when anti-spoofing measures are implemented. The Y code is encrypted and therefore only available to users with the necessary decryption algorithms.

The PRN codes provide SV identification and a timing function for the receiver to measure SV range.

The information contained in the nav and system data message is:

- SV position
- SV clock time
- SV clock error
- Information on ionospheric conditions
- Supplementary information, including the almanac (orbital parameters for the SVs), SV health (P-code only), correlation of GPS time with UTC and other command and control functions.

The two services provided are:

- The standard positioning service (SPS) using the C/A code
- The precise positioning service (PPS) using the C/A and P codes

GLONASS also has an operational constellation of 24 SVs positioned in three orbital planes inclined at 65° to the equator. The orbital height is 10 313 NM (19 099 km) giving an orbital period of 11 hours 15 minutes. As in GPS, GLONASS transmits C/A and P codes. The codes are the same for all SVs, but each SV uses different frequencies. The L1 frequency is incremental from 1602 MHz and the L2 frequency from 1246 MHz.

	NAVSTAR – USA	GLONASS – USSR	Galileo – EU
No. of SVs:	24 SVs	24 SVs	30 SVs
Orbits:	6 Orbits	3 Orbits	3 Orbits
Orbit Height:	20 180 km	19 099 km	23 222 km
	(10 898 NM)	(10 313 NM)	(12 539 NM)
Orbit Inclination:	55° to equator	65° to equator	56° to equator
Orbit Time:	11 h 56 m	11 h 15 m	14 h 8 m
Frequencies:	L1: 1575 MHz	L1: 1600 MHz	E1: 1559 - 1591 MHz
	L2: 1227 MHz	L2: 1250 MHz	E5: 1164 - 1215 MHz
			E6: 1260 - 1300 MHz
Codes:	L1: P & C/A	L1: P & C/A	
	L2: P	L2: P	
Geoid:	WGS 84	PZ 90	ETRS 89

Figure 18.6 GNSS Systems Comparison

The Control Segment

The GPS control segment comprises:

- A Master Control Station
- A Back-up Control Station
- 5 Monitoring Stations

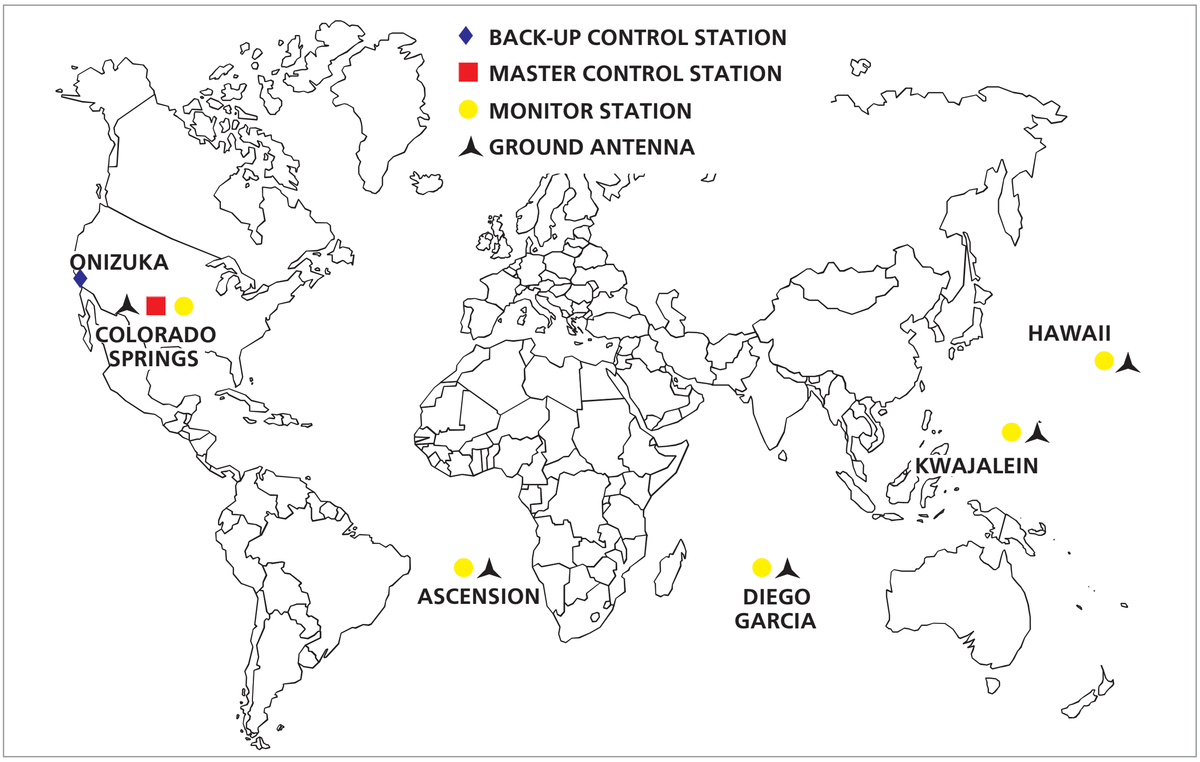


Figure 18.7 GPS Operational Control Segment

The monitoring stations check the SVs' internally computed position and clock time at least once every 12 hours. Although the calculation of position using Keplerian laws is precise, the SV orbits are affected by the gravitational influences of the sun, moon and planets and are also affected by solar radiation, so errors between the computed position and the actual position occur. When a positional error is detected by the ground station, it is sent to the SV for the SV to update its knowledge of position. Similarly if an error is detected in the SV clock time this is notified to the SV, but since the clocks cannot be adjusted, this error is included in the SV broadcast.

The User Segment

The User Segment is all the GPS receivers using the space segment to determine position on and close to the surface of the earth. These receivers may be stand-alone or be part of integrated systems.

There are several types of receiver:

Sequential receivers which use one or two channels and scan the SVs sequentially to determine the pseudo-ranges.

Multiplex receivers may be single or twin channel and are able to move quickly between SVs to determine the pseudo-ranges and hence have a faster time to first fix than the sequential receivers.

Multi-channel receivers monitor several SVs simultaneously to give instant positional information. These include 'all-in-view' receivers which monitor all the SVs in view and select the best 4 to determine position. Because of the speed of operation these are the preferred type for aviation.

Figure 18.8 GPS Receiver, Control Unit

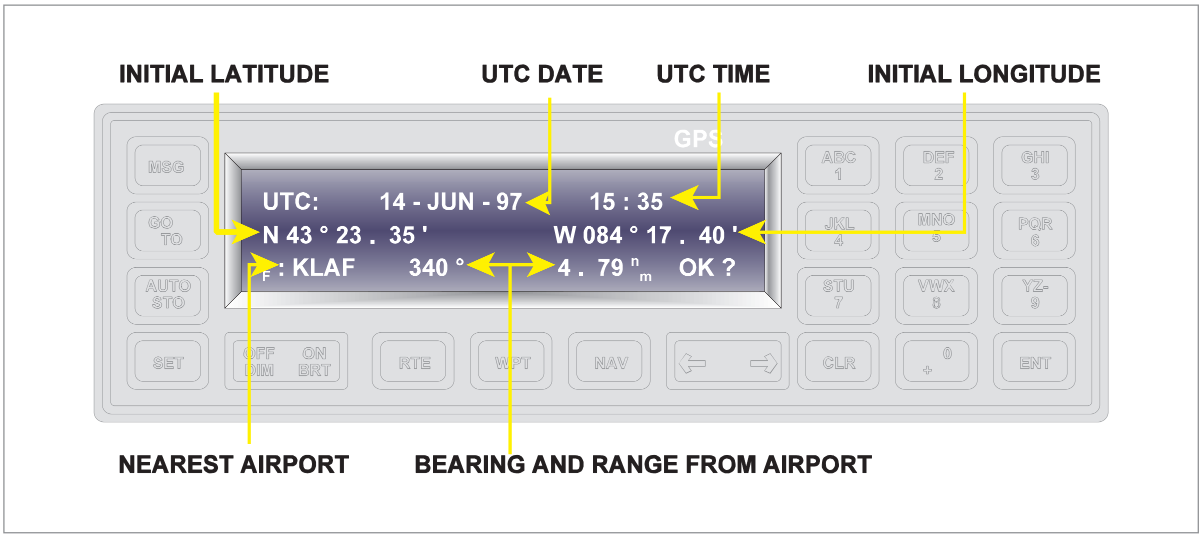


Figure 18.9 Initialization Page

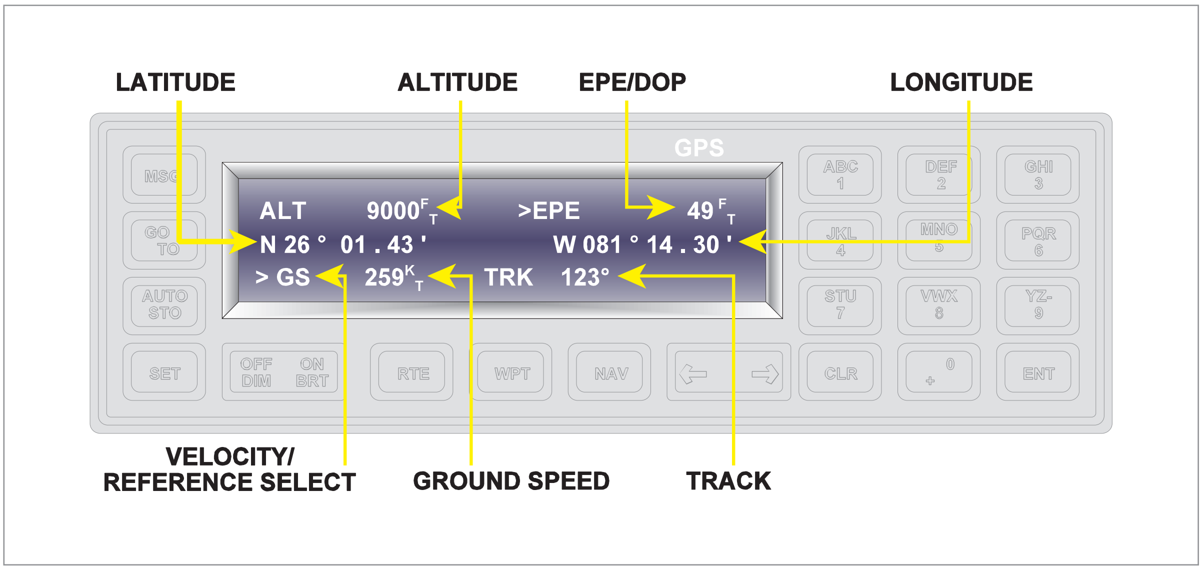


Figure 18.10 Position Page

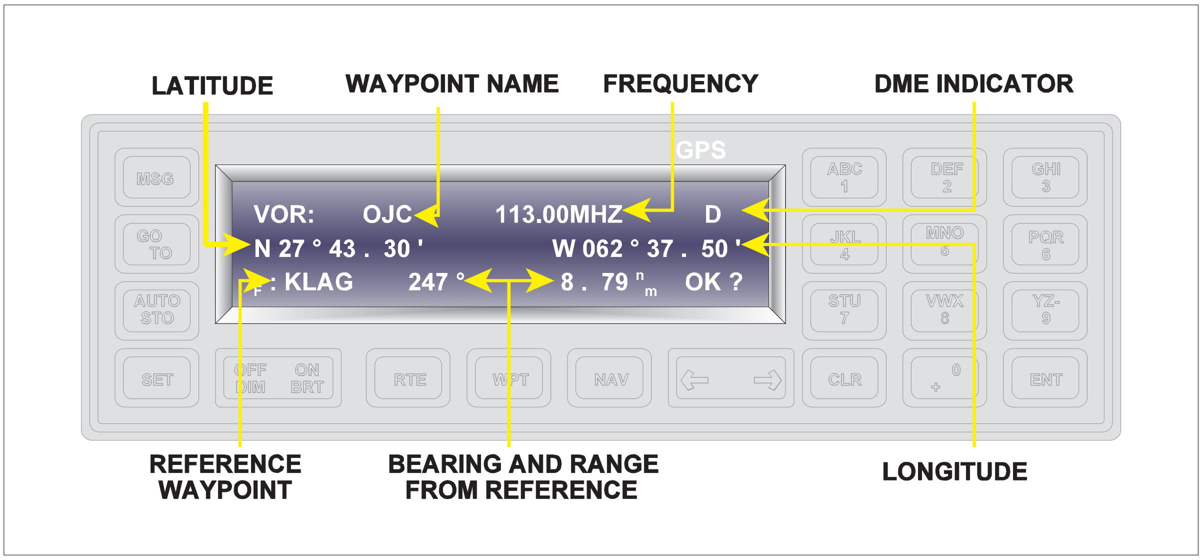


Figure 18.11 Waypoint Definitions Page

Principle Of Operation

The navigation message is contained in one frame comprising 5 sub-frames. The sub-frames each take 6 seconds to transmit, so the total frame takes 30 seconds for the receiver to receive. Frame 1 contains SV clock error, frames 2 and 3 contain the SV ephemeris data, frame 4 contains data on the ionospheric propagation model, GPS time and its correlation with UTC. The fifth frame is used to transmit current SV constellation almanac data. A series of 25 frames is required to download the whole almanac. The almanac data is usually downloaded hourly and is valid from 4 hours to several months dependent on the type of receiver.

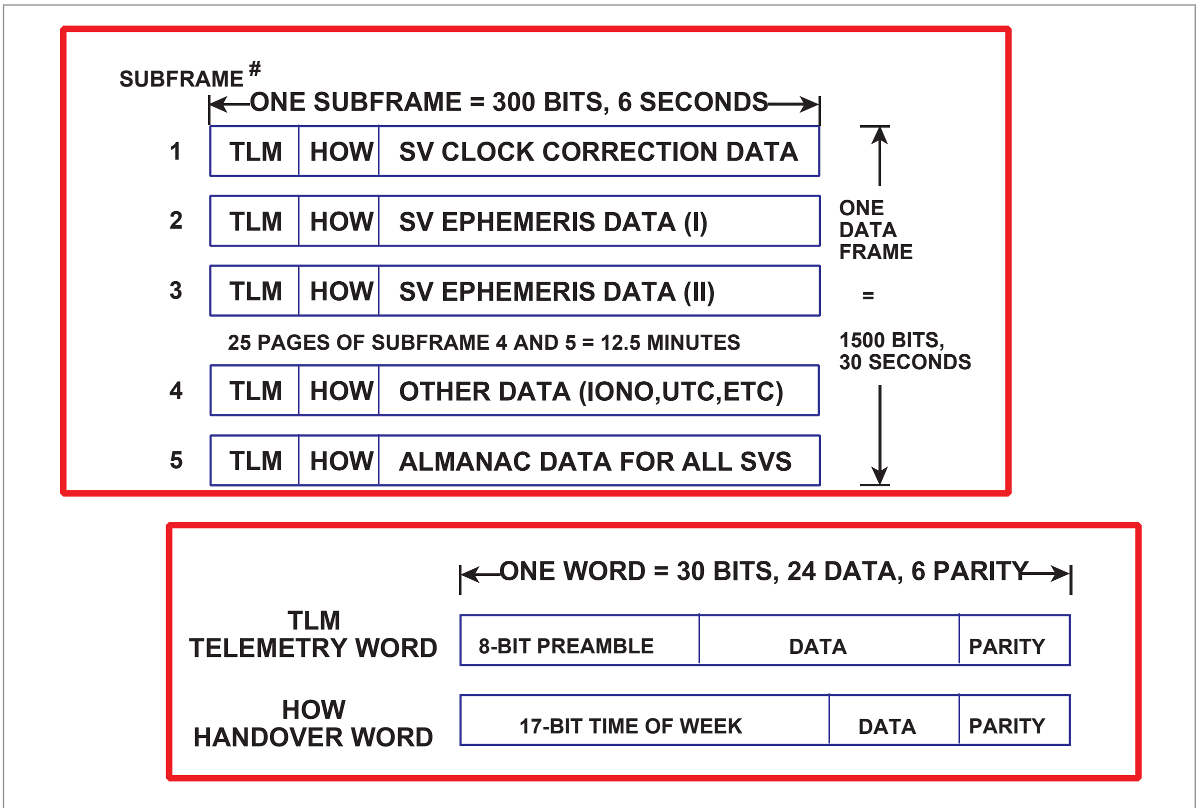


Figure 18.12 GPS Navigation Data Format

Because the orbits are mathematically defined, an almanac of their predicted positions can be and is maintained within the receivers. Thus, when the receiver is switched on, provided it knows its position and time to a reasonable degree of accuracy, it will know which SVs to expect and can commence position update immediately. If the almanac is corrupted, out of date or lost, or if receiver position or receiver clock time are significantly in error it will not find the expected SVs and will download the almanac from the constellation. The almanac data fills 25 frames so it takes 12.5 minutes to download. When the receiver position is significantly in error it will not detect the expected SVs. Having downloaded the almanac the receiver will now carry out a **skysearch**, this involves the receiver checking which SVs are above the horizon and selecting the 4 to give the most accurate fix, then commencing position fixing, this takes a least a further 2.5 minutes. Hence t**he time to first fix** will be at least 15 minutes. If there are no problems then the first fix, on initialization, will be obtained within about 30 seconds.

The GPS receiver internally generates the PRN code and compares the relative position of the two codes to determine the time interval between transmission and reception.

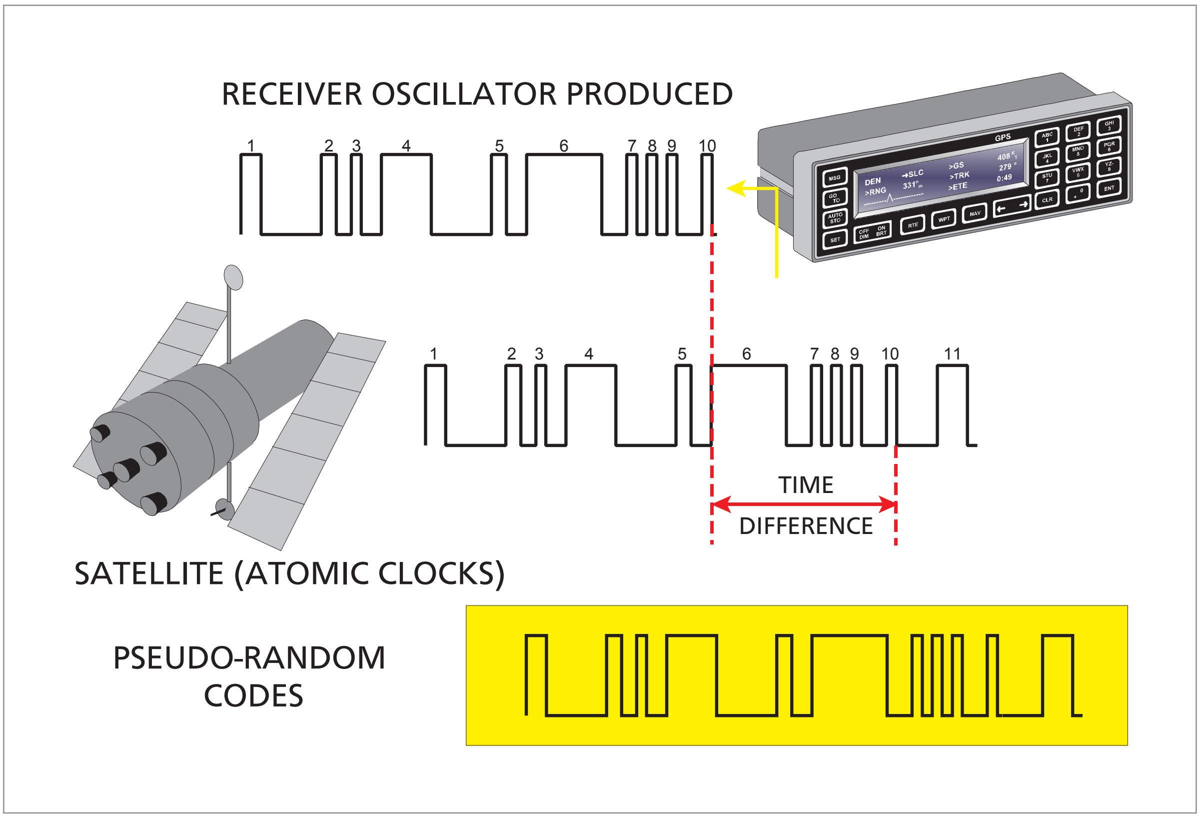


Figure 18.13 Pseudo-Random Code Time Measurement

The initial measurement of range is known as pseudo-range because it has not yet been corrected for receiver clock error.

The receiver uses four SVs and constructs a three dimensional fix using the pseudo-ranges from the 4 SVs. Each range corresponds to a position somewhere on the surface of a sphere with a radius in excess of 10 900 NM.

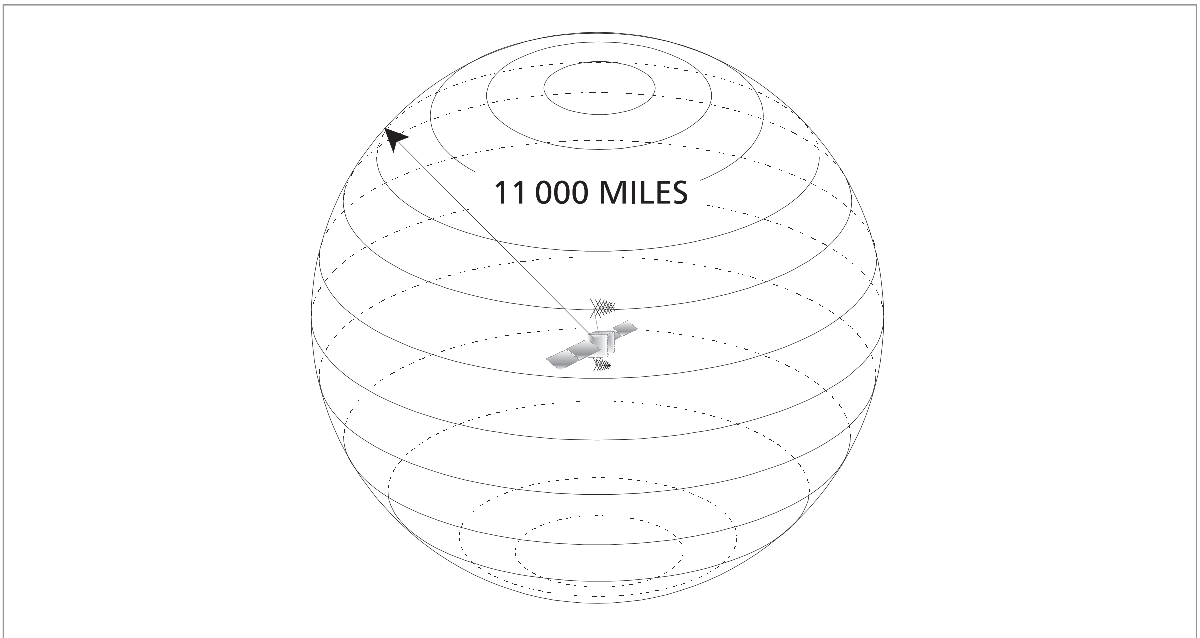


Figure 18.14

The intersection of two range spheres will give a circular position line.

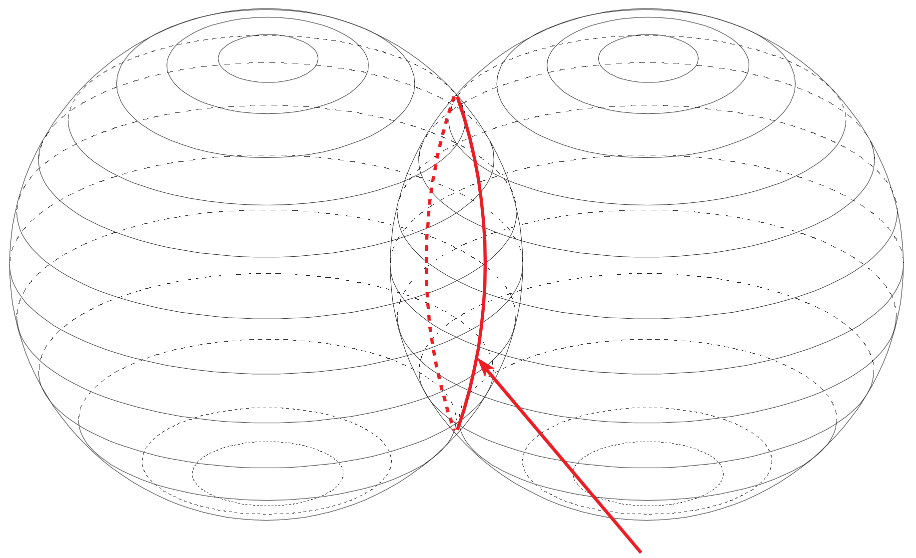


Figure 18.15

The introduction of a third range sphere will produce two positions several thousand miles apart. One position will be on or close to the surface of the earth, the other position will be out in space, so it would be possible to use just three pseudo-ranges to produce a position, by rejecting the space position.

However, a fourth range position line is needed because of the way the receiver compensates for receiver time errors. The receiver has an accurate crystal oscillator to provide time. However, the accuracy does not compare with the accuracy of the SV clocks, so there will always be an error in the time measurement, and hence in the computation of range. Furthermore the receiver clock is deliberately kept in error by a small factor to ensure that the correction process can only go in one direction. This is why the initial calculated range is known as a **pseudo-range**. As a result the position lines will not meet in a point but will form a 'cocked hat'. For example, if the receiver clock is permanently 1 millisecond fast, then the receiver will over estimate each range by about 162 NM. So when the receiver sets about calculating the correct ranges it knows that it must reduce the pseudo-ranges.

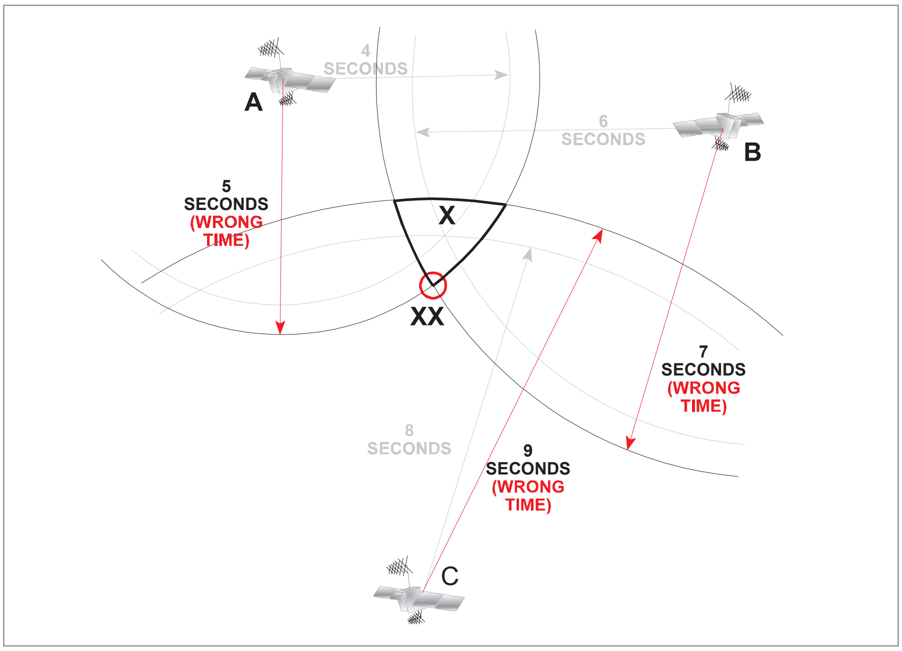


Figure 18.16

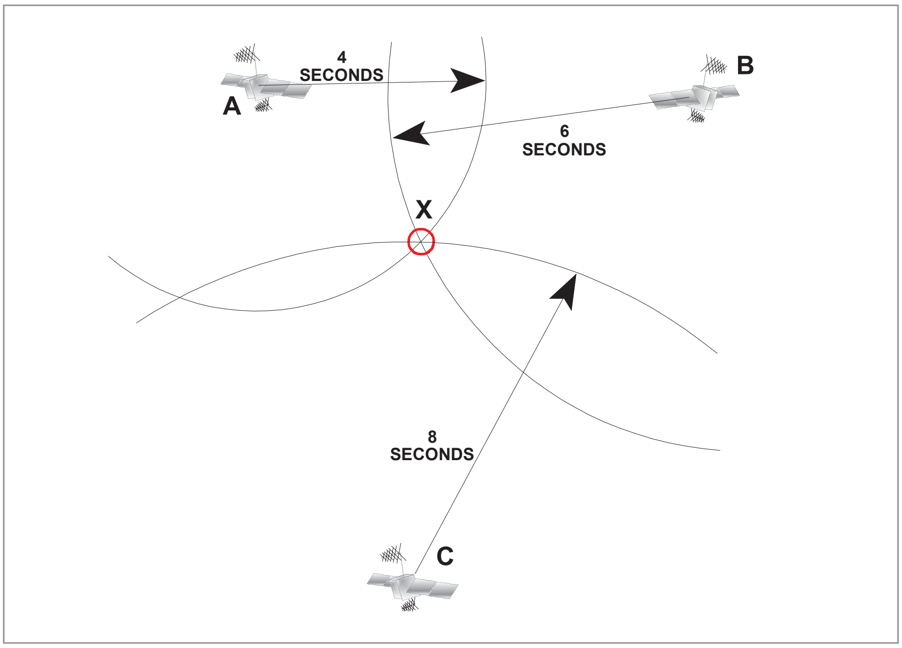


Figure 18.17

The receiver has to correct the X, Y, Z coordinates and time to produce the fix. Since it has each element provided by each SV the receiver can set up 4 linear simultaneous equations each with 4 unknown quantities (X, Y, Z, and T) which it solves by iteration to remove the receiver time error, and hence, range errors. This means that the use of 4 SVs provides a 3D fix and an accurate time reference, i.e. a 4D fix, at the receiver. The X, Y, and Z coordinates can now be transposed into latitude and longitude or any other earth reference system (e.g. the UK Ordnance Survey grid) and altitude.

Note: Some receivers can also produce a three dimensional position using three SVs with an input of altitude, the altitude simulates a fourth SV positioned at the centre of the earth. However the position produced will not be as accurate as the 4D fix.

GPS Errors

All errors are at the 95% probability level.

Ephemeris Errors

These are errors in the SVs calculation of position caused by the gravitational effects of the sun, moon, planets and solar radiation. The SV position is checked every 12 hours and, where necessary, updated. The maximum error will be 2.5 m.

SV Clock Error

As with SV ephemeris, the SV clock is checked at least every 12 hours and any error is passed to the SV to be included in the broadcast. Maximum error 1.5 m.

Ionospheric Propagation Error

The interaction of the radio energy with the ionized particles in the ionosphere causes the radio energy to be slowed down as it traverses the ionosphere, this is known as the ionospheric delay. The delay is dependent on both the level of ionization and the frequency of the radio waves. The higher the frequency is, the smaller the delay and the higher the levels of ionization, the greater the delay. The receiver contains an average model of the ionosphere which is used to make time corrections to the measured time interval. The state of the ionosphere is continuously checked at the monitoring stations and the required modifications to the model is regularly updated to the SVs and thence to the receivers. However, the propagation path from the SV to the monitoring station will be very different to that to the receiver, so this is only a partial solution.

The ionospheric delay is inversely proportional to the square of the frequencies.

As two different frequencies will experience different delays, by measuring the difference in arrival time of the two signals we can deduce the total delay experienced hence minimising the error and calculate a very accurate range.

This is the most significant of the errors in SV navigation systems.

Maximum error for single frequency operation is 5 m.

Tropospheric Propagation Error

Because of the inherent accuracy of SV navigation systems, the effect of variations in tropospheric conditions on the passage of radio waves has become significant. Variations in pressure, temperature, density and humidity affect the speed of propagation, increased density and increased absolute humidity reduce the speed of propagation. For example, a change in transit time of one nanosecond would give an error of 0.3 m. As with ionospheric propagation error this is minimized with the use of two frequencies.

Receiver Noise Error

All radio receivers generate internal noise, which in the case of GNS receivers can cause errors in measurement of the time difference. Maximum 0.3 m.

Multipath Reception

Reflections from the ground and parts of the aircraft result in multipath reception. This can be minimized by careful siting of the aerial and by internal processing techniques. Maximum 0.6 m.

Dilution of Precision (DOP)

The satellite geometry, (angle of cut between position lines), and any error in the pseudo-ranges (time synchronization) will degrade the accuracy of the calculated position.

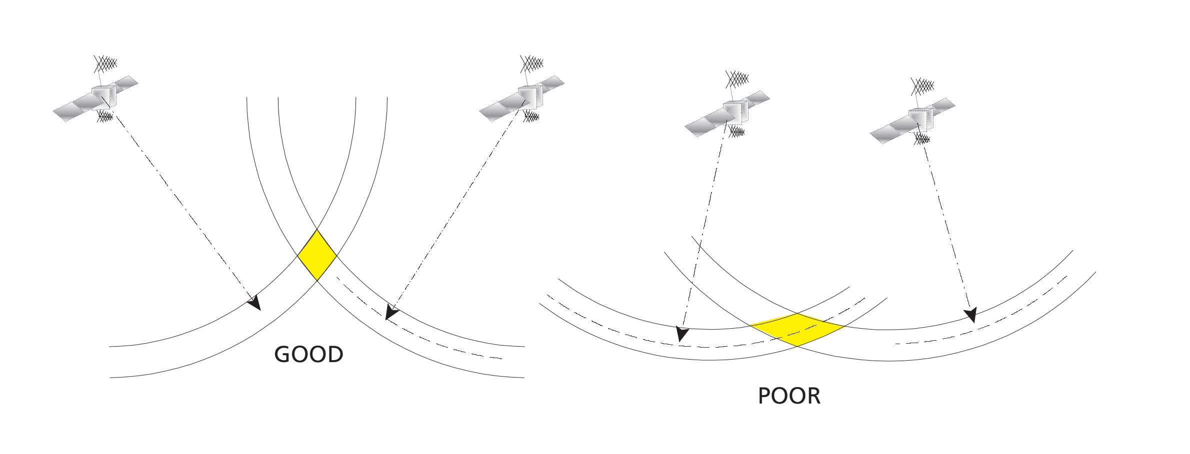


Figure 18.18 PDOP

DOP is further divided:

Horizontal dilution of precision (HDOP). This refers to errors in the X and Y coordinates.

Vertical dilution of precision (VDOP). This refers to errors in the Z coordinate.

Position dilution of precision (PDOP). This is a combination of HDOP and VDOP.

Time dilution of precision (TDOP). This refers to timing errors.

Geometric dilution of precision (GDOP). This is a combination of PDOP and TDOP.

Errors caused by PDOP are minimized by the geometry of the positioning of the SVs in their orbits and by the receivers selecting the four best SVs to determine position. The SV geometry that will provide the most accurate fixing information is one SV directly overhead the receiver and the other three SVs close to the horizon and spaced 120° apart.

Effect of Aircraft Manoeuvre

Aircraft manoeuvre may result in part of the aircraft shadowing one or more of the in-use SVs. There are two possible outcomes of this. Firstly, whilst the SV is shadowed, the signal may be lost resulting in degradation of accuracy, or the receiver may lock onto reflections from other parts of the aircraft again with a reduction in accuracy. The effect of manoeuvre can be minimized by careful positioning of the aerial on the aircraft. The optimum position for the antenna is on top of the fuselage close to the aircraft's centre of gravity.

Selective Availability (SA)

SA was introduced into GPS by the US DOD in about 1995. It deliberately degraded the accuracy of the fixing on the C/A code (i.e. for civilian users). The USA withdrew SA at 0000 on 01 May 2000, and President Clinton stated that it would never be reintroduced. (SA downgraded the accuracy of position derived from the C/A code to the order of 100 m spherical error). SA was achieved by introducing random errors in the SV clock time, known as *dithering the SV clock time*.

System Accuracy

The ICAO specification requires an accuracy (95%) of the SPS to be:

- Horizontal: ± 13 m
- Vertical: ± 22 m
- Time: 40 nanoseconds (10^{-9})

Integrity Monitoring

The ICAO specification for radio navigation systems requires a 2 second warning of failure for precision systems (e.g. ILS) and 8 second warning for non-precision systems. With 4 SVs being used to provide a 3D position, there is no means of detecting the degradation of information in any of the SV data and an operator could potentially experience errors of hundreds of miles unless he was able to cross-check the GNSS position with another system. Therefore differential systems are under development which will determine any degradation in accuracy and allow a timely warning of the failure or degradation of the information provided.

Differential GPS (DGPS)

If the SV information degrades, the GPS receiver has no means of determining the degradation. Consequentially the safety of flight may be seriously endangered. DGPS is a means of improving the accuracy of GPS by monitoring the integrity of the SV data and warning the user of any errors which occur. DGPS systems will provide warning of failure in the SV data and prevent or minimize the effect of such errors, or provide failure warning and improve the accuracy of the deduced position. There are three kinds of DGPS currently in use or under development:

- Air based augmentation systems (ABAS)
- Ground based augmentation systems (GBAS)
- Satellite based augmentation systems (SBAS)

Air Based Augmentation Systems (ABAS)

To determine, at the receiver, if any of the data from any of the SVs is in error requires the use of a fifth SV. By comparing positions generated by the combinations of the five SVs it is possible to detect errors in the data, and hence which SV is in error. The rogue SV can then be deselected. However, once the system is back to 4 SVs the facility is lost. The CAA recommend that a minimum of 6 SVs are available, so that if a SV is deselected the integrity monitoring continues to be available. The GPS term for this is “receiver autonomous integrity monitoring” (RAIM). RAIM has only limited availability at present and would require at least 30 operational SVs to achieve continuous global availability. RAIM will only provide failure warning and either prevent or minimize errors in computed position arising from erroneous SV data.

Ground Based Augmentation Systems (GBAS)

GBAS is a **local area DGPS (LADGPS)** implemented through a **local area augmentation system (LAAS).** This system is used in aviation to provide both failure warning and enhancement of the GPS receiver position by removing ephemeris and SV clock errors and minimizing ionospheric and tropospheric errors. It will not remove errors arising from receiver noise and multipath reception as these errors are particular to the receiver. It is specifically established to provide precision runway approaches.

The implementation of a LAAS requires a precisely surveyed site on the aerodrome and a means of transmitting the corrections to aircraft operating close to the aerodrome. On the site is a GPS receiver which determines the GPS position and compares it with the known position of the site. The **error in the X, Y and Z coordinates is determined** and specially formatted to be transmitted to approaching aircraft. The system will detect any errors in the SV data and either correct the error or give a failure warning indication.

The data is transmitted to aircraft via a dedicated VHF link. A pseudolite (pseudo-satellite) is also provided to give range to the runway threshold using GNSS techniques.

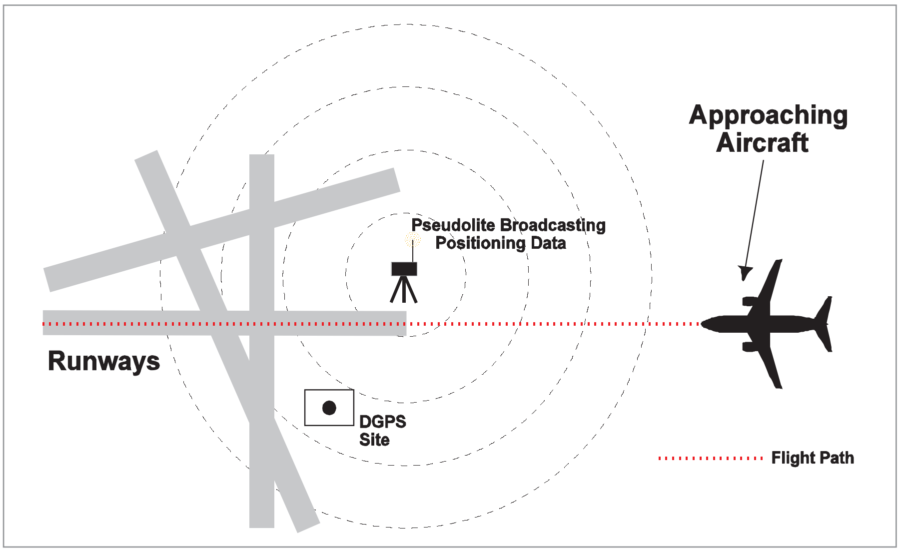


Figure 18.19 LAAS

When the aircraft is close to the DGPS site, the ionospheric and tropospheric transmission paths will be virtually identical so these errors are effectively eliminated. The LAAS has the potential to provide the necessary accuracy to achieve category IIIC type operations.

Satellite Based Augmentation Systems (SBAS)

SBAS utilize a **wide area DGPS (WADGPS)** implemented through a **wide area augmentation system (WAAS).** There are four systems currently operating, these are:

The **European Geostationary Navigation Overlay System (EGNOS),** declared operational in July 2004.

The USA **WAAS,** declared operational in July 2003.

The Japanese **Multifunctional Transport Satellite Augmentation System, (MSAS).**

The Indian **Geo and GPS Augmented Navigation (GAGAN).**

The objectives of these systems are more or less identical, to provide an integrity monitoring and position enhancement to aircraft operating over a large area. The methods of implementation differ slightly between systems, but the end result to the user will be the same (i.e. there will be full compatibility between the systems). The discussion of WADGPS will centre on EGNOS, but the same principles apply to all SBAS.

There are 3 segments making up SBAS:

The space segment which comprises the GPS and GLONASS constellations and geo-stationary SVs.

Note: Geostationary SVs have an orbital period of 24 hours and are found only in equatorial orbits at an altitude of 35 800 km

The ground segment comprising reference stations (RS), regional control stations (RCS) and a master control station (MCS) (or navigation earth station (NES)).

The user segment comprised all who use the service.

RS are established within a region to measure the accuracy of the SV data and the ionospheric and tropospheric effects on the SV transmissions. As with LAAS the RS are precisely surveyed sites containing a GPS receiver and an accurate atomic clock. Each RS is linked to an RCS. The RCS will be linked in turn to MCS (or NES).

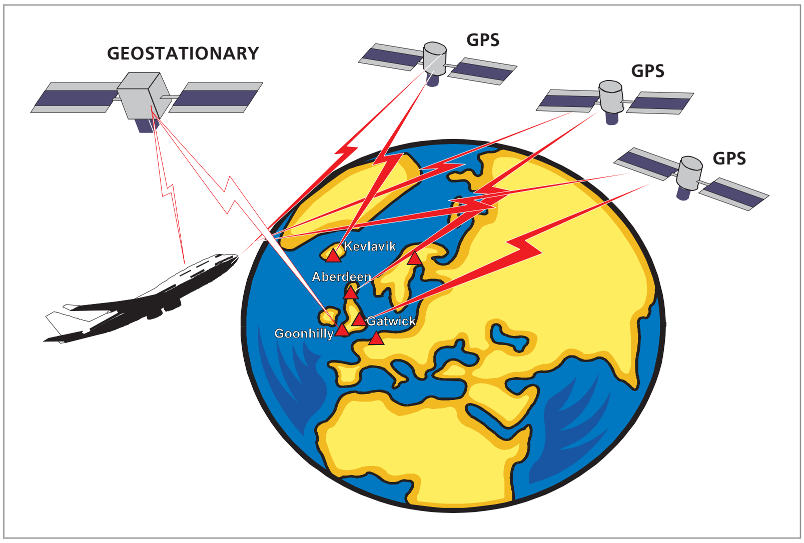


Figure 18.20 EGNOS Segments

The RS determine their GPS position from the SV data. The RS now, since it knows its own position and receives the SV ephemeris, clock time and any clock error corrections, back calculates the true position and time at the SV and determines the **range error** for each SV. It also determines if there are significant errors which render any of the SVs' information unusable, hence providing an integrity check on the system. This range error will not deviate significantly over a considerable range (400+ km), neither will the relative effects of the ionospheric and tropospheric propagation.

The data (SV errors and integrity assessment) is sent via the RCS to the MCS (located at the NATS at Gatwick) where it is formatted for use by suitable equipped GPS receivers. The data is then sent to Goonhilly Down to be uplinked for broadcast on the East Atlantic and Indian Ocean INMARSAT geostationary SVs navigation broadcast channels. The GPS receivers incorporate the data into the calculations and achieve both enhancement of position and failure warning.

Whilst the accuracy of GPS will be greatly enhanced by WADGPS, it cannot and is unlikely to achieve the accuracy required for category I type operations. These will continue for the foreseeable future to require the provision of LAAS. (The best decision height achieved to date is about 300 ft, and this is unlikely to be improved upon in the near future).

Combined GPS and GLONASS Systems

Receiver systems combining GPS and GLONASS are under development. The ability to combine positional information from the two systems will provide improved accuracy and enhanced integrity monitoring. However, since the SV systems use different models of the earth, the GLONASS PZ90 generated information will need to be converted to the GPS WGS84 model, or vice versa, to provide the final position.

Questions

1. NAVSTAR/GPS operates in the .... band the receiver determines position by ....:

a. UHF range position lines
b. UHF secondary radar principles
c. SHF secondary radar principles
d. SHF range position lines

2. The NAVSTAR/ GPS control segment comprises:

a. the space segment, the user segment and the ground segment
b. a ground segment and the INMARSAT geostationary satellites
c. a master control station, a back-up control station and five monitoring stations
d. a master control station, a back-up control station, five monitoring stations and the INMARSAT geostationary satellites

3. The orbital height and inclination of the NAVSTAR/GPS constellation are:

a. 20 180 km, 65°
b. 20 180 km, 55°
c. 19 099 km, 65°
d. 19 099 km, 55°

4. The model of the earth used for NAVSTAR/GPS is:

a. WGS90
b. PZ90
c. WGS84
d. PZ84

5. The minimum number of satellites required for a 3D fix is:

a. 3
b. 4
c. 5
d. 6

6. The NAVSTAR/GPS operational constellation comprises how many satellites?

a. 12
b. 21
c. 24
d. 30

7. The most accurate fixing information will be obtained from:

a. four satellites spaced 90° apart at 30° above the visual horizon
b. one satellite close to the horizon and 3 equally at 60° above the horizon
c. one satellite directly overhead and 3 equally spaced at 60° above the horizon
d. one satellite directly overhead and 3 spaced 120° apart close to the horizon

8. The most significant error of GNSS is:

a. PDOP
b. receiver clock
c. ionospheric propagation
d. ephemeris

9. The frequency available to non-authorized users of NAVSTAR/GPS is:

a. 1227.6 MHz
b. 1575.42 MHz
c. 1602 MHz
d. 1246 MHz

10. The purpose of the pseudo-random noise codes in NAVSTAR/GPS is to:

a. identify the satellites
b. pass the almanac data
c. pass the navigation and system data
d. pass the ephemeris and time information

11. The minimum number of satellites required for receiver autonomous integrity monitoring is:

a. 3
b. 4
c. 5
d. 6

12. If a receiver has to download the almanac, the time to do this will be:

a. 2.5 minutes
b. 12.5 minutes
c. 25 minutes
d. 15 minutes

13. The use of LAAS and WAAS remove the errors caused by:

a. propagation, selective availability, satellite ephemeris and clock
b. selective availability, satellite ephemeris and clock
c. PDOP, selective availability and propagation
d. receiver clock, PDOP, satellite ephemeris and clock

14. The most accurate satellite fixing information will be obtained from:

a. NAVSTAR/GPS & GLONASS
b. TRANSIT & NAVSTAR/GPS
c. COSPAS/SARSAT & GLONASS
d. NAVSTAR/GPS & COSPAS/SARSAT

15. A LAAS requires:

a. an accurately surveyed site on the aerodrome and a link through the INMARSAT geostationary satellites to pass corrections to X, Y & Z coordinates to aircraft
b. an accurately surveyed site on the aerodrome and a link through the INMARSAT geostationary satellites to pass satellite range corrections to aircraft
c. an accurately surveyed site on the aerodrome and a system known as a pseudolite to pass satellite range corrections to aircraft
d. an accurately surveyed site on the aerodrome and system known as a pseudolite to pass corrections to X, Y & Z coordinates to aircraft

16. The position derived from NAVSTAR/GPS satellites may be subject to the following errors:

a. selective availability, sky wave interference, PDOP
b. propagation, selective availability, ephemeris
c. PDOP, static interference, instrument
d. ephemeris, PDOP, siting

17. EGNOS is:

a. the proposed European satellite navigation system
b. a LAAS
c. a WAAS
d. a system to remove errors caused by the difference between the model of the earth and the actual shape of the earth

18. The PRN codes are used to:

a. determine the time interval between the satellite transmission and receipt of the signal at the receiver
b. pass ephemeris and clock data to the receivers
c. synchronize the receiver clocks with the satellites clocks
d. determine the range of the satellites from the receiver

19. The availability of two frequencies in GNSS:

a. removes SV ephemeris and clock errors
b. reduces propagation errors
c. reduces errors caused by PDOP
d. removes receiver clock errors

20. The NAVSTAR/GPS reference system is:

a. A geo-centred 3D Cartesian coordinate system fixed with reference to the sun
b. A geo-centred 3D Cartesian coordinate system fixed with reference to the prime meridian, equator and pole
c. A geo-centred 3D Cartesian coordinate system fixed with reference to space
d. A geo-centred 3D system based on latitude, longitude and altitude

21. **The initial range calculation at the receiver is known as a pseudo-range, because it is not yet corrected for:**

a. receiver clock errors
b. receiver and satellite clock errors
c. receiver and satellite clock errors and propagation errors
d. receiver and satellite clock errors and ephemeris errors

22. **The navigation and system data message is transmitted through the:**

a. 50 Hz modulation
b. the C/A and P PRN codes
c. the C/A code
d. the P code

23. **An *all in view* receiver:**

a. informs the operator that all the satellites required for fixing and RAIM are in available
b. checks all the satellites in view and selects the 4 with the best geometry for fixing
c. requires 5 satellites to produce a 4D fix
d. uses all the satellites in view for fixing

24. **When using GNSS to carry out a non-precision approach the MDA will be determined using:**

a. barometric altitude
b. GPS altitude
c. radio altimeter height
d. either barometric or radio altimeter altitude

25. **If an aircraft manoeuvre puts a satellite being used for fixing into the wing shadow then:**

a. the accuracy will be unaffected
b. the accuracy will be temporarily downgraded
c. the receiver will automatically select another satellite with no degradation in positional accuracy
d. the receiver will maintain lock using signals reflected from other parts of the aircraft with a small degrading of positional accuracy

26. **Which of the following statements concerning NAVSTAR/GPS time is correct?**

a. Satellite time is the same as UTC
b. The satellite runs its own time based on seconds and weeks which is independent of UTC
c. The satellite runs its own time based on seconds and weeks which is correlated with UTC
d. Satellite time is based on sidereal time

Answers

1	2	3	4	5	6	7	8	9	10	11	12
a	c	b	c	b	c	d	c	b	a	c	b

13	14	15	16	17	18	19	20	21	22	23	24
b	a	d	b	c	a	b	b	a	a	b	a

25	26
b	c

Chapter

19

Revision Questions

Questions

1. **When would VDF be used for a position fix?**

   a. When an aircraft declares an emergency on any frequency
   b. When first talking to an FIR on crossing an international boundary
   c. When joining controlled airspace from uncontrolled airspace
   d. When declaring an emergency on 121.500 MHz

2. **What equipment does an aircraft need when carrying out a VDF let-down?**

   a. VHF radio
   b. VOR
   c. VOR/DME
   d. None

3. **Which of the following is an advantage of a VDF let-down?**

   a. No equipment required in the aircraft
   b. No special equipment required in the aircraft or on the ground
   c. Only a VHF radio is needed in the aircraft
   d. It is pilot interpreted, so ATC is not required

4. **What is the maximum range at which a VDF station at 325 ft can provide a service to an aircraft at FL080?**

   a. 134 NM
   b. 107 NM
   c. 91 NM
   d. 114 NM

5. **Which of the following statements regarding VHF direction finding (VDF) is most accurate?**

   a. It is simple and only requires a VHF radio on the ground
   b. It is simple and requires a VHF radio and DF equipment in the aircraft
   c. It is simple requiring only VHF radios on the ground and in the aircraft
   d. It uses line of sight propagation

6. **What is the wavelength corresponding to a frequency of 375 kHz?**

   a. 8 m
   b. 80 m
   c. 800 m
   d. 8000 m

7. **An NDB transmits a signal pattern which is:**

   a. a 30 Hz polar diagram
   b. omni-directional
   c. a bi-lobal pattern
   d. a beam rotating at 30 Hz

8. **The accuracy of ADF within the DOC by day is:**

a. +/- 1°
b. +/- 2°
c. +/- 5°
d. +/- 10°

9. **Given that the compass heading is 270°, the deviation is 2°W, the variation is 30°E and the relative bearing of a beacon is 316°, determine the QDR:**

a. 044
b. 048
c. 074
d. 224

10. **Two NDBs, one 20 NM from the coast and the other 50 NM further inland. Assuming coastal error is the same for each, from which NDB will an aircraft flying over the sea receive the greatest error?**

a. The NDB at 20 NM
b. The NDB at 50 NM
c. Same when the relative bering is 090/270
d. Same when the relative bearing is 180/360

11. **Which of the following is likely to have the greatest effect on the accuracy of ADF bearings?**

a. Interference from other NDBs particularly by day
b. Interference between aircraft aerials
c. Interference from other NDBs, particularly at night
d. Frequency drift at the ground station

12. **Which of the following are all errors associated with ADF?**

a. Selective availability, coastal refraction, night effect
b. Night effect, quadrantal error, lane slip
c. Mountain effect, station interference, static interference
d. Selective availability, coastal refraction, quadrantal error

13. **What action must be taken to receive a bearing from an ADF?**

a. BFO on
b. Select the loop position
c. Both the loop and sense aerials must receive the signal
d. Select the LOOP position

14. **When is coastal error at its worst for an aircraft at low level?**

a. Beacon inland at an acute angle to the coast
b. Beacon inland at 90° to the coast
c. Beacon close to the coast at an acute angle to the coast
d. Beacon close to the coast at 90° to the coast

15. **A radio beacon has a range of 10 NM. By what factor should the power be increased to achieve a range of 20 NM?**

a. 16
b. 2
c. 4
d. 8

16. **Which of the following is the most significant error in ADF?**

a. Quadrantal error
b. Coastal refraction
c. Precipitation static
d. Static from Cb

17. **Which of the following may cause inaccuracies in ADF bearings?**

a. Static interference, height effect, lack of failure warning
b. Station interference, mountain effect, selective availability
c. Coastal refraction, slant range, night effect
d. Lack of failure warning, station interference, static interference

18. **The allocated frequency coverage of NDBs is:**

a. 250 – 450 kHz
b. 190 – 1750 kHz
c. 108 – 117.95 MHz
d. 200 – 500 kHz

19. **The principle used to measure VOR bearings is:**

a. phase comparison
b. switched cardioids
c. difference in depth of modulation
d. pulse technique

20. **When converting VOR and ADF bearings to true, the variation at the ...... should be used for VOR and at the ...... for ADF.**

a.	aircraft	aircraft
b.	aircraft	station
c.	station	aircraft
d.	station	station

21. **An aircraft flies from a VOR at 61N 013W to 58N 013W. The variation at the beacon is 13W and the variation at the aircraft is 5W. What radial is the aircraft on?**

a. 013
b. 005
c. 193
d. 187

22. In a conventional VOR the reference signal and the variable signal have a 30 Hz modulation. The variable signal modulation is produced by:

a. adding 30 Hz to the transmitted signal
b. a 30 Hz rotation producing a 30 Hz modulation
c. varying the amplitude up and down at +/-30 Hz
d. using Doppler techniques to produce a 30 Hz amplitude modulation

23. If the VOR accuracy has a limit of 1.0°, what is the maximum cross-track error at 200 NM?

a. 3.0 NM
b. 2.5 NM
c. 2.0 NM
d. 3.5 NM

24. What is the maximum distance apart a VOR and TACAN can be located and have the same identification?

a. 2000 m
b. 60 m
c. 600 m
d. 6 m

25. What is the maximum distance between VOR beacons designating the centre line of an airway (10 NM wide), if the expected VOR bearing error is 5.5°?

a. 120 NM
b. 109 NM
c. 60 NM
d. 54 NM

26. In a certain VORTAC installation the VOR is coding STN and the DME is coding STZ. This means that the distance between the two beacons is in excess of:

a. 600 m
b. 100 m
c. 2000 m
d. 300 m

27. Using a 5 dot CDI, how many dots would show for an aircraft on the edge of an airway at 100 NM from the VOR beacon?

a. 5
b. 2.5
c. 1.5
d. 3

28. The maximum range an aircraft at FL370 can receive transmissions from a VOR/DME at 800 ft is:

a. 275 NM
b. 200 NM
c. 243 NM
d. 220 NM

29. When tracking a VOR radial inbound the aircraft would fly:

a. a constant track
b. a great circle track
c. a rhumb line track
d. a constant heading

30. Which of the following is a valid frequency (MHz) for a VOR?

a. 107.75
b. 109.90
c. 118.35
d. 112.20

31. Using a VOR beyond the limits of the DOC may result in:

a. loss of signal due to line of sight limitations
b. interference from other VORs operating on the same frequency
c. sky wave contamination of the VOR signal
d. scalloping errors

32. An aircraft is flying a heading of 090° along the equator, homing to a VOR. If variation at the aircraft is 10°E and 15°E at the VOR, what is the inbound radial?

a. 075
b. 105
c. 255
d. 285

33. When identifying a co-located VOR/DME the following signals are heard in the Morse code every 30 seconds:

a. 4 identifications in the same tone
b. 4 identifications with the DME at a higher tone
c. 4 identifications with the DME at a lower tone
d. no DME identification, but if the VOR identification is present and a range is indicated then this shows that both are serviceable

34. What is the maximum range a transmission from a VOR beacon at 169 ft can be received by an aircraft at FL012?

a. 60 NM
b. 80 NM
c. 120 NM
d. 220 NM

35. An aircraft is tracking inbound to a VOR beacon on the 105 radial. The setting the pilot should put on the OBS and the CDI indications are:

a. 285, TO
b. 105, TO
c. 285, FROM
d. 105, FROM

36. When tracking the 090 radial outbound from a VOR, the track flown is:

a. a straight line
b. a rhumb line
c. a great circle
d. a constant true heading

37. The frequency band of VOR is:

a. VHF
b. UHF
c. HF
d. LF & MF

38. On which radial from a VOR at 61N025E (VAR 13°E) is an aircraft at 59N025E (VAR 20°E)?

a. 160
b. 347
c. 193
d. 167

39. What is the minimum height an aircraft must be to receive signals from a VOR at 196 ft AMSL at a range of 175 NM?

a. 26 000 ft
b. 16 000 ft
c. 24 000 ft
d. 20 000 ft

40. For a conventional VOR a phase difference of 090° would be achieved by flying .... from the beacon:

a. west
b. north
c. east
d. south

41. At a range of 200 NM from a VOR, if there is an error of 1°, how far off the centre line is the aircraft?

a. 3.5 NM
b. 1.75 NM
c. 7 NM
d. 1 NM

42. The quoted accuracy of VOR is valid:

a. at all times
b. by day only
c. at all times except night
d. at all times except dawn and dusk

43. Which of the following provides distance information?

a. DME
b. VOR
c. ADF
d. VDF

44. Which of the following would give the best indication of speed?

a. A VOR on the flight plan route
b. A VOR off the flight plan route
c. A DME on the flight plan route
d. A DME off the flight plan route

45. What happens when a DME in the search mode fails to achieve lock-on?

a. It stays in the search mode, but reduces to 60 pulse pairs per second (ppps) after 100 seconds
b. It stays in the search mode, but reduces to 60 ppps after 15 000 pulse pairs
c. It stays in the search mode at 150 ppps
d. It alternates between search and memory modes every 10 seconds

46. The most accurate measurement of speed by DME for an aircraft at 30 000 ft will be when the aircraft is:

a. tracking towards the beacon at 10 NM
b. overhead the beacon
c. tracking away from the beacon at 100 NM
d. passing abeam the beacon at 5 NM

47. A DME beacon will become saturated when more than about .... aircraft are interrogating the transponder.

a. 10
b. 50
c. 100
d. 200

48. A typical DME frequency is:

a. 1000 MHz
b. 1300 MHz
c. 1000 kHz
d. 1575 MHz

49. The DME in an aircraft, cruising at FL210, fails to achieve lock-on a DME at MSL at a range of 210 NM. The reason for this is:

a. the beacon is saturated
b. the aircraft is beyond the maximum usable range for DME
c. the aircraft is beyond line of sight range
d. the aircraft signal is too weak at that range to trigger a response

50. **The aircraft DME receiver accepts replies to its own transmissions but rejects replies to other aircraft transmissions because:**

a. the PRF of the interrogations is unique to each aircraft
b. the pulse pairs from each aircraft have a unique amplitude modulation
c. the interrogation frequencies are 63 MHz different for each aircraft
d. the interrogation and reply frequencies are separated by 63 MHz

51. **When an aircraft at FL360 is directly above a DME, at mean sea level, the range displayed will be:**

a. 6 NM
b. 9 NM
c. 0
d. 12 NM

52. **A DME frequency could be:**

a. 10 MHz
b. 100 MHz
c. 1000 MHz
d. 10 000 MHz

53. **An aircraft at FL360 is 10 NM plan range from a DME. The DME reading in the aircraft will be:**

a. 8 NM
b. 11.7 NM
c. 10 NM
d. 13.6 NM

54. **A DME transceiver does not lock onto its own reflections because:**

a. the PRF of the pulse pairs is jittered
b. it uses MTI
c. the interrogation and reply frequencies differ
d. the reflections will all fall within the flyback period

55. **What information does military TACAN provide for civil aviation users?**

a. Magnetic bearing
b. DME
c. Nothing
d. DME and magnetic bearing

56. **The DME in an aircraft flying at FL430 shows a range of 15 NM from a beacon at an elevation of 167 ft. The plan range is:**

a. 13.5 NM
b. 16.5 NM
c. 15 NM
d. 17.6 NM

57. **What are the DME frequencies?**

a. 1030 & 1090 MHz
b. 1030 – 1090 MHz
c. 960 &1215 MHz
d. 960 – 1215 MHz

58. **The time from the transmission of the interrogation pulse to the receipt of the reply from the DME ground station is 2000 microseconds (ignore the delay at the DME). The slant range is:**

a. 330 NM
b. 185 NM
c. 165 NM
d. 370 NM

59. **The DME counters are rotating continuously. This indicates that:**

a. the DME is unserviceable
b. the DME is trying to lock onto range
c. the DME is trying to lock onto frequency
d. the DME is receiving no response from the ground station

60. **On a DME presentation the counters are continuously rotating. This indicates:**

a. the DME is in the search mode
b. the DME is unserviceable
c. the DME is receiving no response from the transponder
d. The transponder is unserviceable

61. **An aircraft at FL200 is 220 NM from a DME at MSL. The aircraft equipment fails to lock on to the DME. This is because:**

a. DME is limited to 200 NM
b. the aircraft is too high to receive the signal
c. the aircraft is too low to receive the signal
d. the beacon is saturated

62. **On an ILS approach you receive more of the 90 Hz modulation than the 150 Hz modulation. The action you should take is:**

a. fly left and up
b. fly left and down
c. fly right and up
d. fly right and down

63. **The errors of an ILS localizer (LLZ) beam are due to:**

a. emission side lobes
b. ground reflections
c. spurious signals from objects near the runway
d. interference from other systems operating on the same frequency

64. The amplitude modulation of the ILS outer marker is .... and it illuminates the ....light in the cockpit.

a.	400 Hz	blue
b.	1300 Hz	amber
c.	400 Hz	amber
d.	1300 Hz	blue

65. The principle of operation of the ILS localizer transmitter is that it transmits two overlapping lobes on:

a. different frequencies with different phases
b. the same frequency with different phases
c. the same frequency with different amplitude modulations
d. different frequencies with different amplitude modulations

66. The ILS glide slope transmitter generates false glide paths because of:

a. ground returns from the vicinity of the transmitter
b. back scattering of the signals
c. multiple lobes in the radiation pattern
d. reflections from obstacles in the vicinity of the transmitter

67. A category III ILS system provides accurate guidance down to:

a. the surface of the runway
b. less than 50 ft
c. less than 100 ft
d. less than 200 ft

68. A HSI compass rose is stuck on 200°. When the aircraft is lined up on the centre line of the ILS localizer for runway 25, the localizer needle will be:

a. left of the centre
b. centred
c. right of the centre
d. centred with the fail flag showing

69. The coverage of the ILS glide slope with respect to the localizer centre line is:

a. +/-10° to 8 NM
b. +/-10° to 25 NM
c. +/-8° to 10 NM
d. +/-35° to 17 NM

70. The middle marker is usually located at a range of ...., with an audio frequency of .... and illuminates the .... light.

a.	4-6 NM	1300 Hz	white
b.	1 km	400 Hz	white
c.	1 km	1300 Hz	amber
d.	1 km	400 Hz	amber

71. The sequence of marker colours when flying an ILS approach is:

a. white, blue, amber
b. blue, white, amber
c. blue, amber, white
d. amber, blue, white

72. The sensitive area of an ILS is the area aircraft may not enter when:

a. ILS operations are in progress
b. category I ILS operations are in progress
c. category II/III ILS operations are in progress
d. the ILS is undergoing calibration

73. The ILS localizer is normally positioned:

a. 300 m from the downwind end of the runway
b. 300 m from the threshold
c. 300 m from the upwind end of the runway
d. 200 m abeam the threshold

74. The audio frequency of the outer marker is:

a. 3000 Hz
b. 400 Hz
c. 1300 Hz
d. 1000 Hz

75. An aircraft is flying downwind outside the coverage of the ILS. The CDI indications will be:

a. unreliable in azimuth and elevation
b. reliable in azimuth, unreliable in elevation
c. no indications will be shown
d. reliable in azimuth and elevation

76. The frequency band of the ILS glide path is:

a. UHF
b. VHF
c. SHF
d. VLF

77. In which band does the ILS glide path operate?

a. metric
b. centimetric
c. decimetric
d. hectometric

78. The coverage of MLS is .... either side of the centre line to a distance of ....

a. 40° 40 NM
b. 40° 20 NM
c. 20° 20 NM
d. 20° 40 NM

79. **Distance on MLS is measured by:**

a. measuring the time taken for the primary radar pulse to travel from the MLS transmitter to the aircraft receiver
b. measuring the time taken for the secondary radar pulse to travel from the MLS transmitter to the aircraft receiver
c. phase comparison between the azimuth and elevation beams
d. co-located DME

80. **Which of the following is an advantage of MLS?**

a. Can be used in inhospitable terrain
b. Uses the same aircraft equipment as ILS
c. Has a selective access ability
d. Is not affected by heavy precipitation

81. **The frequency band of MLS is:**

a. UHF
b. VHF
c. SHF
d. VLF

82. **Primary radar operates on the principle of:**

a. transponder interrogation
b. pulse technique
c. phase comparison
d. continuous wave emission

83. **The definition of a radar display will be best with:**

a. narrow beamwidth and narrow pulsewidth
b. narrow beamwidth and wide pulsewidth
c. wide beamwidth and narrow pulsewidth
d. wide beamwidth and wide pulsewidth

84. **The main advantage of a continuous wave radar over a pulsed radar is:**

a. more complex equipment but better resolution and accuracy
b. removes the minimum range restriction
c. smaller more compact equipment
d. permits measurement of Doppler in addition to improved range and bearing

85. **Which of the following systems use pulse technique?**

1. secondary surveillance radar
2. airborne weather radar
3. distance measuring equipment
4. primary radar

a. all the above
b. 2 and 4 only
c. 2 only
d. 1 and 3 only

86. To double the range of a primary radar, the power must be increased by a factor of:

a. 2
b. 4
c. 8
d. 16

87. In a primary pulsed radar the ability to discriminate in azimuth is a factor of:

a. pulse width
b. beamwidth
c. pulse recurrence rate
d. rate of rotation

88. The maximum range of a ground radar is limited by:

a. pulse width
b. peak power
c. average power
d. pulse recurrence rate

89. What does pulse recurrence rate refer to?

a. the number of cycles per second
b. the number of pulses per second
c. the ratio of pulse width to pulse repetition period
d. the delay known as flyback or dead time

90. The maximum PRF required for a range of 50 NM is:

a. 300 pulses per second (pps)
b. 600 pps
c. 1620 pps
d. 3280 pps

91. The best radar for measuring very short ranges is:

a. a continuous wave primary radar
b. a pulsed secondary radar
c. a pulsed primary radar
d. a continuous wave secondary radar

92. Which is the most suitable radar for measuring short ranges?

a. Millimetric pulse
b. Continuous wave primary
c. Centimetric pulse
d. Continuous wave secondary

93. The main advantage of a slotted scanner is:

a. reduces side lobes and directs more energy into the main beam
b. removes the need for azimuth slaving
c. side lobe suppression
d. can produce simultaneous map and weather information

94. **The maximum unambiguous (theoretical) range for a PRF of 1200 pps is:**

a. 134 NM
b. 180 NM
c. 67 NM
d. 360 NM

95. **The PRF of a radar is 450 pps. If the speed of light is 300 000 km/s, what is the maximum range of the radar?**

a. 150 km
b. 333 km
c. 666 km
d. 1326 km

96. **The best picture on a primary radar will be obtained using:**

a. low frequency, narrow beam
b. short wavelength, narrow beam
c. high frequency, wide beam
d. long wavelength, wide beam

97. **Which of the following is a primary radar system?**

a. SSR
b. DME
c. GPS
d. AWR

98. **On what principle does primary ATC radar work?**

a. Pulse technique
b. Pulse comparison
c. Continuous wave
d. Transponder interrogation

99. **The airborne weather radar (AWR) cannot detect:**

a. snow
b. moderate rain
c. dry hail
d. wet hail

100. **The frequency of AWR is:**

a. 9375 MHz
b. 937.5 MHz
c. 93.75 GHz
d. 9375 GHz

101. **The use of the AWR on the ground is:**

a. not permitted
b. permitted provided reduced power is used
c. permitted provided special precautions are taken to safeguard personnel and equipment
d. only permitted to assist movement in low visibility conditions

102. Which type of cloud does the AWR detect?

a. Cirrocumulus
b. Altostratus
c. Cumulus
d. Stratus

103. The AWR uses the cosecant squared beam in the .... mode.

a. WEA
b. CONT
c. MAP
d. MAN

104. On the AWR display the most severe turbulence will be shown:

a. in flashing red
b. by a black hole
c. by a steep colour gradient
d. alternating red and white

105. On an AWR colour display, the sequence of colours indicating increasing water droplet size is:

a. blue, green, red
b. green, yellow, red
c. black, amber, red
d. blue, amber, green

106. In an AWR with a 5° beamwidth, how do you orientate the scanner to receive returns from clouds at or above your level?

a. 0° tilt
b. 2.5° uptilt
c. 2.5° downtilt
d. 5° uptilt

107. The ISO-ECHO circuit is incorporated in the AWR:

a. to allow ground mapping
b. to alert pilots to the presence of cloud
c. to display areas of turbulence in cloud
d. to allow simultaneous mapping and cloud detection

108. The main factors which affect whether an AWR will detect a cloud are:

a. the size of the water droplets and the diameter of the antenna reflector
b. the scanner rotation rate and the frequency/wavelength
c. the size of the water droplets and the wavelength/frequency
d. the size of the water droplets and the range of the cloud

109. In an AWR with a colour CRT, areas of greatest turbulence are indicated by:

a. iso-echo areas coloured black
b. large areas of flashing red
c. iso-echo areas with no colour
d. most rapid change of colour

110. As a storm intensifies, the colour sequence on the AWR display will change:

a. black, yellow, amber
b. green, yellow, red
c. blue, green, orange
d. green, yellow, amber

111. The cosecant squared beam is used for mapping in the AWR because:

a. a greater range can be achieved
b. a wider beam is produced in azimuth to give a greater coverage
c. a larger area of ground is illuminated by the beam
d. it allows cloud detection to be effected whilst mapping

112. The AWR can be used on the ground provided:

1. the aircraft is clear of personnel, buildings and vehicles
2. conical beam is selected
3. maximum uptilt is selected
4. the AWR must never be operated on the ground

a. 4
b. 1 and 3
c. 1, 2 and 3
d. 2 and 3

113. Doppler navigation systems use .... to determine the aircraft ground speed and drift.

a. DVOR
b. phase comparison of signals from ground stations
c. frequency shift in signals reflected from the ground
d. DME range measurement

114. Which axes is the AWR stabilized in?

a. Pitch, roll and yaw
b. Roll and yaw
c. Pitch and roll
d. Pitch only

115. With normal SSR mode C altitude coding the aircraft replies by sending back a train of up to 12 pulses contained between 2 framing pulses with:

a. 4096 codes in 4 blocks
b. 2048 codes in 3 blocks
c. 4096 codes in 3 blocks
d. 2048 codes in 4 blocks

116. Why is the effect of returns from storms not a problem with SSR?

a. The frequency is too high
b. SSR does not use the echo principle
c. The PRF is jittered
d. By the use of MTI to remove stationary and slow moving returns

117. **The advantages of SSR mode S are:**

a. improved resolution, TCAS
b. data link, reduced voice communications
c. TCAS, no RT communications
d. better resolution, selective interrogation

118. **The accuracy of SSR mode C altitude as displayed to the air traffic controller is:**

a. +/-25 ft
b. +/-50 ft
c. +/-75 ft
d. +/-100 ft

119. **The SSR ground transceiver interrogates on .... and receives responses on ....**

a.	1030 MHz	1030 MHz
b.	1030 MHz	1090 MHz
c.	1090 MHz	1030 MHz
d.	1090 MHz	1090 MHz

120. **The vertical position provided by SSR mode C is referenced to:**

a. QNH unless QFE is in use
b. 1013.25 hPa
c. QNH
d. WGS84 datum

121. **Why is a secondary radar display free from weather clutter?**

a. The frequencies are too low to detect water droplets
b. The frequencies are too high to detect water droplets
c. Moving target indication is used to suppress the static generated by water droplets
d. The principle of the return of echoes is not used

122. **The availability of 4096 codes in SSR is applicable to mode:**

a. A
b. C
c. S
d. all

123. **With reference to SSR, what code is used to indicate transponder altitude failure?**

a. 9999
b. 0000
c. 4096
d. 7600

124. **In NAVSTAR/GPS the PRN codes are used to:**

a. reduce ionospheric and tropospheric errors
b. determine satellite range
c. eliminate satellite clock and ephemeris errors
d. remove receiver clock error

125. The MDA for a non-precision approach using NAVSTAR/GPS is based on:

a. barometric altitude
b. radio altimeter
c. GPS altitude
d. GPS or barometric altitude

126. If, during a manoeuvre, a satellite being used for position fixing is shadowed by the wing, the effect on position will be:

a. none
b. the position will degrade
c. another satellite will be selected, so there will be no degradation of position
d. the GPS will maintain lock using reflections of the signals from the fuselage

127. The time required for a GNSS receiver to download the satellite almanac for the NAVSTAR/GPS is:

a. 12.5 minutes
b. 12 hours
c. 30 seconds
d. 15 minutes

128. The effect of the ionosphere on NAVSTAR/GPS accuracy is:

a. only significant for satellites close to the horizon
b. minimized by averaging the signals
c. minimized by the receivers using a model of the ionosphere to correct the signals
d. negligible

129. The height derived by a receiver from the NAVSTAR/GPS is:

a. above mean sea level
b. above ground level
c. above the WGS84 ellipsoid
d. pressure altitude

130. The NAVSTAR/GPS constellation comprises:

a. 24 satellites in 6 orbits
b. 24 satellites in 4 orbits
c. 24 satellites in 3 orbits
d. 24 satellites in 8 orbits

131. Selective availability may be used to degrade the accuracy of the NAVSTAR/GPS position. This is achieved by:

a. introducing an offset in the satellites clocks
b. random dithering of the broadcast satellites clock time
c. random dithering of the broadcast satellites X, Y & Z coordinates
d. introducing an offset in the broadcast satellites X, Y & Z coordinates

132. The positioning of a GNSS aerial on an aircraft is:

a. in the fin
b. on the fuselage as close as possible to the receiver
c. on top of the fuselage close to the centre of gravity
d. under the fuselage

133. The NAVSTAR/GPS space segment:

a. provides X, Y & Z coordinates and monitoring of the accuracy of the satellite data
b. provides X, Y, Z & T coordinates and the constellation data
c. monitors the accuracy of the satellite data and provides system time
d. provides geographic position and UTC

134. Concerning NAVSTAR/GPS orbits, which of the following statements is correct?

a. The inclination of the orbits is 55° with an orbital period of 12 hours
b. The inclination of the orbits is 55° with an orbital period of 24 hours
c. The orbits are geostationary to provide global coverage
d. The orbits are inclined at 65° with an orbital period of 11 hours 15 minutes

135. NAVSTAR GPS receiver clock error is removed by:

a. regular auto-synchronization with the satellite clocks
b. adjusting the pseudo-ranges to determine the error
c. synchronization with the satellite clocks on initialization
d. having an appropriate atomic time standard within the receiver

136. The contents of the navigation and systems message from NAVSTAR/GPS SVs include:

a. satellite clock error, almanac data, ionospheric propagation information
b. satellite clock error, almanac data, satellite position error
c. position accuracy verification, satellite clock time and clock error
d. ionospheric propagation information, X, Y & Z coordinates and corrections, satellite clock time and error

137. The NAVSTAR/GPS segments are:

a. space, control, user
b. space, control, ground
c. space, control, air
d. space, ground, air

138. The preferred GNSS receiver for airborne application is:

a. multiplex
b. multi-channel
c. sequential
d. fast multiplex

139. The orbital height of geostationary satellites is:

a. 19 330 km
b. 35 800 km
c. 10 898 NM
d. 10 313 NM

140. The best accuracy from satellite systems will be provided by:

a. NAVSTAR/GPS and TNSS transit
b. GLONASS and COSPAS/SARSAT
c. GLONASS and TNSS transit
d. NAVSTAR/GPS and GLONASS

141. The azimuth and elevation of the satellites is:

a. determined by the satellite and transmitted to the receiver
b. determined by the receiver from the satellite almanac data
c. transmitted by the satellite as part of the almanac
d. determined by the receiver from the broadcast satellite X, Y, Z & T data

142. The skysearch carried out by a GNSS receiver:

a. is done prior to each fix
b. is done when the receiver position is in error
c. involves the receiver downloading the almanac from each satellite before determining which satellites are in view
d. is the procedure carried out by the monitoring stations to check the accuracy of the satellite data

143. An aircraft GNSS receiver is using 5 satellites for RAIM. If the receiver deselects one satellite then the flight should be continued:

a. using 4 satellites with the pilot monitoring the receiver output
b. using alternative navigation systems
c. using alternative radio navigation systems only
d. using inertial reference systems only

144. The WGS84 model of the earth is:

a. a geoid
b. a sphere
c. an exact model of the earth
d. an ellipse

145. The frequency band of the NAVSTAR/GPS L1 and L2 frequencies is:

a. VHF
b. UHF
c. EHF
d. SHF

146. The number of satellites required to produce a 4D fix is:

a. 3
b. 4
c. 5
d. 6

147. How many satellites are needed for a 2D fix?

a. 4
b. 2
c. 3
d. 5

148. Which of the following statements concerning ionospheric propagation errors is true?

a. They are significantly reduced by the use of RAIM
b. They are eliminated using differential techniques
c. They are significantly reduced when a second frequency is available
d. Transmitting the state of the ionosphere to the receivers enables the error to reduced to less than one metre

149. Using differential GNSS for a non-precision approach, the height reference is:

a. barometric
b. GNSS
c. radio
d. radio or GNSS

150. The number of satellites required to provide a 3D fix without RAIM is:

a. 4
b. 5
c. 6
d. 3

151. The number of satellites required for a fully operational NAVSTAR/GPS is:

a. 21
b. 18
c. 24
d. 30

152. 'Unauthorized' civilian users of NAVSTAR/GPS can access:

a. the P and Y codes
b. the P code
c. the C/A and P codes
d. the C/A code

153. When using GPS to fly airways, what is the vertical reference used?

a. Barometric
b. GPS height
c. Radio altitude
d. Average of barometric and GPS

154. The nav/system message from GLONASS and NAVSTAR/GPS is found in the .... band.

a. SHF
b. UHF
c. VHF
d. EHF

155. Which GNSS system can be used for IFR flights in Europe?

a. NAVSTAR/GPS
b. GLONASS
c. COSPAS/SARSAT
d. TNSS transit

156. During flight using NAVSTAR/GPS and conventional navigation systems, you see a large error between the positions given by the systems. The action you should take is:

a. continue the flight in VMC
b. continue using the conventional systems
c. continue using the GPS
d. switch off the faulty system after determining which one is in error

157. What information can a GPS fix using four satellites give you?

a. Latitude and longitude
b. Latitude, longitude, altitude and time
c. Latitude, longitude and altitude
d. Latitude, longitude and time

158. What are the basic elements transmitted by NAVSTAR/GPS satellites?

1. offset of the satellite clock from GMT
2. ephemeris data
3. health data
4. ionospheric delays
5. solar activity

a. 1, 2, 3, 4 and 5
b. 1, 2 and 3
c. 1, 2 and 4
d. 2, 3 and 4

159. What is the purpose of the GPS control segment?

a. To control the use of the satellites by unauthorized users
b. To monitor the satellites in orbit
c. To maintain the satellites in orbit
d. Degrade the accuracy of satellites for unauthorized users

160. In GNSS a fix is obtained by:

a. measuring the time taken for signals from a minimum number of satellites to reach the aircraft
b. measuring the time taken for the aircraft transmissions to travel to a number of satellites in known positions and return to the aircraft
c. measuring the pulse lengths of the sequential signals from a number of satellites in known positions
d. measuring the phase angle of the signals from a number of satellites in known positions

161. The inclination of a satellite is:

a. the angle between the SV orbit and the equator
b. the angle between the SV orbit and the polar plane
c. 90° minus the angle between the SV orbit and the equator
d. 90° minus the angle between the SV orbit and the polar plane

162. How is the distance between the NAVSTAR/GPS SV and the receiver determined?

a. By referencing the SV and receiver positions to WGS84
b. By synchronizing the receiver clock with the SV clock
c. By measuring the time from transmission to reception and multiplying by the speed of light
d. By measuring the time from transmission to reception and dividing by the speed of light

163. The distance measured between a satellite and a receiver is known as a pseudo-range because:

a. it is measured using pseudo-random codes
b. it includes receiver clock error
c. satellite and receiver are continually moving in relation to each other
d. it is measured against idealized Keplerian orbits

164. The task of the control segment is to:

a. determine availability to users
b. monitor the SV ephemeris and clock
c. apply selective availability
d. all of the above

165. To provide 3D fixing with RAIM and allowing for the loss of one satellite requires .... SVs:

a. 4
b. 5
c. 6
d. 7

166. In NAVSTAR/GPS the PRN codes are used to:

a. differentiate between satellites
b. pass satellite ephemeris information
c. pass satellite time and ephemeris information
d. pass satellite time, ephemeris and other information

167. **An 'all in view' satellite navigation receiver is one which:**

a. monitors all 24 satellites
b. tracks selected satellites
c. selects and tracks all (in view) satellites and selects the best four
d. tracks the closest satellites

168. **Which GPS frequencies are available for commercial air transport?**

a. 1227.6 MHz only
b. 1575.42 MHz only
c. 1227.6 MHz and 1575.42 MHz
d. 1227.6 MHz or 1575.42 MHz

169. **Which GNSS is authorized for use on European airways?**

a. GLONASS
b. NAVSTAR/GPS
c. Galileo
d. COSPAS/SARSAT

170. **In GPS on which frequencies are both the C/A and P codes transmitted?**

a. Both frequencies
b. The higher frequency
c. Neither frequency
d. The lower frequency

171. **The orbits of the NAVSTAR GPS satellites are inclined at:**

a. 55° to the earth's axis
b. 55° to the plane of the equator
c. 99° to the earth's axis
d. 99° to the plane of the equator

172. **RAIM is achieved:**

a. by ground monitoring stations determining the satellite range errors which are relayed to receivers via geo-stationary satellites
b. by ground stations determining the X, Y & Z errors and passing the corrections to receivers using pseudolites
c. within the receiver
d. any of the above

173. **The function of the receiver in the GNSS user segment is to:**

a. interrogate the satellites to determine range
b. track the satellites to calculate time
c. track the satellites to calculate range
d. determine position and assess the accuracy of that position

174. **In which frequency band are the L1 and L2 frequencies of GNSS?**

a. SHF
b. VHF
c. UHF
d. EHF

175. Which of the following statements concerning differential GPS (DGPS) is true?

a. Local area DGPS gives the same improvement in accuracy regardless of distance from the station
b. DGPS removes SV ephemeris and clock errors and propagation errors
c. DGPS can improve the accuracy of SA affected position information
d. Wide area DGPS accuracy improves the closer the aircraft is to a ground station

176. The visibility of GPS satellites is:

a. dependent on the location of the user
b. greatest at the equator
c. greatest at the poles
d. the same at all points on and close to the surface of the earth

177. In an RNAV approach phase with a two dot lateral deviation HSI display, a one dot deviation from track would represent:

a. 5 NM
b. 0.5 NM.
c. 5°.
d. 0.5°.

178. The required accuracy of a precision RNAV (P-RNAV) system is:

a. 0.25 NM standard deviation or better
b. 0.5 NM standard deviation or better
c. 1 NM standard deviation or better
d. 1.5 NM standard deviation or better

179. The ETA generated by the FMS will be most accurate:

a. when the forecast W/V equals the actual W/V and the FMS calculated Mach No. equals the actual Mach No.
b. if the ground speed and position are accurate
c. if the forecast W/V at take-off is entered
d. if the ground speed is correct and the take-off time has been entered

180. When is the FMS position likely to be least accurate?

a. TOD
b. TOC
c. Just after take-off
d. On final approach

181. For position fixing the B737-800 FMC uses:

a. DME/DME
b. VOR/DME
c. DME/DME or VOR/DME
d. any combination of VOR, DME and ADF

182. When using a two dot HSI, a deviation of one dot from the computed track represents approximately:

a. 2°
b. 5°
c. 5 NM
d. 2 NM

183. An aircraft, using a 2D RNAV computer, is 12 NM from the phantom station, 25 NM from the VOR/DME designating the phantom station and the phantom station is 35 NM from the VOR/DME. The range read-out in the aircraft will be:

a. 12 NM
b. 25 NM plan range
c. 35 NM
d. 25 NM slant range

184. The FMC position is:

a. the average of the IRS positions
b. the average of the IRS and radio navigation positions
c. computer generated from the IRS and radio navigation positions
d. computer generated from the radio navigation positions

185. When midway between two waypoints, how can the pilot best check the progress of the aircraft?

a. By using the ATD at the previous waypoint
b. By using the computed ETA for the next waypoint
c. By using the ATA at the previous waypoint
d. By using the ETA at the destination

186. Which of the following can be input manually to the FMC using a maximum of 5 alphanumerics?

a. Waypoints, latitude and longitude, SIDs and STARs
b. ICAO aerodrome designators, navigation facilities, SIDs and STARs
c. Waypoints, airways designators, latitude and longitude
d. Navigation facilities, reporting points, airways designators

187. The inputs to the EHSI display during automatic flight include:

a. auto-throttle, IRS and FMC
b. FCC, FMC and ADC
c. IRS, FMC and radio navigation facilities
d. IRS, ADC and FCC

188. The inputs the pilot will make to the FMC during the pre-flight initialization will include:

a. ETD, aircraft position, and planned route
b. planned route, aircraft position, and departure runway
c. navigation data base, aircraft position and departure aerodrome
d. departure runway, planned route and ETD

189. In RNAV mode one dot on the EHSI represents:

a. 2 NM
b. 2°
c. 5 NM
d. 5°

190. The phantom station in a 2D RNAV system may be generated by:

a. VOR/DME
b. twin VOR
c. twin DME
d. any of the above

191. The operation of a 2D RNAV system may be seriously downgraded:

a. because the computer cannot determine if the aircraft is within the DOC of the programmed facilities
b. because the computer cannot determine if the heading and altitude input are in error
c. because the pilot cannot verify the correct frequency has been selected
d. if the selected navigation facility is in excess of about 70 NM

192. The FMS database can be:

a. altered by the pilots between the 28 day updates
b. read and altered by the pilots
c. only read by the pilots
d. altered by the pilots every 28 days

193. Refer to Appendix A diagram C. What is the current drift?

a. 4° left
b. 12° left
c. 4° right
d. 12° right

194. In the B737-400 EFIS which component generates the visual display?

a. Flight control computer (FCC)
b. FMC
c. Symbol generator
d. Navigation database

195. When is the IRS position updated?

a. Continuously by the FMC
b. At VOR beacons on route by the pilots
c. At significant waypoints only
d. On the ground only

196 Refer to Appendix A. Which diagram is the MAP mode?

a. D
b. F
c. E
d. C

197. Refer to diagram E of Appendix A. The track from ZAPPO to BURDY is:

a. 205°(T)
b. 205°(M)
c. 064°(T)
d. 064°(M)

198. Refer to diagram B of Appendix A. The aircraft is:

a. right of the centre line and above the glide path
b. left of the centre line and below the glide path
c. right of the centre line and below the glide path
d. left of the centre line and above the glide path

199. Refer to Appendix A. Diagram F represents:

a. MAP
b. EXP VOR
c. VOR
d. ILS

200. The navigation database in the FMS:

a. may be modified by the pilot to meet routing requirements
b. is read only
c. may be modified by the operations staff to meet routing requirements
d. may be modified by national aviation authorities to meet national requirements

201. In an EHSI the navigation information comes from:

a. INS, weather mapping, radio navigation
b. FMC, radio navigation
c. IRS, radio navigation, TAS and drift
d. FMC, weather mapping, radio navigation

202. On an EFIS display the pictured symbol represents:

a. DME
b. VOR/DME
c. VORTAC
d. aerodrome

203. According to ICAO (Annex 11), the definition of an RNAV system is:

a. one which enables the aircraft to navigate on any desired flight path within the coverage of appropriate ground based navigation aids or within the specified limits of self-contained on-board systems or a combination of the two
b. one which enables the aircraft to navigate on any desired flight path within the coverage of appropriate ground based navigation aids or within the specified limits of self-contained on-board systems but not a combination of the two
c. one which enables the aircraft to navigate on any desired flight path within the coverage of appropriate ground based navigation aids only
d. one which enables the aircraft to navigate on any desired flight path within the specified limits of self-contained on-board systems

204. Which of the following is independent of external inputs?

a. INS
b. Direct reading magnetic compass
c. VOR/DME
d. ADF

205. The track line on an EFIS display indicates:

a. that a manual track has been selected
b. that a manual heading has been selected
c. the actual aircraft track over the ground, which will coincide with the aircraft heading when there is zero drift
d. the aircraft actual track which will coincide with the planned track when there is zero drift

206. The EHSI is showing 5° fly right with a TO indication. The aircraft heading is 280°(M) and the required track is 270°. The radial is:

a. 275
b. 265
c. 085
d. 095

207. On the B737-400 EHSI what happens if the selected VOR fails?

a. The display blanks and a fail warning appears
b. The deviation bar is removed
c. A fail flag is displayed alongside the display bar
d. The display flashes

208. In an RNAV system which combination of external reference will give the most accurate position?

a. GPS/rho
b. Rho/theta
c. Rho/rho
d. GPS/theta

209. If the signal from a VOR is lost, how is this shown on the B737-400 EHSI display?

a. By removal of the deviation bar and pointer
b. By showing a fail flag alongside the deviation bar
c. A flashing red FAIL message appears in the frequency location
d. An amber FAIL message appears in the frequency location

210. The colour used on the B737-400 EHSI weather display to show turbulence is:

a. magenta
b. flashing red
c. white or magenta
d. high colour gradient

211. Refer to diagram D of Appendix A. The current aircraft track is:

a. 130°
b. 133°
c. 156°
d. 165°

212. Refer to appendix A diagram C. The wind velocity is:

a. 129°(M)/20 ms^{-1}
b. 129°(T)/20 kt
c. 129°(M)/20 kt
d. 129°(T)/20 ms^{-1}

213. In order that a waypoint designated by a VOR can be used by a RNAV system:

a. the VOR must be identified by the pilot
b. the VOR must be within range when the waypoint is input
c. the VOR need not be in range when input or used
d. the VOR need not be in range when input but must be when used

214. Which EHSI modes cannot show AWR information?

a. FULL VOR/ILS and MAP
b. PLAN, MAP and EXP VOR/ILS
c. MAP and PLAN
d. PLAN and FULL VOR/ILS

215. Refer to appendix A, diagram C. The symbol annotated KXYZ is:

a. destination aerodrome
b. a diversion aerodrome
c. an en route aerodrome
d. a top of climb/descent point

216. Refer to Appendix B. The distance displayed on the EHSI will be:

a. 10 NM
b. 11 NM
c. 12 NM
d. 21 NM

217. The NAVSTAR/GPS constellation comprises:

a. 6 SVs each in 4 orbits
b. 4 SVs each in 6 orbits
c. 8 SVs each in 3 orbits
d. 3 SVs each in 8 orbits

218. Comparing the L1 and L2 signals helps with the reduction of which GNSS error?

a. Tropospheric propagation
b. SV ephemeris
c. SV clock
d. Ionospheric propagation

219. The normal maximum range for an ATC surveillance radar is:

a. 50 NM
b. 150 NM
c. 250 NM
d. 350 NM

220. The cause of a RNAV giving erratic readings would be:

a. the aircraft is in the cone of confusion of the phantom station
b. the aircraft is beyond line of sight range of the phantom station
c. the aircraft is beyond line of sight range of the reference station
d. the aircraft is outside the DOC of the reference station

221. Flying an ILS approach with a 3° glide slope referenced to 50 ft above the threshold, an aircraft at 4.6 NM should be at an approximate height of:

a. 1400 ft
b. 1380 ft
c. 1500 ft
d. 1450 ft

222. The height of the GPS constellation is:

a. 19300 km
b. 20200 km
c. 10900 km
d. 35800 km

223. What are the ground components of MLS?

a. Separate azimuth and elevation antennae with DME
b. Separate azimuth and elevation antennae with middle and outer markers
c. Combined azimuth and elevation antennae with DME
d. Combined azimuth and elevation antennae with middle and outer markers

224. The accuracy required of a basic area navigation (B-RNAV) system is:

a. +/-5 NM on 90% of occasions
b. all the time
c. +/-5 NM on 95% of occasions
d. +/-5 NM on 75% of occasions

225. What function does the course line computer perform?

a. Uses VOR/DME information to direct the aircraft to the facility
b. Uses VOR/DME information to direct the aircraft along a specified track
c. Converts VOR/DME information into HSI directions to maintain the planned track
d. Uses VOR/DME information to determine track and distance to a waypoint

226. The emissions from a non-directional beacon (NDB) are:

a. a cardioid with a 30 Hz rotation rate
b. omni-directional
c. a phase-compared signal
d. a frequency modulated continuous wave (FMCW)

227. How does night effect affect ADF?

a. Causes false bearings as the goniometer locks onto the sky wave
b. Sky wave interference which affects the null and is worst at dawn and dusk
c. Interference from other NDBs which is worst at dusk and when due east of the station
d. Phase shift in the received signal giving random bearing errors

228. What is an ADC input to the FMC?

a. Heading
b. VOR/DME position
c. TAS
d. Ground speed and drift

229. A typical frequency for DME would be:

a. 300 MHz
b. 600 MHz
c. 900 MHz
d. 1200 MHz

230. When flying under IFR using GPS and a multi-sensor system:

a. if there is a discrepancy between the GPS and multi-sensor positions, then the multi-sensor position must be regarded as suspect
b. the GPS must be operating and its information displayed
c. the multi-sensor system must be operating and its information displayed
d. both systems must be operating but only the primary system information needs to be displayed

231. The indications from a basic RNAV are behaving erratically. The reason is likely to be:

a. the aircraft is in the cone of confusion of the phantom station
b. the aircraft is outside the DOC of the reference VOR/DME
c. the aircraft is below line of sight range of the reference VOR/DME
d. the aircraft is in the cone of confusion of the reference VOR

232. What is the maximum PRF that allows detection of targets to a range of 50 km? (ignore any flyback time).

a. 330 pulses per second (pps)
b. 617 pps
c. 3000 pps
d. 1620 pps

233. **In NAVSTAR/GPS the space segment:**

a. provides the positional information to the receiver
b. the receiver interrogates the satellite and the satellite provides positional information
c. sends information for receiver to determine latitude, longitude and time
d. relays positional data from the control segment

234. **The almanac in the receiver:**

a. determines selective availability
b. assigns the PRN codes to the satellites
c. is used to determine receiver clock error
d. is used to determine which satellites are above the horizon

235. **In a RNAV system the DME is tuned:**

a. by what is selected on the pilots DME and hence is tuned manually
b. automatically by taking pilot's DME selection
c. by selecting DMEs to give suitable angle of cut to get a fix automatically
d. by automatically selecting the nearest suitable DME

236. **Which input to the FMC is taken from sources external to the aircraft?**

a. INS
b. Pressure altitude
c. Magnetic heading from a direct reading compass
d. VOR/DME

237. **In NAVSTAR/GPS range measurement is achieved by measuring:**

a. the time difference between the minimum number of satellites
b. the time taken for the signal to travel from the satellite to the receiver
c. the synchronization of the satellite and receiver clocks
d. the time taken for a signal to travel from the receiver to the satellite and return to the receiver

238. **Quadrantal error in the ADF is caused by:**

a. the metallic structure of the aircraft
b. generative voltages caused by the rotation of the engines
c. the electrical wiring running through the aircraft
d. multipath reception

239. **For the FMC the take-off speeds, V_1, V_R and V_2 are found:**

a. in the operating manual and input to the FMC
b. in the performance database
c. in the checklist and input manually
d. in the navigation database

240. **The optimum climb and descent speeds used by the FMC are found:**

a. in the operating manual and input to the FMC
b. in the performance database
c. in the checklist and input manually
d. in the navigation database

241. The optimum cruise speeds used by the FMC are found:

a. in the operating manual and input to the FMC
b. in the performance database
c. in the checklist and input manually
d. in the navigation database

242. Which of the following external inputs is required by the FMC to determine W/V?

a. Magnetic heading
b. Mach No.
c. TAS
d. Track and ground speed

243. Which of the following is true concerning the use of GNSS position in the FMC?

a. It is used to verify and update the IRS position
b. An alternate source of position must be used and displayed
c. GNSS position is usable stand alone
d. GNSS data may only be used in the absence of other positional information

Answers

1	2	3	4	5	6	7	8	9	10	11	12
d	a	c	a	d	c	b	c	a	b	c	c

13	14	15	16	17	18	19	20	21	22	23	24
c	a	c	d	d	b	a	c	c	b	d	c

25	26	27	28	29	30	31	32	33	34	35	36
b	a	c	a	b	d	b	c	b	a	a	c

37	38	39	40	41	42	43	44	45	46	47	48
a	d	b	c	a	a	a	c	b	c	c	a

49	50	51	52	53	54	55	56	57	58	59	60
c	a	a	c	b	c	b	a	d	c	b	a

61	62	63	64	65	66	67	68	69	70	71	72
c	d	b	a	c	c	a	b	c	c	c	c

73	74	75	76	77	78	79	80	81	82	83	84
c	b	a	a	c	b	d	a	c	b	a	b

85	86	87	88	89	90	91	92	93	94	95	96
a	d	b	d	b	c	a	b	a	c	b	b

97	98	99	100	101	102	103	104	105	106	107	108
d	a	a	a	c	c	c	c	b	b	c	d

109	110	111	112	113	114	115	116	117	118	119	120
d	b	c	c	c	c	a	b	b	b	b	b

121	122	123	124	125	126	127	128	129	130	131	132
d	d	b	b	a	b	a	c	c	a	b	c

133	134	135	136	137	138	139	140	141	142	143	144
b	a	b	a	a	b	b	d	b	c	b	a

145	146	147	148	149	150	151	152	153	154	155	156
b	b	c	c	a	a	c	d	a	b	a	b

157	158	159	160	161	162	163	164	165	166	167	168
b	c	b	a	a	c	b	b	c	a	c	b

169	170	171	172	173	174	175	176	177	178	179	180
b	b	b	c	c	c	c	a	b	c	b	a

181	182	183	184	185	186	187	188	189	190	191	192
a	d	a	c	b	d	c	b	a	a	a	c

193	194	195	196	197	198	199	200	201	202	203	204
c	c	d	d	c	c	b	b	b	c	a	a

205	206	207	208	209	210	211	212	213	214	215	216
c	d	b	c	a	a	b	c	d	d	c	c

217	218	219	220	221	222	223	224	225	226	227	228
b	d	c	d	d	b	a	c	d	b	b	c

229	230	231	232	233	234	235	236	237	238	239	240
d	c	b	c	a	d	c	d	b	c	b	b

241	242	243
b	c	b

Specimen Examination Paper

1. Which wavelength corresponds to a frequency of 5035 MHz?

a. 5.96 mm
b. 5.96 cm
c. 59.6 cm
d. 5.96 m

2. The VDF term meaning 'true bearing from the station' is:

a. QDM
b. QDR
c. QTE
d. QUJ

3. A class B VDF bearing will have an accuracy of:

a. ± 2°
b. ± 10°
c. ± 1°
d. ± 5°

4. An error applicable to VDF would be:

a. synchronous transmission
b. scalloping
c. selective availability
d. garbling

5. The maximum range an ATC facility at 1369 ft AMSL can provide a service to an aircraft at FL350 is:

a. 276 NM
b. 200 NM
c. 224 NM
d. 238 NM

6. The Doppler effect is:

a. the change in frequency caused by the movement of a transmitter and receiver
b. the change in frequency caused by the movement of a receiver
c. the change in frequency caused by the movement of a transmitter
d. the change in frequency caused by the relative movement between a transmitter and receiver

7. The least accurate bearing information taken by an aircraft over the sea from a NDB will be from:

a. a coastal beacon at an acute angle
b. an inland beacon at an acute angle
c. a coastal beacon perpendicular to the coast
d. an inland beacon perpendicular to the coast

8. The accuracy of ADF may be affected by:

a. night effect, tropospheric propagation, quadrantal error
b. static interference, siting errors, slant range
c. angle of bank, mountain effect, station interference
d. angle of bank, static from Cb, siting errors

9. The ADF error which will cause the needle to 'hunt' (i.e. oscillate around the correct bearing) is:

a. night effect
b. Cb static
c. station interference
d. coastal refraction

10. The accuracy of ADF by day and excluding compass error is:

a. +/-1°
b. +/-2°
c. +/-5°
d. +/-10°

11. A NDB has emission designator N0NA1A this will require the use of the BFO for:

a. tuning
b. identification
c. identification and monitoring
d. tuning, identification and monitoring

12. The principle of operation of VOR is:

a. bearing by lobe comparison
b. bearing by frequency comparison
c. bearing by searchlight principle
d. bearing by phase comparison

13. The pilot of an aircraft flying at FL240 is 250 NM from a VOR at 16 ft AMSL which he selects. He receives no signal from the VOR. This is because:

a. the VOR is unserviceable
b. the range of VOR is limited to 200 NM
c. the aircraft is beyond line of sight range
d. there are abnormal atmospheric conditions

14. The phase difference measured at the aircraft from a VOR is 235°. The bearing of the beacon from the aircraft is:

a. 055°
b. 235°
c. 145°
d. 325°

15. A pilot intends to home to a VOR on the 147 radial. The setting he should put on the OBS and the CDI indications will be:

a. 147, TO
b. 147, FROM
c. 327, FROM
d. 327, TO

16. An aircraft is 100 NM SW of a VOR heading 080°. The pilot intends to home to the VOR on the 210 radial. The setting he should put on the OBS is .... and the CDI indications will be:

a. 030, TO, Fly Right
b. 030, TO, Fly Left
c. 210, FROM Fly Right
d. 210, FROM, Fly Left

17. Flying an ILS approach the equipment senses that the 90 Hz modulation predominates on both the localizer and the glide path. The indications the pilot will see are:

a. fly left and fly up
b. fly left and fly down
c. fly right and fly up
d. fly right and fly down

18. On an ILS approach, using a 3° glide path, the height of an aircraft, ground speed 160 kt, at 3.5 NM from touchdown should be:

a. 800 ft
b. 1050 ft
c. 900 ft
d. 1500 ft

19. A category II ILS facility is required to provide guidance to:

a. below 50 ft
b. below 200 ft
c. the surface
d. below 100 ft

20. When flying downwind abeam the upwind end of the runway the indications from the ILS on the CDI will be:

a. in the correct sense for the localizer and no glide path signal
b. erratic on both localizer and glide path
c. erratic on the localizer and in the correct sense on the glide path
d. no localizer signal and in the correct sense for glide path

21. The azimuth coverage of a 3° glide path is:

a. +/-35° to 17 NM
b. +/-10° to 25 NM
c. +/-8° to 10 NM
d. +/-10° to 8 NM

22. **The coverage of the approach azimuth and elevation of a MLS is:**

a. +/-20° to 40 NM
b. +/-20° to 20 NM
c. +/-40° to 40 NM
d. +/-40° to 20 NM

23. **A full MLS system comprises a DME and:**

a. 4 elements multiplexing on 2 frequencies
b. 4 elements multiplexing on one frequency
c. 2 elements using 2 frequencies
d. 2 elements multiplexing on one frequency

24. **MLS has 200 channels available in the frequency band:**

a. 108 – 112 MHz
b. 329 – 335 MHz
c. 960 – 1215 MHz
d. 5031 – 5090 MHz

25. **The type of radar which has no minimum range restriction is:**

a. primary CW radar
b. primary pulsed radar
c. secondary CW radar
d. secondary pulsed radar

26. **The maximum theoretical range of a radar is determined by:**

a. power
b. PW
c. beamwidth
d. PRF

27. **The time interval between the transmission of a pulse and receipt of the echo from a target is 925.5 microseconds. The range of the target is:**

a. 37.5 NM
b. 75 NM
c. 150 NM
d. 300

28. **An advantage of a slotted antenna (planar array) over a parabolic reflector are:**

a. side lobes removed
b. 360° scan without any rotation requirement
c. less power required
d. higher data rate possible

29. **The best resolution will be achieved on a radar display with:**

a. high power output and large parabolic reflector
b. narrow beamwidth and narrow pulse width
c. low frequency and small parabolic reflector
d. wide beamwidth and large pulsewidth

30. **A radar transmitting on 600 MHz has a PRF of 300 pps and an aerial rotation rate of 5 rpm. This radar will be:**

a. an area surveillance radar
b. an aerodrome surface movement radar
c. an aerodrome surveillance radar
d. a terminal area radar

31. **The AWR operating frequency is:**

a. 9375 MHz
b. 9375 GHz
c. 937.5 MHz
d. 93.75 GHz

32. **The AWR frequency is selected because it gives:**

a. good returns from water droplets
b. good returns from turbulence
c. good penetration of cloud
d. good returns from water vapour

33. **On a colour AWR display, the heaviest precipitation will be displayed in:**

a. amber
b. red
c. yellow
d. blue

34. **The SSR code to select when the aircraft is being unlawfully interfered with is:**

a. 7600
b. 7700
c. 7500
d. 7400

35. **In SSR the ground station interrogates the aircraft on .... MHz and receives replies from the aircraft on .... MHz**

a. 1030 1090
b. 1090 1030
c. 1030 1030
d. 1090 1090

36. The altitude read-out at the ground station from a mode C response will give the aircraft altitude within:

a. 300 ft
b. 100 ft
c. 500 ft
d. 50 ft

37. If the aircraft DME interrogates a ground transponder on a frequency of 1199 MHz, it will look for replies on:

a. 1262 MHz
b. 1030 MHz
c. 1090 MHz
d. 1136 MHz

38. A DME recognizes replies to its own interrogating pulses because:

a. each pulse pair has its own unique modulation which is replicated by the transponder
b. the PRF of the interrogating pulses is jittered
c. each aircraft has a different time interval within the pulses pairs which is replicated by the transponder
d. the transponder uses a selective reply system to respond to the aircraft interrogation pulses

39. The DME in an aircraft at FL630 measures a slant range of 16 NM from a ground station at 1225 ft AMSL. The plan range is:

a. 12.5 NM
b. 19 NM
c. 16 NM
d. 10.5 NM

40. If the identification of a VOR is FKL and the paired DME identification is FKZ, then:

a. the transmitters are co-located
b. the beacons are between 600 m and 6 NM apart
c. the transmitters are within 600 m
d. the transmitters are in excess of 6 NM apart

41. The NAVSTAR/GPS operational constellation comprises:

a. 21 satellites in 6 orbits
b. 24 satellites in 6 orbits
c. 24 satellites in 3 orbits
d. 30 satellites in 6 orbits

42. The model of the earth used for GPS is:

a. WGS90
b. PZ84
c. PZ90
d. WGS84

43. **The major limitation in the use of GPS for precision approaches using wide area augmentation systems (WAAS) is:**

a. lack of failure warning
b. the height difference between the ellipsoid and the earth
c. global coverage of WAAS is not available
d. degradation of range measurement because of ionospheric propagation errors

44. **The number of SVs required to produce a 3D fix is:**

a. 3
b. 4
c. 5
d. 6

45. **EGNOS provides a WAAS by determining the errors in .... and broadcasting these errors to receivers using ....**

a.	X, Y & Z coordinates	geostationary satellites
b.	X, Y & Z coordinates	pseudolites
c.	SV range	geostationary satellites
d.	SV range	pseudolites

46. **The principle error in GNSS is:**

a. ionospheric propagation
b. GDOP
c. receiver clock error
d. SV ephemeris error

47. **If the signal from an SV is lost during an aircraft manoeuvre:**

a. the receiver will select another SV with no loss in accuracy
b. the receiver will go into a DR mode with no loss of accuracy
c. the receiver will compensate by using the last calculated altitude to maintain positional accuracy
d. the receiver position will degrade regardless of the action taken

48. **The purpose of the PRN codes in NAVSTAR/GPS is to:**

a. identify the satellites
b. synchronize the receiver clocks with the SV clocks
c. pass navigation and system data to the receiver
d. all of the above

49. **If the receiver almanac becomes corrupted it will download the almanac from the constellation. This download will take:**

a. 15 minutes
b. 2.5 minutes
c. 12.5 minutes
d. 25 minutes

50. The provision of RAIM requires a minimum of .... SVs.

a. 3
b. 4
c. 5
d. 6

51. The best position on an aircraft for the GNSS aerial is:

a. in the cockpit as close as possible to the receiver
b. on the fuselage close to the centre of gravity
c. on the aircraft as far as possible from other aerials to reduce reflections
d. close to each wing tip to compensate for manoeuvre errors

52. The NAVSTAR/GPS constellation is inclined at .... to the equator with an orbital period of ....

a. 55° 11 h 15 min
b. 65° 11 h 15 min
c. 65° 12 h
d. 55° 12 h

53. The NAVSTAR/GPS frequency available to non-authorized users is:

a. 1227.6 MHz
b. 1575.42 MHz
c. 1215.0 MHz
d. 1090.0 MHz

54. The NAV and system data message is contained in the .... signal.

a. 50 Hz
b. C/A PRN code
c. P PRN code
d. C/A & P PRN code

55. A 2D RNAV system takes fixing inputs from:

a. co-located VOR/DME
b. twin DME
c. VOR and/or DME
d. any of the above

56. The accuracy required of a basic RNAV system is:

a. 5 NM
b. 5°
c. 1 NM
d. 1°

57. An aircraft using a 2D RNAV system is 23 NM from the waypoint on a 50 NM leg. The waypoint is 45 NM from the VOR/DME and the aircraft is 37 NM from the VOR/DME. The range indicated to the pilot will be:

a. 23 NM
b. 27 NM
c. 37 NM
d. 45 NM

58. The navigation database in an FMC:

a. can be modified by the flight crew to meet the route requirements
b. can be modified every 28 days
c. can only be read by the flight crew
d. cannot be accessed by the flight crew

59. The RNAV function of the FMC produces a position which:

a. combines the short term accuracy of the external reference with the long term accuracy of the IRS
b. produces a long term accuracy from the short term accuracy of the external reference and the IRS
c. produces a long term accuracy from the long term accuracy of the external reference and the IRS
d. combines the long term accuracy of the external reference with the short term accuracy of the IRS

60. The most accurate external reference position will be provided by:

a. VOR/DME
b. Twin DME
c. Twin VOR
d. Suitable combination of VOR and DME

61. Refer to Appendix A. Which diagram shows the MAP display?

a. A
b. C
c. D
d. F

62. Refer to Appendix A, diagram E. What is the track from BANTU to ZAPPO?

a. 360°(M)
b. 130°(M)
c. 360°(T)
d. 130°(T)

63. Refer to Appendix A, diagram A. What is the deviation from the required track?

a. 3 NM left
b. 3 NM right
c. 8° left
d. 8° right

64. **Refer to appendix A, diagram F. What is the required track?**

a. 165°
b. 173°
c. 157°
d. 130°

65. **Refer to Appendix A, diagram C. What is the symbol designated DFC which is coloured cyan?**

a. an in-use VORTAC
b. an available VORTAC
c. an in-use NDB
d. an available NDB

66 **The FMC position is:**

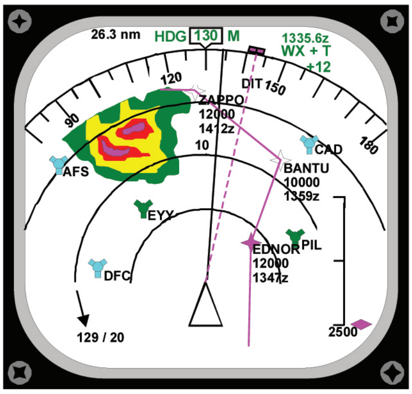
a. the selected IRS position updated by external reference using Kalman filtering
b. derived from IRS and external reference positions using the Kalman filtering process
c. derived from external reference position and monitored against the IRS position using the Kalman filtering process
d. the external reference position updated by IRS information through the Kalman filtering process

Appendix A

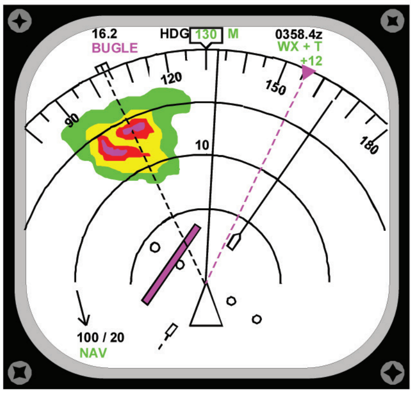
A

B

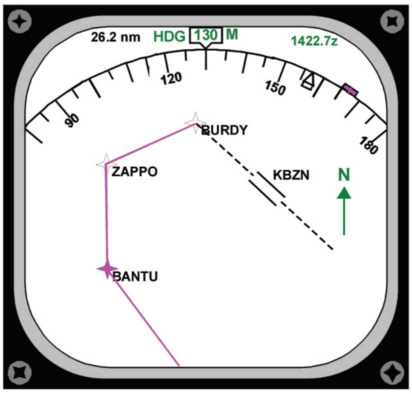
C



D



E



F

Answers to Specimen Examination Paper

1	2	3	4	5	6	7	8	9	10	11	12
b	c	d	a	a	d	b	c	a	c	d	d

13	14	15	16	17	18	19	20	21	22	23	24
c	a	d	a	d	b	a	b	c	d	b	d

25	26	27	28	29	30	31	32	33	34	35	36
a	d	b	c	b	a	a	a	b	c	a	d

37	38	39	40	41	42	43	44	45	46	47	48
d	b	a	b	b	d	b	b	c	a	d	a

49	50	51	52	53	54	55	56	57	58	59	60
c	c	b	d	b	a	a	a	a	c	d	b

61	62	63	64	65	66
b	c	b	a	b	b

Explanation of Selected Questions

Q1. Use $c = \frac{f}{\lambda}$

Q5. Line of sight formula: $Range\ (NM) = 1.23\ (\sqrt{h_{TX}} + \sqrt{h_{RX}})$ (height in feet)

Q13. Line of sight formula again! Maximum range at which reception can be achieved is 195 NM.

Q14. The phase difference is the bearing of the aircraft from the beacon (radial).

Q15/16. Draw a diagram!

Q18. $Height = Glide\ path\ angle \times range \times 100\ ft$

Q27. $Range = \frac{Time\ interval}{2 \times 6.17}\ NM$

Q36. The mode C increments in 100 ft steps.

Q37. 1262 MHz is outside the allocated band for DME.

Q39. Pythagoras!

Q54. The 50 Hz modulation passes the Nav and System Data message. The PRN codes provide a timing function and SV identification.

Q57. The range displayed is to the waypoint.

Q62. Remember the PLAN display is orientated to TRUE north.

Chapter

20

Index

H

I

J

K

L